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Heliothis and fruit fly integrated pest management strategies for tomato, vegetable and melon crops

Iain Kay
QLD Department of Primary Industries and Fisheries

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Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

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Heliothis and Fruit Fly Integrated Pest Management Strategies for Tomato, Vegetable and Melon Crops

Iain Kay *et al.*

Department of Primary Industries
Agency for Food and Fibre Sciences, Horticulture,
Queensland

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Project Leader
Iain Kay
Bundaberg Research Station
49 Ashfield Road
Bundaberg
Q 4670
Telephone: 07-41556244
E-mail: iain.kay@dpi.qld.gov.au

Key Personnel and Report Co-authors
Annice Lloyd
John Brown
Edward Hamacek

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Media Summary

Fruit flies and heliothis are major pests of tomatoes, capsicums, melons and other vegetables. Integrated pest management systems with less dependence on disruptive insecticides are needed for their management. This project investigated several aspects of the management of fruit flies and heliothis in these crops.

Tomatoes and capsicums must be free from fruit fly, particularly for some export markets. Protein baits, known to be effective in controlling fruit flies in some tree crops and that have no adverse effects on beneficial insects, were tested in tomatoes and capsicums. Unfortunately their effectiveness was not demonstrated because of difficulties in conducting the trials but positive and useful information was gathered. Protein baits should be effective in vegetables and studies using alternative techniques are needed to demonstrate their effectiveness.

Surveys of commercial capsicum crops demonstrated the importance of fruit flies, with up to 40% of fruit infested.

The project tested biopesticides and new insecticides against heliothis on tomatoes, capsicums, zucchinis and melons, and contributed to the registration of several insecticides more compatible with IPM systems on tomatoes and capsicums.

Trials of a heliothis specific virus product showed it had some effectiveness and that it may have a role when pest pressure is low. Bioassays and a field trial showed that the control of heliothis using biopesticides was not improved when an additive was included with the spray.

Heliothis eggs were found mainly on the leaves near the tops of tomato and capsicum plants, on the lower surface of zucchini leaves, and on melon leaves near the tips of runners. This knowledge will improve monitoring procedures and targeting of insecticide sprays for heliothis on these crops.

Managing vegetable pests using IPM systems requires on-going continual research and development. Protein baiting systems for fruit fly must be established and demonstrated. Studies on the management of heliothis in vegetables must continue and its management must be integrated with IPM programs for other pests in the crops. Each crop is different and specific programs are needed for specific crops.

Technical Summary

The project investigated aspects of the management of fruit fly in tomatoes and capsicums and the management of heliothis in tomatoes, capsicums, melons and zucchini.

Fruit flies, particularly *Bactrocera tryoni*, Queensland fruit fly, are important pests of tomatoes and capsicums by causing direct damage and because of their quarantine status. They normally are controlled by cover sprays of organophosphate insecticides in the field and/or post-harvest disinfestation.

A series of eight trials was done in tomatoes and capsicums to evaluate whether protein bait sprays (Mauri's Pinnacle Protein Lure plus maldison) were effective in controlling fruit flies. Each trial had unreplicated treatments of an untreated check plot; a plot treated with protein bait; and a plot treated with standard insecticides. Infestation levels in fruit were assessed. The effectiveness or otherwise of baits was not demonstrated in the trials, with factors such as plot size and other aspects of trial design, and complications caused by other insect pests deemed responsible. In a ninth trial the use of Naturalure Fruit Fly Bait reduced the infestation rate in a block of capsicums from 17% to 3%. Associated trials investigated the use of thickeners in baits and the effectiveness of a range of insecticides in controlling *B. tryoni*.

Surveys of fruit fly infestation rates in capsicums collected from commercial crops in the Lockyer Valley and Bundaberg districts showed infestation rates from 0% to 40%, with rates related to fruit fly population levels and to insecticide use in the crops.

Helicoverpa spp., heliothis, are key pests of tomatoes and major pests of other vegetable and melon crops. The project investigated the effectiveness of insecticides and biopesticides against heliothis, the use of an additive with biopesticides, and *H. armigera* oviposition sites on several crops.

The efficacy of methoxyfenozide (400g ac/ha), XenTari (250, 500, 1000 and 2000g/ha) and DiPel Forté (1000g/ha) in controlling heliothis on tomatoes was assessed in a replicated field trial at Bundaberg in spring 1999. Fourteen applications of the pesticides were made at approximately three to four day intervals. All fruit were harvested in eight picks, and yield and damage recorded. Heliothis eggs were sampled to monitor pressure, which was low to moderate, species composition, which was predominantly *H. armigera*, and egg parasitism, which reached high levels. Methoxyfenozide was effective, resulting in higher yields and less damage (80.15% of fruit undamaged by heliothis) than all the other treatments. There were no significant differences in yield or damage levels between DiPel Forté and XenTari 1000g/ha or 2000g/ha, but XenTari at 250g/ha and 500g/ha was less effective than DiPel Forté. None of the pesticides controlled moderate infestations of potato tuber moth, *Phthorimaea operculella*, but all were effective against low numbers of cluster caterpillar, *Spodoptera litura*. In a trial at Ayr in 1999 there was a significantly lower percentage of heliothis damaged tomato fruit in bifenthrin, acephate and XenTari treatments than in MVP, Gemstar and untreated check treatments.

Two small plot replicated trials were conducted at Bundaberg during 2000 to determine the efficacy of a range of insecticides in controlling heliothis, predominantly *H. armigera*, on capsicums. Heliothis pressure was low in both trials. In Trial 1 XenTari (2000 g/ha) applied

twice weekly, and spinosad (48 g a.i./ha), indoxacarb (51 g a.i./ha), methoxyfenozide (400 g a.i./ha), novaluron (75 g a.i./ha), and a standard (methomyl at 450 g a.i./ha), applied weekly, all gave good control of heliothis compared to the untreated check as measured by the percentage of fruit damaged by heliothis. DiPel Forté (1000 g/ha) was not effective, an unexpected result. In Trial 2 thrice weekly applications of Gemstar (500 ml/ha) resulted in significantly less ($P<0.05$) damaged fruit than the untreated check. Emamectin (11 g a.i./ha), novaluron (75 g a.i./ha), indoxacarb (37.5 g a.i./ha), indoxacarb (51 g a.i./ha), methoxyfenozide (400 g a.i./ha), and a standard (methomyl 450 g a.i./ha alternated with methamidophos 1102 g a.i./ha), applied weekly, all gave good control of heliothis.

The effectiveness of a range of insecticides in controlling *H. armigera* in zucchinis was tested in two small plot replicated trials at Bundaberg in late 2001 and early 2002. Heliothis larvae were common in flowers but little damage was done to fruit. Bifenthrin (60 g a.i./ha), spinosad (48 g a.i./ha), emamectin (11 g a.i./ha), indoxacarb (37.5 g a.i./ha), and methoxyfenozide (400 g a.i./ha) were effective in controlling larvae in flowers, methomyl (450 g a.i./ha), *Bacillus thuringiensis* subsp. *kurstaki* (1000 g/ha) and *B. thuringiensis* subsp. *aizawai* (1000 g/ha) were marginally effective while novaluron (75 g a.i./ha) was ineffective. None of the insecticides significantly ($P>0.05$) reduced the amount of major damage (i.e. bent fruit) caused by heliothis larvae to fruit.

The effectiveness of a range of biopesticides and insecticides in controlling heliothis, *Helicoverpa* spp., on rockmelons was tested in a series of trials at Ayr. Spinosad was effective while acephate and trichlorfon were reasonably effective. Several *B. thuringiensis* products, Gemstar, and novaluron showed some promise for use in IPM programs.

A series of bioassays tested whether adding Amino-Feed to Gemstar (heliothis nuclear polyhedrosis virus) or to a *B. thuringiensis* product on tomatoes and capsicums improved the efficacy of the biopesticides. The bioassay technique involved spraying plants, collecting leaves at various time intervals after spraying, placing 2d-old *H. armigera* larvae on the leaves in petri dishes in the laboratory and then recording mortality. The bioassays demonstrated that both biopesticides were effective against *H. armigera* immediately after spraying, that their effectiveness decreased with time after spraying, but there was no improvement in effectiveness if Amino-Feed was added to the spray. In a replicated, small plot, season-long field trial on tomatoes there were no significant differences in yield or in the percentage of fruit damaged by *H. armigera* between treatments of the *B. thuringiensis* product alone or with Amino-Feed or between treatments of Gemstar alone or with Amino-Feed. Neither the bioassays nor the field trial demonstrated any benefit from adding Amino-Feed to the biopesticides.

H. armigera oviposition sites on tomatoes, capsicums and zucchini were determined by caging moths on plants and counting eggs on plant parts, and on rockmelons by counting eggs laid naturally by wild moths. On trellised tomatoes most eggs were laid on leaflets (91%) on the top 40 cm of the plants (78%). On capsicums eggs were laid on leaves (89%) (mainly on the upper surface) in the top 20 cm of the plants (82%). On zucchini most eggs were laid on leaves (95%), mainly on the lower surface (66%) rather than the upper (29%). On rockmelons most eggs were found on leaves (93%) towards the tips of the runners (49%) or the middle section of runners (34%). This information on oviposition sites allows sections of the plants to be targeted for monitoring and for insecticide application.

These studies have increased our knowledge of fruit fly and heliothis in these vegetable and melon crops, which will allow the development of better pest management strategies. Valuable information has been gathered on the management of both pests, some of which can be used by growers immediately (e.g. several products have been registered) and some of which can be developed further. The development of IPM is a continual process, however, so studies of these and other pests in these crops should continue.

Introduction

Fruit flies, in particular Queensland fruit fly *Bactrocera tryoni*, are important pests of tomatoes and capsicums. The Queensland fresh market tomato industry is worth over $100 million a year, and the capsicum industry is worth approximately $50 million. The fruit is sold in Queensland and large quantities are exported to southern states and to New Zealand, while smaller amounts are exported to south-east Asia and Pacific nations. Fruit must be of high quality and free from insects and their damage.

Certain markets demand field sprays and/or post harvest disinfestation treatments for these fruit. At present accepted field treatment requires cover sprays with dimethoate, fenthion or trichlorfon. These sprays may be disruptive to integrated pest management programs for other pests in the crops, such as heliothis, potato moth, silverleaf whitefly or two-spotted mites, and excessive insecticide use is environmentally unsound. Hence it is important that alternatives to chemical sprays are made available.

Protein bait sprays are used for fruit fly control in certain tree crops (e.g. citrus) where they have minimal effect on beneficial insects and therefore are of great value in IPM programs. However there is very little information on the efficacy of protein bait sprays on vegetable crops.

Hence a major aim of the project was to evaluate the effectiveness of protein bait sprays in controlling fruit flies in tomato and capsicum crops, work that has the potential to provide significant benefits to the tomato and capsicum industries in terms of continued or greater market access and improved IPM systems in the crops. It was planned that the efficacy of protein baits would be assessed and associated studies would be done on the various components of the baits. A further aim of quantifying the importance of fruit flies in commercial capsicum crops was added as the project progressed.

Heliothis, *Helicoverpa* spp., are the key pests of tomatoes and capsicums, and important pests in other horticultural crops such as melons and vegetable cucurbits. The annual costs of heliothis (control plus 5% residual damage) to the Queensland horticultural industry (principally vegetables and vegetable fruits) was estimated at $17.4 million and to the Australian industry at $37.2 million (Adamson *et al.* 1997). The increasing development of resistance to insecticides by *H. armigera* threatens the growers' ability to control the pest, and the increased adoption of IPM systems dependant on parasitoids and predators for other pests in the crops requires alternative technologies to 'hard' insecticides for heliothis management to be developed and adopted.

Several alternative technologies for heliothis management that may be useful are being developed in other cropping systems. These include the use of nuclear polyhedrosis virus products that affect only heliothis, the use of new *Bacillus thuringiensis* products, the use of additives with biopesticides to improve their performance, and the development and use of new insecticides that are more specific in their action and less disruptive to beneficial insects.

A major aim of the project was to investigate and evaluate a number of these technologies in vegetable crops. Studies were to be done on evaluating the effectiveness of nuclear polyhedrosis virus products and *B. thuringiensis* products in controlling heliothis in various vegetable crops; on assessing the benefits of including additives in biopesticide sprays; on

evaluating new insecticides for heliothis control with the aim of having suitable ones registered; and increasing knowledge of heliothis in the crops to improve monitoring procedures.

The investigations into fruit fly and heliothis management conducted during the course of the project are presented in this report. The report is separated into two sections, the first dealing with the studies on fruit flies and the second with the studies on heliothis. Chapters within each section report in detail on separate facets of the studies undertaken.

Fruit Fly Studies

Fruit flies and in particular *Bactrocera tryoni* (Froggatt), the Queensland fruit fly, are important pests of tomatoes and capsicums. They cause direct damage to fruit and also are a quarantine problem for fruit exported to some markets. Studies on the management of fruit flies in tomatoes and capsicums formed a major component of the work undertaken in this project.

Reports on the following topics comprise the Fruit Fly Studies section of this Final Report:

- Testing protein baits for fruit fly control in capsicums and tomatoes;
- Evaluating the components of baits;
- Testing insecticides against Queensland fruit fly;
- Monitoring fruit fly infestations in commercial capsicum crops.

Testing protein baits for fruit fly control in capsicums and tomatoes

Introduction

Fruit flies, in particular Queensland fruit fly (*Bactrocera tryoni* (Froggatt)), are important pests of capsicums and tomatoes. The adult flies oviposit into the fruit and the resultant larvae feed within the fruit, causing major damage. As well as the potential for fruit fly to cause direct damage to tomatoes and capsicums there is a quarantine issue in that some export markets demand certain protocols for fruit fly management be applied to ensure that the fruit are free from fruit flies. These protocols include the application of insecticide cover sprays in the field and/or post-harvest disinfestation.

The insecticides used as cover sprays are dimethoate, fenthion and trichlorfon. These can be disruptive to IPM programs for other pests in the crops, and excessive use of insecticides is not environmentally sound.

Protein bait sprays are used effectively for fruit fly control in several tree crops in Queensland (e.g. citrus) where they have minimal disruptive effect on beneficial insects and therefore are of great value in IPM programs.

There is however very little information on the efficacy of protein bait sprays on vegetable crops, and no information could be found for *B. tryoni*. Heimoana *et al.* (1996) reported reduced *Bactrocera facialis* (Coquillett) infestation rates in baited capsicum and chilli crops in Tonga. Stonehouse *et al.* (2002) reported lower infestation rates of *Bactrocera cucurbitae* (Coquillett) in melons from baited crops compared to those from untreated crops in Pakistan.

The aim of the trials reported here was to evaluate the effectiveness of protein baits sprays in controlling fruit flies in tomatoes and capsicums in Queensland.

Materials and methods

Eight trials were conducted from mid 1999 to mid 2001 at Redland Bay, Bundaberg and Ayr on tomatoes and capsicums (Table F1) to test the efficacy of protein bait sprays in preventing fruit fly infestations in fruit.

Similar methods were used in all eight trials. In each trial plots (size varied from 5 rows by 30m, 9 or 10 rows by 60m, to 8 rows by 80m) of crops were grown using standard agronomic practices, with one plot grown for each treatment. Plots were separated by several hundred metres in most cases in an attempt to minimise interference between the treatments while keeping them close enough hopefully to experience similar fruit fly pressure. Fungicides (e.g. mancozeb) and copper sprays were applied regularly to the plants for disease control.

The following treatments were applied:

1. no fruit fly control and no insecticides except for *Bacillus thuringiensis* products (e.g. Dipel) weekly or twice weekly for heliothis control i.e. check treatment;

2. protein bait spray and no insecticides except *B. thuringiensis* weekly or twice weekly;
3. no specific fruit fly control but standard organophosphate (methamidophos) and carbamate (methomyl) insecticides for heliothis control.

(In Trial 1 only the check and bait treatments were used and in Trial 2 a fourth treatment of bait plus a thickener was added.)

Table F1
The locations, dates and crops of the eight fruit fly baiting trials.

Trial No.	Location	Date	Crop
1	Redland Bay	Spring 1999	Tomato and capsicum
2	Redland Bay	Spring 2000	Tomato
3	Bundaberg	Autumn 2000	Tomato
4	Bundaberg	Spring 2000	Capsicum
5	Bundaberg	Autumn 2001	Capsicum
6	Bowen	Autumn 2000	Capsicum
7	Ayr	Spring 2000	Tomato
8	Ayr	Autumn 2001	Tomato

The protein bait spray consisted of 2L of Mauris Pinnacle Protein Lure plus 435ml Hy-Mal (1150g/L maldison) per 100L water. It was applied at 30L of bait mix per crop hectare, as a coarse spray to a narrow band (10-15 cm wide) to foliage along the top third of the plants. It was applied to every second or third row of the crop, and alternate applications were made to different rows or sides of rows. Bait sprays were applied weekly from early fruit set to the completion of harvesting, and sprays were re-applied if there was rain to the point of run-off within 24h of an application.

Fruit were harvested from plots over four to five weeks, with at least several hundred fruit harvested per plot on each harvest date. Fruit were picked from throughout the plots and were picked irrespective of condition provided they were not rotten.

Harvested fruit were returned to the laboratory and assessed for maturity stage and for damage. They then were placed on moist Number 1 grade vermiculite in 10L plastic containers with fine mesh material lids and held in a constant temperature room at approximately 24-25ºC to allow eggs to hatch and larvae to develop. After eight to 10 days the fruit were cut and carefully examined for the presence of fruit fly larvae, and the vermiculite was sieved to recover pupae. The number of infested fruit and the number of larvae and pupae per infested fruit was recorded.

Lynfield traps baited with cue lure were placed beside each plot to obtain a measure of fruit fly populations.

A ninth trial (Trial 9) was conducted at Redland Bay in 2003 to assess the efficacy of baiting using a different technique. Previous field trials (Trials 1-8) did not successfully demonstrate efficacy of bait for fruit fly control in tomatoes or capsicums. The untreated blocks showed very low levels of infestation possibly due to the fruit fly control measures undertaken on the other blocks. To avoid these influences, this trial was based on the methods of Heimoana *et al.* (1996) using only one block of capsicums. This method initially leaves the capsicums untreated while carrying out weekly assessments for infestation. Once infestation levels of

untreated capsicums were established, weekly baiting commenced in an attempt to significantly reduce this level.

Two borders (20 x 70 m containing 12 rows, 25 cm single plant spacing) of green/red bell peppers were planted at the Redlands Horticulture Research Station in mid January 2003. The crop was grown using standard agronomic practices and was sprayed weekly with mancozeb, Dipel and copper. On the 23rd January, two fruit fly traps were installed within the block and 2 traps located elsewhere on the research station, well removed from the trial block. These traps were cleared weekly and the flies counted and identified.

All previous bait trials in this project were undertaken with industry standard bait (Mauri's Protein Autolysate + Hy-Mal insecticide). This trial provided the opportunity to test a new bait product, Dow AgroSciences Naturalure, which had been extensively tested in tree crops in a separate HAL project (AH00012) lead by DPI fruit fly researchers (A. Lloyd pers. comm.) but which had not previously been tested in vegetable crops. Naturalure Fruit Fly Bait was diluted 1:1.5 and applied using a hand sprayer at a rate of 7.5L/ha at weekly intervals from late March.

Fruit were sampled approximately weekly from early March. At each sampling date approximately 300 commercial size fruit were taken from the block. These fruit were randomly selected with no bias, i.e. fruit were not rejected if blemished. After each sample was taken, all commercial size fruit were stripped from the block and disposed of in an area well removed from the trial site. This was to simulate a commercial pick and to maintain the vigour of the plants. The sampled fruit were returned to the Indooroopilly laboratory where they were counted, weighed and then held for assessment as in previous trials.

Results

Table F2 shows the results of Trial 2 while the results of Trials 1 and 3-8 are summarised in Table F3. The percentage of fruit recorded as infested with fruit flies and the number of fruit harvested in each treatment are shown.

Table F2
The numbers of fruit harvested, the percentages of infested fruit and the larval load in Trial 2.

Treatment	Number of fruit sampled	Percentage infested	Mean number larvae per infested fruit
Check	1319	3.64	12.52
Protein bait	916	4.68	11.51
Bait + thickener	1280	3.83	8.76
Insecticide	949	3.58	8.62

In Trial 1 the infestation rate in both tomatoes and capsicums in the bait sprayed plot was higher than that in the check plot. This may have been a positional effect. There were the remnants of another tomato trial approximately 10m from the bait sprayed plot and unsprayed papaws approximately 30m away. The control plot was located at one corner of the research station with no other fruit fly hosts nearby. Fruit flies were reared from all tomato and

capsicum stages sampled, from green mature to full colour. A significant proportion of the tomato fruit assessed were green damaged and most of the damage was caused by *Helicoverpa* spp. Twelve percent of the tomatoes that were examined and considered to be undamaged were infested with fruit fly, which shows that oviposition cannot necessarily be detected by visual inspection of the fruit. Of the capsicums, over 90% of the fruit examined were mature green unblemished, and 16% of these were infested, again showing that oviposition cannot necessarily be detected by visual inspection of the fruit. Similar numbers of flies were caught in traps in the check and baited plots throughout the trial, with numbers fairly high. Species trapped included *B. tryoni* (mainly) and *Bactrocera neohumeralis* (Hardy), while these and a few *Bactrocera cucumis* (French) were reared from infested tomatoes.

Table F3
The percentages of fruit infested with fruit fly and the numbers of fruit harvested.

Trial number	Percentage infested fruit (number fruit harvested) in each treatment		
	Check	Protein bait	Insecticide
1 – capsicum	16.6 (839)	34.1 (733)	-
1 – tomato	4.4 (1512)	24.3 (1488)	-
3	0.07 (1469)	0.14 (1478)	0 (1512)
4	4.19 (1502)	1.06 (1503)	0.07 (1507)
5	0 (1199)	0 (1197)	0 (1196)
6	0 (752)	0 (741)	0 (761)
7	0 (317)	0.17 (587)	0 (484)
8	0 (1211)	0 (1104)	0 (1192)

In Trial 2 there were no differences between any of the treatments, including the check. Heliothis control was much better than in Trial 1, however Fusarium Wilt caused severe damage in the Standard Bait and Check blocks, which may have had an impact on the efficacy of these treatments.

In Trial 3 the level of fruit fly infestation in any of the treatments was disappointingly low. Cue lure traps in each block sampled the fruit fly population during the trial and showed that while fruit flies were present the populations were not high. Species collected were mainly *B. tryoni*, *B. neohumeralis*, and *Bactrocera bryoniae* (Tryon) with several *Bactrocera. chorista* (May) and a single specimen of *Dacus aequalis* Coquillett.

In Trial 4 more fruit were infested with fruit flies in the check plot (with 270 flies, predominantly *B. tryoni* and *B. neohumeralis* caught in the trap), than in the baited plot (671 flies trapped), and the insecticide treated plot (722 flies trapped). *B. tryoni* and *B. neohumeralis* were the only species reared from infested fruit. These results were promising

as, even with a higher population of fruit flies, the infestation level in the baited block was considerably lower than that in the check. The standard insecticides gave good control of fruit flies.

No infested fruit were reared from sampled fruit in Trial 5 although adult flies were caught in cue lure traps in the plots.

In Trial 6 no fruit fly larvae or pupae were found in fruit harvested from any of the treatments throughout the duration of the trial. Small numbers of adult fruit flies were collected from the six traps located in the plots and on the research station. The low trap numbers and the failure to find any fruit fly larvae in the samples suggest that there may not have been a high enough population in the area to cause damage to the fruit.

Sampling in Trial 7 was restricted to a period of two weeks due to severe Fusarium Wilt disease problems that were encountered in the trial. High numbers of adult fruit flies were collected from the traps during this trial but despite the obviously large fruit fly population in the area only one infested fruit was recorded.

Similarly in Trial 8 fruit flies did not infest fruit in any of the plots.

Other insects caused some problems in these trials, particularly in tomatoes. Heliothis, *Helicoverpa* spp., damaged a lot of fruit despite the efforts to manage the pest by using *B. thuringiensis* products on the crops. The damage often resulted in fruit breaking down while being held, which complicated the holding and assessment process. Cluster caterpillar, *Spodoptera litura* (F.), was an occasional pest, causing similar damage to that caused by heliothis. Eggs and larvae of *Atherigona orientalis* Schiner, commonly known as the pepper fruit fly or tomato fly or Atherigona, were commonly found on and in sampled fruit, particularly those with damage as the fly oviposits on damaged fruit and the larvae feed in decaying tissue.

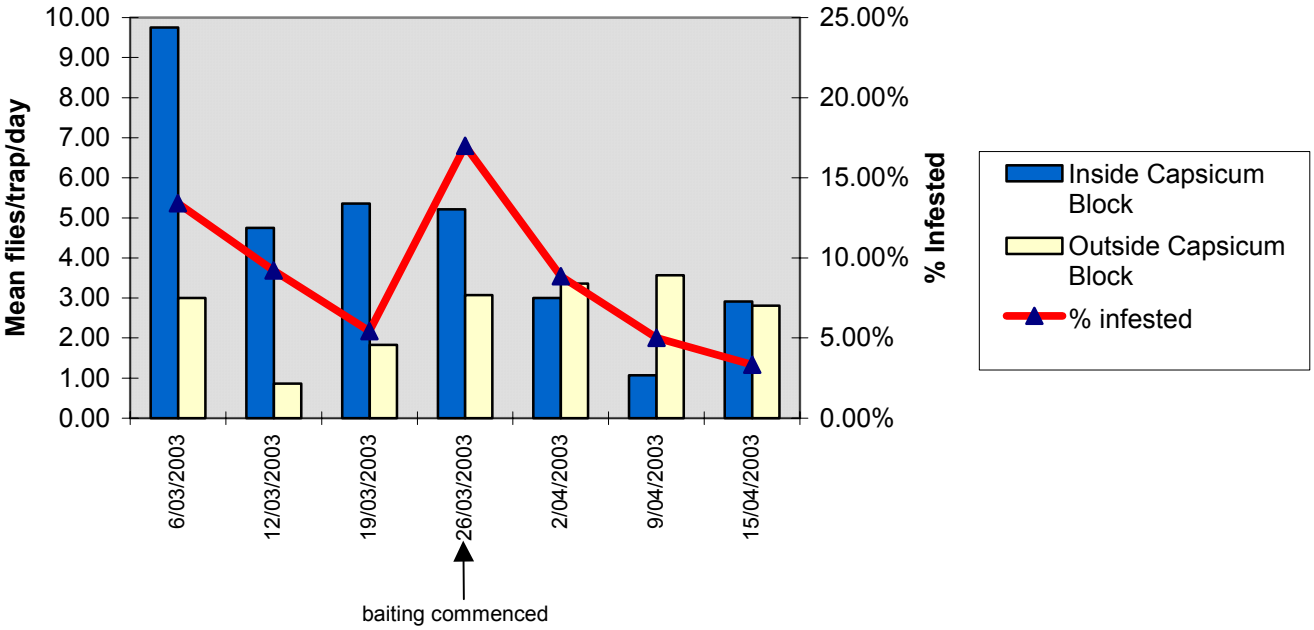
The results from Trial 9 are shown in Figure F1. The first pick was on the 6th March with subsequent weekly picks. The first bait spray was applied after the fourth pick (26th March). The last pick was on the 15th April at which point the trial was abandoned due to extremely high levels of caterpillar damage (heliothis and cluster caterpillar) to the fruit and leaves which was causing many of the plants to collapse. The results obtained indicate an effect on the fruit fly activity within the block once baiting commenced. Both the percentage of infested fruit and the numbers of flies in the traps inside the block decreased whereas the trapping numbers outside the block increased over the same period (Figure F1).

Discussion

The primary aim of these trials was to determine the efficacy of protein bait sprays for fruit fly control in tomatoes and capsicums. If successful, baiting could replace cover sprays of dimethoate, fenthion or trichlorfon, which are the currently registered treatments for fruit fly but which may be disruptive to IPM systems that are being developed in these crops. If baiting was shown to be effective then the case would be argued for the inclusion of baiting in ICA protocols for fruit fly management thereby reducing the overall chemical usage in these crops.

The approach taken in this project was to compare fruit fly infestations in small blocks of the crops either untreated, sprayed with conventional insecticides, or baited. If baiting was effective then fruit fly infestation levels should have been much lower in the baited block than in the untreated check. Infestation levels in the insecticide block would indicate the effectiveness of some standard heliothis insecticides (e.g. methomyl and methamidophos) against fruit fly. Despite considerable efforts over nearly two years the trials have not successfully demonstrated the efficacy of baiting. It is thought that this is probably due to the inherent difficulties of evaluating baits rather than baiting not being efficacious.

Figure F1
Fruit fly trap catches and percent infestation in capsicums before and after baiting with Naturalure Fruit Fly Bait – Redlands 2003.



With the exception of Trial 9, which provided the best indication that baiting in vegetable crops could provide effective fruit fly control, as shown by the reduction in infestation levels from 17% to approximately 3%, the results have been disappointing. Promising results were recorded in Trial 4 where 4.19% of fruit were infested in the check, 1.06% in the bait treatment, and 0.07% in the insecticide treatment. Despite fruit flies being trapped in plots no fruit flies were reared from harvested fruit from any treatments in Trials 5, 6 and 8, while very low numbers were reared in Trial 3 (0.07% and 0.14% in the check and baited blocks respectively) and Trial 7 (0.17% in bait block). In Trial 1 higher infestation levels were recorded in the baited plots than in the check plots for both tomatoes and capsicums (4.4% and 24.3% respectively for tomatoes, and 34.1% and 16.6% respectively for capsicums), a result possibly due to the location of the plots relative to other fruit fly hosts on the Research Station. In Trial 2 there were no apparent differences in infestation between the treatments (3.64%, 4.68%, 3.83% and 3.58%).

Bait treatments for fruit flies are difficult to evaluate. It is probable that the inconsistencies in these trial results are related to these difficulties.

Protein baits have long been known to be most effective when applied on an area wide basis (e.g. in citrus in the Central Burnett). Fruit flies are highly mobile insects and protein baits rely on their ability to attract flies in and around a treated plot to provide effective control. The size of a trial plot, the presence of alternative hosts around a plot, the host status of the crop (e.g. highly preferred or poor host) will all impact on the effectiveness of a bait treatment. A number of these complications are relevant to the types of trials conducted in this project and attempts to overcome them as much as was logistically possible were made.

- Plot size. Baits are most effective when applied over a large area. Plots were as large as possible within the restraints of cost, resources and practical management. At Bundaberg the baited plot in each trial was within the boundaries of a citrus grove that was also baited so increasing the area effectively baited, and this may have contributed to the positive result obtained in Trial 4. However it seems that much larger treated areas may be needed to demonstrate the effectiveness of baits.

- Fruit fly mobility. Flies can move long distances so there was a risk of mated gravid female flies moving into baited plots and ovipositing in fruit. This probably occurred in the Redland Bay trials. This problem is linked to plot size.

- Attractiveness of baits. Baits attract flies over a considerable distance. Hence plots for the different treatments had to be separated by some distance so that baiting did not interfere with other treatments. The risk associated with this is that fruit fly populations may be different at each plot, and there is evidence that this occurred eg in Trials 4 and 5 at Bundaberg where there were large differences in numbers of males caught in traps. A possible solution to this would be to replicate each treatment several times in each trial, but this was impossible due to the logistics of growing the plots, and harvesting, holding and examining the fruit. (It was intended that the scientific requirement for replication would be achieved by each trial being one replicate of an experiment consisting of all the trials.)

- Presence of alternative hosts. Other hosts near to a plot may be a source of fruit flies to infest that plot. It is likely that this factor was particularly relevant in trials at Redland Bay.

- Other pests. Heliothis is the major pest of tomatoes and capsicums and it was imperative to control it in these trials. However conventional insecticides could not be used in the check or baited treatments because of the likelihood they would kill fruit fly. *B. thuringiensis* was used, and while it was reasonably effective some heliothis damage still occurred, which complicated fruit assessment. Other pests and diseases (eg aphids and cluster caterpillar, fusarium) also damaged plants and fruit in the trials and caused considerable difficulties. The problem of minimising the effects of other pests while not interfering with fruit fly control so that the effectiveness of the bait can be determined is a difficult one.

- Seasonal occurrence and suitability of host. The lack of infestations in autumn trials at Bundaberg and in all trials at Ayr-Bowen indicates that fruit flies numbers may be low enough in some areas and seasons to be a minor problem only. Fruit flies

generally are arboreal and may not prefer lower growing crops such as tomatoes and capsicums. If the pest is not present the trials will not be successful.

- Relevance of trap catches. Results from these trials and from many other field trials carried out by the Horticulture fruit fly team clearly demonstrate that male lure trap catches are not directly related to crop infestation. Lures such as cue-lure are very strong attractants and may draw male flies into a trap over considerable distances (up to a kilometre). Hence a trap catch in a treated block does not necessarily accurately indicate the number of female flies present.

- Control or check plots. Trials in the first year showed that the "control" or "check" plots had to be treated for heliothis to ensure that enough sound fruit were available to determine fruit fly infestation. The level of infestation in check plots in all trials has been much lower than expected. This raises the possibility that the risk of fruit fly infestation in commercially grown tomatoes and capsicums is much lower than generally accepted. However, no data were currently available to support this, although such data for capsicums since has been gathered in this project (see chapter "Monitoring fruit fly infestation levels in commercial capsicum crops").

These difficulties are not easily overcome.

A lot useful information was gathered despite the problems and the apparent lack of success. This includes the knowledge that fruit fly will infest all the colour stages of large tomatoes and capsicums, and that not all stung and infested fruit can be identified by visual inspection. Useful experience was gained in conducting baiting trials on vegetables.

In citrus, baiting was tested by treating large commercial orchards and sampling fruit to demonstrate the absence of fruit fly infestation. Similar trials would be useful in tomatoes and capsicums but the necessity to control heliothis and other pests in these crops with conventional insecticides would make it extremely difficult to determine whether the bait or the insecticides were responsible for fruit fly control. It is likely that many of the older insecticides, particularly the organophosphates, are effective against fruit fly although they are not registered for that use. However some of the new, more specific, insecticides currently being developed and registered may not affect fruit flies and may allow such trials to be done in tomatoes and capsicums.

Evaluating the components of baits

Introduction

The baiting trials in tomatoes and capsicums using standard baits (Mauri's protein lure plus Hy-Mal) were not successful. There are a number of possible reasons for that, as discussed in the section on those trials. The standard baits are effective in other crops, particularly tree crops, but it is possible that their efficacy may be improved, and an improved bait formulation may help to make them effective in vegetables.

Fruit fly baits generally include two main components – a proteinaceous fruit fly attractant and an insecticide to kill the flies that are attracted. The protein component is frequently an autolysed or hydrolysed yeast protein but other protein sources have been shown to be effective. Other components such as thickeners or extenders can also be added to increase the effectiveness of a bait. Important factors in the action of a bait include its ability to attract fruit flies, its ability to kill the flies, and the length of time it remains effective once applied in the field.

A number of experiments were conducted to evaluate various components of the baits. These were:

(i). Evaluation of three corn starch thickeners.

The ability of three corn starch thickeners/extenders (Ultra-Sperse, K4484, and Instant Clearjel) to improve the efficacy and longevity of yeast autolysate baits was evaluated in a trial at Redlands Research Station.

(ii). Evaluation of Nu-Film products in fruit fly baits.

In this trial two Nu-Film products, Nu-Film 17 and Nu-Film P, and Keltrol (a Vanthan gum thickening agent) were evaluated as extenders/thickeners to improve the efficacy and longevity of yeast autolysate baits for fruit fly control.

(iii). Comparison of bait formulations with wild flies in a guava orchard.

A trial was conducted in March 2001 in the guava orchard at Redlands Research Station to evaluate Keltrol thickening agent and to compare two insecticides, Hy-Mal (maldison) and Lorsban (chlorpyrifos), which are registered for use in protein baits in Queensland. Hy-Mal is currently registered for all fruit fly hosts including tomatoes but chlorpyrifos is registered for a number of tree crops only and not for vegetable crops.

(iv). Comparison of the attractancy of three protein sources to Queensland fruit fly.

In this experiment three commercial protein bait products were tested for their ability to attract Queensland fruit flies of different ages. It is important that baits attract and kill young, immature female flies before they start ovipositing.

(v). Field assessment of Naturalure in capsicums.

All baiting trials in this project were carried out using the industry standard bait (Mauri's Protein Autolysate plus Hy-Mal insecticide). In this trial a new bait product, Dow AgroSciences Naturalure Fruit Fly Bait, was tested. Naturalure had been tested extensively in tree crops in a separate Horticulture Australia project (AH00012), but it had not previously been tested in vegetables. Naturalure is a formulated bait which contains an attractant protein source, spinosad as a toxicant and a number of other components which increase efficacy and longevity. Spinosad is far less toxic than the insecticides currently registered for fruit fly baits in Australia. Data generated by Project AH00012 is currently being used to seek registration for Naturalure in Australia. This trial has been reported as Trial 9 in the section on baiting trials, "Testing protein baits for fruit fly control in capsicums and tomatoes".

Materials and methods

(i). Evaluation of three corn starch thickeners.

The relative effectiveness of bait formulations with different thickening agents was evaluated using spot bait sprays over knockdown sheets in a fruit fly netted nectarine block at the DPI Redlands Research Station. The corn starch thickeners used were Ultra-Sperse, K4484, and Instant Clearjel.

A randomised block design with four treatments replicated four times inside the enclosure was used. Each treatment was represented by 50ml of a bait formulation applied to the foliage of a single tree over an area of approximately one metre square. A 1.5m square calico sheet suspended on an aluminium frame 60cm above the ground was erected under each spray application area. The three test products were evaluated in comparison to the standard fruit fly bait formulation without thickener.

The thickeners were all mixed at a rate of 4% as recommended by Dr Robert Mangan USDA (pers. comm.). The thickeners were mixed with water on the day previous to the test to allow complete mixing. All baits were mixed using Mauris Pinnacle Fruit Fly Bait as the protein source (2%) and Hy-Mal as the toxicant at the registered rate (4.35ml/L). The bait formulations are detailed in Table F4.

Approximately 5000 *B. tryoni* (Queensland fruit fly) from a laboratory colony were released into the cage immediately after the baits were applied on day 0, and approximately the same number of flies were released again on day 4. At the 0 day release, these flies were 7 days old and had been fed sugar and water only so that their response to protein would be maximised.

Dead flies on the sheets were counted on an hourly basis on the first day and then once a day for 10 days. The total numbers of flies for each bait treatment, for each 24 hour period from 8am one day to 8am the next day were calculated. All flies were returned to the laboratory at Indooroopilly for counting and sexing.

Table F4
Thickened bait formulations using corn starch thickeners for sheet knockdown test in nectarine orchard.

Formulation	Water	Mauris Protein	Hy-Mal	Thickener
1. Ultra-Sperse	975ml (thickened water)	20ml	4.35ml	40g
2. K 4484	975ml (thickened water)	20ml	4.35ml	40g
3. Instant Clearjel	975ml (thickened water)	20ml	4.35ml	40g
4. Standard	975ml	20ml	4.35ml	-

(ii). Evaluation of Nu-Film products in fruit fly baits.

The relative effectiveness of bait formulations with different Nu-Film thickening agents was evaluated using spot bait sprays over knockdown sheets in a nectarine block at the Redlands Research Station in October 2000. Half of the nectarine block (approximately 70 trees) was fully enclosed in a permanent fruit fly proof netted structure that allowed laboratory reared flies to be released into the enclosure for the test (as in *(i)* above). The remaining trees were fully exposed to wild fruit fly populations. The test was replicated in both the enclosed trees and in the exposed trees at the same time.

A randomised block design with four treatments replicated four times both inside and outside the enclosure was used. Each treatment was represented by 50ml of a bait formulation applied to the foliage of a single tree over an area of approximately one metre square. A 1.5m square calico sheet suspended on an aluminium frame 60cm above the ground was erected under each spray application area. The two Nu-Film products and Keltrol were evaluated in comparison to the standard fruit fly bait formulation.

The mixing rates for the two Nu-Film products were the equivalent of 300ml/ha based on standard baiting practice in citrus where bait is applied at a rate of 15L/ha. All baits were mixed using Mauris Pinnacle Fruit Fly Bait as the protein source and Hy-Mal as the toxicant at the registered rate (4.35ml/L). The bait formulations are detailed in Table F5.

Approximately 5000 *B. tryoni* were released into the cage immediately after the baits were applied on day 0 and approximately the same number of flies were released again on day 8. At release, these flies were 16 days old and had been fed sugar and water only so that their response to protein would be maximised.

Dead flies on the sheets were counted on an hourly basis on the first day and then twice a day for 13 days. The total number of flies for each bait treatment, both inside and outside the cage,

for each 24 hour period from 8am one day to 8am the next day were calculated. All flies were returned to the laboratory at Indooroopilly for counting and sexing.

Table F5
Bait formulations using Nu-Film products for sheet knockdown test in nectarine orchard.

Formulation	Water	Mauris Protein	Hy-Mal	Thickener
1. Nu-film 17	955ml	20ml	4.35ml	20ml
2. Nu-Film P	955ml	20ml	4.35ml	20ml
3. Keltrol	975ml (thickened water)	20ml	4.35ml	40g
4. Standard	975ml	20ml	4.35ml	-

(iii). Comparison of bait formulations with wild flies in a guava orchard.

The trial was conducted in a block of approximately 60 untreated guava trees at the time when fruiting was heavy thus ensuring a large population of wild flies. The following four bait formulations were evaluated.

1. Mauris Pinnacle Protein Lure (20ml) + Hy-Mal (4.35ml) + 975ml water
2. Mauris Pinnacle Protein Lure (20ml) + Hy-Mal (4.35ml) + 975ml thickened water (5g Keltrol per litre)
3. Mauris Pinnacle Protein Lure (20ml) + chlorpyrifos (4ml) + 976ml water
4. Mauris Pinnacle Protein Lure (20ml) + chlorpyrifos (4ml) + 976ml thickened water (5g Keltrol per litre).

The experiment was conducted in a four by four randomised block design with a single bait spot (50ml) being applied to an area of foliage approximately one metre square on each of 16 trees evenly spaced throughout the block. A calico drop sheet (1.5m by 1.5m) supported on an aluminium frame (60cm high) was placed under each bait application area. Dead flies on the sheets were counted on an hourly basis on the first day and then twice a day for 15 days. The mean number of flies for each bait treatment for each 24 hour period from 8am one day to 8am the next day were calculated. All flies were returned to the laboratory at Indooroopilly for identification, counting and sexing.

(iv). Comparison of the attractancy of three protein sources to Queensland fruit fly.

The three protein source products were: Solulys, a spray dried corn-steep protein; Millers Nulure Protein Bait; and Mauri's Pinnacle Protein Lure.

Laboratory bioassays were carried out in a constant temperature room at 26^{o}C and 60-70% RH as per the procedures detailed in Lloyd and Drew (1996). Cages used were 30 x 30 x 30cm, with aluminium rod frames and gauze sleeves.

All flies used in the experiment were from one batch of pupae. Their emergence date was recorded, and they were fed sugar and water only. Males and females were tested in separate cages. Each cage contained 20 flies.

All baits were diluted to make a 2% solution, and 1ml of this solution was applied to 4cm^2 wettex. Controls were 1ml of tap water applied to 4cm^2 wettex. At the beginning of each run (3 cages x 3 treatments x 1 sex), the sugar and water were removed from all cages and 2 dry wettex squares were placed on top of each cage for 10 minutes to allow the flies to investigate the sponges. The dry wettex sponges were then removed and replaced with one control and one test sponge per cage (randomised distribution of test sponges allocation to cages) with the sponges in diagonal positions on the top of each cage.

The numbers of flies on each sponge were recorded after 2, 4, 6, 8, and 10 minutes. At 5 minutes the cages were rotated 180^o to avoid any light attractancy factors. At the end of the test all sponges were discarded and all of the flies used were killed and discarded.

(v). Field assessment of Naturalure in capsicums.

This trial has been reported as Trial 9 in the section on baiting trials, "Testing protein baits for fruit fly control in capsicums and tomatoes".

Results

(i). Evaluation of three corn starch thickeners.

Total number of flies knocked down for each treatment over the four replicate sheets for the 10 day period are shown in Table F6.

Table F6
Total number of flies knocked down for each treatment.

Treatment	*Total flies*
Instant Clearjel	170
Ultra-Sperse	140
K 4484	363
Standard Mauris	368

The mean daily counts on the sheets are shown in Figure F2.

(ii). Evaluation of Nu-Film products in fruit fly baits.

The daily totals of wild flies killed by each bait treatment on trees outside of the cage are shown in Figure F3.

Figure F2
Mean number of flies caught on sheets under bait spots. Flies released on Day 0 (2/12/99) and on Day 4 (7/12/99).

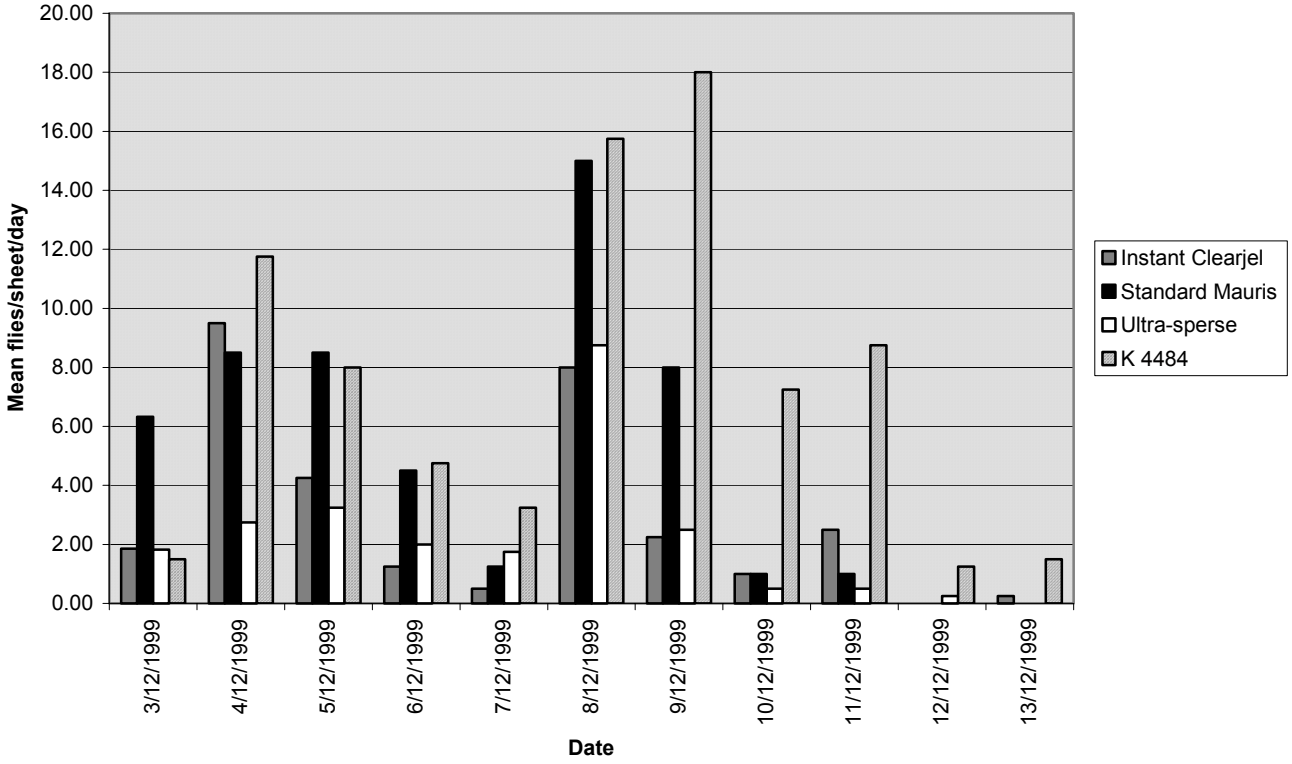
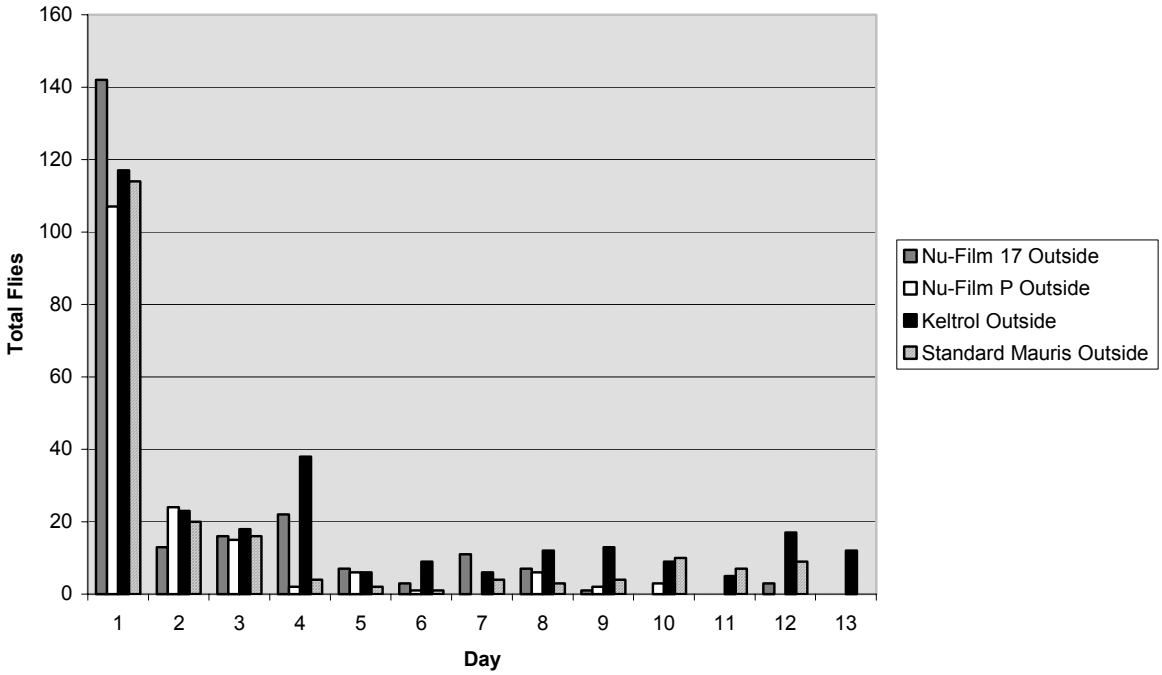


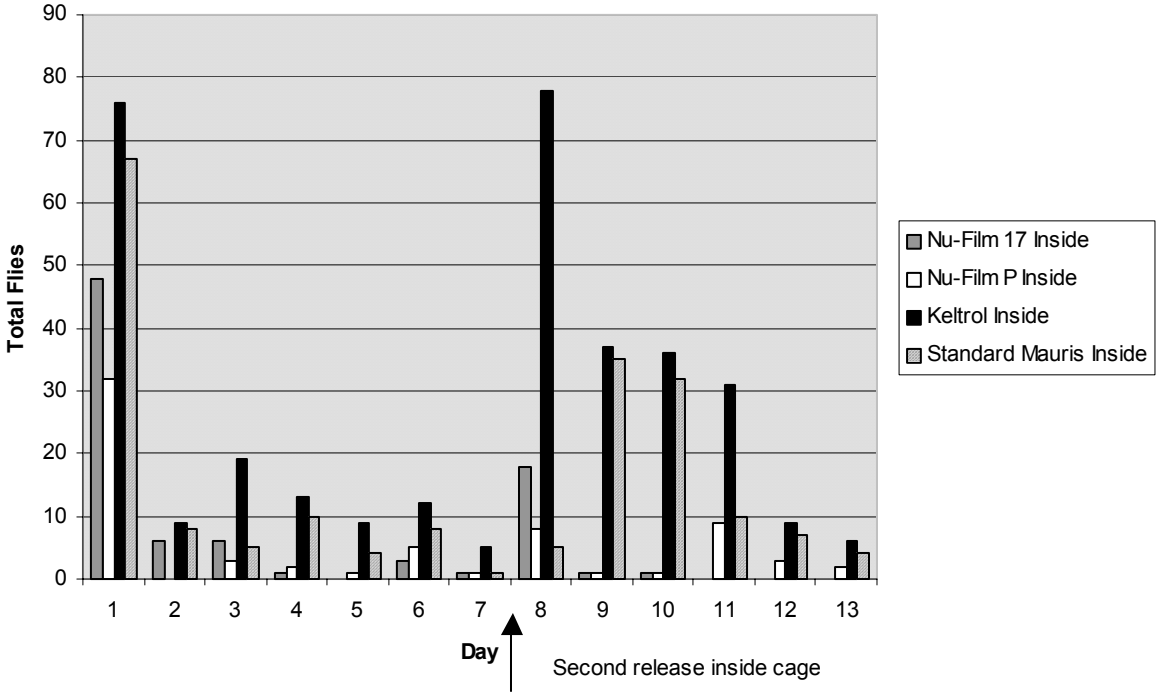
Figure F3
Total number of flies per treatment per day from trees outside of the cage.



The trial significantly impacted on the wild population within the first four days, which meant that any improvement in the longevity of the bait could not be detected. The results were therefore analysed on the basis of the overall knockdown for the 13-day period. The analysis showed no significant differences between the treatments (p=0.252). The variability outside the cage was much greater than under the controlled conditions inside the cage.

The daily totals of Queensland fruit flies killed by for each of the bait treatments inside the cage are shown in Figure F4**.**

Figure F4
Total number of flies per treatment per day from trees inside of the cage.



Analysis of the total fly catch inside the cage across the 13 days of the trial showed significant differences between the treatments (p=0.001).

Nu-Film P	17.00	a
Nu-Film 17	21.25	a
Standard Mauris	49.00	b
Keltrol	85.00	c

(Treatments followed by the same letter were not significantly different (LSD 5% =27.44).)

The Keltrol significantly improved the performance of the standard bait but both of the Nu-Film products decreased performance of the standard bait.

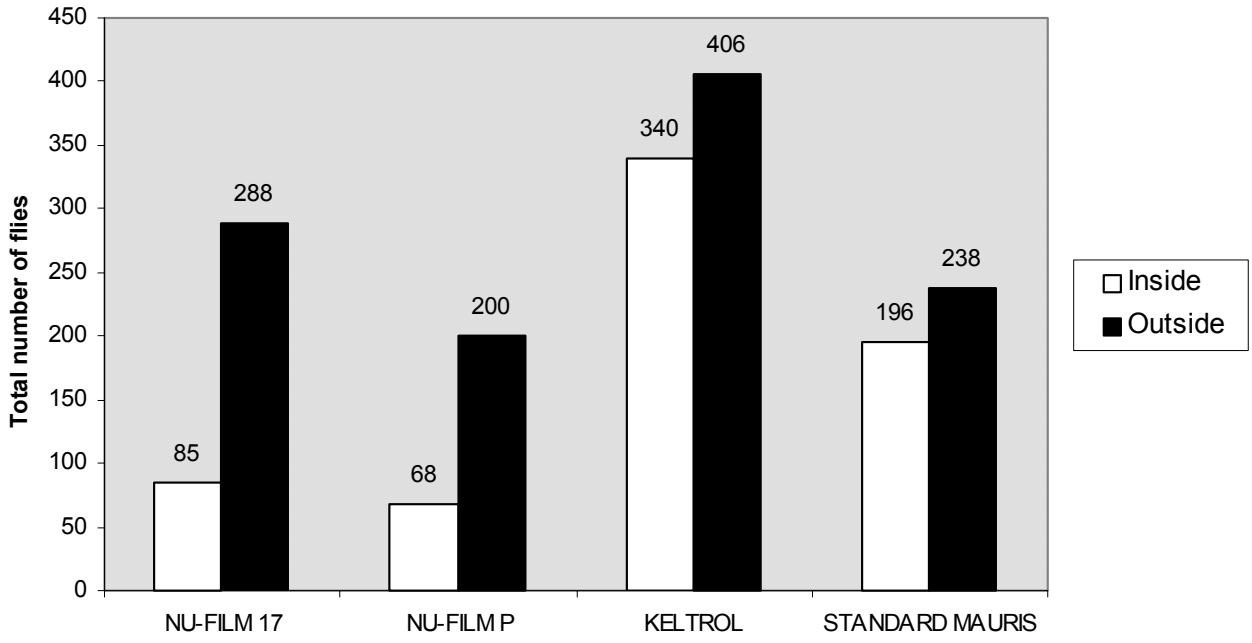
Analysis of the fly catch inside the cage across Days 1 to 3 from the first release showed no significant differences between the treatments (p=0.177), however, across Days 8-10 (after the second release) analysis showed significant differences between the treatments (p=0.012).

Nu-Film P	2.50	a
Nu-Film 17	5.00	a
Standard Mauris	18.00	ab
Keltrol	37.75	b

(Treatments followed by the same letter were not significantly different (LSD 5% =20.15).)

An overall summary of the numbers of flies knocked down by each treatment both inside and outside the field cage is shown in Figure F5.

Figure F5
Comparison of total knockdown for each bait inside and outside field cage.



Although the previous two analyses indicated no significant treatment differences at the initial time and significant differences at the subsequent time the split plot analysis did not yield a significant interaction between treatment and time (p=0.210). Also, although three of the four treatments had lower fly counts for the second period, the fourth treatment (Keltrol) had an increased count which meant that there were no differences between the two time periods (mean count Days 1-3 = 15.9, Days 9-11 = 15.8; p=0.976). There were significant treatment differences (p=0.007).

Nu-Film P	5.25	a
Nu-Film 17	9.63	ab
Standard Mauris	18.62	bc
Keltrol	30.00	c

(Treatments followed by the same letter were not significantly different (LSD 5% =12.60).)

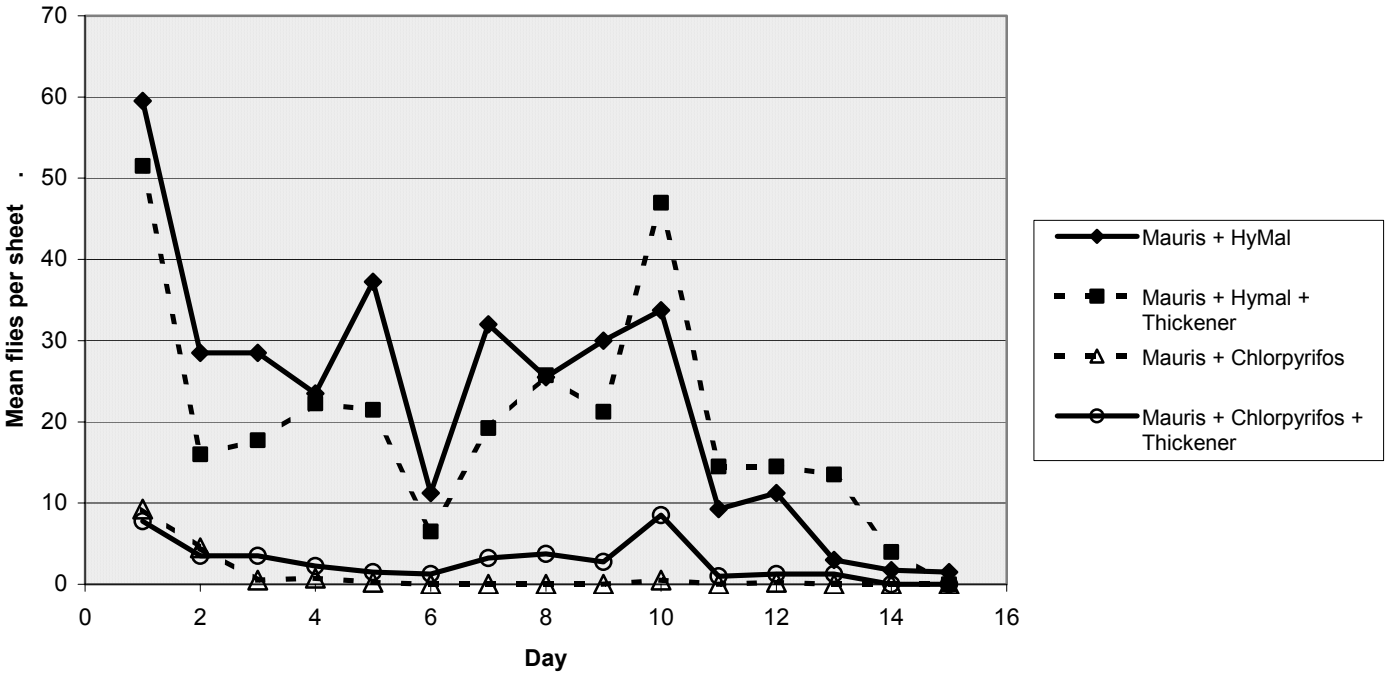
It is unlikely that with a new release of flies on day 7 that the efficacy of Keltrol actually increased but on that particular day it clearly outperformed the other three baits. Since the

catches of the other baits had reduced, the slight improvement in longevity of the bait was compounded because more flies were probably available to be caught by Keltrol.

(iii). Comparison of bait formulations with wild flies in a guava orchard.

The mean numbers of flies caught with each bait formulation over the fifteen day period are shown in Figure F6.

Figure F6.
Efficacy of bait formulations in sheet knockdown trial in guava block at Redlands Horticulture Research Station.



The fifteen day total numbers of flies killed by each bait formulation were analysed using a square root transformation and ANOVA (Table F7). The two baits containing Hy-Mal were not significantly different to each other, but both were significantly different to the two baits with chlorpyrifos, which also were not significantly different to each other.

Significantly more flies were recovered from sheets under the two Hy-Mal bait formulations than under the chlorpyrifos formulations. The addition of xanthan gum thickener did not increase the efficacy of bait with either of the insecticides. The highest knockdowns with all bait formulations were in the first 24 hours. Ten days after application, the Hy-Mal baits caught approximately three times the number of flies as the chlorpyrifos baits in the same 24 hour period. Only very small numbers of flies were caught on sheets on day 15 and the experiment was discontinued at this time.

Of the total of 2,696 flies caught on sheets during this experiment, 84.97% were *B. tryoni,* 14.72% were *B. neohumeralis* with the remaining 0.31% being represented by *B. jarvisi*, *B. cucumis* and *B. nigra*. Of the total flies responding to the baits, 36.5% were males and 63.5%

females with approximately similar distribution of the sexes occurring with each bait formulation.

Table F7
Ranked means of total flies killed by bait formulations over 15 days.

Bait formulation	Transformed mean*	Back transformed mean
Mauris + chlorpyrifos	3.96 a	15.68
Mauris + chlorpyrifos + thickener	6.17 a	38.07
Mauris + Hy-Mal	16.46 b	270.93
Mauris + Hy-Mal + thickener	17.99 b	323.64

*Means with same subscript are not significantly different at the 5% level (LSD = 4.334).

(iv). Comparison of the attractancy of three protein sources to Queensland fruit fly.

The means of the maximum number of flies feeding are shown in Table F8.

Table F8
The mean maximum numbers of female and male flies feeding at each protein source.

		Mean of the maximum numbers feeding		
Fly age (days)	Sex	Mauris	NuLure	Solulys
3	female male	8.33 11.33	9.67 11.33	10.67 10.00
5	female male	13.33 13.00	12.67 14.00	12.33 14.00
7	female male	13.33 13.00	12.67 14.00	12.33 14.00
10	female male	9.00 7.33	8.00 10.67	11.33 11.33
14	female male	7.67 10.00	8.00 10.33	7.67 6.33
18	female male	9.67 8.33	7.33 5.00	7.33 6.33
22	female male	7.67 10.00	7.00 6.33	7.00 10.67

Analysis of these results showed no significance differences in the feeding response of Queensland fruit fly to any of these protein sources. However, there was an overall increase in feeding activity in 5 and 7 day old flies compared to younger and older flies.

(v). Field assessment of Naturalure in capsicums.

This trial has been reported as Trial 9 in the section on baiting trials, "Testing protein baits for fruit fly control in capsicums and tomatoes".

Discussion

(i). Evaluation of three corn starch thickeners.

Although the thickener K44-84 appeared to improve the efficacy of the standard bait, particularly after the second release of flies five days after the initial release, analysis of the results showed the differences between thickeners were not significant.

Five analyses of the data were undertaken (the first 2 both as randomised block analyses and repeated measures analyses):
Release 1: 3/12 to 7/12 (using totals for the randomised block analysis)
Release 2: 8/12 to 13/12 (using totals for the randomised block analysis)
Overall total (as a randomised block only)

Each data set was analysed as a randomised block design. None of the analyses showed a significant difference between treatments. For release 1 the treatment effect was close to significance ($p=0.080$). Though Ultrasperse and Clearjel were considerably lower than the Standard Mauris the differences were not significant using Fisher's Protected LSD test. For release 2, K44-84 had the largest catch (it and the Standard were basically interchanged to what they were in release 1). Ultrasperse and Clearjel were again considerably lower, though the differences were not statistically significant.

Analysis of the data for release 1 and 2 as repeated measures analyses (taking the counts at each day rather than totalling them across the period) reflected the same result as the randomised block analyses excepting that the known difference across time was significant. There was no significant interaction between the treatments and time i.e. for a particular release, each treatment behaved in essentially the same way as time from release increased.

This research indicated that further work was warranted to investigate potential improvements in bait efficacy by the addition of an appropriate thickener, but not all thickeners appeared to enhance bait efficacy.

(ii). Evaluation of Nu-Film products in fruit fly baits.

At the rate tested, Nu-Film 17 and Nu-Film P provided no improvement to the efficacy or longevity of standard fruit fly bait. Keltrol appears to provide some improvement in the longevity of bait when compared to the standard. However, further testing using a non-competitive experimental design would be required to confirm this improvement.

(iii). Comparison of bait formulations with wild flies in a guava orchard.

This experiment again failed to demonstrate any improvement in the efficacy or longevity of standard bait due to the addition of a food type thickener.

The finding that baits containing Hy-Mal performed significantly better than baits containing chlorpyrifos was unexpected. The differences between the two insecticides were clearly evident from the first 24 hour period so it seems unlikely that the results were due to differential breakdown of the insecticide components. Chlorpyrifos is registered for use in baits in Queensland on a variety of tree crops and is know to provide a high level of fruit fly control in commercial orchard situations (eg citrus in the Central Burnett area).

The reason for the poor performance of the chlorpyrifos baits in the field knockdown test is not entirely clear. The responses of flies to baits with chlorpyrifos or Hy-Mal insecticide applied to fresh guava leaves were also tested in a laboratory cage bioassay. On the day of application, the chlorpyrifos bait resulted in 98% mortality and the Hy-Mal bait resulted in 85% mortality. Initial responses and feeding behaviour with the two baits were observed, and there was no indication that the either of the insecticides was repellent. The most likely explanation is that in the choice situation with wild flies in the guava block where baits with chlorpyrifos and baits with Hy-Mal were both available, flies showed a preference for the Hy-Mal baits. In a commercial orchard situation where there is no choice, flies obviously respond to bait containing chlorpyrifos because this insecticide has been shown in numerous trials to provide a high level of field control.

(iv). Comparison of the attractancy of three protein sources to Queensland fruit fly.

The laboratory cage feeding tests showed that there were no significant differences between the three different protein types, Mauri's, NuLure and Solulys in terms of their ability to attract flies over short distances. This suggests that protein seeking flies will respond to a wide range of proteinaceaous odours and that other factors may be more important in determining the efficacy of baits in field control.

(v). Field assessment of Naturalure in capsicums.

This trial provided a good indication that baiting in vegetable crops could provide effective fruit fly control, as shown by the reduction in infestation levels from 17% to approximately 3% once baiting started. However, proving the effectiveness of baits for fruit fly remains difficult when complicated by the high level of damage caused by other insect pests, particularly heliothis. Clearly the level of control of heliothis provided by *B. thuringiensis* was unsatisfactory in this trial, but other insecticides could not be used as they also may have affected fruit flies. This clearly is a difficult problem to overcome when assessing baits (or other insecticides) for fruit fly control in capsicums and tomatoes.

The activities carried out in this section of the project were aimed at finding methods for improving the efficacy of baiting in vegetable crops based on the fact that field trials undertaken in other parts of the project did not deliver the desired outcomes.

Results can be summarised as follows.

- The addition of corn starch thickeners to standard bait did not improve efficacy.
- Nu-film extender products did not improve bait efficacy.

- Results with the addition of Keltrol thickener to baits were variable. In Experiment (ii) in a protected field cage environment, Keltrol improved bait efficacy but in Experiment (iii), in an exposed orchard situation, Keltrol did not significantly enhance bait efficacy with either maldison or chlorpyrifos as the bait insecticide.
- Maldison performed significantly better than chlorpyrifos as a bait insecticide when mixed with the standard protein attractant.
- There were no significant differences in attractancy between three different commercially available protein sources when evaluated in laboratory cage tests.
- An innovative approach to testing the field efficacy of the new spinosad bait Naturalure in capsicums showed that weekly baiting was effective in reducing the level of fruit fly infestation. However, further research will be required to develop fully integrated insect pest management strategies for fruit fly susceptible vegetable crops.

Testing insecticides against Queensland fruit fly

Introduction

Fruit flies are important pests of many fruit and vegetable crops. Queensland fruit fly, *Bactrocera tryoni* (Froggatt), is the main pest species in both tomatoes and capsicums causing direct damage when the females lay eggs into fruit and the larvae feed inside the fruit. As well, they are a quarantine problem with some countries and some other states of Australia imposing strict quarantine barriers to prevent their introduction. Growers can use a variety of methods to control fruit flies in tomato and capsicum crops. These can include spraying crops in the field and/or treating fruit after harvest to disinfest them. Often both field spraying and post-harvest disinfestation methods are used.

Three insecticides, dimethoate, fenthion and trichlorfon, currently are registered or permitted for use against fruit flies as field cover sprays in tomatoes and capsicums. They have few other uses in these crops so usually are applied solely to satisfy interstate quarantine requirements for field control of fruit flies (as defined in Interstate Certification Assurance (ICA) protocols). Often it is suspected that other insecticides applied to the crops for other purposes (e.g. to control heliothis) may also control fruit flies. If they do, then the specific fruit fly sprays really are unnecessary and are wasteful. As well, many growers claim that these fruit fly sprays, which have broad spectrum activity, disrupt effective IPM systems by killing beneficial insects in the crop.

The aim of the research reported here was to test if various insecticides used, or that might be used, as cover sprays for the control of other insect pests in tomatoes and capsicums also have the ability to affect adult fruit flies or prevent development of eggs and larvae, thereby reducing the risk of infestation. Both laboratory and field experiments were done.

The laboratory tests were carried out under controlled conditions as a preliminary study to determine which non-fruit fly insecticides would be used in the field trial. Insecticides were applied to fruit by dipping to simulate 100% coverage with a field spray treatment. The effects of treatments at 0.5, 1.0, 4.0 and 24 hours after application to the fruit were determined. Fly response to treated fruit (landings and ovipositions), adult mortality, and survival of immature stages (fly emergence) were recorded.

The field trial was done to assess the efficacy of a number of insecticides applied as cover sprays in controlling fruit flies in capsicums. No references could be found to earlier studies on comparative field-testing of insecticides against fruit flies that might have indicated useful trial techniques so a small plot randomised block design was used. The insecticides included two of the fruit fly chemicals, dimethoate and trichlorfon, as well as old and new insecticides that are or could be used against heliothis or other pests in the crop. Insecticides that showed promise in the laboratory tests were included.

Materials and methods

Laboratory tests
Mature, fully coloured organic tomatoes from a certified supplier were used for all tests to ensure freedom from other pesticide residues. Flies were from the laboratory colony of *B. tryoni* at DPI Indooroopilly and were 10-14 days old and fed sugar, water and protein from emergence until testing. Hence, female flies were mature and ready to oviposit at the time of each test.

For each insecticide to be tested, three replicate samples of fruit for each of the four post treatment times were treated at the same time. Five litres of the test insecticide was prepared at the recommended dilution rate for field application. Fruit of approximately uniform size were selected and two fruit (100-150 g) were allowed for each treatment. Fruit were placed in nylon mesh bags for dipping in the insecticide (approximately 2 min to ensure complete coverage).

After removal from the dip solution, fruit were placed in a single layer on wire mesh over drip trays within a large, fruit fly proof cage. Fruit were held for the required times (0.5, 1.0, 4.0 and 24h) and then two fruit per treatment were placed in each gauze mesh cage (30 x 30 x 30cm) containing 10 male and 10 female flies. Sugar and water were provided for flies during the test period. The treated fruit were placed onto a petri dish to minimise chemical contamination of the cage. All cages were held in controlled temperature rooms at 25°C and 67% relative humidity.

For each insecticide test on any one day, three control cages containing untreated fruit were set up at the beginning of the experiment in a separate CT room to avoid any contamination or fumigant effect from the test chemical (i.e. a total of 15 cages for each insecticide tests).

Fly response to the fruit such as landing and ovipositing, and visibly affected or knocked down flies were recorded at 5, 10, 15, 30 min, 1.0, 1.5, 2.0, 2.5 and 3.0h during the fruit exposure period. Fruit were removed from cages at the end of three hours. Further mortality counts were done after 24 and 48 h. Fruit from each treatment cage were set up on drip trays over moist vermiculite, to rear through any eggs that may have been deposited during the exposure period by females not affected by the test insecticides. This was done to give some qualitative indication of the residual effects of different insecticides on immature development inside treated fruit. However, it was recognised that infestation levels across treatments would be variable due to the fact the different insecticides would result in differences in female mortality and possibly differences in ovipositional behaviour. Fruit were assessed after 5-7 days holding, the numbers of dead larvae in fruit were recorded, and pupae were recovered from the vermiculite and held for adult emergence.

The insecticides were tested at the highest recommended mixing rates as follows:

Dimethoate	75ml / 100L
Chlorpyrifos (Lorsban)	200 ml / 100L
Trichlorfon	100ml / 100L
Spinosad (Success)	80 ml / 100L
Abamectin (Vertimec)	90 ml / 100 L
Methamidophos (Nitofol)	190ml / 100L
Emamectin (Proclaim)	30g / 100L
Indoxacarb (Avatar)	17g / 100L

Methomyl (Lannate)	
+ wetter	200 ml /100L
Dipel Forte	100g / 100L
Azamax (Neem)	300ml / 100L
Eco-oil	500ml / 100L

Field trial

The trial was conducted on a crop of capsicums, variety Matrix, grown at Bundaberg Research Station from October 2001 through January 2002, a time of year when fruit flies were expected to be active. The crop was grown on plastic mulch using standard agronomic practices. The crop was sprayed twice weekly with *Bacillus thuringiensis* as DiPel DF to manage heliothis, and with Kocide alternated with copper oxychloride for disease control.

The trial was a randomised block design with eight treatments and three replicates. Plots were 4 rows by 10 m, with 1.5 – 2 m untreated guard areas between plots. Insecticide treatments were applied in the equivalent of 1000 L water/ha using a motorised sprayer fitted with a boom and four Albuz brown hollow cone nozzles operated at 690 kPa. Treatments were applied weekly from 17 December to 14January with a total of five applications. The treatments used in the trial were:

Untreated check
Dimethoate – Rogor (400 g/L EC) – used at 300 g ai/ha = 750 ml/ha
Trichlorfon – Lepidex (500 g/L EC) – used at 1200 g ai/ha = 2400 ml/ha
Methamidophos – Nitofol (580 g/L EC) - used at 1102 g ai/ha = 1900 ml/ha
Emamectin – Proclaim (44 g/kg WG) - used at 11 g ai/ha = 250 g/ha
Abamectin – Vertimec (18 g/L EC) - used at 5.4 g ai/ha = 300 ml/ha
Spinosad – Success Naturalyte (120 g/L SC) - used at 96 g ai/ha = 800 ml/ha
Methomyl – Lannate (225 g/L) - used at 450 g ai/ha = 2000 ml/ha

Fruit were harvested on three occasions. Twenty-five fruit from half to full colour were picked from each plot on 2nd January, 50 on 8th January, and 25 on 15th January. Fruit were selected on colour and obviously rotten fruit were not picked but apart from that the selection of fruit was unbiased. The fruit were returned to the laboratory and placed, five to seven to a box, on fine vermiculite in plastic containers with meshed lids and held in a constant temperature room at approximately 24°C for nine days to allow eggs to hatch so that larvae could be easily found. The fruit were then cut and carefully examined to determine the presence of larvae and the vermiculite was sieved to find pupae. The numbers of infested fruit and the numbers of larvae and pupae found were recorded. Pupae were kept and the resulting adults identified. Analyses of variance were done on the numbers of infested fruit on each sample date and in total.

Two Lynfield design fruit fly traps baited with cue lure, one on either side of the planting, were monitored throughout the trial. Traps were cleared weekly and the flies counted and identified using the keys in Drew *et al.* (1982) and Drew (1989).

Results

Laboratory tests
Maximum effectiveness for almost all insecticide treatments was shown with fruit treated 30 minutes prior to testing so detailed results for these tests only are shown in Table F9. During the 3h exposure period, none of the insecticides had a strong repellent effect on flies as fly landings were recorded on all treated fruit. The total numbers of landings on treated fruit were, however, generally less than that on control fruit. This could have been due to weak repellency or it may have been simply due to the fact that fast acting insecticides began killing flies soon after exposure thus reducing the number of flies available to land on the fruit. The highest number of landings were recorded on spinosad treated fruit (even higher than on any of the control fruit) and the highest number of ovipositions were recorded on fruit treated with Dipel Forte and with Eco-oil indicating that these products had no inhibitory short term effect on fruit fly behaviour.

Mean percent mortality at the end of 3h exposure to fruit treated 30 min prior to testing (Table F9) showed that the standard fruit fly cover spray insecticide, dimethoate, was the most effective, fast acting treatment with 72% mortality. Chlorpyrifos, which is registered for use in fruit fly baits but not as a cover spray for fruit flies, resulted in 60% mortality under the conditions of this test but mortality is likely to be much higher when the insecticide is mixed with a food source such as bait protein and ingested. Forty-eight hours after exposure, fly mortality had increased to 95% with dimethoate and 80% with chlorpyrifos. Trichlorfon, which is used as a field cover spray and in protein baits (on fruit trees) for fruit fly control, produced only 32% mortality after 48 hours. Its use in baits in fruit trees is known to provide effective field control. This suggests that ingestion of trichlorfon mixed with a protein food source greatly increases mortality. Slower acting insecticides resulted in higher levels of mortality after 48h (eg spinosad 60%, abamectin 68%, methamidophos 90%, emamectin 82%). The remaining insecticides, indoxacarb, Dipel Forte, Azamax and Eco-oil were ineffective in killing adult flies.

The effects of fruit treated with insecticides at various times up to 24 h prior to exposure to flies on adult fly mortality are shown in Figure F7. The effectiveness of all insecticides (except dimethoate) had decreased rapidly by 24h after fruit treatment. Adult fly mortality from exposure to 24h treated fruit remained high (88%) with dimethoate. The next highest residual effect of insecticide was with methamidophos at 73% mortality after 24h.

The rearing through of eggs deposited during the insecticide exposure period was only ever intended to provide qualitative data because the infestation levels in the test fruit would have been very variable due to the different effects of chemicals on adult females. No flies emerged from 30min post treatment fruit, which had been dipped in dimethoate, chlorpyrifos, spinosad, abamectin, methamidophos, emamectin and methomyl. In some of these treatments (dimethoate, chlorpyrifos, trichlorfon, methamidophos, methomyl) no dead larvae were found when treated fruit were dissected after holding. This indicated that these insecticides caused either high female mortality or an inability to oviposit.

Adult flies were reared from all but one batch of control (untreated) fruit, but numbers were extremely variable. Furthermore, large numbers of dead larvae were found in many of the control samples. This may have been due to larval overcrowding in the infested fruit or to drowning of larvae in the rotting fruit. In disinfestation experiments conducted by DPI researchers at Indooroopilly, high larval mortality in artificially infested tomatoes is

frequently encountered. It has been shown to be reduced to some extent by breaking open fruit and allowing fluid to escape, which may reduce larval drowning (Marianne Eelkema pers. comm.). This was not done in these tests.

Significant numbers of dead larvae but no emerged adults were found in fruit treated with spinosad, abamectin, and emamectin. This suggested that flies exposed to these treatments were able to oviposit into fruit but larvae were unable to develop possibly due to the effects of absorbed insecticide and possibly due to the inherent adverse characteristics of tomatoes for larval survival. Adult flies were reared from fruit treated with indoxacarb, Dipel Forte, Azamax. and Eco-oil which showed that these products were ineffective against both adult and immature fruit fly stages.

Field trial

The fruit fly species and numbers caught in the traps each week are given in Table F10. The numbers for the two traps have been totalled. Only four species were trapped, with Queensland fruit fly, *Bactrocera tryoni* (Froggatt) the most common.

Table F10
Numbers and species of fruit flies trapped around the trial site.

Date of trap clearance	Number of each species		
	Bactrocera tryoni	*B. neohumeralis*	Other
5 Dec. 2001	194	14	3 *B. bryoniae*
12 Dec. 2001	196	19	-
19 Dec. 2001	85	14	1 *Dacus absonifacies*
26 Dec. 2001	225	13	-
2 Jan. 2002	326	18	-
9 Jan. 2002	382	36	-
16 Jan. 2002	89	10	2 *B. bryoniae*

The infested fruit data are shown in Table F11. Mean numbers of infested fruit at each harvest and the total are shown as well as the back-transformed means for the total. The total values were subjected to square root (x + 0.5) transformation before analysis. Analyses of variance were carried out on each data set but only that for the total numbers of infested fruit is reported. F-tests were not significant at the 5% level in each case. Coefficients of variation for each set of data are shown. Infestation rates were very variable throughout the trial and there were no significant differences between treatments.

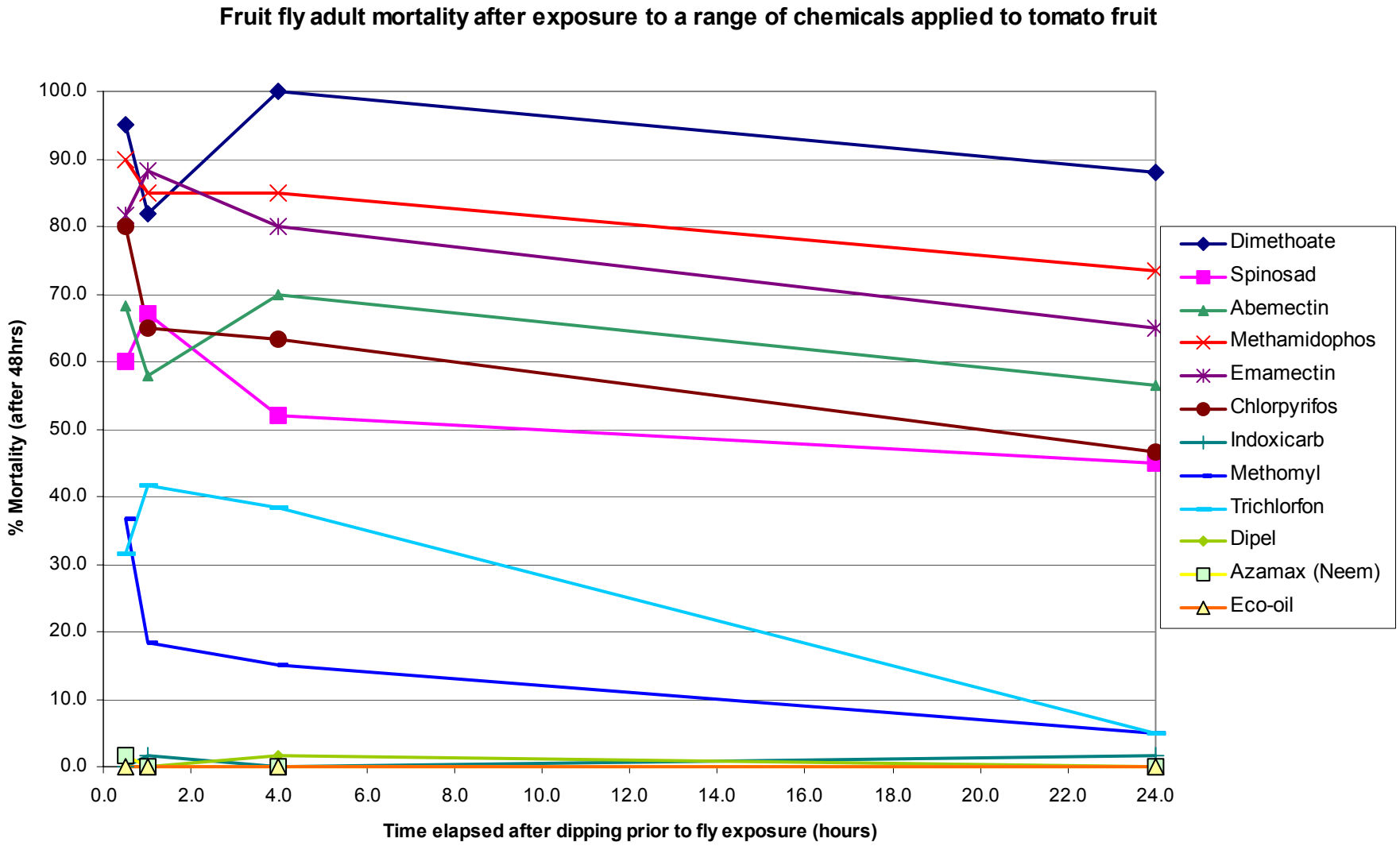
All of the 250 adults that emerged from pupae collected from infested fruit were *B. tryoni*. As well seven parasitic wasps, *Biosteres kraussi* (Fullaway) (Braconidae), emerged.

Table F9

Effects on Queensland fruit fly (adults and immatures) of 3 hours exposure to tomatoes treated with various insecticides 30 min prior to testing. The numbers of flies landing and ovipositing on fruit during the exposure period are also included.

Chemical	Total count of flies on fruit	Total count of Ovipositing flies	Mean % mortality (3hr)	Mean % mortality (48hr)	Total Dead Immatures	Total emerged Flies
Dimethoate (75ml/100L)	24	5	72	95	0	0
Control	99	33	0	1.6	149	140
Chlorpyrifos (200ml/100L)	13	0	60	80	1	0
Control	67	21	0	0	127	17
Trichlorfon (100ml/100L)	19	1	28	32	4	19
Control	38	14	0	1.6	0	14
Spinosad (80ml/100L)	114	12	0	60	90	0
Control	70	4	0	0	225	162
Abamectin (90ml/100L)	49	9	0	68	24	0
Control	73	23	0	0	145	11
Nitofol (190ml/100L)	23	4	45	90	0	0
Control	73	15	0	0	58	29
Emamectin (30g/100L)	44	4	7	82	20	0
Control	80	24	0	5	33	42
Indoxicarb (17g/100L)	65	15	0	0	130	25
Control	64	22	0	1.6	66	12
Methomyl (200ml/100L) + wetter	13	4	35	37	0	0
Control	40	15	0	0	0	0
Dipel Forte (100g/100L)	43	31	0	0	83	24
Control	50	40	0	0	52	18
Azamax (Neem) (300ml/100L)	26	8	0	2	30	18
Control	35	9	0	3	187	87
Eco-oil (500ml/100L)	23	20	0	0	8	59
Control	30	12	0	0	10	254

Figure F7


Fruit fly adult mortality after exposure to a range of chemicals applied to tomato fruit
% Mortality (after 48hrs)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
Time elapsed after dipping prior to fly exposure (hours)
Dimethoate
Spinosad
Abemectin
Methamidophos
Emamectin
Chlorpyrifos
Indoxicarb
Methomyl
Trichlorfon
Dipel
Azamax (Neem)
Eco-oil

Discussion

Laboratory tests
The laboratory tests provided valuable data on the efficacy of a range of insecticides against fruit fly infestation. Many of these products are used for control of other insect pests in vegetable crops but the effectiveness of some of them against fruit flies has not previously been documented.

Field trial
Despite the high numbers of fruit flies caught in the two cue lure traps beside the trial (Table F10), very few fruit were infested. Only 5.3% of harvested fruit from the untreated check plots were infested, a low value compared with figures of 43% and 21% recorded from commercial capsicum crops in the Lockyer Valley and Bundaberg respectively (see commercial crop sampling). The reasons for this low infestation rate are not known. Fruit flies were present in large numbers, there were reasonable numbers of ripening fruit in the crop, and the trial area was not over-sprayed with other insecticides that may have controlled fruit flies. DiPel DF is specific against lepidopteran insects.

Table F11
Mean number of fruit fly infested fruit

Treatment (rate g ai/ha)	Mean number of infested fruit in harvest number: 1	2	3	Total	Total (trans)*
Untreated check (-)	0.33	3.67	1.33	5.3	3.84
Dimethoate (300)	0.33	0.67	0.00	1.0	0.70
Trichlorfon (1200)	0.33	3.67	1.33	5.3	5.15
Methamidophos (1102)	0.67	0.67	0.67	2.0	1.70
Emamectin (11)	0.33	1.00	1.67	3.0	2.48
Abamectin (5.4)	2.33	4.00	1.67	8.0	4.99
Spinosad (96)	0.67	2.67	0.67	4.0	3.84
Methomyl (450)	0.67	2.33	1.33	4.3	4.26
C. V. %	220	144	116	128	55

* Back-transformed means following $\sqrt{(x + 0.5)}$ transformation before analysis. The F-test was not significant at the 5% level.

Overall the condition of the plants and the fruit was quite poor by harvest time. The trial deliberately was done during summer to ensure there was fruit fly activity, but the 2001-2002 summer was abnormally hot with unusual hot, dry northerly winds. The plants were stressed by the weather, and many fruit were sunburnt or affected by fruit rots. Numbers of other insect pests including silverleaf whiteflies, heliothis, cluster caterpillar, and green vegetable bug were high and they also damaged fruit. While DiPel DF gives some control of heliothis

and cluster caterpillar it is not highly effective against them, and no conventional insecticides could be used in case they compromised the trial. Possibly the poor quality of the plants and fruit reduced their attractiveness to the fruit fly.

No differences in numbers of infested fruit between treatments were shown for any harvest or for the total harvest. Infestation was variable across the trial area, as shown by the very high coefficients of variation in Table F10. Figure F8 shows a plan of the trial with the total numbers of infested fruit for each plot, and it clearly shows how uneven the infestation was. There were several large trees near the C6 corner of the trial and possibly they provided shelter for fruit flies that attacked plot C6. (Treatment 6 had low infestation rates in replicates A and B.) The right hand side of the trial (A5 to C7) was bordered by young, densely planted citrus trees, which may have provided shelter for fruit flies.

Clearly, no conclusions can be drawn from this trial about the effectiveness of any of the insecticides treatments in preventing fruit fly damage in the field. It is worth noting that some fruit were infested in the two treatments currently registered for fruit fly control. This may not be of concern as even the best insecticide will not give total control of a pest.

How should trials to test the efficacy of insecticides against fruit fly in the field be done so that useful results are obtained? The experience of this trial indicates that small plot trials do not work because of uneven distribution of fly attack over the trial area, possibly due to the location of shelter and/or host trees. Possibly placing a trial in the middle of a bare block or in the middle of a large capsicum planting may overcome this, but the risk then would be that the insect would not find the trial plants and there would be no infestation. Larger scale trials may be better but trial design issues (e.g. with replication), cost, and the requirements for labour and facilities to store fruit to assess the trial would be problems. It may be necessary to test one insecticide at a time in comparison to an untreated check using large areas of crop with minimal or no replication. It would be interesting to know how efficacy data for the insecticides currently registered for fruit fly control were collected.

Trials also have to be done at times when it is likely that fruit fly are active, but other pests that damage fruit are likely to be active then and controlling them poses problems. Standard insecticides cannot be used in case they also affect the fruit flies.

In summary, the laboratory and field tests have provided valuable information on the efficacy of a number of insecticides against Queensland fruit fly, and on the methods and techniques that can be used to do such studies. The outcomes of this work have important implications in developing IPM programs in fruit fly host vegetable crops.

Figure F8

The plan of the fruit fly insecticide field trial. The numbers in brackets are the treatments, numbered in order of the list in the text. The numbers in bold are the total numbers of infested fruit from that plot.

C	(6) **22**	(2) **3**	(8) **6**	(7) **6**	
	(4) **0**	(3) **3**	(1) **3**	(5) **5**	
B	(3) **8**	(2) **0**	(1) **0**	(8) **4**	
	(4) **3**	(7) **2**	(5) **0**	(6) **2**	
A	(3) **5**	(6) **0**	(2) **0**	(4) **3**	
	(1) **13**	(7) **4**	(8) **3**	(5) **4**	

Monitoring fruit fly infestations in commercial capsicum crops

Introduction

It is well known that capsicums are hosts of fruit flies, particularly of *Bactrocera tryoni* (Queensland fruit fly) and *B. neohumeralis* (lesser Queensland fruit fly) (see Hancock *et al.* 2000), and that many growers either treat crops with insecticides for fruit fly control in the field and/or use post-harvest insecticide treatments against fruit flies. However there is no information available on the levels of fruit fly infestation that actually occur in commercial capsicum crops (i.e. what percentage of fruit are infested in the field) or on the effect of insecticides, applied for a variety of reasons, on the levels of infestation.

There are three main capsicum growing areas in Queensland. In the Lockyer Valley capsicums normally are grown in the summer months; in the Bundaberg area crops are grown for most of the year with fruit harvested from March to December, although with peaks in production from April to August and from October to December; while in the Dry Tropics (Bowen – Gumlu – Ayr) capsicums are grown from March to November. The districts experience different climatic conditions and crops may be surrounded by different vegetation types that may influence the fruit fly populations in the districts and hence pressure on the crops.

The studies reported here were done to obtain information on the fruit fly populations and infestation levels in commercial capsicum crops in these areas.

Materials and methods

(i) Lockyer Valley

Three commercial farms in the Lockyer Valley were selected to undertake the survey of fruit fly populations and infestation levels during the 2001-2002 summer cropping season.

Four Lynfield traps baited with cue lure and maldison were erected on the edges of each crop and two traps were placed inside each crop. The traps were cleared each week and the flies identified and counted.

On each farm at harvest time a random sample of fruit was picked across the entire block. The number of fruit per row required to give a total of approximately 500 fruit was predetermined. The picker walked between two rows picking one fruit from each side at appropriate intervals to give the required number per row. Fruit of harvest size, irrespective of quality, were taken provided the fruit was still whole (i.e. not completely rotten in any place). Two harvests, separated by approximately a week, were done on two of the farms. However on the third farm the grower abandoned the block after the first pick mainly because of the high level of sunburn damage and very poor quality of fruit caused by the unseasonably high temperatures at the time. The quality of the remaining fruit was so poor as to preclude a second sample. Hence approximately 1000 fruit were sampled from two farms and 500 from the third. Growers were asked to provide spray records for the sampled blocks.

The fruit were returned to the laboratory, examined and classified as green, half coloured or ripe (i.e. fully coloured). In each colour category fruit were divided into damaged (i.e. any blemish, sun-burn, heliothis damage, and possible fruit fly stings) and undamaged (i.e. no blemishes at all). No attempt was made to separate fruit on the basis of regular or irregular shapes. Fruit were placed into containers and the numbers of infested fruit determined using the procedures described in the Materials and methods section of the baiting trials. The percentages of fruit infested, and the larval load (i.e. the number of larvae and pupae in each infested fruit) were recorded.

In early 2002 a questionnaire was circulated to all (or as many as could be identified) Lockyer Valley capsicum growers in an attempt to obtain additional information about fruit fly infestation levels in commercial capsicum crops in that season. The three growers whose crops were sampled were not included in this survey, as information on their situation with regard to fruit flies had already been obtained. The questionnaire is shown as Figure F9.

(ii) Bundaberg

A total of seven commercial crops were surveyed in the Bundaberg district: one, designated B1 in the 2001 spring season; four in the 2002 spring season (B2, B3, B4, and B5); and two in the 2003 autumn season (B6 and B7). (B1, B2 and B6 were crops grown in different seasons and locations by the same farmer. B3 and B7 were crops grown by another farmer in close spatial proximity to each other.)

Similar methods were used for each crop, and the methods were similar to those used in the Lockyer Valley survey. Spray records were obtained for the crops where possible.

Four Lynfield traps baited with cue lure and maldison were erected around each crop and two were placed inside each crop. The traps were cleared each week and the flies identified and counted.

Fruit were harvested on several occasions for each crop. These harvests were separated by between one and four weeks. The initial aim had been to harvest 1000 fruit from each crop over two or three picks, but this had to be modified due to factors such as the grower destroying the crop, limited constant temperature room space or limited labour. Each crop had been planted as a series of borders (a group of 9 or 12 rows, with borders separated by a tractor-way) so the number of fruit per border needed to give the required total of fruit was calculated and picked at appropriate intervals from either two or four rows per border. Fruit of harvest size irrespective of quality was picked without bias, with only rotten fruit rejected.

The fruit were returned to the laboratory, examined and classified in the same way as the Lockyer Valley fruit. Fruit were placed into containers and the numbers of infested fruit determined using the procedures described in the Materials and methods section of the baiting trials. The percentages of fruit infested, and the larval load (i.e. the number of larvae and pupae in each infested fruit) were recorded.

The variety of capsicums, approximate area of sampled crop, dates of harvests and number of fruit harvested are listed in Table F12.

Table F12
Crop information and collection data for the Bundaberg district crop sampling

	Crops sampled						
	B1	B2	B3	B4	B5	B6	B7
Variety	Warlock	Warlock	Warlock	Tycoon	Target	Warlock	Predator
Area (ha)	4.4	9.0	3.6	6.0	2.9	2.3	1.7
Harvest date 1	11 Dec 2001	28 Nov 2002	24 Oct 2002	30 Oct 2002	3 Dec 2002	7 April 2003	9 April 2003
No. fruit	352	400	331	501	200	300	403
Harvest date 2	19 Dec 2001	-	5 Nov 2002	12 Nov 2002	10 Dec 2002	6 May 2003	23 April 2003
No. fruit	514	-	340	300	200	301	390
Harvest date 3	-	-	19 Nov 2002	-	-	-	20 May 2003
No. fruit	-	-	330	-	-	-	400
Total no. fruit	866	400	1001	801	400	601	1193

(iii) Dry Tropics

Commercial crops were not sampled in the Dry Tropics. Instead fruit were sampled from crops grown without insecticide sprays (fungicides were applied) at Ayr Research Station in 2001 and 2002.

In 2001 a block of capsicums 60 m by 10 rows (approximately 0.12 ha) was grown using standard agronomic practices except that no insecticides were applied. Approximately 300 fruit were collected randomly from the crop each week for eight weeks from mid October to late November. They were returned to the laboratory, weighed, assessed as green or red, and then held in containers in a constant temperature room at 25^{o}C for 14 days before being cut and examined for the presence of fruit flies. Lynfield traps baited with cue lure and maldison were placed in mango trees around the trial crop and two traps were placed in the crop. They were cleared each week and the flies counted and identified.

In 2002 capsicum fruit were harvested from an unsprayed block of capsicums at Ayr on two occasions in December. Fruit were assessed as damaged or undamaged, placed in containers and held for 13 days (first pick) and 6 days (second pick) before being cut, and the numbers of fruit fly recorded. Many of the fruit had decomposed badly so that it often was impossible to determine which fruit, or how many fruit, in a container had been infested. The presence and numbers of fruit fly in containers was recorded.

Figure F9
The questionnaire sent to Lockyer Valley capsicum growers.

CAPSICUM GROWER QUESTIONNAIRE - LOCKYER VALLEY 2002

For QDPI Project VX99035 Fruit fly and Heliothis control in vegetable crops.

GROWER : **LOCATION:**

1. **Have you had any fruit fly problems in capsicums this season?**
   YES / NO
   To what extent?

2. **How did the fruit fly problem this season compare to previous years?**

3. **What fruit fly control do you normally use for capsicums?**

   Chemical : **Mixing rate:**

   Application rate: **Timing :**

4. **Could you provide an estimate (%) of your crop loss in the field due to fruit fly infestation.**

5. **Approximately what % of your crop is culled on the packing line because of likely fruit fly infestation.**

6. **Do you have fruit fly monitoring traps installed on your property?**

   How many?

7. **If so, what is the approximate trap catch per week? (please circle)**

<50 50-100 100-200 200-300 300-400 >400

Thank you for taking the time to answer these questions. Your responses will be useful in interpreting survey data we have collected this season to find out more about fruit fly problems in your area.

The Project Team QHI Indooroopilly
Annice Lloyd, Ed Hamacek, Thelma Peek, Chris Neale.
With assistance from Julian Winch, Valley Crop Monitoring, Gatton .
(Project Leader Iain Kay , DPI Bundaberg)

Results

(i) Lockyer Valley

The results of the fruit monitoring from the three Lockyer Valley growers are presented in Tables F13 to F15 and the trap catches from the farms in Figure F10. Table F13 shows the percentage of infested fruit in each fruit colour and damage category, Table F14 summarises the percentage of infestation in damaged and undamaged fruit while the fruit quantities are shown in Table F15. The spray records are shown in Table F16. The growers are listed as LV1, LV2 and LV3 to protect their privacy.

Table F13
Percentage fruit fly infestation and larval load per fruit at different stages of maturity – Lockyer Valley

Grower (total fruit) (larval load/fruit)	Percentage of fruit infested in each category						Total % infestation
	Green		Half coloured		Ripe		
	damaged	undam.	damaged	undam.	damaged	undam.	
LV1 (1083)	1.6	0.0	0.3	3.3	1.0	0.0	0.9
(load)	(2.0)	(0.0)	(1.0)	(2.5)	(2.0)	(0.0)	(2.0)
LV2 (1069)	6.4	3.0	10.3	1.8	10.1	18.0	8.0
(load)	(10.4)	(7.2)	(4.8)	(1.0)	(9.7)	(9.1)	(8.4)
LV3 (483)	45.2	30.0	33.5	32.6	53.1	66.7	39.0
(load)	(13.0)	(5.9)	(11.3)	(16.0)	(20.6)	(15.7)	(14.5)

Table F14
Overall percentage infestation in damaged and undamaged fruit.

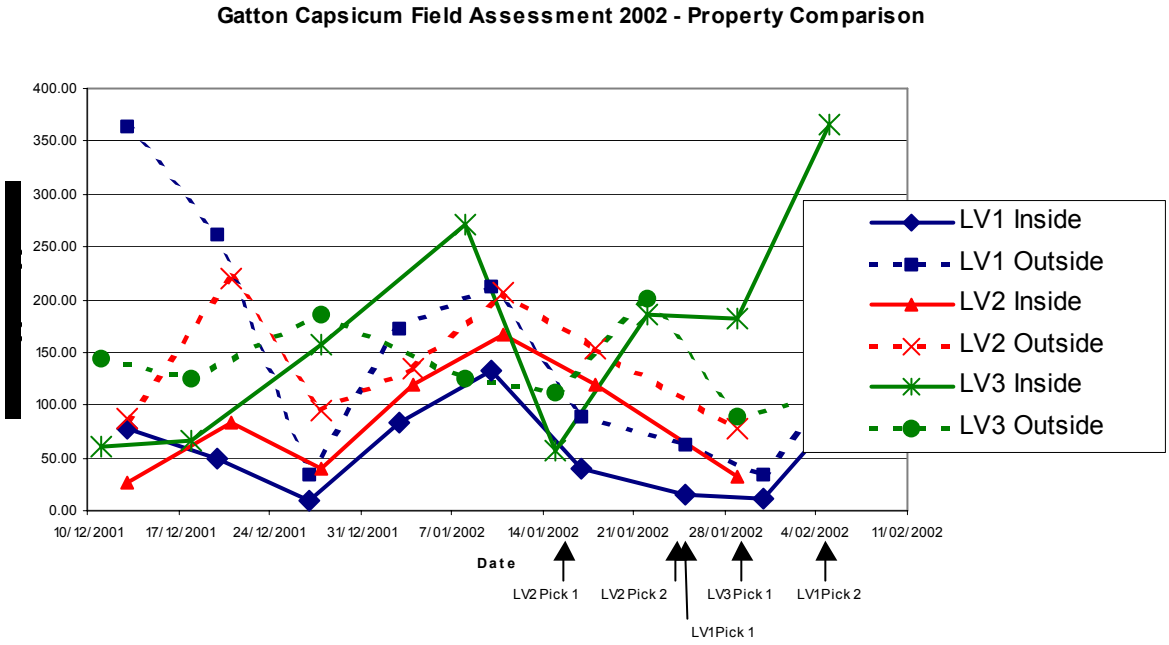
Grower	% of sample damaged	% infestation in damaged fruit	% of sample undamaged	% of infestation in undam fruit
LV1	63.0	0.7	37.0	1.3
LV2	71.3	10.2	28.7	5.2
LV3	65.4	41.1	34.6	34.7

All farms had some fruit infested by fruit fly but the level of infestation varied greatly between farms, ranging from approximately 1% to 40%. Fruit flies were recorded from all colour stages of fruit and from both damaged and undamaged fruit.

Table F15
The number and weight of fruit in each category sampled from each Lockyer Valley farm

Grower	Damaged fruit	Undamaged fruit
LV1		
Green - no of fruit	128	211
Green - Wt of fruit	17.8 kg	32.4 kg
Half coloured-no	349	150
Half coloured-wt	45.7kg	26.7
Red -no of fruit	205	40
Red- wt	23.9kg	8.5kg
Totals	682 fruit 87.4kg	401 67.6 kg
LV2		
Green - no of fruit	109	197
Green - wt of fruit	9.9kg	22.8kg
Half coloured - no	155	110
Half coloured wt	16.7kg	13.9kg
Red -no of fruit	437	61
Red-wt of fruit	48.0kg	8.1kg
Totals	701 74.6kg	368 44.8kg
LV3		
Green - no of fruit	42	60
Green- wt of fruit	6.4kg	10.2kg
Half coloured - no	176	92
Half coloured -wt	27.0kg	18.4kg
Red- no of fruit	98	15
Red-wt of fruit	17.4kg	3.8kg
Totals	316 fruit 50.8kg	167 fruit 32.4kg

Figure F10
Mean weekly trap catches of Queensland fruit fly on the Lockyer Valley farms



The trap catches clearly show that Queensland fruit flies were active in and around all three crops throughout the growing season. The numbers caught are high.

Table F16
Spray records for the sampled Lockyer Valley crops. Spray records were not obtained for LV3. (Bt is *Bacillus thuringiensis kurstaki*.)

Grower LV1		Grower LV2	
Date	Insecticides applied	Date	Insecticides applied
23 Nov 01	dimethoate	1 Dec 01	methomyl + dimethoate
30 Nov 01	methomyl	19 Dec 02	methomyl + dimethoate
4 Dec 01	methomyl + Bt	27 Dec 01	methomyl + dimethoate
10 Dec 01	methomyl + Bt	6 Jan 02	methomyl + dimethoate
24 Dec 01	methomyl	12 Jan 02	methomyl + dimethoate
28 Dec 01	methomyl + Bt		
3 Jan 02	methomyl + Bt		
8 Jan 02	methomyl + trichlorfon + pirimicarb		
15 Jan 02	trichlorfon		
22 Jan 02	trichlorfon		
30 Jan 02	trichlorfon		
5 Feb 02	trichlorfon		
12 Feb 02	trichlorfon		

These spray records show that both growers applied insecticides registered for use against fruit flies (dimethoate and trichlorfon). Fruit were sampled from LV1 in late January and early February 2002, and from LV2 in mid January to late January. The records show that LV1 applied sprays before and during the harvest period, and that LV2 stopped spraying just before harvest.

Only three replies to the questionnaire were received. The responses are summarised in Table F17.

Table F17
Responses to the questionnaire

Question	Response Grower A	Response Grower B	Response Grower C
1. Did you have any fruit fly problems in your capsicums this season	NIL	YES Very little	NIL
2. How did this compare to last year	Less than last year	Less than last year	None
3. Fruit fly control used in capsicums	Lebaycid (= fenthion) Label rate Every 10 days	No sprays specifically for fruit fly	Dimethoate Every 7-10 days
4. % crop loss in field due to fruit fly	2-5%	NIL	NIL
5. % of crop loss in packing line due to fruit fly	This season-NIL	1%	NIL
6. How many fruit fly traps do you have on your property?	6	None	None
7. What is your approx. trap catch per week?	<50	Not applicable	Not applicable

(ii) Bundaberg

The fruit fly catches from the traps around and in crops, the fruit fly infestation results from the fruit harvests, and the crop spray records for each crop surveyed at Bundaberg are presented in the following series of tables (Tables F18 – F30) and in the text.

B1: Trap catches for crop B1 are given in Table F18, and the results from the fruit collection in Table F19. The fruit were not separated into damaged and undamaged, but a high proportion was affected by sunburn.

Table F18
The number of fruit flies collected each week in cue lure traps in crop B1.

Date 2001	Number of fruit flies in each trap					
	Trap 1	Trap 2*	Trap 3	Trap 4	Trap 5*	Trap 6
7 Dec	0	2	2	1	4	2
14 Dec	0	2	2	0	6	4
21 Dec	0	2	1	2	7	0

(* traps in the crop)

Numbers of flies were low. The majority of the flies were *B. tryoni* (76%), with 22% *B. neohumeralis*, and 2% *B. bryoniae*.

Table F19
The number of fruit in each category and percentage infested with fruit flies in crop B1

Fruit category	Number of fruit and percentage infested with fruit flies					
	Harvest 1		Harvest 2		Total	
	No. fruit	% infested	No. fruit	% infested	No. fruit	% infested
Green	21	0	0	0	21	0
Half colour	222	0	278	0	500	0
Full	109	0	236	0	345	0
Total	352	0	514	0	866	0

No fruit infested with fruit fly were recorded in the two harvests. Spray records for this crop were not obtained but the farmer's normal practice is to apply methomyl and *B. thuringiensis kurstaki* as a mix several times a week, and it is presumed that this was done with this crop.

B2. Trap catches for crop B2 are given in Table F20. Five traps only were used, four around the crop and one inside. Only one harvest, all of green fruit, was made in this crop. The farmer picked the crop as green fruit over a short period so preventing further sampling, or sampling of half or full coloured fruit. No infested fruit were recorded in the 400 fruit (324 undamaged and 76 damaged) collected. Spray records for this crop were not obtained but it is assumed that methomyl and *B. thuringiensis kurstaki* were applied several times a week, the farmer's normal practice.

Table F20
The number of fruit flies collected each week in cue lure traps in crop B2.

Date 2002	Number of fruit flies in each trap				
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*
25 Nov	3	2	4	4	1
2 Dec	4	7	6	10	9
9 Dec	2	1	2	6	3
16 Dec	3	4	5	9	0

(* trap in the crop)

Again, few flies were caught in the traps. The majority of the flies were *B. tryoni* (68%), and the remainder were *B. neohumeralis*.

B3. Trap catches for crop B3 are given in Table F21, and the results from the fruit collections in Table F22.

Table F21
The number of fruit flies collected each week in cue lure traps in crop B3.

Date 2002	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*	Trap 6*
17 Sept	32	37	34	113	6	60
24 Sept	25	113	38	165	34	76
1 Oct	6	106	29	135	45	70
8 Oct	28	101	45	131	15	34
15 Oct	43	143	89	240	32	87
22 Oct	155	399	333	780	271	390
29 Oct	225	495	missing	881	208	425
5 Nov	364	364	missing	487	166	310
13 Nov	449	554	missing	467	202	337
19 Nov	245	260	missing	492	139	255

(* traps in the crop)

Trap 3 disappeared during the week ending 29th October and was not replaced. Large numbers of flies were caught in the traps, especially in late October and November as spring progressed. *B. tryoni* made up 87% of the flies trapped, *B. neohumeralis* 12.5%, *B. bryoniae* 0.4%, and five *Callantra* sp. were trapped.

The grower supplied a record of sprays for the crop and it is presented in Table F23. The records indicate that two dimethoate sprays were applied and presumably these were applied for fruit fly control.

Table F23
Spray records for the B3 crop. (Bt is *Bacillus thuringiensis kurstaki*.)

Date 2002	Insecticides applied	Date 2002	Insecticides applied
27 June	methomyl	3 Oct	methomyl, Bt
7 August	methomyl	7 Oct	abamectin
17 August	methomyl, Bt	10 Oct	methomyl, Bt
27 August	methomyl, spinosad	17 Oct	methomyl, spinosad, dimethoate
9 Sept	methomyl, fipronil	24 Oct	methomyl, fipronil
17 Sept	methomyl, dimethoate	31 Oct	methomyl, Bt, abamectin
25 Sept	methomyl, endosulfan	7 Nov	methomyl

Table F22
The number of fruit in each category, the percentage infested with fruit flies, and the mean larval load in infested fruit in crop B3

Fruit category	Number of fruit and percentage infested with fruit flies							
	Harvest 1		Harvest 2		Harvest 3		Total	
	No. fruit	% infested (load)	No. fruit	% infested (load)	No. fruit	% infested (load)	No. fruit	% infested (load)
Green undam.	103	0 (-)	25	4.0 (4)	24	8.3 (16)	152	2.0 (11.7)
Green dam.	17	0 (-)	5	0 (-)	0	0 (-)	22	0 (-)
Half col. undam.	105	0 (-)	179	1.7 (3.3)	93	8.6 (9)	377	2.9 (7.5)
Half col. dam.	52	0 (-)	72	1.4 (3)	36	38.9 (14)	160	9.4 (13.3)
Full undam.	40	0 (-)	45	6.7 (1.3)	97	17.5 (9.2)	182	11.0 (7.9)
Full dam.	14	0 (-)	14	0 (-)	80	35.0 (10.7)	108	25.9 (10.7)
Total undam.	248	0 (-)	249	2.8 (2.6)	214	12.6 (9.2)	711	4.8 (7.9)
Total dam.	83	0 (-)	91	1.1 (3)	116	36.2 (11.8)	290	14.8 (11.6)
Total	331	0 (-)	340	2.4 (2.6)	330	20.9 (10.8)	1001	7.7 (9.9)

Adult flies were reared from 55 infested fruit and all were *B. tryoni*.

B4. Trap catches for crop B4 are given in Table F24.

Table F24
The number of fruit flies collected each week in cue lure traps in crop B4

Date 2002	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*	Trap 6*
8 Oct	0	2	0	0	0	0
15 Oct	2	6	2	5	3	2
22 Oct	32	30	17	30	3	5
29 Oct	3	7	8	24	1	7
5 Nov	10	2	18	26	3	9
12 Nov	10	19	21	28	5	4

(* traps in the crop)

Trap catches were quite low. Sixty-five percent of the flies trapped were *B. tryoni*, 31% were *B. neohumeralis* and 4% were *B. bryoniae*.

No infested fruit were recorded from 501 fruit sampled at the first harvest. The numbers of fruit in each category were: green undamaged 152; green damaged 39; half coloured undamaged 150; half coloured damaged 54; full coloured undamaged 72; and full coloured damaged 34.

No infested fruit were recorded from 300 fruit sampled at the second harvest. The numbers of fruit in each category were: green undamaged 32; green damaged 4; half coloured undamaged 136; half coloured damaged 66; full coloured undamaged 48; and full coloured damaged 14.

The farmer provided spray records for the crop but did not give the exact dates for many applications. As a result it is difficult to tabulate them so they are presented here:

- methomyl: approximately weekly from 1 August to 11 November (15 or 16 applications);
- methamidophos: five applications on 24 July, 17 August, 24 August, 31 August, and 5 October;
- endosulfan: two applications on 10 August and 15 September;
- *B. thuringiensis kurstaki* on 1August;
- fipronil: two applications on 15 September and 27 September;
- trichlorfon: six applications approximately weekly (7 – 10 d apart) from 27 September to 11 November.

The trichlorfon sprays were for fruit fly management.

B5. Trap catches for crop B5 are given in Table F25. Large numbers of flies were trapped, and 77% were *B. tryoni*, 23% were *B. neohumeralis* and 0.2% were *B. bryoniae*.

Table F25
The number of fruit flies collected each week in cue lure traps in crop B5

Date 2002	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*	Trap 6*
25 Nov	46	16	48	19	54	86
2 Dec	269	550	338	203	726	663
10 Dec	291	555	250	98	348	291
16 Dec	28	109	30	11	60	38

(* traps in the crop)

The results of the fruit collections are presented in Table F26.

The grower reported that the crop was sprayed with *B. thuringiensis kurstaki* (as the bioencapsulated product MVP) approximately weekly, and that it was treated with dimethoate on 12 November and 29 November for fruit fly control.

Table F26
The number of fruit in each category, the percentage infested with fruit flies and the mean larval load in infested fruit in crop B5

Fruit category	Number of fruit and percentage infested with fruit flies					
	Harvest 1		Harvest 2		Total	
	No. fruit	% infested (load)	No. fruit	% infested (load)	No. fruit	% infested (load)
Green undamaged	53	7.6 (7)	38	2.6 (-)*	91	5.5 (7)
Green damaged	8	0 (-)	6	16.7 (-)*	14	7.1 (-)*
Half colour undamaged.	65	1.5 (4)	60	1.7 (4)	125	1.6 (4)
Half colour damaged	34	2.9 (7)	36	8.3 (2.7)	70	5.7 (3.8)
Full undamaged	22	9.1 (8)	19	10.5 (5)	41	9.8 (6.5)
Full damaged.	18	16.7 (7)	41	9.8 (1.3)	59	11.9 (3.7)
Total undamaged	140	5.0 (6.9)	117	3.4 (3.5)	257	4.3 (5.6)
Total damaged	60	6.7 (7)	83	9.6 (16.3)	143	8.4 (3.4)
Total	200	5.5 (6.9)	200	6.0 (2.3)	400	5.8 (4.5)

* fruit were damaged but no fruit fly larvae or pupae were found.

Adult flies were reared from four of the infested fruit and all were *B. tryoni*.

B6. The catches from the cue lure traps are shown in Table F27.

Table F27
The number of fruit flies collected each week in cue lure traps in crop B6

Date 2003	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*	Trap 6*
19 March	1	1	1	0	0	0
26 March	1	6	3	1	0	1
2 April	0	2	1	0	1	0
10 April	0	1	0	0	1	0
16 April	1	3	2	0	0	0
23 April	0	0	0	0	0	0
30 April	1	2	0	0	0	0
8 May	0	0	0	0	0	0
16 May	0	2	0	0	4	2

(* traps in crop)

Very few flies were trapped. Ninety-two percent of the flies were *B. tryoni* and the remainder were *B. neohumeralis*.

No infested fruit were recorded from 300 fruit sampled at the first harvest. The numbers of fruit in each category in the first harvest were: green undamaged 90; green damaged 24; half coloured undamaged 75; half coloured damaged 39; full coloured undamaged 50; and full coloured damaged 22. One half coloured undamaged capsicum had typical internal fruit fly damage but no larvae or pupae were recovered from it. Assuming this fruit was damaged by fruit fly then the infestation rate in this harvest was 0.33% and 0.17% overall.

No infested fruit were recorded from 301 fruit sampled at the second harvest. The numbers of fruit in each category were: green undamaged 115; green damaged 14; half coloured undamaged 81; half coloured damaged 44; full coloured undamaged 22; and full coloured damaged 25.

The crop was sprayed twice weekly with methomyl plus *B. thuringiensis kurstaki*, but no other insecticides were applied.

B7. The catches from the cue lure traps are shown in Table F28 and the results from the fruit collections in Table F29.

Table F28
The number of fruit flies collected each week in cue lure traps in crop B7

Date 2003	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5*	Trap 6*
12 March	64	22	52	124	44	92
19 March	22	9	49	71	48	90
26 March	45	29	33	62	42	77
2 April	33	8	21	46	18	59
9 April	7	2	20	13	6	14
16 April	20	7	12	23	6	19
23 April	0	1	4	6	1	0
30 April	5	4	12	11	2	7
8 May	1	1	4	10	0	3
14 May	0	4	14	12	2	4
22 May	4	6	31	6	3	6
28 May	1	0	3	4	0	3

(* traps in crop)

Moderate numbers of flies were trapped in March and early April but catches fell as autumn progressed. The majority of the flies were *B. tryoni* (88%) while 11% were *B. neohumeralis*, 0.8% were *B. bryoniae* and 0.2% were *Callantra* sp.

Table F29
The number of fruit in each category, the percentage infested with fruit flies and the mean larval load in infested fruit in crop B7

Fruit category	Number of fruit and percentage infested with fruit flies							
	Harvest 1		Harvest 2		Harvest 3		Total	
	No. fruit	% infested (load)	No. fruit	% infested	No. fruit	% infested	No. fruit	% infested (load)
Green undam.	134	0.8 (1)	38	0	43	0	215	0.5 (1)
Green dam.	30	0 (-)	3	0	2	0	35	0 (-)
Half col. undam.	132	0.8 (3)	162	0	157	0	451	0.2 (3)
Half col. dam.	23	0 (-)	53	0	47	0	123	0 (-)
Full undam.	56	0 (-)	74	0	93	0	223	0 (-)
Full dam.	28	0 (-)	60	0	58	0	146	0 (-)
Total undam.	322	0.6 (2)	274	0	293	0	889	0.3 (2)
Total dam.	81	0 (-)	116	0	107	0	304	0 (-)
Total	403	0.5 (2)	390	0	400	0	1193	0.2 (2)

The grower supplied a record of sprays for the crop and it is presented in Table F30. The records indicate that two dimethoate sprays were applied and presumably these were applied for fruit fly control.

Table F30
Spray records for the B7 crop. (Bt is *Bacillus thuringiensis kurstaki*.)

Date 2003	Insecticides applied	Date 2003	Insecticides applied
29 Jan	methomyl	22 March	methomyl, abamectin, dimethoate
2 Feb	methomyl	29 March	methomyl, Bt
18 Feb	methomyl, Bt	6 April	methomyl, dimethoate
25 Feb	methomyl, Bt	13 April	methomyl, fipronil
1 March	methomyl, abamectin	20 April	methomyl, dimethoate
8 March	methomyl, spinosad, dimethoate	4 May	methomyl, dimethoate
15 March	methomyl, Bt		

The insecticides applied include five sprays of dimethoate for fruit fly control.

(iii) Dry Tropics

The numbers of flies caught in traps around and in the capsicum block in 2001 are shown in Table F31.

Table F31
The number of fruit flies collected each week in cue lure traps at Ayr in 2001. Traps 1, 2, 5 and 6 were in mango trees and traps 3 and 4 were in the capsicum block.

Date 2001	Number of fruit flies in each trap					
	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5	Trap 6
23 Oct	57	42	41	24	6*	15*
30 Oct	428	579	575	263	218*	8*
7 Nov	319	475	642	238	135*	15*
19 Nov	532	772	1409	735	385*	1*

(* ants were found in these traps)

B. tryoni was the main species trapped at 97.04% of the catch, with *B. neohumeralis* at 1.98%, *B. bryoniae* at 0.54%, *Dacus aequalis* at 0.01%, *Bactrocera alyxiae* at 0.28%, and *Bactrocera quadrata* at 0.14%.

The results of the fruit collections are shown in Table F32. Quite high numbers of fruit were damaged by heliothis and caterpillars were found in fruit. Consequently many fruit broke down and rotted and some fruit fly damaged fruit may have been overlooked because of this.

Table F32
Numbers of capsicums collected and numbers infested for each collection date at Ayr in 2001

Date 2001	No. fruit collected	Colour of fruit	No. infested by fruit fly	% infested
18 October	307	green	0	0
24 October	304	green	0	0
31 October	301	green and some red	1	0.33
6 November	312	green but mostly red	3	0.96
13 November	312	mostly red	0	0
20 November	291	mostly red	0	0
27 November	312	mostly red	2	0.64
Total	2139		6	0.28

The infestation rate was very low.

It was not possible to determine the numbers of infested fruit in the collections from the 2002 crop because many of the fruit rotted and broke down in the containers. However the number

of containers in which fruit fly larvae or pupae were found provides some record of infestation.

The first collection on 12 December comprised 270 fruit placed in 26 containers. Fruit flies were found in eight containers (in five of 18 containers of undamaged fruit and in three of eight containers of damaged fruit), indicating that at least eight fruit or 3.0% of the fruit were infested. The second collection on 17 December comprised 317 fruit placed in 37 containers. Fruit flies were found in 13 containers (in six of 21 containers of undamaged fruit and in seven of 16 containers of damaged fruit), indicating that at least 13 fruit or 4.1% of the fruit were infested. These still are fairly low rates of infestation.

Discussion

The three study blocks in the Lockyer Valley reflected a broad spread of fruit fly damage from low (LV1) to very high (LV3). Reasonably high numbers of fruit flies were trapped in and around each crop, although catches in traps inside the LV3 crop generally were higher than those in the other two crops. Similarly the study blocks at Bundaberg covered a wide range of infestation rates, from 0% to 36% in one harvest.

In both the Lockyer Valley and Bundaberg the trap catches generally reflected the levels of infestation in the crop. However at Ayr in 2001 there were very large numbers of flies trapped (Table F31) but very low levels of infestation (<1%) in fruit in the unsprayed crop, and in 2002 there again was a low level of infestation in fruit. The reasons for these apparently anomalous results are unknown. Similarly, in both the Lockyer Valley and Bundaberg the larval loads (i.e. the number of fruit fly larvae developing in each infested fruit) reflected the levels of infestation in the crop. These relationships might be expected. A higher level of infested fruit may be due to higher pest pressure combined with poorer control, resulting in more flies in the population to be caught, and to oviposit. There would be more fruit infested, more ovipositions per fruit, and more eggs and larvae to survive. As well, survival will be greater if insecticidal controls are ineffective.

The percentage of fruit infested and the larval load are important considerations for post-harvest disinfestation. The higher they are the more effective the post-harvest treatment needs to be. They are very important factors in a systems approach to fruit fly management in which each step in the pre-harvest and post-harvest treatment of the fruit is part of a whole management system for fruit flies.

In the Lockyer Valley catches of fruit flies in traps were quite high in and around all three crops, although catches fell to lower levels at LV1 in January around harvest. These crops were grown in summer when it would be expected that fruit fly numbers would be at their peak.

Fruit fly numbers, as recorded in traps, varied greatly between the Bundaberg crops studied. Some of the differences may have been due to seasonal effects. For example, the same farmer grew crops B3 and B7 in spring and autumn respectively in fields separated by approximately 50 m using similar spray programs. Trap catches at B3 increased to high levels as spring progressed (Table F21) while at B7 they decreased as autumn progressed (Table F28).

The uses of, and vegetation on, surrounding land may have been an important factor influencing the numbers of fruit flies present at each crop. Crops B1, B2 and B6, which all were heavily sprayed, were located in quite dry areas and were surrounded by other heavily sprayed capsicums, sugar cane crops, dry pasture, and areas of bare fallow, with few alternative hosts or trees nearby. Very few fruit flies were caught around these crops indicating that the local populations were small. Crop B4 was grown in a more intensively farmed area, and was surrounded by sugar cane crops and a range of vegetable crops that were all treated intensively with insecticides. Some, but not many, fruit flies were trapped, again indicating low local population levels. Crop B5, where fairly high numbers of fruit flies were trapped, was grown with other blocks of capsicums and eggplants on a farm surrounded by sugar cane and macadamia orchards, and some dry scrub. Insecticide use in the area was generally low, and particularly so on the farm. Quite high numbers of fruit flies were trapped around crops B3 and B7 although these crops and others nearby were sprayed heavily. The farm on which these crops were grown is close to suburbia, treed watercourses and patches of scrub containing alternative hosts such as guavas, all of which would contribute to the high fruit fly population.

Capsicums harvested at all stages of colour development were infested by fruit flies, although there appeared to be higher levels of infestation in fully coloured red fruit than in green or half coloured fruit.

Fruit flies were recorded from both undamaged and damaged fruit. Most of the damage in both the Lockyer Valley and Bundaberg crops was due to sunburn, and it can be concluded that such damage does not increase or decrease the level of fruit fly infestation. Of more interest and concern are the high levels of infestation in "undamaged" fruit. These fruit had been carefully inspected and either the oviposition stings were missed or the fruit flies had oviposited in hidden sites such as under the calyx. It is unlikely that commercial pickers and sorters would inspect the fruit any more carefully than was done for these samples, so it is probable that such infested fruit would be sent to market.

The spray regimes on the different properties had a significant effect on infestation levels. Both LV1 and LV2 crops were sprayed with insecticides registered for use against fruit flies, with LV1 sprayed with trichlorfon through the harvest period. The LV2 crop had its final spray several days before the first harvest, and this absence of sprays during the harvest period may have allowed fruit flies to successfully infest fruit, resulting in higher levels of infestation than were recorded in LV1. Spray records were not obtained for the heavily infested LV3 crop but it is probable that few sprays were applied as the crop was rather neglected. At Bundaberg the fruit fly numbers in and around several of the crops (B1, B2, B4 and B6) were too low to judge whether the heavy spray regimes on those crops provided protection from infestation. In particular it was not possible, unfortunately, to assess whether the use of methomyl alone (*B. thuringiensis kurstaki* is specific to lepidopteran insects) provided protection in B1, B2 and B6.

Crop B3 with a high population of fruit flies provides good evidence that insecticide sprays provided protection. The final dimethoate spray was applied on 17th October, while other insecticides were applied on 24th and 31st October and on 7th November (Table F23). It would appear that fruit were well protected by the insecticides to the first harvest on 24th October (0% infestation), and reasonably well at the second on 5th November (2.4% infestation). The final harvest on 19th November, a month after the last dimethoate spray and 12 days after the

last application of any insecticide, was heavily infested (20.9%) and with a large larval load (10.8). Clearly the infestation levels rose when the insecticidal protection was removed.

It was disappointing that only three growers responded to the questionnaire. However, the responses obtained, when considered in conjunction with the fruit fly assessment results from three other commercial capsicum properties, do provide some useful information about fruit fly control in vegetables in the Lockyer Valley. One overall conclusion would be that fruit fly problems in this area may be very localised and may vary considerably from property to property. Infestation in one poorly sprayed trial block was quantitatively determined to be 39% while grower B (Table F17) claimed to have zero crop loss when no specific fruit fly treatments had been applied. (It is not known if the farmer used other insecticides for other reasons that also provided fruit fly control.) It is likely that many growers underestimate their crop loss to fruit fly because damaged, blemished and potentially infested fruit is normally discarded by pickers in the field and never reaches the packing line, and a proportion of fruit that appears undamaged may be infested but show no external signs.

The reasons for the low infestation rates in capsicums in the surveys in the Dry Tropics, despite high catches of adult flies in traps, are not known. Possibly some infested fruit were not recorded because they rotted and broke down, drowning the larvae and making them difficult to find. Nearby fruiting mango trees may have been more attractive to the fruit flies, and the females may have preferred to oviposit in mangoes than in the capsicums.

In summary, these surveys have provided useful information on fruit fly infestation in commercial capsicum crops in southeast Queensland. They have shown that high levels of damage do occur, that fruit flies can infest fruit at all colour stages, and that apparently undamaged fruit may be infested. They have indicated that the numbers of fruit flies caught in traps give a broad indication of the level of infestation in fruit, and that insecticides do protect the fruit. Fruit flies are an important problem in capsicums.

Heliothis Studies

Helicoverpa armigera (Hübner) and *Helicoverpa punctigera* (Wallengren), commonly known as heliothis, are major pests of many vegetable crops. Studies on the management of heliothis in tomatoes, capsicums, zucchinis and melons formed a major component of the work undertaken in this project.

Reports on the following topics comprise the Heliothis Studies section of this Final Report:

- Evaluating insecticides against heliothis in tomatoes;
- Evaluating insecticides against heliothis in capsicums;
- Evaluating insecticides against heliothis in zucchinis;
- Evaluating insecticides against heliothis in melons;
- Do additives improve bio-pesticide efficacy?;
- *Helicoverpa armigera* oviposition sites on vegetables and melons;
- Heliothis seasonal occurrence at Bundaberg;
- Protocols for conducting trials with bio-pesticides;
- Bio-pesticides meeting report.

Evaluating insecticides against heliothis in tomatoes

Introduction

Two species of *Helicoverpa*, *H. armigera* (Hübner) and *H. punctigera* (Wallengren) (Lepidoptera: Noctuidae), commonly called heliothis or tomato grubs, are major pests of tomatoes. Moths lay eggs on the plants, usually around the flowers and young fruit but also on leaves, and the larvae feed mainly on flowers and fruit. Damage by *Helicoverpa* spp. to tomatoes causes serious losses in yield, while the quality of fruit with minor damage is affected. Secondary microbial infections cause damaged fruit to rot and break down. Most growers apply insecticides regularly and frequently to control *Helicoverpa* spp. in their crops.

Many insecticides are used to manage heliothis in tomatoes. Interest in biological insecticides and in minimising insecticide use is increasing as interest in IPM develops in the crop. As often the management of other pests in the crop depends upon minimal insecticide use, the use of softer, non-disruptive insecticides against heliothis, the key pest, is needed. The efficacy of several biological insecticides in controlling heliothis in tomatoes was tested in the trials reported here.

Preparations of *Bacillus thuringiensis* subsp. *kurstaki* are used against *Helicoverpa* spp. in tomatoes. One of these preparations is DiPel Forté. There is a need to develop alternative chemicals to allow rotation with DiPel Forté to control *Helicoverpa* spp. in tomatoes using integrated pest management (IPM) programs. (Note: DiPel Forté is now known as DiPel DF following company changes and reorganisation within the agricultural chemical industry.)

The aim of the first trial, done at Bundaberg, reported here was to test the efficacy of XenTari, a preparation of *B. thuringiensis* subsp. *aizawai*, at several rates and the efficacy of methoxyfenozide (ROY 2390), an insecticide in development, in controlling *Helicoverpa* spp. on tomatoes. DiPel Forté was included as a standard for comparison. Data also were collected on the efficacy of these insecticides against potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) and cluster caterpillar, *Spodoptera litura* (F.) (Lepidoptera: Noctuidae), which also were present.

In the second trial, done at Ayr, several bio-pesticides were compared with two conventional insecticides for their control of heliothis.

Materials and methods

Trial 1
The trial was done at Bundaberg Research Station in 1999.

The tomato crop used in the trial was grown as follows. Seedling tomatoes, variety Florida 7481, a variety resistant to Fusarium Wilt Race 3 and close to commercial release (J Barnes pers. comm.), were planted into a field plot of nine rows by 90m on 17th September 1999. The tomatoes were grown using standard commercial fertiliser and irrigation practices on plastic mulch with trickle irrigation and they were trellised. Plants within each row were planted 0.5m apart and rows were 1.5m apart. The plants were sprayed regularly with

mancozeb (Dithane) and copper hydroxide (Kocide) or copper oxychloride for disease control using a tractor-mounted boom spray with droppers. Imidacloprid (Confidor 200) was applied through the trickle system on 20th October to control silverleaf whitefly, *Bemisia tabaci*, and the crop was sprayed with dicofol on 11th November and 15th November to control tomato russet mite, *Aculops lycopersicii*.

The trial was a randomised block design with seven treatments and four replicates. Plots were 3 rows by 8m, and plots were separated along rows by 1m of untreated tomato plants.

The insecticide treatments applied are shown in Table H1.

Table H1
Insecticide treatments applied to the tomatoes

Treat-ment No.	Product code Trade name (Common name)	Formulation	Product No. (or source of commercial products)	Batch No.	Dosage	
					Product mL/ha or g/ha	Active g a.i./ha
1.	Untreated check				Nil	Nil
2.	ROY 2390 (methoxyfenozide)	240 SC	Rohm & Haas	Lot 6559B01P	1667 mL	400
3.	DiPel Forté	DF	Abbott	50-661-PG	1000 g	
4.	XenTari	WG	Abbott	Lot 15 763-PG	250 g	
5.	XenTari	WG	Abbott	Lot 15 763-PG	500 g	
6.	XenTari	WG	Abbott	Lot 15 763-PG	1000 g	
7.	XenTari	WG	Abbott	Lot 15 763-PG	2000 g	

Treatments were applied using a motorised Echo sprayer, fitted with a boom and Albuz APT brown hollow cone nozzles and operated at 690kPa, in the equivalent of 1000L of water per sprayed hectare. The principle used in calculating the area to be sprayed was that each vertical surface of the trellised row required spraying. For example, for plants 0.5m high an 8m length of row had $8m^2$ to be sprayed (i.e. $4m^2$ on each side of the row). The sprayer boom was held vertically to simulate droppers. The dates on which sprays were applied and the weather data for those dates are shown in Table H2. Fourteen spray applications were made.

The crop was monitored to determine the number of *Helicoverpa* spp. eggs present with the intention of applying spray treatments when thresholds were exceeded. In practice the thresholds were exceeded on almost every monitoring date, and time restraints prevented monitoring on some occasions, so sprays were applied on a three and four day schedule (modified somewhat due to rain and other disturbances) for most of the trial. Two monitoring

methods were used. In the first method, based on that used by local crop consultants, the top terminal (main growing point and two leaves plus two hands of flowers plus top hand of fruit) on each of 10 randomly selected plants throughout the trial was inspected and the number of *Helicoverpa* spp. eggs counted. This method suggests that a spray should be applied when the egg count is between three and 10 on the 10 terminals. The second method was based on that suggested for use on processing tomatoes in Victoria (Smith *et al.* 1994). The number of eggs on the first full leaf below the top opened flower on each of 10 plants were counted, and a threshold of two eggs per 10 leaves was used. (Smith *et al.* 1994 suggested five viable eggs per 30 leaves but the trial area was too small to sample 30 leaves.)

Table H2
Spray application dates and weather data

Date of application	Time of application	General conditions	Cloud cover	Wind	Relative humidity %	Temp. ºC max-min
18 Oct.	3-5.30 pm	fine	0	none-light SE	55	26-15
22 Oct.	9.30 am-1.30 pm	overcast	7/8	light NE	69	27-19
25 Oct.	1.30-5 pm	fine	0	none-light S	36	29-19
1 Nov.	9.30 am-1 pm	overcast	7/8	none	76	27-17
5 Nov.	7-10.30 am	fine	1/8	none-light SE	60	27-16
9 Nov.	9 am-12.30 pm	fine	0-1/8	light-mod. S	64	27-20
12 Nov.*	9 am-12.30 pm	fine-overcast	0-3/8	none-light E	59	26-13
15 Nov.	1.30-5.30 pm	fine	0	light-mod. N	62	26-11
19 Nov.	8.30 am-12.30 pm	fine	2/8	none-light SE-E	54	26-19
22 Nov.	1.30-5 pm	fine	3/8	moderate NE	57	27-19
27 Nov.	5-9 am	overcast	8/8	none	-	25-16
30 Nov.	3-6 pm	fine	1/8	none-light SE	75	26-19
3 Dec.	3-6 pm	fine	0	none	58	27-16
10 Dec.	3-6 pm	fine	2/8	moderate N	57	29-20

* Light rain shower at 1.30 pm and more rain at 4 pm.

Fruit were harvested from the central eight plants (i.e. 4m of row) of the middle row of each plot on eight harvest dates (26 Nov., 30 Nov., 3 Dec., 7 Dec., 10 Dec., 14 Dec., 17 Dec., 21 Dec.). For the first seven harvests fruit from the breaker or quarter-colour stage onwards plus any damaged fruit were picked. On the final harvest all remaining fruit larger than golf ball

size were picked. Harvested fruit were returned to the laboratory and each piece was examined carefully and allotted to one of the following categories:

Undamaged: fruit undamaged by *Helicoverpa* spp. These fruit may have had other damage or blemishes.

Minor pinhole: fruit with one or two small pinholes or stings caused by *Helicoverpa* spp. larval feeding at an early stage of fruit development. These fruit may be marketable.

Major pinhole: fruit with three or more pinholes or with large pinholes. These fruit are not marketable.

Gross damage: fruit with major feeding damage by *Helicoverpa* spp.

The number and weight of fruit in each category were recorded. The number of fruit damaged by *P. operculella* or by *S. litura* was recorded also. Data from the individual harvests were combined and analyses of variance were done on the yield data and on the damage data using Genstat 5, Release 4.1.

Helicoverpa spp. eggs were collected from the crop for species determination on two occasions (4 Nov. and 2 Dec.), returned to the laboratory and the subsequent larvae reared on artificial diet to the adult stage when they were dissected for identification (Common 1953). *Helicoverpa* spp. eggs were collected on four occasions (18 Oct., 25 Oct., 11 Nov., and 22 Dec.), returned to the laboratory and placed in microtitre trays to determine the level of egg parasitism.

Trial 2

The trial was conducted at Ayr Research Station from April to June 1999. The tomatoes were grown as a ground crop using standard agronomic practices. The trial was a randomised block design with six treatments and five replicates. Plots were two rows by 10 m.

The treatments used were:

1. MVP (the delta endotoxin of *Bacillus thuringiensis kurstaki* encapsulated in killed *Pseudomonas fluorescens*) at 2 L/ha plus DC Tron at 0.16% plus skim milk powder at 2 kg/ha.
2. Heliothis nuclear polyhedrosis virus as Gemstar at 750ml/ha plus DC Tron at 0.16%
3. Acephate as Orthene Xtra at 970 g a.i./ha (= 1000 g product/ha)
4. *Bacillus thuringiensis aizawai* as XenTari at 1000 g/ha
5. Bifenthrin as Talstar at 60 g a.i./ha (= 600 ml/ha)
6. Untreated check

The treatments were applied with a motorised knapsack sprayer fitted with a boom and hollow cone nozzles in the equivalent of 1000 L/ha of water at weekly intervals from 12th May to 5th June. Five applications were made.

On six occasions the numbers of heliothis eggs and larvae on three leaves on each of five plants in one row of each plot (i.e. 15 leaves per plot) were counted. Analyses of variance were done on each set of data.

Fruit were harvested from five plants in one row (the row not sampled for eggs and larvae) on 1st June and on 15th June. Mature fruit only were harvested in the first pick and all remaining fruit were picked in the second harvest. The fruit were examined, separated into the following categories, and counted: undamaged by heliothis; pinhole damage, where the fruit had minor pinhole damage; major damage, where the fruit had major chewing damage caused by heliothis larvae. The results for the two harvests were combined, and analyses of variance carried out on the data.

Results

Trial 1

The results of egg monitoring are shown in Table H3. The total number of eggs found on the 10 plants sampled with each method and a comment on the spray decision are given.

Table H3
Helicoverpa spp. egg monitoring results

Date 1999	Total no. of eggs on 10 plants		Comment
	Method 1	Method 2	
13 October	8	2	Marginal thresholds for both methods.
18 October	6	4	Marginal for method 1, exceeds threshold for method 2.
22 October	23	9	Threshold exceeded for both methods.
25 October	4	3	Thresholds marginal; rain on previous days.
29 October	9	3	Marginal for thresholds, most eggs white.
4 November	24	9	Greatly exceeds thresholds and larvae present.
11 November	15	9	Thresholds exceeded.
25 November	20	4	Thresholds exceeded.

Table H4 shows the combined yield and *Helicoverpa* damage data, and the number and the percentage of fruit damaged by *P. operculella* or by *S. litura* are given in Table H5.

Of the 116 *Helicoverpa* spp. eggs collected on 4 November only 31 developed into moths. Of these 28 were *H. armigera* and three were *H. punctigera*. Very few larvae emerged from 259 eggs collected on 2 December and only 10 moths developed. All were *H. armigera*. The egg parasitism results are shown in Table H6.

Table H4
Mean fruit yields and mean numbers and percentage of fruit undamaged by *Helicoverpa* spp.

Treatment (rate/ha)	Mean yield		Mean % undamaged fruit	Mean % minor pinhole	Mean % undamaged + pinhole
	No. of fruit	Weight kg			
Unsprayed check	196.5 a*	17.20 a	27.70 a	5.24 a	32.96 a
Methoxyfenozide (400 g a.i.)	334.3 c	50.82 e	80.15 d	11.99 b	92.14 d
DiPel Forté (1000 g)	312.0 bc	39.39 d	50.58 c	19.37 c	69.94 c
XenTari (250 g)	271.3 b	30.84 bc	36.90 b	13.05 b	49.96 b
XenTari (500 g)	262.3 b	28.33 b	40.68 b	11.60 b	52.28 b
XenTari (1000 g)	294.0 bc	37.16 cd	43.80 bc	18.48 c	62.29 c
XenTari (2000 g)	291.8 bc	42.10 d	50.65 c	19.73 c	70.41 c

In each column numbers followed by the same letter are not significantly different at the 5% level.

Table H5
The mean number and percentage of fruit damaged by *P. operculella* or *S. litura*

Treatment (rate/ha)	No. fruit damaged by *P. operculella*	% of fruit damaged by *P. operculella*	No. fruit damaged by *S. litura*	% of fruit damaged by *S. litura* #
Unsprayed check	35.00 a*	20.0 a	13.50 c	6.89 c
Methoxyfenozide (400 g a.i.)	76.00 c	22.1 a	0.75 a	0.21 a
DiPel Forté (1000)	49.75 ab	15.8 a	5.25 ab	1.45 ab
XenTari (250 g)	65.25 bc	24.1 a	4.50 ab	1.34 ab
XenTari (500 g)	66.75 bc	25.6 a	9.00 bc	3.19 b
XenTari (1000 g)	56.50 abc	19.5 a	2.00 a	0.69 a
XenTari (2000 g)	58.00 bc	20.1 a	1.50 a	0.48 a

* In each column numbers followed by the same letter are not significantly different at the 5% level. # Back-transformed means following square root (x + 0.5) transformation applied before analysis.

Table H6
Parasitism of *Helicoverpa* spp. eggs

Date of collection 1999	Number of eggs collected	Total percent parasitism	Numbers in each parasitoid genus
18 October	13	15.4	1 *Trichogramma*; 1 *Telenomus*
25 October	6	33.3	2 *Trichogramma*
11 November	13	100	13 *Trichogramma*
22 December	19	94.7	17 *Trichogramma*; 1 *Trichogrammatoidea*

Trial 2
The numbers of eggs and larvae counted on each sampling date are shown in Table H7.

Table H7
The numbers of heliothis eggs and larvae found on 15 leaves on each sampling date.

Treatment (rate /ha)	Mean number of eggs and larvae on 15 leaves on each date (1999) 6 May	11 May	18 May	27 May	1 June	8 June
	Eggs					
MVP + (2000 ml)	59.5	3.0	4.6	1.0	0.0	0.4 a*
Gemstar + (750 ml)	23.0	2.6	2.2	1.8	0.0	0.2 a
Acephate (970 g a.i.)	29.0	3.2	5.6	2.4	0.0	3.0 b
XenTari (1000 g)	28.5	3.6	4.0	3.0	0.0	0.2 a
Bifenthrin (60 g a.i.)	50.0	4.6	2.8	2.0	0.4	1.2 a
Untreated check (-)	27.5	3.4	1.8	0.8	0.0	0.2 a
	Larvae					
MVP + (2000 ml)	5.0	2.0	1.2 ab*	1.2	0.2 a*	1.0 a*
Gemstar + (750 ml)	5.0	2.2	1.0 a	1.0	0.6 a	4.4 b
Acephate (970 g a.i.)	3.5	1.0	0.2 a	0.2	1.4 a	0.4 a
XenTari (1000 g)	3.0	2.0	0.2 a	0.6	0.4 a	2.2 a
Bifenthrin (60 g a.i.)	3.5	1.8	0.4 a	0.4	0.2 a	0.8 a
Untreated check (-)	4.5	2.4	2.6 b	1.6	4.0 b	4.6 b

For eggs and larvae, in each column numbers followed by the same letter are not significantly different at the 5% level. Where there are no letters the F-values were not significant.

Both egg and larval counts were quite high on 6th May at the start of the trial. Egg counts were low for the remainder of the trial, and there were no significant differences between treatments except on 8th June when there were significantly ($P<0.05$) more eggs in the acephate treatment than in the others. Larval counts generally were low, and on several occasions there were significantly more ($P<0.05$) larvae in the check than in the other treatments.

The harvest and damage results are shown in Table H8.

Table H8
The number of fruit harvested and the percentage damaged by heliothis.

Treatment (rate /ha)	Total no. of fruit	No. of undamaged fruit	Mean % heliothis damaged fruit		
			Pinhole #	Major #	Total #
MVP + (2000 ml)	395.8 ab*	150.0 ab*	23.4 bc*	39.1 bc*	62.9 bc*
Gemstar + (750 ml)	431.4 b	151.2 ab	23.5 bc	41.3 c	65.3 bc
Acephate (970 g a.i.)	488.2 b	285.8 c	19.4 ab	19.8 a	40.3 a
XenTari (1000 g)	497.8 b	212.8 b	28.8 c	27.6 ab	57.1 b
Bifenthrin (60 g a.i.)	511.8 b	310.8 c	19.6 ab	18.5 a	38.5 a
Untreated check (-)	297.0 a	97.6 a	16.6 a	50.8 c	67.9 c

Back-transformed means following inverse sine transformation before analysis. * In each column numbers followed by the same letter are not significantly different at the 5% level.

Discussion

Trial 1
The effectiveness of the pesticides against *Helicoverpa* spp. was judged by yield and by the absence of damage (Table H4).

All sprayed treatments yielded significantly more ($P<0.05$) fruit, by total number and total weight, than the untreated check. The number of fruit in the methoxyfenozide treatment was not significantly different ($P>0.05$) from the DiPel Forté or XenTari 1000g/ha or XenTari 2000g/ha treatments, but the weight of fruit in the methoxyfenozide treatment was significantly higher ($P<0.05$) than the weight of fruit in all the other treatments. There were no significant differences ($P>0.05$) in either number or weight of fruit between the DiPel Forté and XenTari 1000g/ha and 2000g/ha treatments, but the weight of fruit in both the DiPel Forté and XenTari 2000g/ha treatments was significantly higher ($P<0.05$) than in the XenTari 250g/ha and 500g/ha treatments.

All the sprayed treatments had a significantly higher ($P<0.05$) percentage of undamaged fruit than the unsprayed check. Over 80% of the fruit in the methoxyfenozide treatment were

undamaged, a significantly higher ($P<0.05$) percentage than in the other sprayed treatments. There were no significant differences ($P>0.05$) in percent undamaged fruit between the DiPel Forté and XenTari 1000g/ha and 2000g/ha treatments. There were significant differences ($P<0.05$) in percent undamaged fruit between the XenTari 2000g/ha and XenTari 250g/ha and 500g/ha treatments, but not between the XenTari 1000g/ha and XenTari 250g/ha and 500g/ha treatments.

The mode of action of *Bacillus thuringiensis* (and other pesticides that work through ingestion) requires that the larva bites a treated surface to ingest the pesticide. This bite, if on a young fruit, will result in pinhole damage to that fruit, but if the dose of pesticide is effective then the larva should stop feeding and further damage should be prevented. The damage should not proceed to major pinhole or gross damage or complete loss of the fruit. Fruit with minor pinhole damage (i.e. one or two small pinholes) may be marketable as Quality Assurance standards allow 10% of fruits to show minor defects, which may include healed insect damage such as pinholes (J. Maltby pers. comm.). Care must be taken, however, when interpreting data on levels of minor pinhole damage for a low percentage of minor pinhole damage may be indicative of very poor control, with all the fruit being badly damaged, rather than the fruit being reasonably well protected. However it is reasonable to consider the level of minor pinhole damage together with the percentage of undamaged fruit when assessing the effectiveness of the pesticides.

When the number and weight of undamaged plus minor pinhole damaged fruit are considered then again the methoxyfenozide treatment yielded significantly more than the other treatments ($P<0.05$), and there were no significant differences ($P>0.05$) in yield between the DiPel Forté and the XenTari 1000g/ha and 2000g/ha treatments. The methoxyfenozide treatment had a significantly higher ($P<0.05$) percentage of undamaged plus minor pinhole damaged fruit than the other treatments. There were no significant differences ($P>0.05$) in the percentage of undamaged plus minor pinhole damaged fruit between the DiPel Forté and the XenTari 1000g/ha and 2000g/ha treatments, but all three of these had a significantly higher ($P<0.05$) percentage than the XenTari 250g/ha and 500g/ha treatments.

The results show that methoxyfenozide was the most effective of the treatments in controlling *Helicoverpa* spp. in this trial. Its use resulted in higher yields and a higher percentage of undamaged fruit than the other treatments. The level of 80% undamaged fruit is an acceptable level, particularly as assessed in this trial when all fruit, irrespective of damage from the target insect or from other causes were picked. It is unfortunate that a standard insecticidal treatment (eg methomyl or sulprofos or both in rotation) was not included in the trial so that the performance of methoxyfenozide could be compared against it.

There were no significant differences ($P>0.05$) in yield or in percent undamaged fruit or in percent undamaged plus minor pinhole damaged fruit between the DiPel Forté (1000g/ha) and the XenTari 1000g/ha and 2000g/ha treatments. DiPel Forté at 1000g/ha currently is registered against *Helicoverpa* spp. in tomatoes, and the results of this trial show that XenTari at 1000g/ha and 2000g/ha gives statistically equivalent control. XenTari at 250g/ha and 500g/ha resulted in lower yields and lower percent undamaged fruit than DiPel Forté.

The *Helicoverpa* spp. egg collections and subsequent rearing indicate that *H. armigera* was the dominant species present during the trial. This is not the normal pattern of species occurrence for usually both *H. armigera* and *H. punctigera* are present in approximately equal proportions (3:7, 1:1, to 7:3) at this time of year at Bundaberg (Kay 1999). However the

usual immigration flight of *H. punctigera* in September-October did not occur in 1999 (Figure H1).

The egg monitoring data in Table H3 indicate that *Helicoverpa* spp. pressure was low to moderate during much of the trial, and this was supported by low catches of moths in nearby pheromone traps. (It has been generally reported that *Helicoverpa* spp. numbers were low throughout southern Queensland during the 1999-2000 season.) However thresholds based on egg numbers in fresh market tomatoes are low and these were reached or exceeded on most sampling dates. It should be noted that the true threshold in Method 2 is five "viable" eggs per 30 leaves (Smith *et al.* 1994). This means that more eggs may be found but they should be assessed for viability i.e. whether the egg will produce a larva. The egg parasitism data (Table H6) shows that most eggs collected in mid November and late December were parasitised and so were not viable, and it would be expected from previous experience that parasitism levels would have been similarly high during that time period. Unfortunately there is no rapid field method for determining parasitism levels so decisions in fresh market tomatoes have to be made on actual egg counts.

The percent parasitism levels recorded in the two collections in November and December were very high. Studies of egg parasitism in unsprayed tomato crops in spring 1996 and spring 1997 showed parasitism rates that rose from low levels (5-8%) early in the crop, similar to the 15.4% recorded here in mid October, to high rates of 75-88% late in the crop. Most of the parasitoids reared then were *Trichogrammatoidea* sp. (Kay 1999). In this trial a *Trichogramma* sp. was the almost exclusive parasitoid species reared. *T. pretiosum* was released in a nearby block of tomatoes and it would appear that those wasps spread to the trial block. Certainly the egg parasitoids helped the pesticides to control *Helicoverpa* spp. in the trial.

In summary, methoxyfenozide at 400g a.i./ha was effective in controlling *Helicoverpa* spp. in tomatoes. XenTari at rates of 1000g/ha and 2000g/ha gave control equivalent to DiPel Forté at 1000g/ha, but XenTari at rates of 500g/ha and 250g/ha was not as effective. Parasitism of *Helicoverpa* spp. eggs by *Trichogramma* sp. was high and this would have had a large impact on *Helicoverpa* spp. control. Possibly the pesticides, particularly DiPel Forté and XenTari, may not have appeared to be as effective if trialed in a situation where the parasitoids were absent. However they still would be very useful in an IPM context.

There were no significant differences ($P>0.05$) between any of the treatments in the percentage of fruit damaged by *P. operculella* (Table H5), so it would seem that none of the insecticides are effective against this pest.

The untreated check had a significantly higher ($P<0.05$) percentage of fruit damaged by *S. litura* than any of the sprayed treatments (Table 5), while the XenTari 500g/ha treatment had a significantly higher ($P<0.05$) percentage of fruit damaged than the methoxyfenozide and XenTari 1000g/ha and 2000g/ha treatments. Care should be taken in interpreting these results, as the actual number of fruit damaged was very low. However the results do suggest that all three products are effective against *S. litura*.

Methoxyfenozide has since been registered as the product Prodigy for use against heliothis on tomatoes, and this trial provided useful data to support the registration application.

Trial 2

The species composition of heliothis present in the trial was not determined but all probably were *H. armigera* as it usually is the only species active at this time of year (Brown 2000, Kay 1989).

The egg counts show that while heliothis numbers were quite high at the start of the trial, the pressure dropped as the trial progressed. Usually heliothis pressure falls during late May and June in this region (Brown 2000, Kay 1989). There were no significant differences ($P>0.05$) in numbers of eggs between treatments indicating even heliothis pressure across the trial, except on 8th June when there were more eggs on leaves in the acephate treatment. There appears to be no good biological reason for this difference, and the numbers are not high (a mean of three eggs per 15 leaves), so it is probable the difference is due to chance.

There were significant differences ($P<0.05$) between numbers of larvae on various treatments on three sample dates. The untreated check had more larvae than all the other treatments except MVP on 18th May; than all the other treatments on 1st June; and than all the other treatments except Gemstar on 8th June, when there were more larvae on the Gemstar treatment than the other insecticide treatments. These results indicate that all the insecticide treatments exerted control over heliothis by reducing larval numbers, and that even Gemstar was effective much of the time. The higher final count in the Gemstar treatment may have been due to a breakdown in the level of control exerted by the virus product. Alternatively, as virus infected larvae may take 7-9 days to die and often move to higher, more prominent position on the plant before death, the larvae may have been infected and simply more easily seen.

Significantly fewer ($P<0.05$) fruit were harvested from the untreated check than from the insecticide treatments except for MVP. There were no differences ($P>0.05$) between the insecticide treatments. Heliothis will damage flowers preventing fruit set, and damaged fruit may abort in young or rot if more mature, so better control will result in higher yield. The comparatively (to the other treatments and to the percent major damage) low percentage of pinhole-damaged fruit in the check further demonstrates this. Uncontrolled larvae in the check tend to cause major damage to fruit, whereas in the insecticide treatments the larvae start to feed, causing pinholes, but then are killed resulting in less major damage.

The best control of heliothis was given by the conventional insecticides bifenthrin and acephate, which had a significantly lower ($P<0.05$) percentage of total damaged fruit than the bio-pesticides and a significantly higher ($P<0.05$) number of undamaged fruit, but even their damage levels were quite high. XenTari gave significantly better ($P<0.05$) control than the check, but the other bio-pesticides, MVP and Gemstar, did not control heliothis in this trial.

Gemstar breaks down very quickly in sunlight and so is effective for only a short period of time, so weekly sprays are a less than optimum application frequency for it. More frequent application at a lower rate may be a better strategy for its use. More frequent applications may improve the efficacy of all the insecticides, but particularly the bio-pesticides.

Evaluating insecticides against heliothis in capsicums

Introduction

Capsicums, (*Capsicum annuum*), are an important horticultural crop in Queensland. Approximately 1200 ha of capsicums worth approximately $48m were grown in Queensland in 1999, mainly in the Dry Tropics region around Bowen, Gumlu and Ayr, and at Bundaberg. (These figures were derived from QHI extension staff whose figures often are higher than ABS figures but are considered more accurate.) ABS data indicate that Queensland produces about 70% of the total Australian crop.

Heliothis, *Helicoverpa armigera* (Hübner) and *H. punctigera* (Wallengren), are important pests of capsicums. The larvae feed on flowers causing them to fall, with consequent potential yield loss. Young larvae may cause pinhole damage to fruit, and those small holes may later be the point of disease or rot entry, or fruit breakdown. Larger larvae may burrow into the fruit causing obvious damage. Occasionally young larvae enter the fruit and feed and grow inside the fruit with no external evidence of their presence. Obvious damage and fruit breakdown occurs when the mature larvae tunnel out of the fruit.

Insecticides are used to manage heliothis in capsicums, often as a major component of an integrated pest management (IPM) program. Very few insecticides were registered for use against heliothis in capsicums. Only endosulfan, methamidophos, methomyl, sulprofos (not currently commercially available) and spinosad were registered in Queensland, and a NRA Permit based on an old QDPI Board Approval allowed the use of *Bacillus thuringiensis* subsp. *kurstaki* in Queensland (QDPI 2000). (A general registration for DiPel DF against lepidopteran pests on vegetables now covers this use.) Not all of these insecticides are registered in other states. There are restrictions on the use of endosulfan, and levels of resistance to methomyl and other carbamates are high in many populations of *H. armigera*. Effectively the number of insecticides available for use in Queensland against heliothis in capsicums is small and even fewer are available in other states. This has adverse implications for insecticide resistance management, and for integrated pest management in the crop.

Clearly there is a need for more insecticides, particularly those that may be more compatible with IPM, to be registered for use against heliothis in capsicums. As IPM programs are being further developed in capsicums (J. Brown pers. comm.) the need to register insecticides that are less disruptive to predators and parasites of heliothis and other pests becomes greater.

The two trials reported here were done to test the effectiveness of a number of biopesticides and new insecticides in controlling heliothis in capsicums. The biopesticides tested are specific in the insects they affect, with the *B. thuringiensis* products effective only against lepidopteran insects and Gemstar specific to heliothis, and some of the new insecticides claim to have minimal impact on beneficial arthropods. It is expected that the data will be used to support registration applications for some of the insecticides.

Materials and methods

The insecticides used in the trials were:

Bacillus thuringiensis subsp. *kurstaki* - DiPel Forté - DF
Bacillus thuringiensis subsp. *aizawai* - XenTari - 35000 DBM units/mg WG
Heliothis nucleopolyhedrovirus - Gemstar
Spinosad - Success Naturalyte - 120 g a.i./L SC
Indoxacarb - Avatar - 300 g a.i./kg WDG
Methoxyfenozide - ROY 2390 - 240 g a.i./L SC
Novaluron - Rimon - 100 g a.i./L EC in Trial 1; 7.5 g a.i./kg WDG in Trial 2
Emamectin - Proclaim - 44 g a.i./kg WG
Methomyl - Lannate L - 225 g a.i./L EC
Methamidophos - Nitofol - 580 g a.i./L EC

Two trials were conducted at the Bundaberg Research Station. Trial 1 was done between March and July 2000 and Trial 2 was done from October to December 2000.

The variety Target was grown on plastic mulch with trickle irrigation in both trials. Plants were grown in single rows with a plant spacing of 25 cm, using standard irrigation and fertiliser practices. The crops were sprayed twice weekly with alternate applications of copper hydroxide (Kocide) and copper oxychloride for disease control.

Trial 1

Trial 1 was a randomised block design with eight treatments by three replicates. The plots were four rows by 5 m, with 1 m of untreated guard along each row between plots and an untreated row lengthways between plots. Treatments were applied in the equivalent of 1000 L of water per sprayed hectare using a motorised Echo sprayer fitted with a boom and Albuz APT brown hollow cone nozzles and operated at 690 kPa. It was planned to apply the DiPel Forté and XenTari treatments twice weekly (ie every 3 and 4 days) and all other treatments weekly but some modifications were made to this program due to factors such as adverse weather conditions. The DiPel Forté and XenTari treatments were applied 19 times and the other treatments were applied 13 times. Methomyl was included as a standard commercial treatment.

Fruit were harvested on four occasions from 14 plants in the middle of one of the centre rows of each plot. Large fruit plus any that were obviously damaged were picked in the first three harvests while all remaining fruit larger than 5 cm long were picked in the final harvest. Harvested fruit were returned to the laboratory and weighed, and each piece was examined carefully externally and internally and allocated to one of the following categories:

- Undamaged: fruit undamaged by heliothis. These fruit may have had other damage or blemishes.

- Minor damage: fruit with very minor damage caused by heliothis, such as some damage to the stalk or calyx or a small, healed bite mark to the skin of the fruit that had not penetrated to the interior. These fruit probably would be marketable.

- Major damage: any other heliothis damage.

The number of fruit in each category was recorded.

Some fruit had been damaged by cluster caterpillar, *Spodoptera litura* (F.), and this also was recorded. It sometimes was difficult to distinguish between heliothis and *S. litura* damage unless the caterpillar was present, which happened occasionally. The examiners could reliably distinguish between the two on the characteristics of the frass if internal feeding had occurred, and usually by the size of the entrance/exit hole or by gouges in the flesh of the fruit. A very few cases were unresolved and such fruit were classified as heliothis damaged.

Data from the individual harvests were combined and analyses of variance were done on the yield data and on the damage data using Genstat 5, Release 4.1.

Heliothis egg or larval numbers were not assessed in the trial but *H. armigera* and *H. punctigera* pheromone traps nearby recorded adult numbers.

Trial 2

Trial 2 was a randomised block design with eight treatments and four replicates.

Plot size and guard areas, the methods of insecticide application, harvesting and data gathering and analysis were the same as in Trial 1 with the following exceptions:

- The Gemstar treatment was applied three times a week (Monday, Wednesday, Friday) in the late afternoon, and 17 applications were made. The other treatments were applied weekly with a total of seven applications. There were a few minor variations to the timing of spray applications due to rain. The standard commercial treatment was applications of methomyl and methamidophos alternated weekly.

- Fruit were harvested from 10 plants in the middle of each of the two centre rows of each plot (i.e. 20 plants per plot) on three occasions, with all remaining fruit over 5 cm long picked in the final harvest.

Heliothis eggs and larvae on 25 randomly selected plants in the central guard row were counted on six occasions during the trial. Adult numbers were recorded in the pheromone traps. Larvae found in fruit at harvest were kept and reared on a navy bean-based diet to the adult stage when they were identified (Common 1953).

Results

The yield and damage results from Trials 1 and 2 are shown in Table H9. The percentage damaged figure includes all fruit damaged by heliothis (both minor and major damage), while the percentage unmarketable fruit assumes that fruit with minor damage could be sold.

The percentage of fruit damaged by *S. litura* is shown in Table H9 as well. These data were not analysed as the incidence of damaged fruit was very low, in general confined to a few treatments, and not consistent between replicates.

Table H9
Mean fruit yield and mean percentage of damaged and unmarketable fruit in Trials 1 and 2

Treatment (g a.i./ha)	% heliothis damaged fruit #	% unmarketable fruit #	Yield		% *S. litura* damaged fruit
			Wt. (kg)	No. of fruit	
Trial 1 Untreated check (-)	25.75 b*	19.27 b	11.72 a	73.67 a	0.49
DiPel Forté (1000)	31.32 b	24.60 b	13.48 ab	68.67 a	3.40
XenTari (2000)	7.36 a	4.73 a	14.06 abc	77.67 a	0.42
Spinosad (48)	2.49 a	1.34 a	18.38 cd	89.67 ab	0.74
Indoxacarb (51) (0.125% Agral)	2.28 a	0.28 a	13.49 ab	71.00 a	0
Methoxyfenozide (400)	1.47 a	1.16 a	16.84 bcd	87.33 ab	0
Novaluron (75)	3.71 a	3.18 a	13.64 ab	74.00 a	0
Methomyl (450)	2.33 a	1.50 a	19.86 d	106.33 b	0
Trial 2 Untreated check (-)	12.94 e	9.19 d	23.89 a	149.0 a	1.84
Gemstar (500)	6.63 d	3.79 c	22.54 a	143.5 a	1.06
Emamectin (11)	1.28 ab	0.58 ab	24.44 a	152.3 ab	0
Novaluron (75)	3.24 bc	1.21 abc	22.21 a	142.8 a	0
Indoxacarb (37.5) (0.025% Agral)	1.01 a	0.41 ab	22.19 a	138.5 a	0
Indoxacarb (51) (0.025% Agral)	0.54 a	0.09 a	20.16 a	137.5 a	0
Methoxyfenozide (400)	2.20 abc	0.82 ab	24.55 a	167.0 b	0
Methomyl (450), methamidophos (1102)	3.65 cd	1.75 bc	22.00 a	146.5 a	0

back-transformed means following inverse sine transformation before analysis. * in each column in each Trial numbers followed by the same letter are not significantly different (P>0.05)

Weekly *Helicoverpa* spp. moth catches in pheromone traps during 2000 are shown in Figure H2. This shows that small numbers of moths, almost exclusively *H. armigera*, were caught from March to July (i.e. during Trial 1). Both species were trapped in large numbers from mid August to mid October (i.e. early in Trial 2) while low numbers of *H. armigera* only were caught in November and December (i.e. late in Trial 2).

The heliothis egg and larval counts on 25 plants in Trial 2 are shown in Table H10. The larval numbers are those seen externally on the plants as fruit were not cut to detect larvae feeding internally.

Table H10
Numbers of heliothis eggs and larvae on 25 plants during Trial 2

Date	6 Oct.	10 Oct.	25 Oct.	14 Nov.	23 Nov.	29 Nov.
No. eggs	1	0	3	4	3	1
No. larvae	0	0	0	1	7	3

Fifteen of the 16 larvae found inside fruit during the post-harvest assessment in Trial 2 were *H. armigera* and one was *Helicoverpa assulta* (Guenée).

Discussion

Heliothis numbers were low during both trials, which was unexpected. A three year study (1996-1998) of heliothis occurrence at Bundaberg showed high numbers (almost exclusively of *H. armigera*) normally occur from March to early May, falling to low levels during June and July, before rising again from August on, with both *H. armigera* and *H. punctigera* present during the spring and summer (Kay 1999). However in 2000 populations were low from March to June, and although large numbers of moths were trapped in September and early October numbers again were low during November and December, and they were almost exclusively *H. armigera*. It is probable from the evidence in Figure H2 and from Kay (1999) that *H. armigera* was the only species causing damage during Trial 1. In Trial 2 the pheromone trap data (Figure H2) and the rearing results indicate that *H. armigera* again was the main species present. One *H. assulta* larva was found inside a fruit. While Matthews (1999) does not include *C. annuum* in a table of recorded hosts of *H. assulta* in Australia he does say that "The larvae of *H. assulta* feed very largely, but not exclusively, on solanaceous food plants." He also says that *H. assulta* is reported to be a serious pest of *C. annuum* in Japan. Probably *H. assulta* is not a common pest of capsicums in the Bundaberg district.

Differences in yield can be a useful measure of differences in effectiveness of insecticides in controlling heliothis, and that certainly is the case with tomatoes where differences in yield often reflect differences in percentage damaged fruit (eg Kay 1993). In Trial 1 only the spinosad, methoxyfenozide and standard insecticide treatments produced a significantly greater ($P<0.05$) weight of fruit than the untreated check, and only the standard insecticide treatment had significantly more ($P<0.05$) fruit than the untreated check, despite considerable differences in the percentage of fruit damaged by heliothis between the untreated check and most of the insecticide treatments. In Trial 2 there were no significant differences ($P>0.05$) in weight of fruit between the treatments while only the methoxyfenozide treatment produced

significantly more ($P<0.05$) fruit than the untreated check (and the other treatments except emamectin). In summary, yield differences were not a good measure of differences in efficacy between the treatments. Possibly capsicums can compensate for damage to flowers caused by young larvae, and larger fruit with minor damage or with larvae feeding internally tend to remain on the plant and develop rather than quickly breaking down and being lost from records of yield.

In Trial 1 there was a significantly greater ($P<0.05$) percentage of heliothis damaged and unmarketable fruit in the untreated check and DiPel Forté treatments than in the other treatments, but there were no significant differences ($P>0.05$) between the other treatments. The poor control of heliothis by DiPel Forté, particularly in comparison to XenTari, was unexpected as normally the *B. thuringiensis* subsp. *kurstaki* products are reasonably effective against heliothis and are registered for use against heliothis on some crops eg tomatoes, cotton (QDPI 2000). One contributing factor may have been that in one replicate the DiPel Forté treatment had a very high level of damage (61%), which was attributed to heliothis but may have been caused by *S. litura*. However even if that DiPel Forté value is excluded from the analysis there still is no significant difference ($P>0.05$) in percentage heliothis damaged fruit between the untreated check and DiPel Forté treatments. All the other insecticides were effective in preventing heliothis damage to the capsicum fruit.

XenTari at 2000g/ha was effective in controlling heliothis in capsicums in this trial. Registration of XenTari for this purpose, or addition of *B. thuringiensis* subsp. *aizawai* to the current off-label permit for *B. thuringiensis* subsp. *kurstaki*, would provide an extra insecticide available for use in IPM programs or for organic growers, and for the management of resistance development in *H. armigera* to *B. thuringiensis*.

Damage caused by heliothis was low in Trial 2 with only 12.94% of fruit damaged in the untreated check. All the insecticide treatments resulted in significantly lower ($P<0.05$) percentages of damaged or unmarketable fruit than the untreated check. Both rates of indoxacarb had a significantly lower ($P<0.05$) percentage of damaged fruit than the novaluron and standard insecticide treatments, and emamectin had significantly less ($P<0.05$) damaged fruit than the standard treatment. There were no differences ($P>0.05$) in the percentage of damaged or unmarketable fruit or in yield between the two rates of indoxacarb, indicating that the lower of the two rates would be adequate to provide control of heliothis.

The performance of Gemstar was promising. Its use resulted in significantly less ($P<0.05$) heliothis damaged or unmarketable fruit than the untreated check, with no significant difference ($P>0.05$) between it and the standard insecticide treatment. It was applied frequently and further studies to determine optimum application frequencies may be warranted. The results indicate that under low heliothis pressure it can provide adequate control, but its efficacy should be confirmed under conditions of high pressure. It may be a useful product under suitable conditions in IPM systems or for organic growers.

All of the treatments were applied on a large number of occasions in Trial 1 (19 each for DiPel Forté and XenTari, and 13 for the remainder). The winter growing season extended the duration of the trial, and as the treatments were applied on a schedule basis to allow easy comparison between them this resulted in many applications. Only seven applications of insecticides, other than Gemstar, were made in Trial 2. Many insecticides now are registered with recommendations that they be applied only a limited number of times to the one crop, as a strategy to help prevent the development of resistance. For example, the label for Success

Naturalyte (spinosad) states "To help prevent the development of resistance DO NOT apply more than 4 applications of Success Naturalyte Insect Control, or any product containing an active constituent from the same class or mode of action, to any vegetable crop in any one season." It is likely that similar recommendations for restricted use would be made for the new insecticides used in these trials so any one would be applied only a few times rather than the 13 or seven times they were applied in the trials. The results from the trials clearly demonstrate that the insecticides are effective in controlling heliothis on capsicums so each still would be effective when used a limited number of times.

Novaluron, indoxacarb and methoxyfenozide performed well in both trials and emamectin was effective in Trial 2. These results demonstrate that all these insecticides are effective in controlling heliothis in capsicums. The insecticides currently registered, spinosad, methomyl and methamidophos, also gave effective control of heliothis.

The incidence of *S. litura* damaged fruit was very low in both trials, and it was not consistent between replicates. Often damaged fruit were found in only one replicate of a particular treatment. While values for percentage of fruit damaged by *S. litura* are presented in Table 1 they were not analysed and they should be interpreted with caution as the incidence of the insect was so low and sporadic. However *S. litura* damage was recorded only in the untreated check, *B. thuringiensis* products and spinosad treatments in Trial 1, and in the untreated check and Gemstar treatments (the two treatments that would be expected to give no control of *S. litura*) in Trial 2. There was no *S. litura* damage recorded in the indoxacarb, methoxyfenozide, novaluron, or standard insecticide treatments in either trial, or in the emamectin treatment in Trial 2, which may indicate that these insecticides are effective against *S. litura*. More trial work and evidence are needed to properly demonstrate this.

In conclusion, the two trials have demonstrated that XenTari, novaluron, indoxacarb, methoxyfenozide and emamectin are effective in controlling heliothis on capsicums. It would be of great advantage to the industry to have them registered and available for use. The results shown in this report provide efficacy data that would support registration applications.

Indoxacarb has since been registered for use against heliothis on capsicums. DuPont (Australia) Pty. Ltd. used the efficacy data from these trials, combined with residue data they produced, to register indoxacarb (as the product Avatar).

Evaluating insecticides against heliothis in zucchinis

Introduction

Zucchini (*Cucurbita pepo* var. *melopepo*) is a small but important horticultural crop in Queensland. The Australian Bureau of Statistics estimated the area and value of marrows, squashes and zucchinis in Queensland in 1999 at 2170 ha and $24.3m (ABS 2002). The area and value of zucchini production at Bundaberg are estimated at 935 ha and $12.8m, 970 ha and $15.4m, and 900 ha and $13.9m in 1999, 2000, and 2001 respectively (J. Lovatt pers. comm.).

Heliothis, *Helicoverpa* spp., usually are regarded as minor and infrequent pests of zucchinis, feeding on young, developing fruit (Hargreaves *et al.* 1994). However growers sometimes report severe damage to zucchini crops caused by heliothis and insecticidal control of the pest sometimes is required. There are few insecticides available to use. Carbaryl is registered for use against heliothis on cucurbits, an off-label permit (PER 5974) allows the use of endosulfan on cucurbits, an off-label permit (PER 5378) allows the use of bifenthrin on zucchinis, and DiPel DF (*Bacillus thuringiensis* subsp. *kurstaki*) has a general registration against lepidopterous pests on vegetables.

Clearly there is a need for more insecticides to be registered for use against heliothis in zucchinis, particularly those that would be more compatible with integrated pest management programmes than carbaryl and without the restrictions on use of endosulfan. As IPM programmes are being further developed in zucchinis against pests such as aphids and silverleaf whitefly (*Bemisia tabaci* (Gennadius)) the need to register insecticides that are less disruptive to predators and parasitoids becomes greater.

The two trials reported here were done to test the effectiveness of a number of insecticides in controlling heliothis in zucchinis. Data on other lepidopterous pests encountered were gathered also.

Materials and methods

The insecticides used in the trials were:

Bacillus thuringiensis subsp. *kurstaki* - DiPel DF
Bacillus thuringiensis subsp. *aizawai* - XenTari - 35000 DBM units/mg WG
Spinosad - Success Naturalyte - 120 g a.i./L SC
Indoxacarb - Avatar - 300 g a.i./kg WDG (applied with Agral 0.025%)
Methoxyfenozide - Prodigy - 240 g a.i./L SC
Novaluron - Rimon - 100 g a.i./L EC in Trial 1; 7.5 g a.i./kg WDG in Trial 2
Emamectin - Proclaim - 44 g a.i./kg WG
Methomyl - Lannate L - 225 g a.i./L EC
Bifenthrin - Talstar - 100 g a.i./L EC

Two trials were conducted at the DPI Bundaberg Research Station. Trial 1 was done from August to October 2001 and Trial 2 was done from late February to April 2002.

The variety Regal Black Improved was grown on plastic mulch (black in Trial 1 and white in Trial 2) with trickle irrigation in both trials. Plants were grown in single rows with plant spacing of 0.5m, using standard irrigation and fertiliser practices. Fenamiphos (Nemacur) was applied to the soil before planting for nematode control, and imidacloprid (Confidor) was applied though the trickle to each crop on several occasions to control silverleaf whitefly. The crops were sprayed twice weekly with fungicides for disease control.

Trial 1

Trial 1 was a randomised block design with eight treatments by four replicates. The plots were three rows (1.5m apart) by 5 m, with 3 m of bare ground as a guard along each row between plots. Treatments were applied in the equivalent of 1000 L of water per sprayed hectare using a motorised Echo sprayer fitted with a boom and Albuz APT brown hollow cone nozzles and operated at 690 kPa. It was planned to apply the *B. thuringiensis* treatments twice weekly (i.e. every 3 and 4 days) and all other treatments weekly but some modifications were made to this program due to factors such as adverse weather conditions. The *B. thuringiensis* treatments were applied seven times and the other treatments were applied five times. Treatment dates are given in Table H11.

Fruit were harvested twice-weekly for four weeks (18 September to 12 October), a total of eight harvests, from nine plants in the central row of each plot. Fruit approximately 10 cm long and larger were picked on each occasion. Commercially, zucchinis are picked daily or every second day because of their rapid growth, and 10 cm fruit are very small. Picking fruit this size was a compromise, meaning that fruit too small one day were not too large by the subsequent pick. Harvests ceased when the plants became too old and damaged.

Harvested fruit were counted and assessed for damage. Heliothis larvae mainly damage zucchinis by biting the very young fruit causing them to develop with a pronounced bend, the inside of which has a bite scar or deformity, and these fruit are unmarketable. Other damage attributed to heliothis such as scarring from feeding or holes from bites was recorded also, but there is some risk that not all this damage was caused by heliothis but was due to other causes. Many of these fruit may have been marketable. The category "total heliothis damage" includes bent fruit plus this other damage. Feeding damage to the surface of fruit by larvae of cucumber moth, *Diaphania indica* (Saunders), was distinctive and was not confused with heliothis damage. The data from the eight harvests were combined and analysis of variance conducted on the combined data using Genstat 5, Release 4.2.

Twenty-five open female flowers were collected from each plot on two occasions, 3 October and 10 October. The flowers were returned to the laboratory and examined carefully for damage and the presence of larvae. The numbers of flowers with heliothis larvae, and the number of small (1st and 2nd instar), medium (3rd and 4th instar), and large (5th and 6th instar) heliothis larvae in flowers were recorded. Cluster caterpillar (*Spodoptera litura* (F.)) larvae also were recorded on the second sample date. Data were analysed by analysis of variance (Genstat 5, Release 4.2).

H. armigera and *H. punctigera* pheromone traps nearby recorded adult numbers during the course of the trial. Heliothis larvae from flowers in the check plots were collected and reared on navy bean based diet to the adult stage for species identification.

Table H11
The dates of treatment applications in Trial 1 and Trial 2.

Treatment	Dates of application	
	Trial 1 (2001)	Trial 2 (2002)
unsprayed check	nil	nil
B. thuringiensis subsp. *kurstaki*	13, 20, 25, and 28 Sept; 1, 5, and 8 Oct.	-------
B. thuringiensis subsp. *aizawai*	13, 20, 25 and 28 Sept; 1, 5 and 8 Oct.	26 March; 2, 9, and 16 April
methoxyfenozide	13, 20 and 25 Sept; 1 and 8 Oct.	26 March; 2, 9, and 16 April
emamectin	13, 20 and 25 Sept; 1 and 8 Oct.	26 March; 2, 9, and 16 April
indoxacarb	13, 20 and 25 Sept; 1 and 8 Oct.	26 March; 2, 9, and 16 April
bifenthrin	13, 20 and 25 Sept; 1 and 8 Oct.	26 March; 2, 9, and 16 April
methomyl	13, 20 and 25 Sept; 1 and 8 Oct.	26 March; 2, 9, and 16 April
spinosad	-------	26 March; 2, 9, and 16 April
novaluron	-------	26 March; 2, 9, and 16 April

Trial 2

Trial 2 was a randomised block design with nine treatments and four replicates. Plots were single rows with 3 m of bare ground as a guard along each row between plots, and 4.5m of bare ground between each row. The methods of insecticide application were the same as in Trial 1 and the dates of application are given in Table H11. Harvest and assessment methods were similar to those in Trial 1. Fruit were picked from 10 plants per plot twice weekly for seven picks from 28 March to 19 April and examined, and the resulting data analysed, as in Trial 1. Ten female flowers per plot were sampled on 11 April and on 22 April, assessed for damage, and the numbers of heliothis, cluster caterpillar and cucumber moth larvae recorded. Heliothis larvae from flowers in the check plots were collected and reared on navy bean based diet to the adult stage for species identification, and the pheromone traps were monitored.

Results

Table H12 shows the number of fruit harvested (a measure of yield), and the percentage of fruit damaged by heliothis (% bent fruit and % total heliothis damage) for Trials 1 and 2. Some data sets could not be analysed because of a large number of zero values in the sets.

Table H13 shows the number of flowers (out of 25 sampled) containing heliothis larvae and the numbers of heliothis larvae and cluster caterpillar larvae on each sampling date in Trial 1. The number of flowers (out of 10 sampled) containing heliothis larvae and the numbers of heliothis larvae, cluster caterpillar and cucumber moth larvae on each sampling date in Trial 2 are shown in Table H14.

Table H12
The mean number of zucchini fruit harvested and the mean percentage damaged by heliothis in Trials 1 and 2.

Treatment (g a.i./ha)	No. of fruit #	% bent fruit #	% total heliothis damage #*
Trial 1 unsprayed check	162.3 a	** 1.42	5.76 a
B. thuringiensis subsp. *kurstaki* (1000 g product)	186.3 a	1.08	3.74 a
B. thuringiensis subsp. a*izawai* (1000 g product)	172.8 a	1.27	3.50 a
methoxyfenozide (400)	178.5 a	0.65	3.11 a
emamectin (11)	173.3 a	0.77	1.51 a
indoxacarb (37.5)	174.3 a	0.15	1.67 a
bifenthrin (60)	175.0 a	0.56	1.69 a
methomyl (450)	182.8 a	0.27	2.43 a
Trial 2 unsprayed check	136.8 a	* 4.77 a	7.80 d
B. thuringiensis subsp. a*izawai* (1000 g product)	151.8 a	4.08 a	7.15 cd
methoxyfenozide (400)	145.0 a	3.77 a	5.49 abcd
emamectin (11)	144.3 a	2.55 a	3.37 a
indoxacarb (37.5)	147.8 a	2.55 a	4.26 ab
bifenthrin (60)	138.0 a	2.71 a	5.78 bcd
methomyl (450)	149.8 a	2.22 a	4.84 abc
spinosad (48)	147.0 a	2.94 a	4.63 abc
novaluron (75)	148.3 a	3.44 a	6.23 bcd

in each column means followed by the same letter are not significantly different at the 5% level; * back-transformed means following inverse sine transformation before analysis; ** excessive zero values so not analysed.

Table H13
The mean numbers of infested flowers and heliothis and cluster caterpillar larvae in flowers in Trial 1.

Treatment (g a.i./ha)	Flowers /25 with heliothis larvae #*	Number of heliothis larvae in 25 flowers small #*	medium #*	large	total #*	No. cluster caterpillar larvae
Sample 1 (3 Oct.) unsprayed check	21.00 d	28.52 c	15.80 e	** 3.75	48.72 f	-
B. thuringiensis subsp. *kurstaki* (1000 g)	19.98 d	21.37 c	5.82 cd	1.00	28.98 d	-
B. thuringiensis subsp. *aizawai* (1000 g)	20.42 d	26.68 c	9.21 d	1.25	37.24 e	-
methoxyfenozide (400)	13.46 c	9.32 b	5.70 cd	1.25	16.46 c	-
emamectin (11)	12.62 c	10.62 b	4.16 bc	0.75	15.69 c	-
indoxacarb (37.5)	8.73 b	8.44 b	1.14 ab	0.50	10.56 b	-
bifenthrin (60)	3.97 a	2.81 a	0.36 a	0.75	4.21 a	-
methomyl (450)	12.63 c	10.13 b	4.33 c	0.75	15.36 c	-
Sample 2 (10 Oct.) unsprayed check	15.68 f	9.15 bcd	11.83 d	** 2.00	23.64 f	** 1.00
B. thuringiensis subsp. *kurstaki* (1000 g)	12.16 def	10.80 cd	4.49 bc	0.50	16.01 def	1.75
B. thuringiensis subsp. *aizawai* (1000 g)	13.99 ef	11.49 d	5.85 bc	1.50	19.17 ef	1.50
methoxyfenozide (400)	9.15 bcd	6.07 abcd	3.66 bc	0.50	10.38 bcd	0.00
emamectin (11)	7.70 bc	4.88 ab	3.52 ab	0.50	9.10 ab	0.00
indoxacarb (37.5)	6.32 ab	5.22 abc	3.24 ab	0.75	9.66 bc	0.00
bifenthrin (60)	4.41 a	3.21 a	1.16 a	0.00	4.63 a	0.00
methomyl (450)	11.07 cde	7.69 abcd	6.91 c	0.75	15.32 cde	0.25

in each column means followed by the same letter are not significantly different at the 5% level; * back-transformed means following square root (x + 0.5) transformation before analysis; ** excessive zero values so not analysed.

Table H14
The mean numbers of infested flowers and heliothis, cluster caterpillar (cl. cat.) and cucumber moth (cuc. moth) larvae in flowers in Trial 2.

Treatment (g a.i./ha)	Flowers /10 with heliothis larvae #*	Number of heliothis larvae in 10 flowers				No. cl. cat. larvae	No. cuc. moth larvae
		small # *	medium # *	large	total # *		
Sample 1 (11 April)				**		**	**
unsprayed check	4.59 bcde	3.86 bc	1.14 a	1.25	6.74 cd	0.75	7.50
B. thuringiensis subs *aizawai* (1000 g)	4.67 cde	2.70 abc	2.39 a	0.25	5.49 bc	0.50	3.50
spinosad (48)	1.47 a	1.23 a	0.20 a	0.25	1.68 a	1.00	0.25
methoxyfenozide (400)	2.93 abcd	1.47 ab	1.68 a	0.25	3.42 ab	0.00	0.00
emamectin (11)	2.24 a	1.23 a	0.70 a	0.25	2.24 a	0.00	0.00
indoxacarb (37.5)	2.39 abc	1.86 abc	0.43 a	0.00	2.58 a	0.00	0.25
novaluron (75)	6.70 e	7.93 d	2.04 a	0.25	10.35 d	0.00	0.25
bifenthrin (60)	2.35 ab	0.90 a	0.50 a	1.25	2.53 a	0.00	0.25
methomyl (450)	4.95 de	3.94 c	1.90 a	0.50	6.59 bcd	0.00	0.25
Sample 2 (22 April)		**	**	**	**	**	**
unsprayed check	2.06 a	1.50	1.25	0.00	2.75	4.00	26.00
B. thuringiensis subs *aizawai* (1000 g)	1.47 a	1.25	0.50	0.00	1.75	0.25	3.00
spinosad (48)	0.20 a	0.25	0.00	0.00	0.25	0.00	0.00
methoxyfenozide (400)	0.20 a	0.00	0.25	0.00	0.25	0.00	0.00
emamectin (11)	0.90 a	0.75	0.00	0.25	1.00	0.00	0.25
indoxacarb (37.5)	0.36 a	2.50	0.00	0.00	2.50	0.00	0.00
novaluron (75)	1.48 a	3.25	0.00	0.00	3.25	0.00	0.00
bifenthrin (60)	0.20 a	0.00	0.25	0.00	0.25	0.00	0.00
methomyl (450)	0.43 a	0.25	0.25	0.00	0.50	0.00	0.25

in each column means followed by the same letter are not significantly different at the 5% level; * back-transformed means following square root (x + 0.5) transformation before analysis; ** excessive zero values so not analysed.

All of the heliothis larvae reared in Trial 1 (52) and Trial 2 (10) were *H. armigera*. The pheromone trap catches for the period August 2001 to May 2002 are shown in Figures H3 and H4.

Discussion

The two trials were conducted at times of the year when populations of heliothis are usually at their peaks in the Bundaberg district (Kay 1999). Usually both *H. armigera* and *H. punctigera* are present in September and October (i.e. during Trial 1) while *H. armigera* is present during March and April (i.e. during Trial 2) (Kay 1999). The pheromone trap catches in Figure H3 and Figure H4 show that low numbers only of *H. punctigera* were caught in September while large numbers were caught in mid October, and that *H. armigera* were caught in reasonable, but not high, numbers during both trials. Only *H. armigera* adults were reared from larvae collected from flowers in the unsprayed check plots in Trial 1 although both species were present in the traps, and as cucurbits are known to be hosts of *H. punctigera* (Zalucki *et al.* 1986) their absence here is surprising. Possibly they were not present in large enough numbers to be recorded in the samples taken, or they were out-competed by *H. armigera* larvae in the flowers, or zucchini is not a good host for *H. punctigera*. More intensive collecting at times when both species are active would be needed to check this.

What damage do heliothis do to zucchinis? A bite by a larva to a young fruit causes it to bend, and there is a scar or deformity at the point of the bend. Such damage is easy to see. In addition some fruit have marks, scars and blemishes that look as if they could have been caused by heliothis larvae but may have been caused by some other agent, either mechanical or biological. Fruit with such damage were categorised as heliothis damage in these trials and included in "total heliothis damage", so some caution should be taken in interpreting the total damage results because of this uncertainty. (Cucumber moth larvae graze on the surface of the fruit, causing distinctive damage that was not included in this category.)

There were no significant differences ($P>0.05$) between treatments in the number of fruit harvested in either trial indicating that heliothis did not prevent fruit from developing to harvest, and did not affect total yield.

There were very few bent fruit in Trial 1, with many plots having none so the data could not be analysed. In Trial 2 there were low levels of bent fruit damage but there were no significant differences ($P>0.05$) between treatments. This indicates that at moderate heliothis pressure none of the insecticides were effective in preventing all small larvae from biting fruit, resulting in bent damage, before the larvae were killed. There was a trend towards higher levels of damage in the check, the two *B. thuringiensis*, and the novaluron treatments, which corresponds to the generally higher number of larvae in flowers in these treatments (Tables H13 and H14).

In Trial 1 there were no significant differences ($P>0.05$) between treatments in the amount of total heliothis damage, although there was a trend to higher levels of damage in the check and "softer" insecticide treatments (i.e. *B. thuringiensis* and methoxyfenozide). In Trial 2 the emamectin, indoxacarb, spinosad and methomyl treatments had significantly less ($P<0.05$) damage than the check, while the levels in the bifenthrin and novaluron treatments did not

differ from the check (P>0.05). The damage levels were low, with even the check having less than 8% of fruit damaged.

Female flowers develop on the distal end of the developing zucchini fruit. They have tightly closed petals which elongate and turn from green to yellow over several days before opening (at which stage the fruit are 45-100mm long), but become flaccid in one day, and then collapse and start to decompose after another day (Kay, unpub. data). Flowers collected in this study were either open or flaccid. A high proportion of the flowers sampled in both trials contained heliothis larvae, which were feeding mainly on the fleshy base of the style. They clearly preferred feeding in the flowers rather than on the fruit as often the internal parts of the flowers were completely consumed while fruit suffered only minor feeding damage. Late instar larvae were found inside undamaged or little-damaged flowers indicating that larvae moved from flower to flower.

In Trial 1 high proportion (about 80%) of flowers in the check and *B. thuringiensis* treatments contained heliothis larvae in Sample 1, and in both samples this was a significantly higher (P<0.05) number than all the other treatments, except for methomyl in Sample 2. The bifenthrin treatment had the least number of infested flowers and the lowest number of heliothis larvae, indicating that it gave the best control of heliothis in flowers. The indoxacarb, emamectin, methoxyfenozide and methomyl treatments had significantly fewer (P<0.05) infested flowers and significantly fewer (P<0.05) larvae than the check on both sample dates. Neither *B. thuringiensis* treatment differed (P>0.05) from the check in the number of infested flowers in either sample but in Sample 1 both had significantly fewer (P<0.05) total heliothis larvae than the check. In both samples the numbers of small larvae in the check and the *B. thuringiensis* treatments did not differ but the *B. thuringiensis* treatments had fewer medium larvae than the check indicating that larval mortality was higher in the *B. thuringiensis* treatments than in the check. There were no significant differences (P>0.05) between the two *B. thuringiensis* treatments in any of the performance indicators except that there were fewer (P<0.05) total heliothis larvae in Sample 1 in the *B. thuringiensis* subs *kurstaki* treatment than in the *B. thuringiensis* subs *aizawai* treatment. These results indicate that the two *B. thuringiensis* subspecies effectively performed equally.

Fewer flowers were collected in Trial 2 because plots were only one row. Heliothis pressure was low at Sample 2, shown by the low pheromone trap catches for the two weeks before that sample date (Figure 1) and the low proportion of infested flowers in the check. There were no significant differences (P>0.05) between treatments in the number of infested flowers (although a trend towards higher numbers in the check, *B. thuringiensis* and novaluron treatments might be discerned), and larval numbers were too low for analysis. Further discussion on Trial 2 refers only to Sample 1. In Sample 1 only spinosad and emamectin had significantly fewer (P<0.05) infested flowers than the check. The novaluron treatment had the highest number of infested flowers, significantly more (P>0.05) than all but the check, *B. thuringiensis* and methomyl treatments. There were significantly fewer (P<0.05) heliothis larvae in flowers in the spinosad, methoxyfenozide, emamectin, indoxacarb and bifenthrin treatments than in the check, indicating that these treatments were effective in controlling heliothis larvae in flowers. Methomyl had similar numbers of infested flowers and heliothis larvae as the check, indicating it was not effective. High levels of carbamate resistance, with quite high proportions of homozygotes, have been recorded in *H. armigera* collections from Bundaberg in summer over several years (R. Gunning pers. comm.), which may account for the poor performance by methomyl in this trial.

Cucumber moth larvae were quite common in flowers in the unsprayed check, much less so in the *B. thuringiensis* subsp. a*izawai* treatment, and only very low numbers were found in the other treatments in Trial 2. The large number of plots with zero counts meant that the data could not be meaningfully analysed, but the very definite differences in numbers clearly show that *B. thuringiensis* subsp. a*izawai* was quite effective in controlling cucumber moth and that spinosad, methoxyfenozide, emamectin, indoxacarb, novaluron, bifenthrin, and methomyl were very effective. Too few cluster caterpillar larvae were found to allow meaningful assessments of the effectiveness of the insecticides in controlling the pest.

The trials showed that large numbers of heliothis larvae occur in zucchini crops, which then could act as a source of heliothis to infest other crops. This would be important in mating disruption and area-wide management programmes.

In summary, while none of the insecticides tested prevented heliothis infesting zucchini flowers, bifenthrin, spinosad, emamectin, indoxacarb and methoxyfenozide provided good to reasonable control of heliothis larvae in flowers. Methomyl and the two *B. thuringiensis* treatments had some effect but were not good, while novaluron was ineffective. None of the insecticide treatments in these trials was effective in preventing the most important type of damage to fruit, bent fruit, although some reduced the amount of total fruit damage.

Rather than determining the relative performance of insecticides in controlling heliothis in zucchinis the trials have posed a conundrum. Despite the fact that large percentages of flowers contained heliothis larvae only a small percentage of fruit were damaged, which raises the question as to whether or not heliothis are a pest needing to be controlled in zucchinis. The evidence from these trials is that they are not, and that while the larvae feed voraciously in flowers they cause little damage to fruit and do not lower yield, and that using insecticides does not significantly reduce the amount of that damage. However growers genuinely believe that at times heliothis are a major problem and that they cause significant damage, and crops with large amounts of bent fruit have been witnessed (J. Maltby pers. comm.). It would be useful to repeat these trials at times of heavy heliothis pressure (which was attempted here by timing the trials to coincide with usual times of heliothis seasonal peak occurrence) to see if using insecticides can prevent damage when pressure is very high. The insecticides that were effective against larvae in flowers should be included in those trials.

Evaluating insecticides against heliothis in melons

Introduction

Melon crops such as rockmelons and honeydew melons are attacked by a wide range of insect pests. Aphids, particularly cotton aphid (*Aphis gossypii* Glover) and green peach aphid (*Myzus persicae* (Sulzer)), are the most important as they are vectors of several mosaic virus diseases. Lepidopteran insects also can be important. Heliothis (*Helicoverpa armigera*) larvae fed on flowers and on young, developing fruit, causing the fruit to abort or to develop scars, while cucumber moth (*Diaphania indica* (Saunders)) larvae feed mainly on leaves but occasionally on fruit, gouging out irregularly shaped holes (Hargreaves *et al.* 1994).

There are very few insecticides registered for use against heliothis or cucumber moth on melons. Diazinon is registered for use against caterpillars, endosulfan is registered against both heliothis and cucumber moth, while bifenthrin can be used against heliothis under an off-label permit. Recently DiPel DF (*Bacillus thuringiensis kurstaki*) has obtained a general registration for use against lepidopteran pests of fruit and vegetables. Several of these insecticides are reasonably broad spectrum in their activity, and the use of endosulfan is restricted.

Integrated pest management, with particular emphasis on biological control, is becoming more important in fruit and vegetables to manage old pests such as aphids and new ones like silverleaf whitefly (*Bemisia tabaci* Biotype B (Gennadius)). There is therefore a need to determine the efficacy of newer insecticides and some biopesticides that are more compatible with IPM systems against heliothis and cucumber moth on melons. The trials reported here were done for that purpose.

Materials and methods

Three trials were done at Ayr Research Station from 1999 to 2001. Similar methods were used in each trial.

Trial 1
This trial was done in 1999 on rockmelons grown using standard agronomic practices. The trial was a randomised block design with six treatments and five replicates. Plots were one row by 10 m, with untreated guards rows and lengths of rows on melons between plots.

The treatments applied were:

1. Heliothis nuclear polyhedrosis virus as Gemstar at 750ml/ha.
2. Spinosad as Success at 96 g a.i./ha (= 800 ml product/ha).
3. Acephate as Orthene Xtra at 97 g a.i./100 L (= 120 g product/100 L or 1200 g/ha).
4. MVP (the delta endotoxin of *Bacillus thuringiensis kurstaki* encapsulated in killed *Pseudomonas fluorescens*) at 2 L/ha plus DC Tron at 0.16% plus skim milk powder (calf milk replacer) (Daisyvite) at 2 kg/ha.
5. *Bacillus thuringiensis aizawai* as XenTari at 1000 g/ha.
6. Untreated check.

The insecticide treatments were applied with a backpack mister in the equivalent of 1200 L/ha of water at seven day intervals from first fruit set until the completion of the trial, with four sprays applied.

All fruit were harvested from six plants per plot. The fruit were separated into young fruit, which had smooth skins and old fruit, defined as those on which netting had developed. Each fruit was examined carefully for damage, which could be either chewing of the fruit skin or holes chewed into the fruit, and the numbers in each category were counted. Analyses of variance were done on the data.

Trial 2
This trial was done in 2000 on rockmelons grown using standard agronomic practices. The trial design and methods used were similar to those used in Trial 1 except for some minor differences as described below.

The treatments applied were:

1. Heliothis nuclear polyhedrosis virus as Gemstar at 750ml/ha plus Brella Spray Adjuvant at 1%.
2. *Bacillus thuringiensis aizawai* as XenTari at 1000 g/ha.
3. Novaluron as Rimon at 100 g a.i./ha (= 1000 g product/ha).
4. MVP (the delta endotoxin of *Bacillus thuringiensis kurstaki* encapsulated in killed *Pseudomonas fluorescens*) at 2 L/ha plus Brella Spray Adjuvant at 1%.
5. *Bacillus thuringiensis aizawai* as XenTari at 1000 g/ha plus Brella Spray Adjuvant at 1%.
6. Untreated check.

Treatments were applied at the same frequency and water rate as in Trial 1 but using a motorised knapsack sprayer fitted with a boom and hollow cone nozzles.

Mature fruit were harvested from 5 m of row per plot on two occasions and assessed for damage.

Trial 3
This trial was done in March – April 2001 on rockmelons grown using standard agronomic practices. The trial design and methods used were similar to those used in Trials 1 and 2.

The treatments applied were:

1. *Bacillus thuringiensis aizawai/kurstaki* as Agree WG at 1000 g/ha.
2. *Bacillus thuringiensis aizawai* as XenTari at 1000 g/ha plus Brella Spray Adjuvant at 2%.
3. Spinosad as Success at 72 g a.i./ha (= 600 ml product/ha) plus Brella Spray Adjuvant at 2%.
4. Trichlorfon as Lepidex at 700 g a.i./ha (= 1400 ml product/ha).
5. MVP (the delta endotoxin of *Bacillus thuringiensis kurstaki* encapsulated in killed *Pseudomonas fluorescens*) at 2 L/ha plus Brella Spray Adjuvant at 2%.
6. Untreated check.

Treatments were applied at seven day intervals using a motorised knapsack sprayer fitted with a boom and hollow cone nozzles in the equivalent of 1000 L/ha of water.

All fruit were harvested from 5 m per plot on one occasion and assessed for damage. On a separate occasion a 1 m^2 quadrat was placed over each of two plants (outside the 5 m used for fruit sampling) per plot and the runner stems and leaves within the 1 m^2 quadrat were collected. The stems and leaves were oven dried and weighed.

Results

Trial 1
The numbers of undamaged, damaged and total number of fruit harvested in Trial 1 are shown in Table H15.

Table H15
The number of damaged and undamaged fruit in Trial 1.

Treatment (rate/ha)	Mean number of fruit in each category						
	Young			Old			Total
	damaged	undam.	total	damaged	undam.	total	fruit
Gemstar (750 ml)	5.6 c*	1.2	6.8	3.6	0.0	3.6	10.4
Spinosad (96 g a.i.)	2.2 ab	2.8	5.0	2.8	2.0	4.8	9.8
Acephate (97 g a.i.)	1.0 a	4.2	5.2	3.4	2.2	5.6	10.8
MVP + (2000 ml)	4.0 bc	2.8	6.8	4.0	0.8	4.8	11.6
XenTari (1000 g)	1.6 a	3.4	5.0	3.4	2.4	5.8	10.8
Untreated check (-)	4.8 c	2.0	6.8	5.2	0.4	5.6	12.4

In each column numbers followed by the same letter are not significantly different at the 5% level. The F-values were not significant where there are no letters.

Fruit numbers were low, and there were significant differences ($P<0.05$) only in the numbers of damaged young fruit, where the acephate, XenTari and spinosad treatments had fewer damaged fruit than the check.

Trial 2
The numbers of undamaged, damaged and total number of fruit harvested in Trial 2 are shown in TableH16.

Few fruit were picked in the first harvest. In the second harvest and overall there were significantly ($P<0.05$) more damaged fruit and fewer undamaged fruit in the untreated check than in the insecticide treatments. There were several differences between insecticide treatments in the number of damaged fruit in the second harvest and as a total, but no differences in total number of undamaged fruit.

Table H16
The number of damaged and undamaged fruit in Trial 2.

Treatment (rate/ha)	Mean number of fruit in each category						
	Harvest 1		Harvest 2		Total		Total
	damaged	undam.	damaged	undam.	damaged	undam.	number
Gemstar + Brella (750 ml + 1%)	0.4	0.8	6.2 b*	23.8 bc	6.6 b	24.6 b	62.4
XenTari (1000 g)	0.2	1.0	1.4 a	26.6 c	1.6 a	27.6 b	58.4
Novaluron (100 g a.i.)	0.2	0.6	3.2 ab	24.6 bc	3.4 ab	25.2 b	57.2
MVP + Brella (2000 ml + 1%)	1.4	1.8	3.6 ab	22.2 b	5.0 ab	24.0 b	58.0
XenTari + Brella (1000 g + 1%)	0.2	2.0	2.0 a	24.0 bc	2.2 a	26.0 b	56.4
Untreated check (-)	0.2	1.2	16.0 c	10.6 a	16.2 c	11.8 a	56.0

In each column numbers followed by the same letter are not significantly different at the 5% level. The F-values were not significant where there are no letters.

Trial 3

The results from the Trial 3 fruit harvest and for the plant dry weights are shown in Table H17.

Table H17
The number of damaged and undamaged fruit, and the plant dry weights in Trial 3.

Treatment (rate/ha)	Mean number of fruit			Mean dry weights (g)		
	damaged	undam.	total	stem	leaf	total vine
Agree (1000 g)	9.0 bc*	2.8 ab*	11.8	308.2	366.4	675
XenTari + Brella (1000 g + 2%)	6.2 b	5.8 bc	12.0	268.0	326.8	595
Spinosad + Brella (72 g a.i. + 2%)	2.0 a	9.4 d	11.4	263.6	338.4	602
Trichlorfon (700 g a.i.)	7.4 b	6.4 cd	13.8	267.8	343.2	611
MVP + Brella (2000 ml + 2%)	11.4 c	1.2 a	12.6	280.6	341.2	622
Untreated check (-)	11.8 c	0.6 a	12.4	289.0	320.4	609

In each column numbers followed by the same letter are not significantly different at the 5% level. The F-values were not significant where there are no letters.

There were significant differences ($P<0.05$) in numbers of damaged and undamaged fruit between the untreated check and the XenTari, spinosad and trichlorfon treatments, and there were fewer damaged fruit in the spinosad treatment than in any other treatment. There were

no differences between treatments in the total number of fruit harvested. No differences in plant dry weights were apparent.

Discussion

Both heliothis and cucumber moth were present in all trials, and both damaged fruit. The damage caused to fruit by each one could not easily be distinguished and separated, and it would have been risky to try to do so. Accordingly, fruit damage has been reported without attributing it to either pest.

In Trial 1 there were no differences between treatments in numbers of fruit. The overall numbers were very low, possibly due to poor pollination as the weather was cold and wet around the flowering period and there was little honeybee activity. The low fruit numbers makes it difficult to assess the effectiveness of the treatments. There were differences ($P<0.05$) between treatments in numbers of damaged young fruit with fewer in the acephate, spinosad, and XenTari treatments than in the unsprayed check, and these three treatments gave reasonable control. The MVP and Gemstar treatments were not effective in preventing fruit damage. It must be remembered that Gemstar will only infect heliothis larvae, so the cucumber moth larvae in these plots would not have been controlled and would have continued to cause damage. As well, a shorter spray interval than weekly may be needed to obtain control of heliothis with Gemstar.

All of the insecticide treatments in Trial 2 are regarded as "soft" as they are generally target-specific and regarded as IPM compatible. (Gemstar is specific to heliothis larvae, XenTari and MVP are *B. thuringiensis* products specific to lepidopteran larvae, and novaluron is an insect growth regulator that acts by inhibiting chitin formation and so will not affect adult parasitoids and predators.)

In Trial 2 there were no differences ($P>0.05$) between treatments in the total number of fruit, but all treatments had more undamaged and fewer damaged fruit than the untreated check ($P<0.05$), showing that they all provided some control of the pests. The Gemstar treatment had significantly more ($P<0.05$) damaged fruit than both the XenTari treatments, but again Gemstar will not control cucumber moth. There was no significant difference ($P>0.05$) between the number of damaged fruit in the plots treated with XenTari or XenTari plus Brella. Brella Spray Adjuvant is an oil containing a UV-screen that is designed to protect pesticides that are susceptible to degradation by UV light. Its addition did not improve the performance of XenTari under the conditions of this trial.

The performance of all the biopesticides and the insect growth regulator in this trial was promising in an IPM context.

In Trial 3 the numbers of fruit again were low, and with no significant differences ($P>0.05$) between treatments in total numbers of fruit. The severity of attack by the pest larvae was high with 90% of fruit in the untreated check damaged, and high percentages of damaged fruit, not significantly different ($P>0.05$) from the check, in the MVP and Agree treatments. Only spinosad performed well in protecting fruit from damage, and it was significantly better ($P<0.05$) than the other insecticides. Trichlorfon was moderately effective.

The trial compared three different types of *B. thuringiensis*. MVP contains the delta endotoxin of *B. thuringiensis kurstaki* encapsulated in killed *P. fluorescens*, XenTari is *B. thuringiensis aizawai*, while Agree is a combination of *B. thuringiensis aizawai* and *B. thuringiensis kurstaki* in which the cry1Ac gene from a *kurstaki* cell has been transferred to an *aizawai* cell through conjugation (M. A. Ericson, Certis USA, pers. comm.). The results indicate that XenTari gave better control than MVP, that Agree and MVP did not differ significantly ($P>0.05$), and that XenTari and Agree did not differ significantly ($P>0.05$) in the level of protection provided. It would be interesting to conduct further comparative trials between the different *B. thuringiensis* strains and products.

There was a lot of damage caused by cucumber moth to leaves in Trial 3, and visually there appeared to be differences in the amount of leaf damage between plots. Damage to leaves translates to reduced photosynthetic area, which could result in lowered yield, either fruit number or weight. However the dried leaf weights showed no significant differences ($P>0.05$) between treatments.

This series of trials have demonstrated that a number of the more IPM compatible pesticides show promise for managing heliothis and cucumber moth on melons. Spinosad in particular is effective, and its registration for use on melons would be of great benefit to industry. Further comparisons of the *B. thuringiensis* products are needed, although the results indicate that MVP is perhaps the least effective. Further comparisons of biopesticides with and without Brella Spray Adjuvant are needed to establish whether or not the adjuvant does improve the performance of the biopesticides against these lepidopteran pests on melons. Gemstar showed some promise in these trials, but it is likely to be more effective if applied at shorter intervals than seven days, and trials to establish effective intervals and dose rates would be useful. It is effective only against heliothis and will not control cucumber moth larvae, emphasising the importance of and need for good pest monitoring and correct pest identification in melons.

Do additives improve biopesticide efficacy?

Introduction

Various substances have been added to sprays of biopesticides in attempts to improve the performance of the biopesticides. Murray (1999) evaluated the effect of adding skim milk powder or calf supplements to *Bacillus thuringiensis* and a heliothis nuclear polyhedrosis virus (NPV) on the control of *H. armigera* larvae in chickpeas and cotton. Using bioassays he showed that the additives improved the performance of NPV on chickpeas but no consistent benefit was found with *B. thuringiensis* on cotton. Murray *et al.* (2000) tested a range of additives including milk powders and Amino-Feed with *B. thuringiensis* and NPV against *H. armigera* larvae in mungbeans and cotton using bioassays. They reported increased larval mortality when Denkavit (a calf feeding supplement) was added to both *B. thuringiensis* and NPV, and that the results with Amino-Feed were mostly equivalent to Denkavit.

Amino-Feed at 1 L/ha now is routinely added to biopesticides used on field crops (D. Murray, C. Hauxwell pers. comm.) although hard data showing improved control leading to improved quantity or quality yield appears not to be available. Amino-Feed is the preferred additive as it is inexpensive and does not have the nozzle clogging problems that sometimes occur with the milk products.

The work reported here was done to investigate the effect of including additives with biopesticides on the control of *H. armigera* larvae in capsicums and tomatoes. The additives trialed were skim milk powder, Amino-Feed at 1L/ha (the standard rate in field crops) and at 4L/ha (the manufacturers of Amino-Feed suggested the higher rate may be necessary for high volume spraying), and Amino-Feed UV, a formulation containing UV "enhancers which assist in reducing the effect of UV degradation". A series of simple bioassays and several replicated bioassays were done on both crops, and a large field trial was conducted on tomatoes.

Materials and methods

(i) Simple bioassays
Similar methods were used in all the simple bioassays. The crop, source of plants, biopesticide, and additives tested are summarised in Table H18.

Plants used in bioassays were grown either in pots in a plant-house or in the field, and received occasional fungicide sprays but no insecticide sprays.

All treatment sprays were applied using a motorised Echo sprayer fitted with a boom and Albuz APT brown hollow cone nozzles and operated at 690 kPa in the equivalent of 1000 L water per hectare. Ten potted plants were sprayed for each treatment in each bioassay and check plants were sprayed with water. Potted plants were held under cover in a plastic-roofed plant-house. In field bioassays, plots of two by 5m lengths of row were sprayed for each treatment. Plots were well separated in a larger block of the crop. The biopesticides used were *B. thuringiensis* as DiPel Forté at 1000 g/ha, and NPV as Gemstar at 500 ml/ha.

Leaves were collected from sprayed plants immediately after treatment as soon as the sprays had dried, and on several days following treatment, and returned to the laboratory. A 50 mm disc leaf was cut from each leaf and placed in a 50 mm Falcon petri dish. A single two-day old *H. armigera* larva sourced from a laboratory colony was placed on each leaf disc. The petri dishes were held in a constant temperature room at 24 – 25º C. In bioassays with *B. thuringiensis* larvae remained on the leaf discs for the duration of the bioassay, but in bioassays with NPV the larvae were left on the treated leaf disc for 24 hours and then transferred to a 1 oz plastic cup (Solo) containing an artificial navy bean based diet. Mortality was recorded daily for a number of days. Death was defined as complete lack of movement when prodded, and obviously moribund larvae were counted as alive. Usually 30 but occasionally 40 larvae were used for each treatment in each bioassay.

Great care was taken to minimise the risk of cross-contamination between treatments when conducting the bioassays.

Table H18
Information on crop, location, biopesticide and additives for each bioassay.

Bioassay No.	Crop	Location	Biopesticide	Additives
Simple				
1	tomato	pot	NPV	skim milk, Amino-Feed 1L
2	capsicum	field	*B. thuringiensis*	skim milk, Amino-Feed 1L
3 a	tomato	field	*B. thuringiensis*	Amino-Feed 1L
3 b	capsicum	field	*B. thuringiensis*	Amino-Feed 1L
4 a	tomato	field	NPV	Amino-Feed 1L
4 b	capsicum	field	NPV	Amino-Feed 1L
5 a	tomato	pot	*B. thuringiensis*	Amino-Feed 1L
5 b	capsicum	pot	*B. thuringiensis*	Amino-Feed 1L
6	tomato	pot	NPV	Amino-Feed 1L
7	tomato	pot	*B. thuringiensis*	Amino-Feed 1L
8	capsicum	pot	*B. thuringiensis*	Amino-Feed 4L
9	capsicum	pot	NPV	Amino-Feed 4L
10	tomato	pot	*B. thuringiensis*	Amino-Feed 4L
Replicated				
11	tomato	field	*B. thuringiensis*	Amino-Feed 1L, 4L, UV
12	capsicum	field	*B. thuringiensis*	Amino-Feed 1L, 4L, UV
13	capsicum	field	*B. thuringiensis*	Amino-Feed 1L, 4L, UV

(ii) Replicated bioassays
Three replicated bioassays were conducted, one on tomatoes (Bioassay 11) and two with capsicums (Bioassays 12 and 13), all using *B. thuringiensis*. Similar methods were used in each bioassay. Each bioassay had five treatments and four replicates, with 5 m long single row plots separated by adequate guard areas. Treatments were applied with the motorised Echo sprayer in the equivalent of 1000 L/ha of water. Ten leaflets or leaves were sampled from each plot in each bioassay, and the same laboratory methods as used in the simple bioassays were used in these bioassays. In Bioassay 11 samples were taken immediately after spraying (day 0) and on days 1 and 2. In Bioassay 12 samples were taken on day 0 and day 1,

and from one replicate only on days 3 and 6 because of a shortage of larvae. Samples were taken on days 0, 2, and 4 in Bioassay 13. Analyses of variance were conducted on the data from each bioassay.

(iii) Field trial

The trial was conducted at Bundaberg Research Station from March to July 2001. It was timed so that the crop would experience the normal medium to high heliothis pressure in mid April to early May but would finish in the low pressure period from mid May onwards.

The round variety Queensland Red was grown on plastic mulch with trickle irrigation. Plants were grown in single rows with a plant spacing of 50 cm, using standard irrigation and fertiliser practices, and were trellised. The crops were sprayed twice weekly with mancozeb and alternate applications of copper hydroxide (Kocide) and copper oxychloride for disease control.

The trial was a randomised block design with six treatments by four replicates. The plots were three rows by 5 m, with 3 m of untreated guard along each row between plots and three untreated rows lengthways between plots. Treatments were applied in the equivalent of 1000 L of water per sprayed hectare using a motorised Echo sprayer fitted with a boom and Albuz APT brown hollow cone nozzles and operated at 690 kPa.

The treatments were:

1. Untreated check
2. Standard insecticide. Methamidophos (Nitofol) at 1102 g a.i./ha was alternated with methomyl (Lannate) at 450 g a.i./ha.
3. *B. thuringiensis* as DiPel Forté at 1000 g/ha
4. *B. thuringiensis* as DiPel Forté at 1000 g/ha plus Amino-Feed at 1000 ml/ha
5. Heliothis nuclear polyhedrosis virus as Gemstar at 500 ml/ha
6. Heliothis nuclear polyhedrosis virus as Gemstar at 500 ml/ha plus Amino-Feed at 1000 ml/ha.

The standard insecticide and *B. thuringiensis* treatments were applied twice weekly (Monday and Friday), with a total of 26 applications. The NPV treatments were applied thrice weekly (Monday, Wednesday and Friday in the late afternoon) from early April until the end of May and then twice weekly until mid July, with a total of 32 applications.

Heliothis activity during the trial was assessed by counting the numbers of eggs and larvae on the first full leaf below the top opened flower on each of 10 randomly selected plants from each of the three central guard rows on an approximately weekly schedule.

The incidence of virus in heliothis larvae in the trial area was assessed on three occasions. Ten small (instars one to three, but predominantly two) larvae were collected from each of the outer two rows of each sampled plot (i.e. 20 larvae per plot) with fine forceps that were washed in alcohol between each larva collected. Collected larvae were placed individually into plastic cups (Solo 1 oz) with navy bean based diet and then held in the laboratory at 25ºC, and observed to determine if they died from infection with virus. On 19 April larvae were collected from the untreated plots and from each of the NPV treatments. On 27 April and 4 May larvae were collected from the untreated plots only.

Fruit were harvested on seven occasions (approximately weekly) from the central eight plants in the centre row of each plot from early June to late July. Large fruit plus any that were obviously damaged were picked in the first six harvests while all remaining fruit larger than a table tennis ball were picked in the final harvest. Harvested fruit were returned to the laboratory and weighed, and each piece was examined carefully and allocated to one of the following categories:

- Undamaged: fruit undamaged by heliothis. These fruit may have had other damage or blemishes.

- Minor pinhole damage: fruit with one to three small pinholes caused by heliothis larvae feeding at an early stage of fruit development. These fruit probably would be marketable if present in low numbers.

- Major damage: fruit with more than three pinholes or with large pinholes or with major feeding damage by heliothis.

The number of fruit in each category was recorded. Fruit damaged by cluster caterpillar, *Spodoptera litura* (F.), also was recorded. Cluster caterpillars usually graze widely on the fruit surface. Data from the individual harvests were combined and analyses of variance were done on the yield data and on the damage data using Genstat 5, Release 4.1.

Results

(i) Simple bioassays
The results for Bioassay 1 are recorded in Table H19. This bioassay, which used 40 larvae, was only sampled on the day of spraying and mortality was recorded at 3, 5, 7 and 9 days after larvae were placed on treated leaves. It was an initial trial mainly done to test the methods.

Table H19
Cumulative mortality in Bioassay 1.

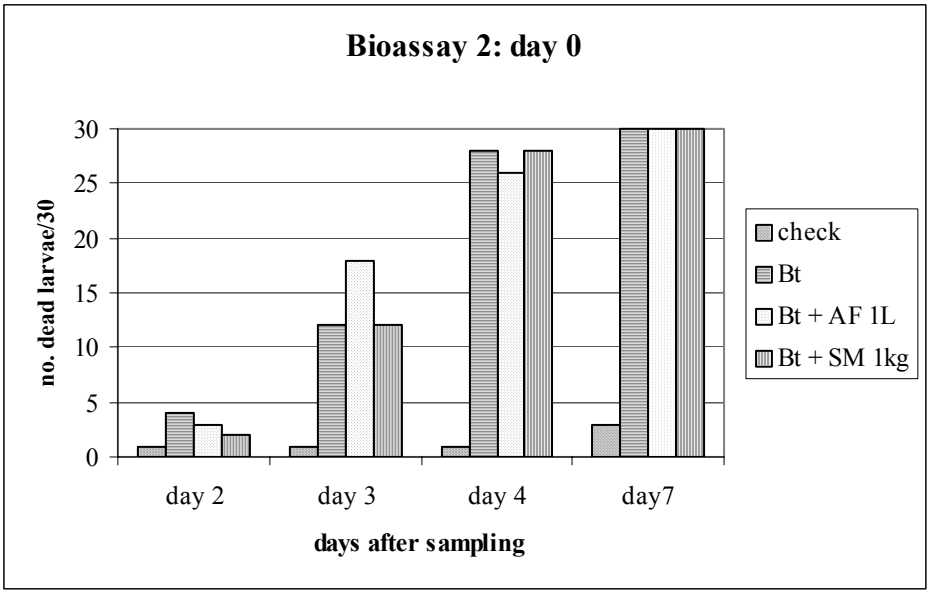
Treatment	Cumulative number dead larvae/40 at n days			
	3 d	5 d	7 d	9 d
Untreated check	6	14	17	19
NPV (500 ml/ha)	12	23	33	39
NPV + Amino-Feed 1 L/ha	12	28	39	40
NPV + skim milk 1.25 kg/ha	10	26	39	40

No analyses were done on the data. All of the NPV treatments resulted in very high larval mortality, but there also was excessively high mortality in the check, possibly due to contamination in the laboratory colony used for this bioassay, so the results should be treated with caution. The data possibly indicate that the additives shorten the time to death.

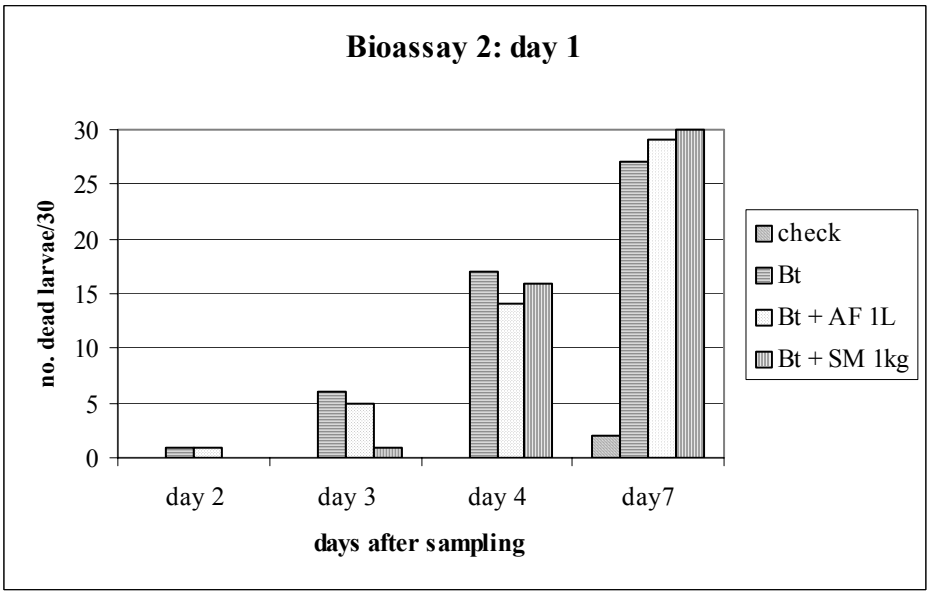
The results for each of bioassays 2 –10 are graphed below. For each bioassay, graphs are presented of numbers of larvae dead at various time intervals after larvae were placed on treated leaves for each day after treatment (i.e. day 0 is immediately after spraying, day 1 is

24 hours after spraying, and so on). The following abbreviations are used in the graphs: Bt for *B. thuringiensis*; AF for Amino-Feed; and SM for skim milk.

Bioassay 2: capsicum.

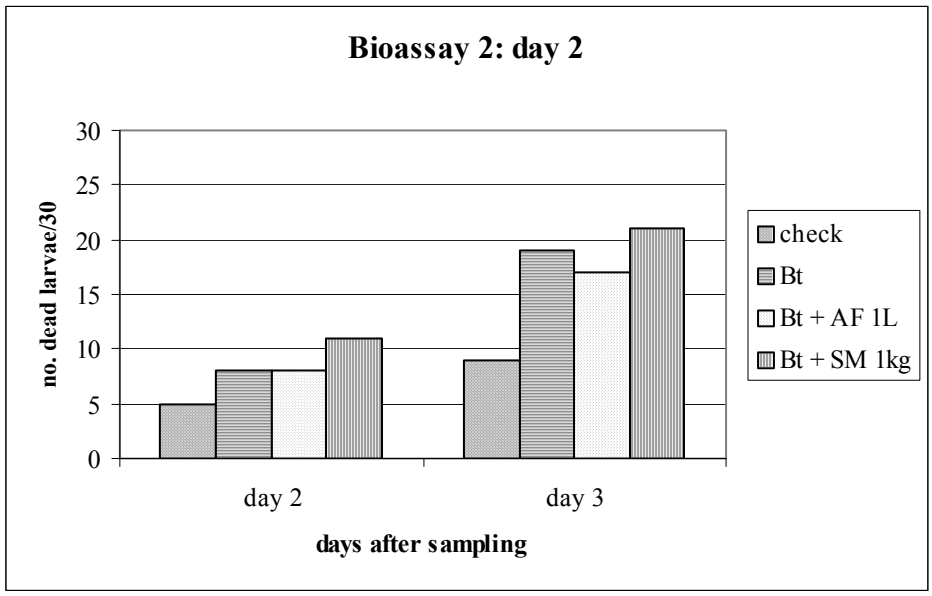


A homogeneity test on the day 3 *B. thuringiensis* with and without additives data, which showed the greatest differences, adjusted for check mortality was not significant (χ^2 = 3.3462, 2 df, P>0.05). This indicates that there are no significant differences between the treatments on any day after sampling.



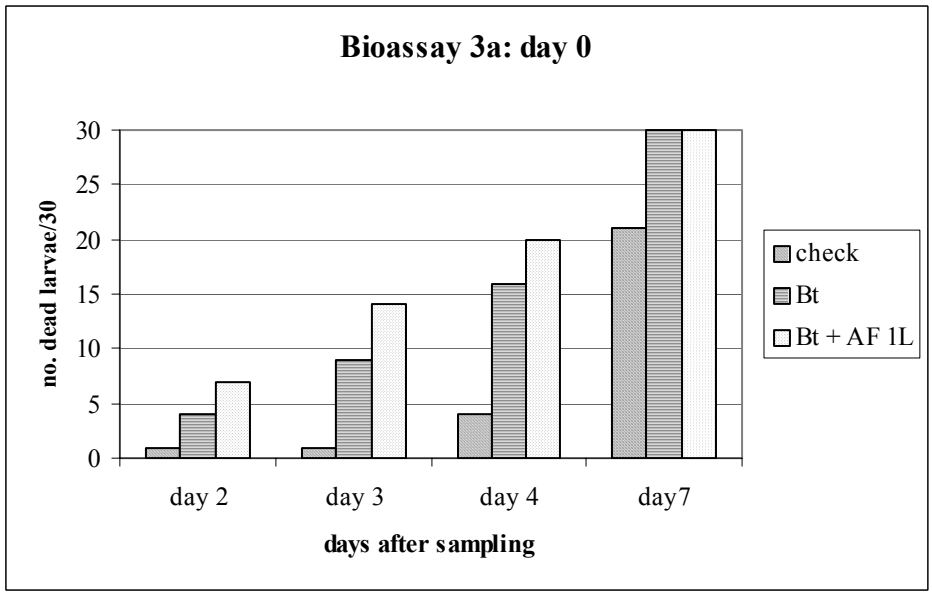
A homogeneity test on the day 3 *B. thuringiensis* with and without additives data, which showed the greatest differences, was not significant (χ^2 = 4.0385, 2 df, P>0.05). This

indicates that there are no significant differences between the treatments on any day after sampling.

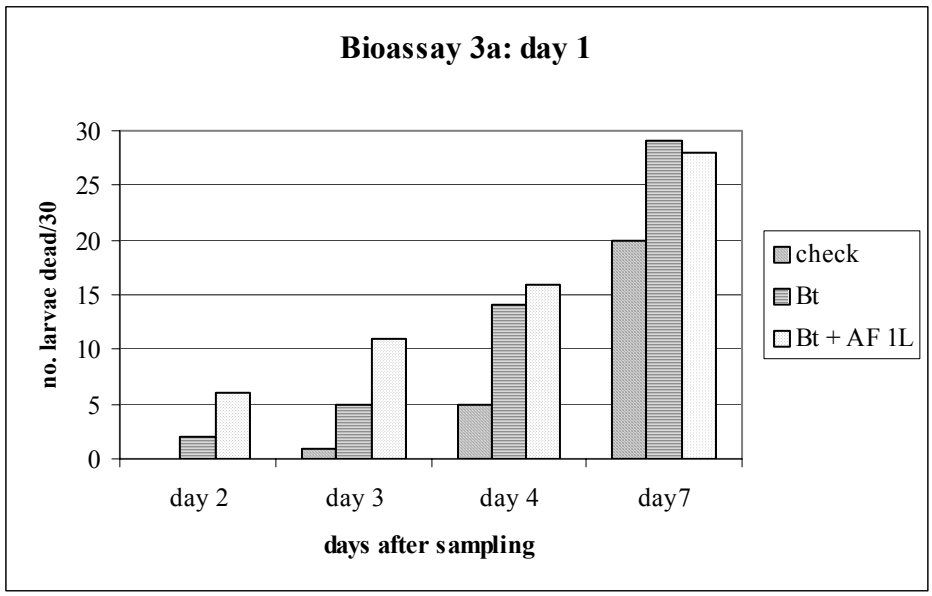


The data were not analysed. Mortality was low in the treatments compared with the check on day 2, and check mortality was high (30%) on day 3. Data were not collected beyond day 3 as there was NPV contamination in the test.

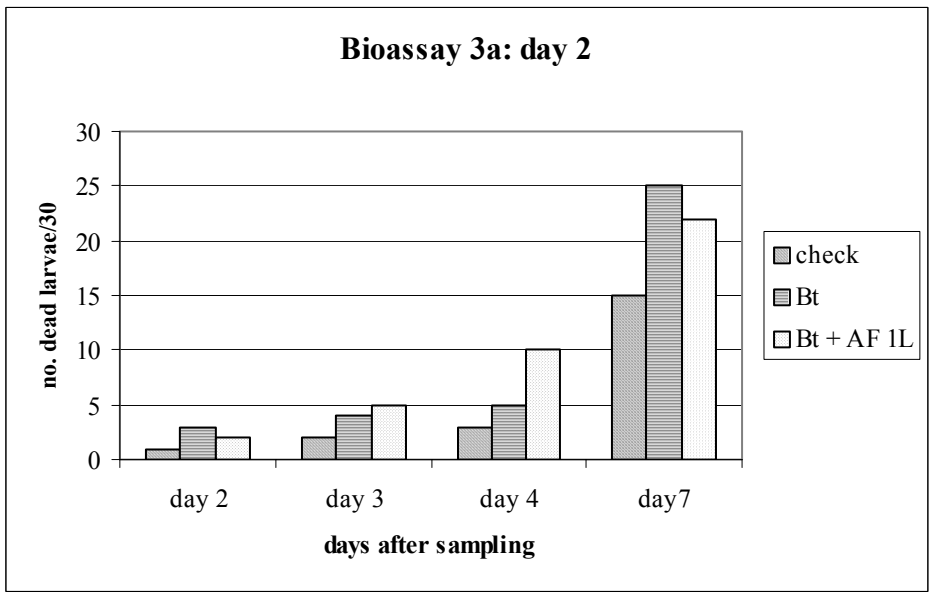
Bioassay 3a: tomato.



A homogeneity test on the day 3 *B. thuringiensis* with and without additives data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 1.9408$, 1 df, $P>0.05$). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.



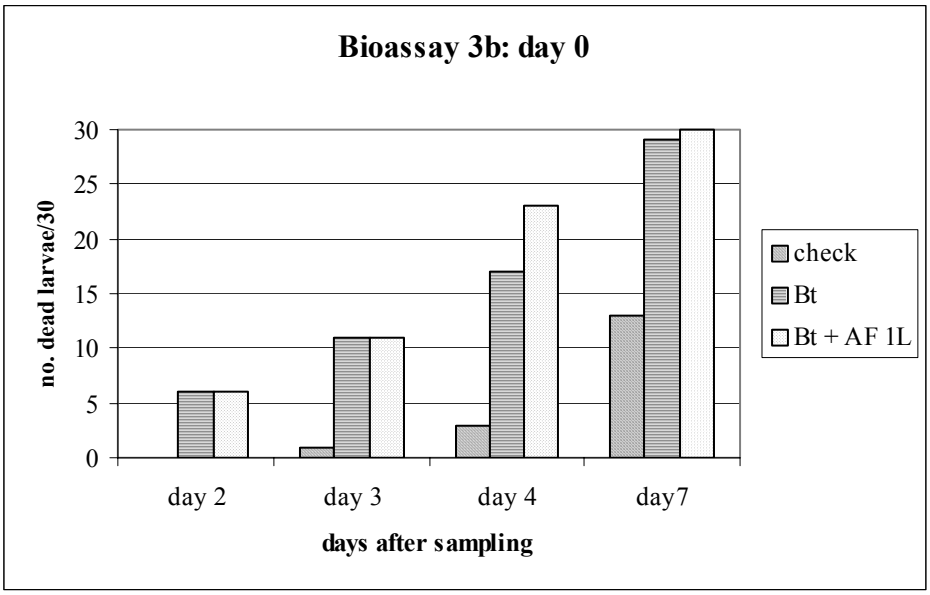
A homogeneity test on the day 3 *B. thuringiensis* with and without additives data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 3.4838$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.



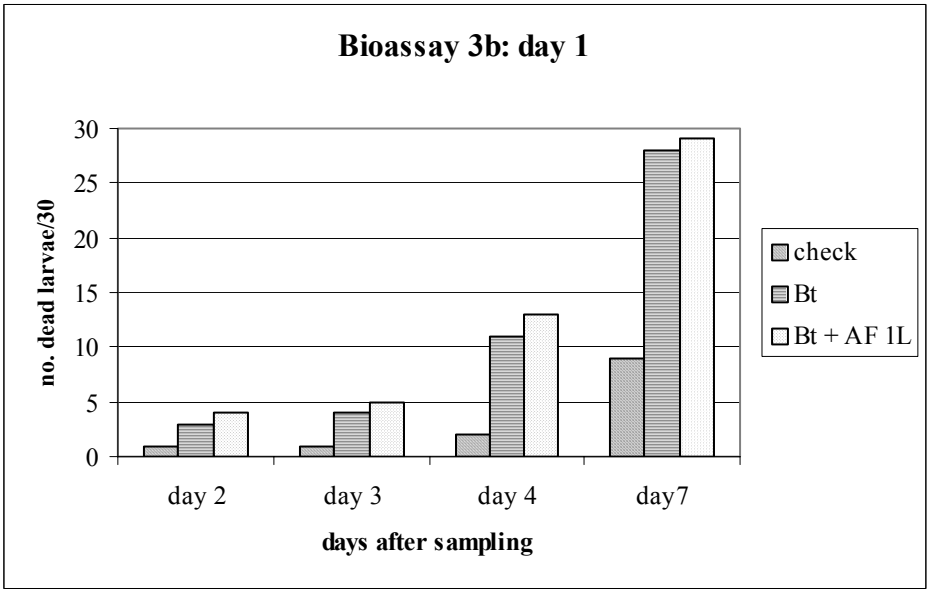
A homogeneity test on the day 4 *B. thuringiensis* with and without additives data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 3.4667$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

There were trends on each of the three sample dates towards higher mortality in the Amino-Feed treatment, but there were no significant differences (P>0.05). Check mortality was high after 7 days as the leaf discs had dried out.

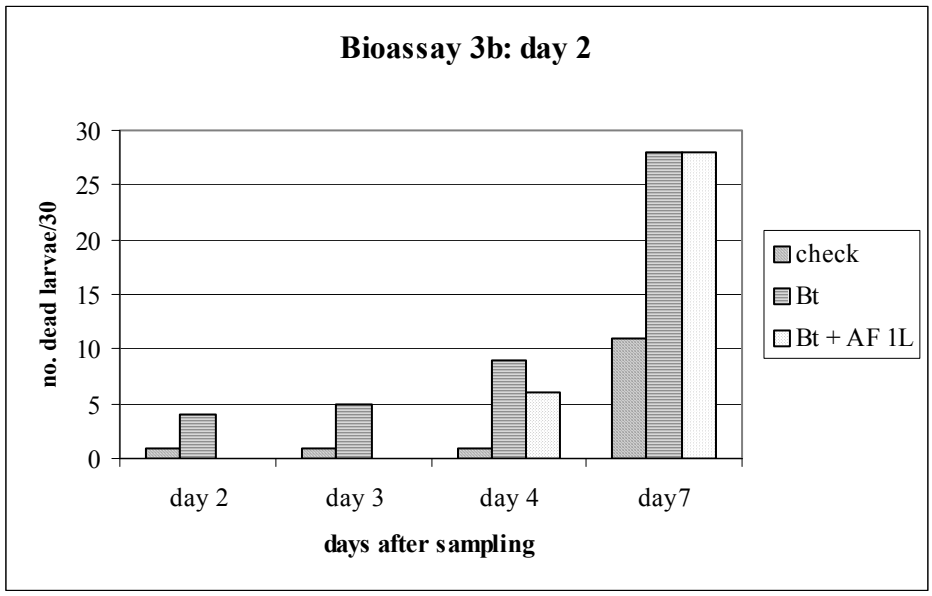
Bioassay 3b: capsicum.



A homogeneity test on the day 4 *B. thuringiensis* with and without additives data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 2.9382$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

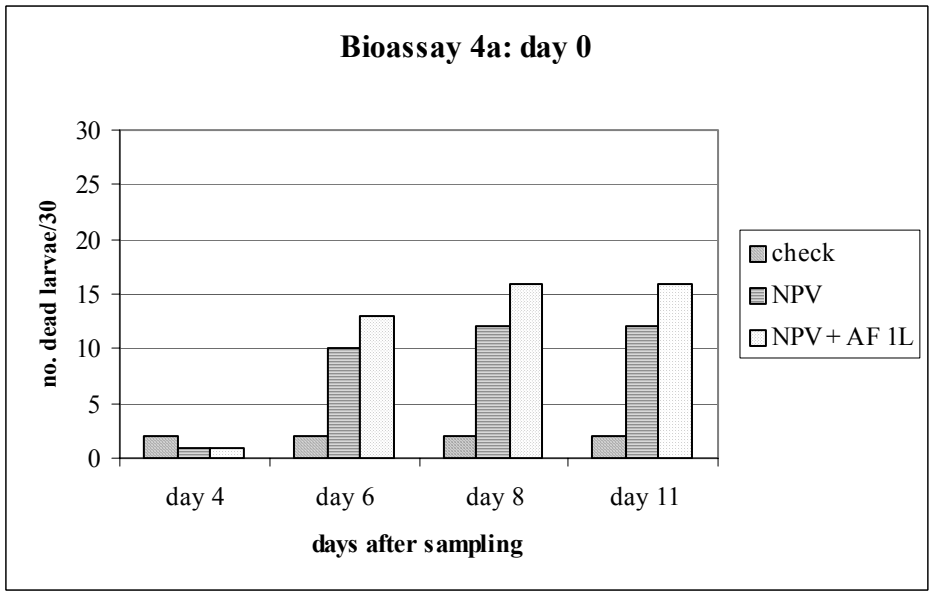


Differences between *B. thuringiensis* treatments were small so no homogeneity analyses were done.

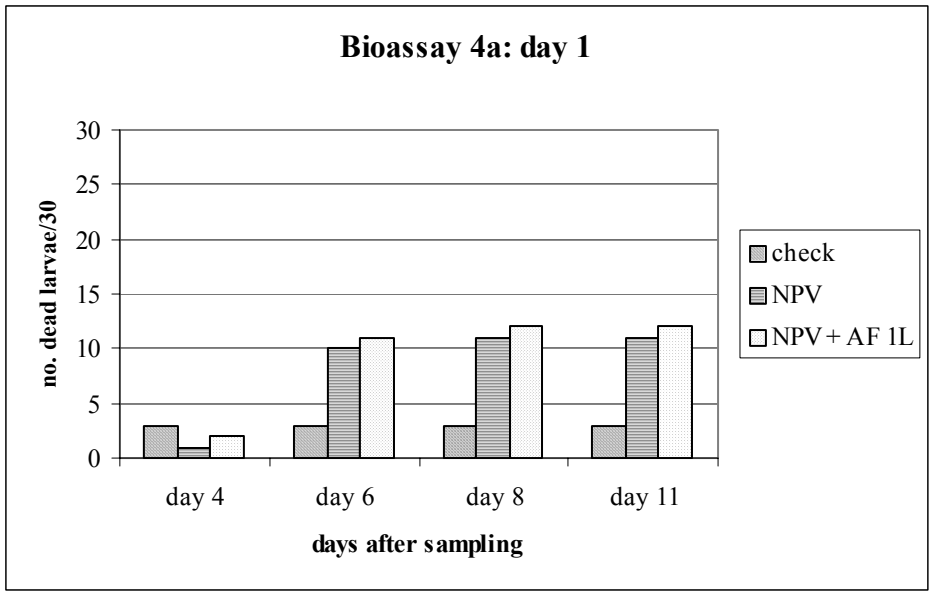


Only a few larvae had died in the *B. thuringiensis* treatments at 2 and 3 days while none had died in the *B. thuringiensis* plus Amino-Feed treatment, but this difference has little meaning given the low numbers involved. No homogeneity tests were done.

Bioassay 4a: tomato.



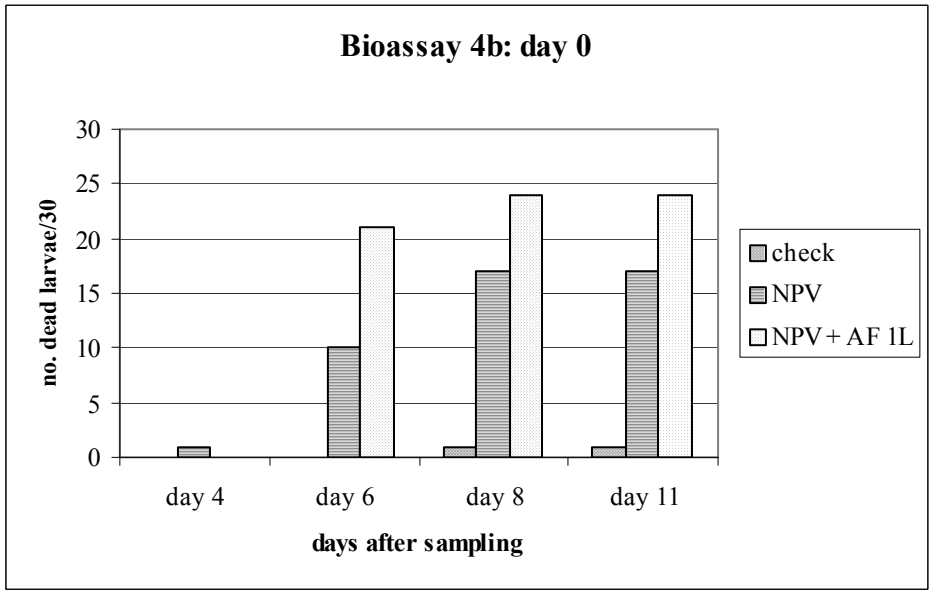
A homogeneity test on the day 8 and 11 NPV with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 1.2395$, 1 df, $P>0.05$



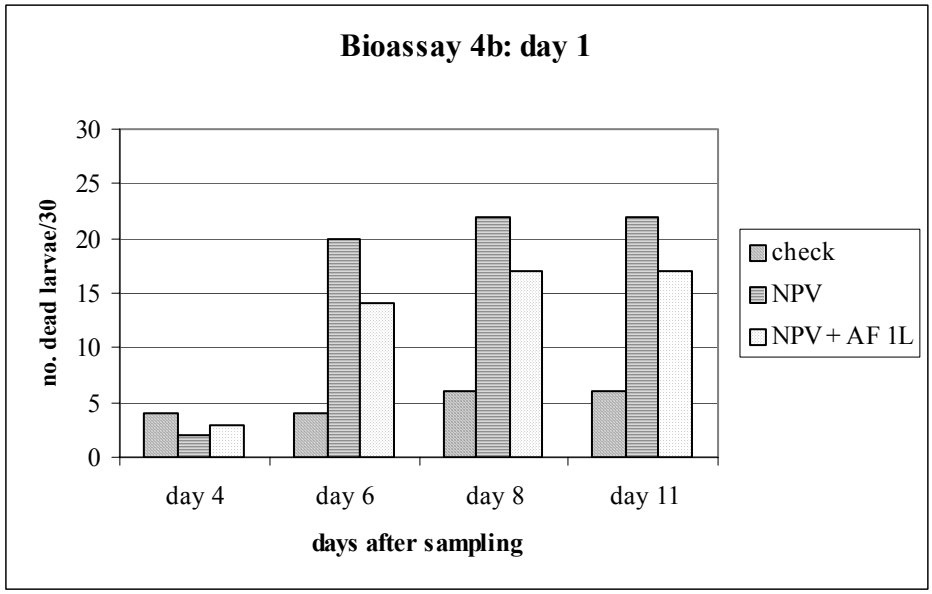
There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

There were no indications of differences between the two NPV treatments. Mortality had peaked by day 8 and no more deaths were recorded after that time.

Bioassay 4b: capsicums.

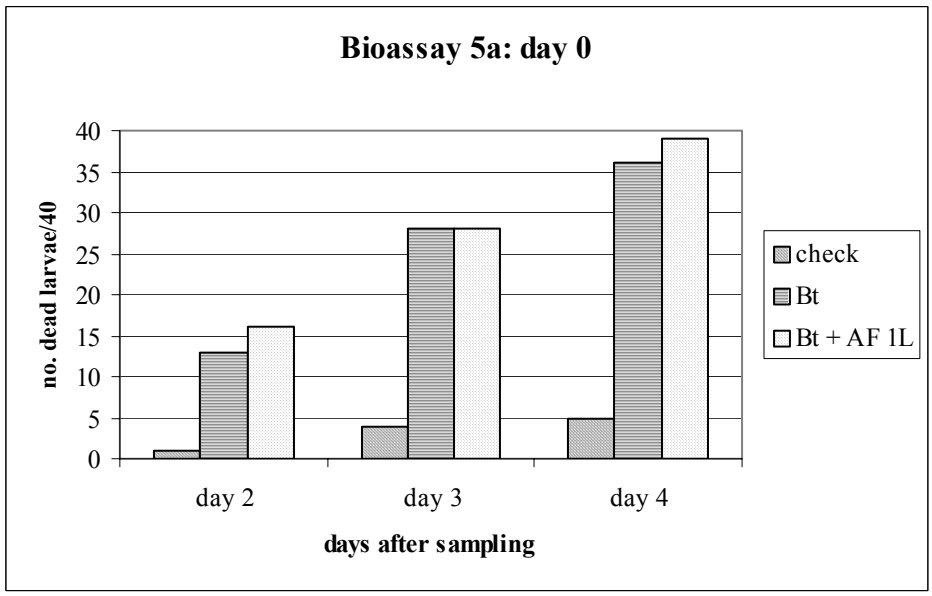


Homogeneity tests showed there was significantly higher mortality in the NPV plus Amino-Feed treatment than in the NPV treatment on day 6 ($\chi^2 = 8.1424$, 1 df, $P<0.05$), and on days 8 and 11 using data adjusted for check mortality ($\chi^2 = 3.916$, 1 df, $P<0.05$).

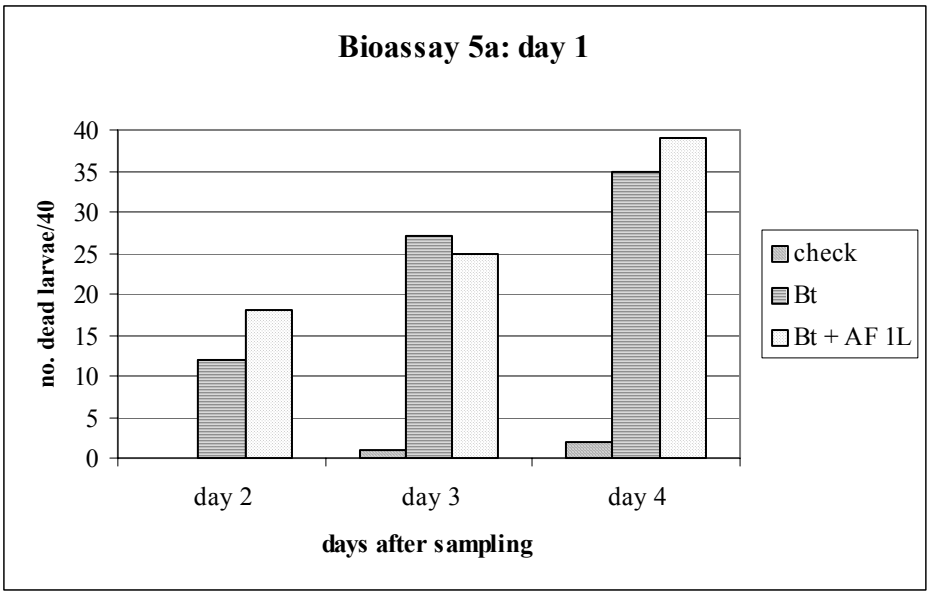


A homogeneity test on the day 6 NPV with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant (χ^2 = 2.8462, 1 df, P>0.05). This indicates that there are no significant differences between the NPV treatments on any day after sampling.

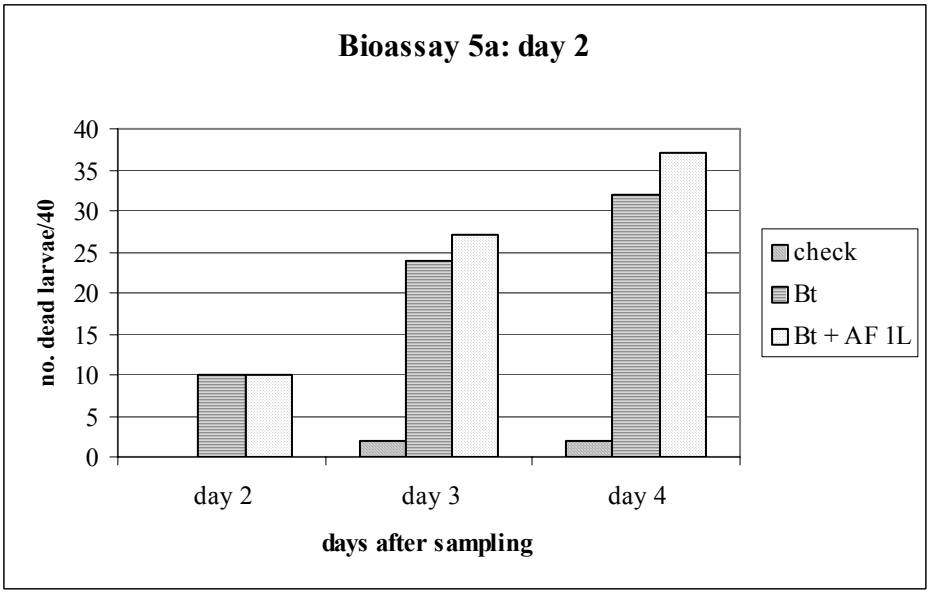
Bioassay 5a: tomato.



There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

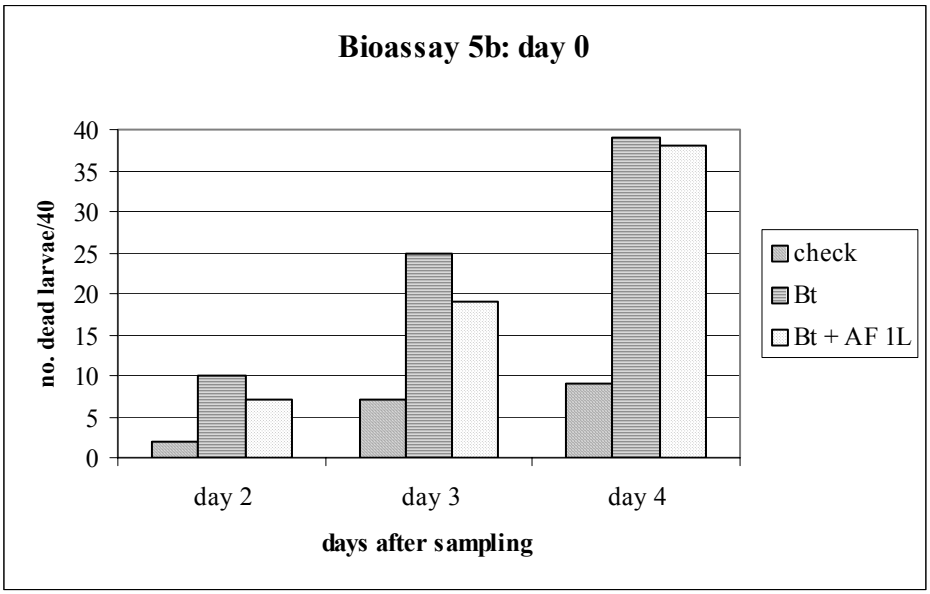


A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, was not significant (χ^2 = 1.9734, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

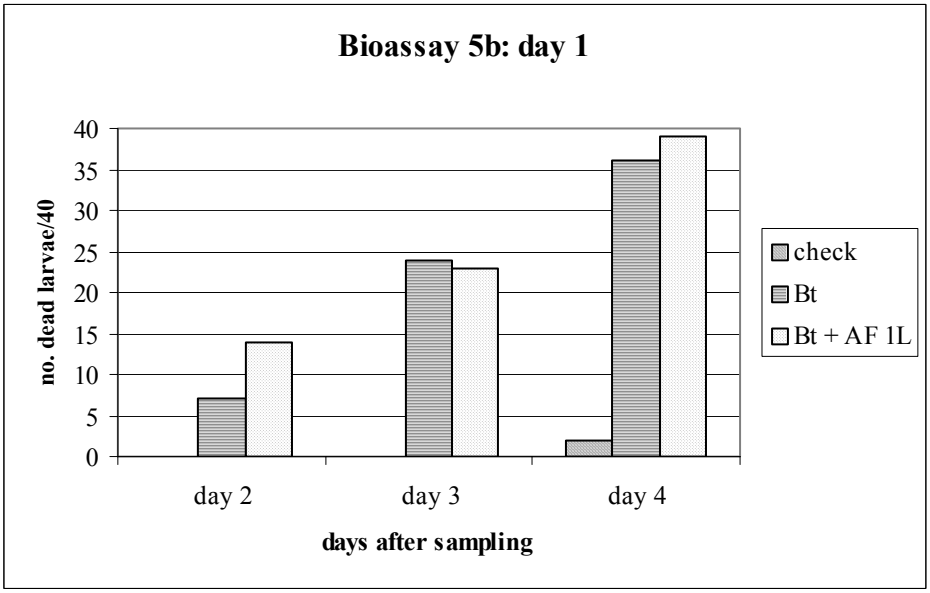


A homogeneity test on the day 4 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant (χ^2 = 3.1728, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

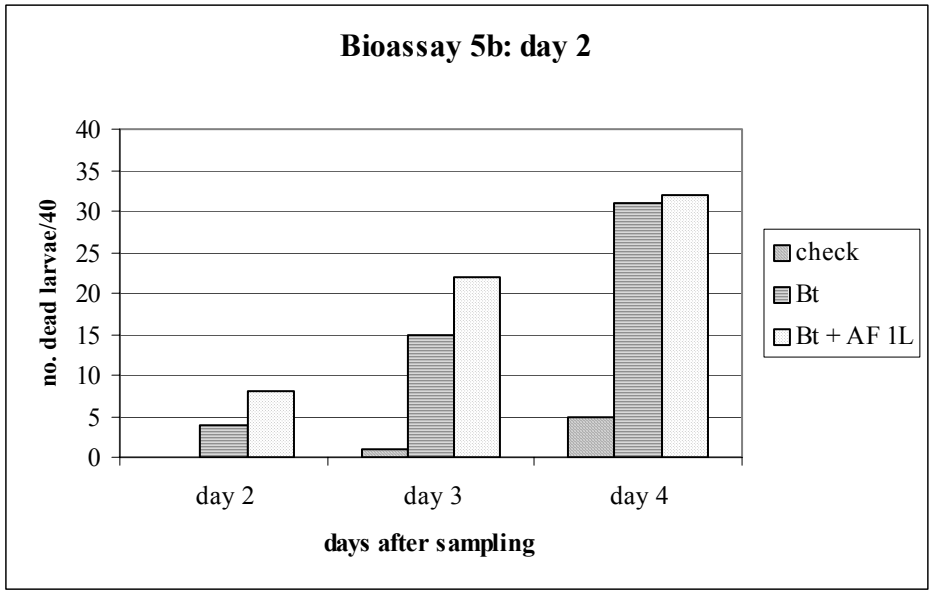
Bioassay 5b: capsicum.



A homogeneity test on the day 3 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 2.2612$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.



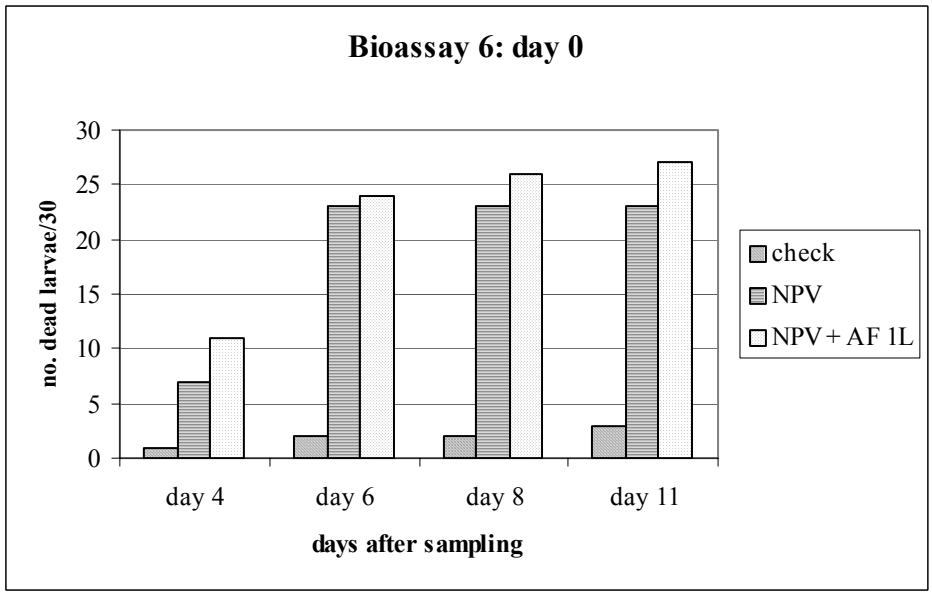
A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, was not significant ($\chi^2 = 3.2284$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.



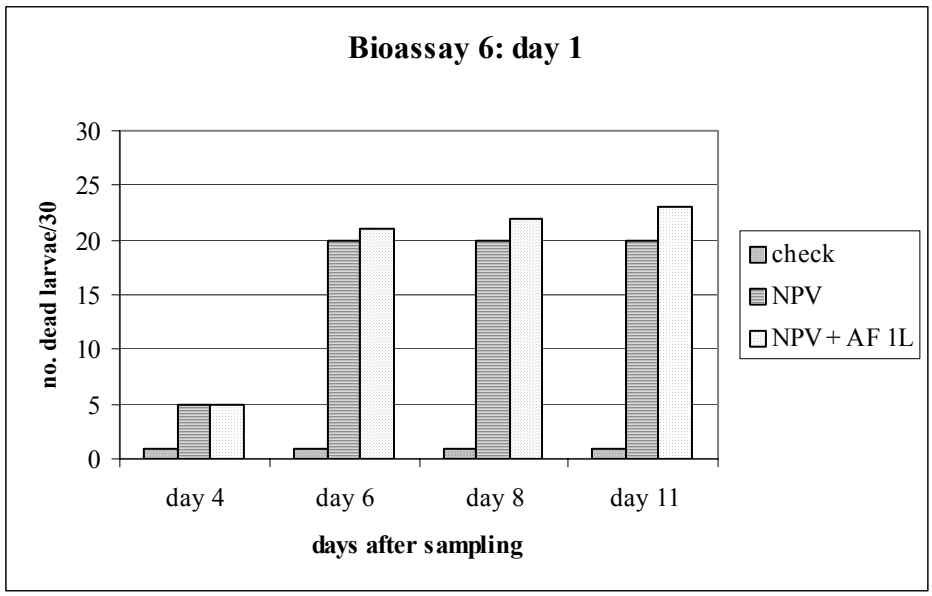
A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data was not significant (χ^2 = 1.6667, 1 df, P>0.05). A homogeneity test on the day 3 *B. thuringiensis* with and without Amino-Feed data, adjusted for check mortality was not significant (χ^2 = 2.5914, 1 df, P>0.05).

While there appears to be a trend to increased mortality with Amino-Feed the differences are not significant (P>0.05).

Bioassay 6: tomato.



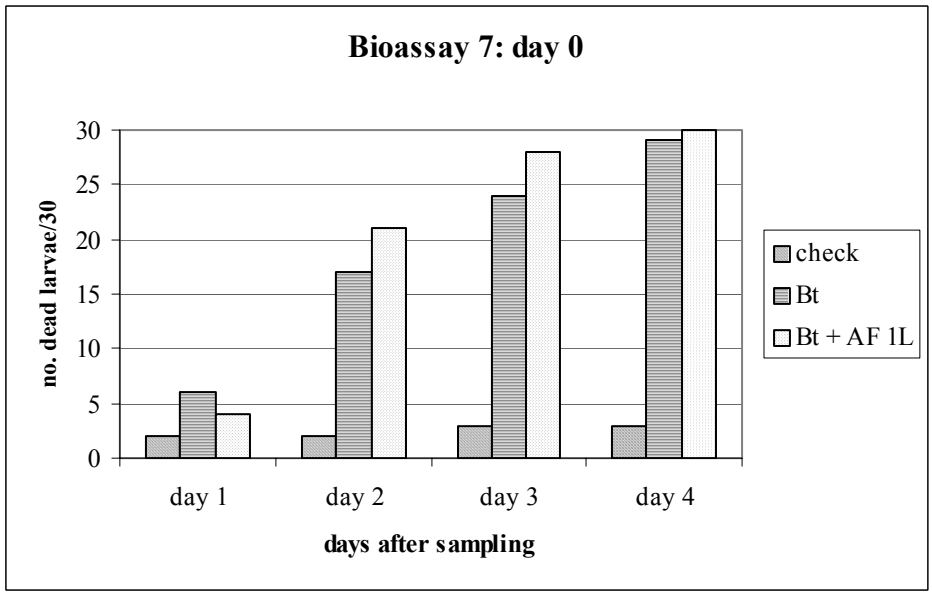
Homogeneity tests on the day 4 and day 11 NPV with and without Amino-Feed data, adjusted for check mortality were not significant (χ^2 = 1.4673, 1 df, P>0.05; χ^2 = 2.0864, 1 df, P>0.05). This indicates that there are no significant differences between the NPV treatments on any day after sampling.



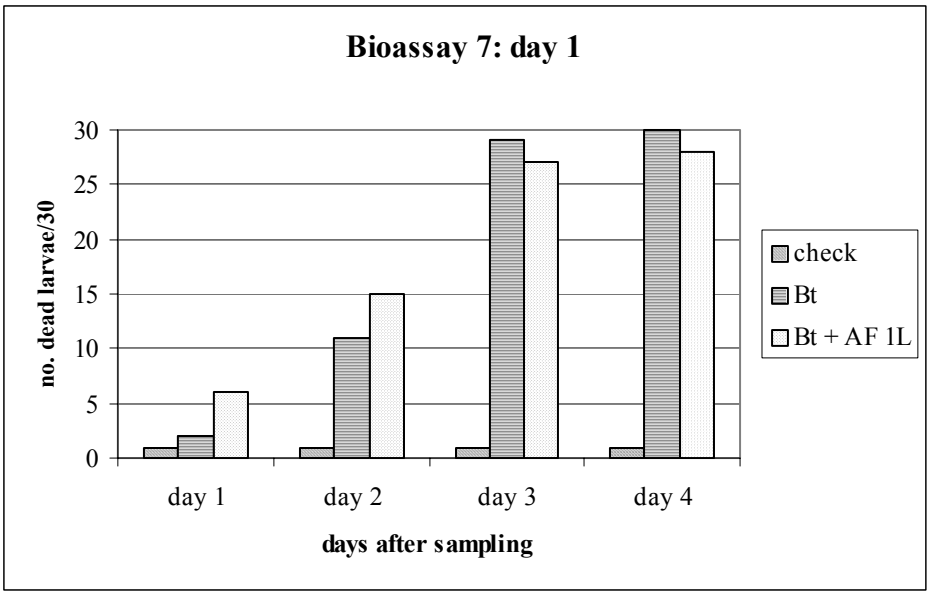
There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

There was an apparent slight trend towards increased mortality on both sample days with Amino-Feed but the differences were not significant (P>0.05).

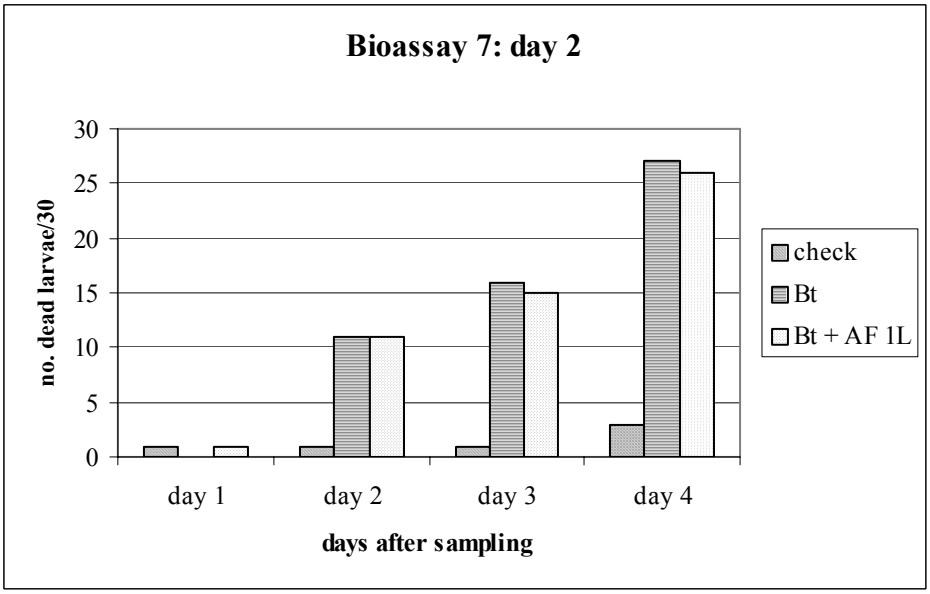
Bioassay 7: tomato.



There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

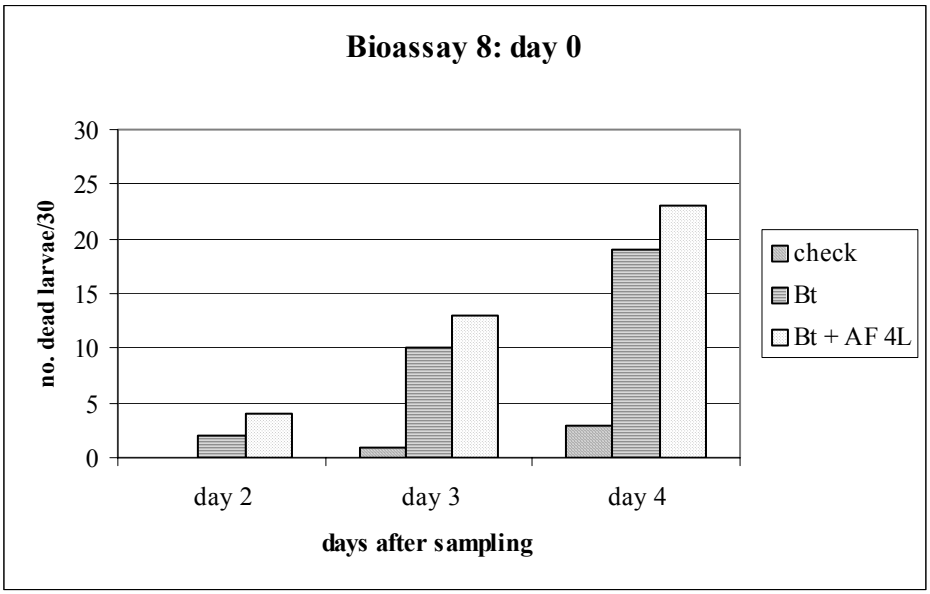


A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant ($\chi^2 = 1.2083$, 1 df, P>0.05). This indicates that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

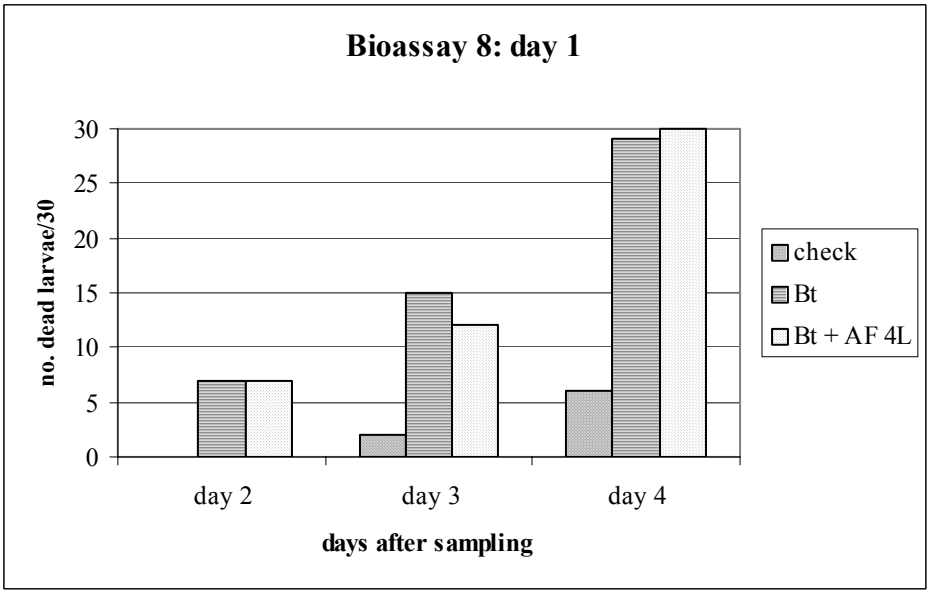


There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

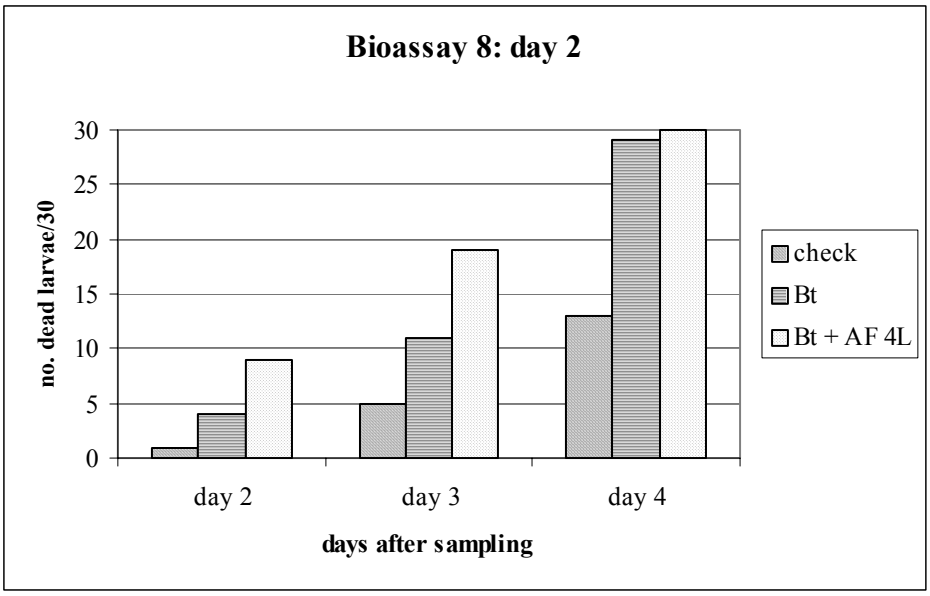
Bioassay 8: capsicum.



There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

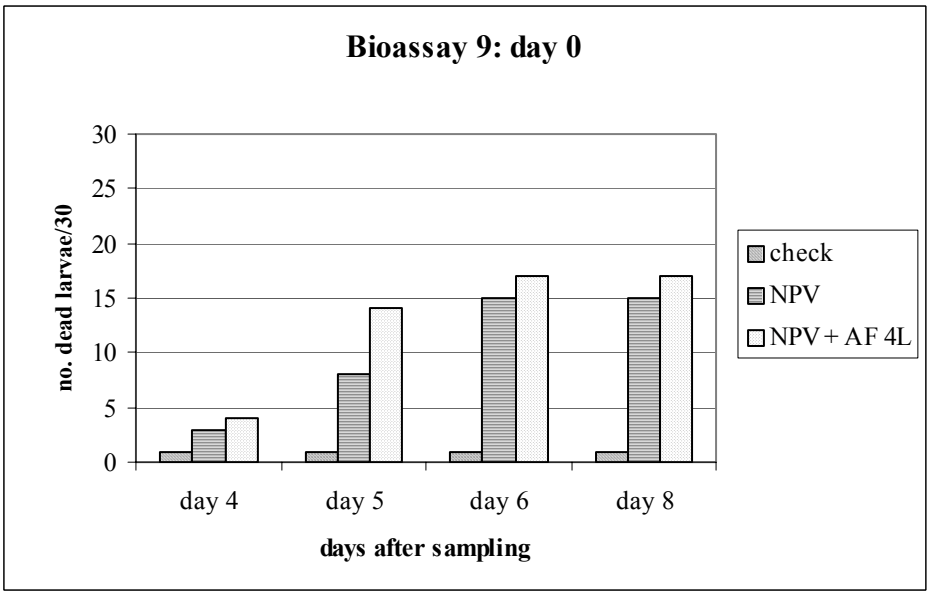


There were only small differences between treatments on any day after sampling so no homogeneity tests were done.

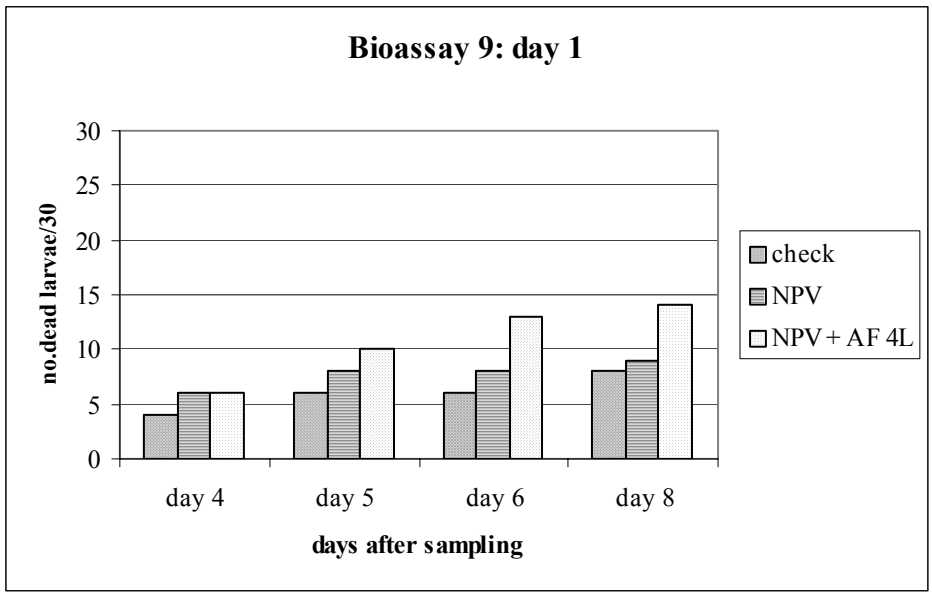


A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, adjusted for check mortality was not significant (χ^2 = 2.9169, 1 df, P>0.05). However a test of the day 3 data, adjusted for check mortality was significant (χ^2 = 5.4167, 1 df, P>0.05), indicating that *B. thuringiensis* plus Amino-Feed killed more larvae at 3 days after sampling than did *B. thuringiensis* alone, although the reasonably high check mortality (17%) means that this result should be treated with some caution.

Bioassay 9: capsicum.

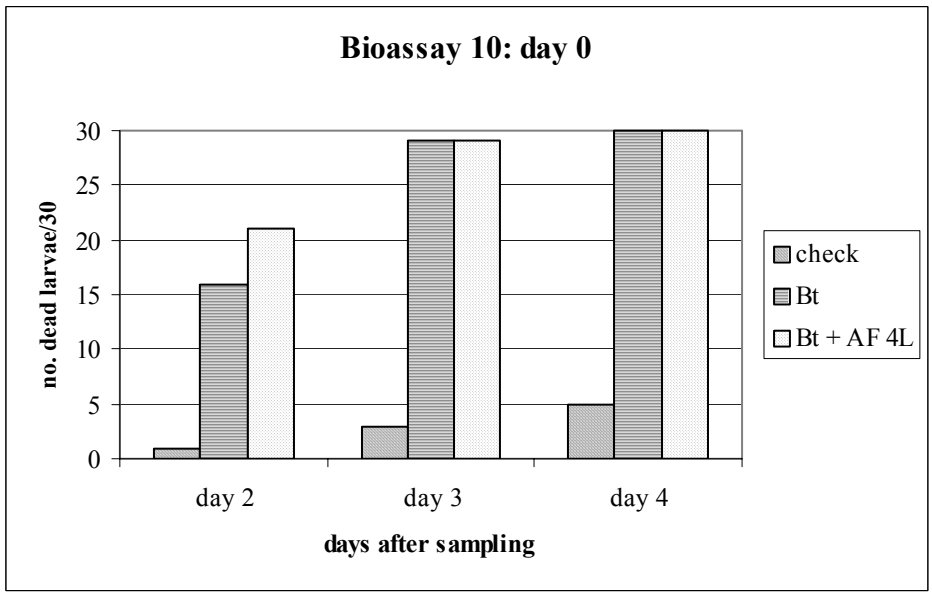


A homogeneity test on the day 5 NPV with and without Amino-Feed data, which showed the greatest differences, adjusted for check mortality was not significant (χ^2 = 2.8236, 1 df, P>0.05). This indicates that there are no significant differences between the NPV treatments on any day after sampling.

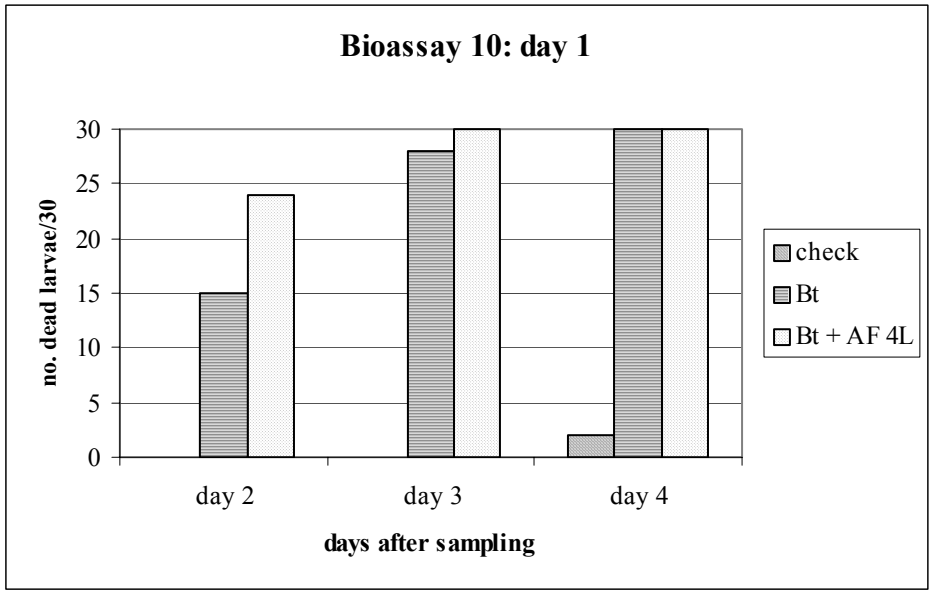


No analyses have been done as check mortalities are high both absolutely and in relation to the treatment mortalities, and differences between treatments are not large.

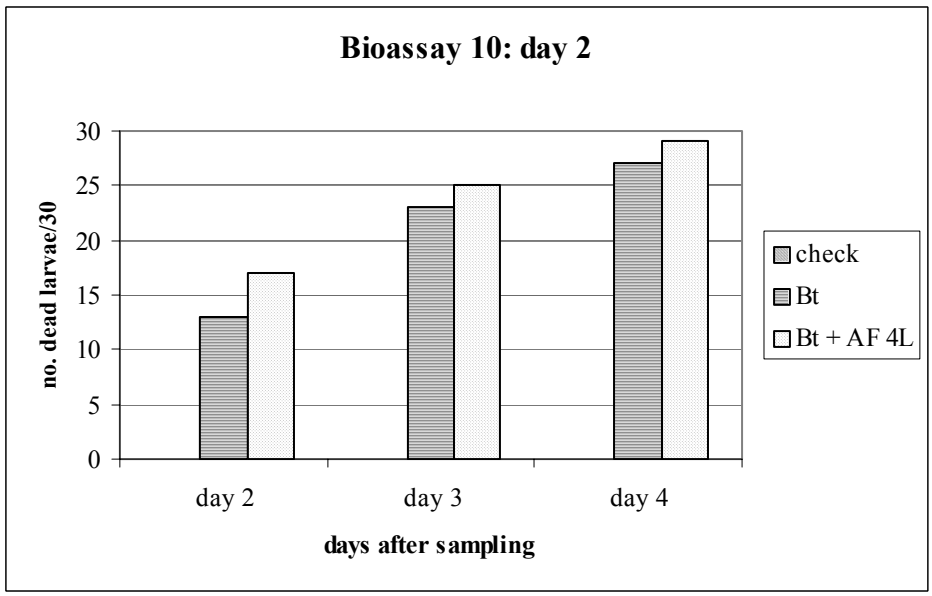
Bioassay 10: tomato.



A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, adjusted for check mortality was not significant (χ^2 = 1.7756, 1 df, P>0.05). There were no differences between the *B. thuringiensis* treatments on days 3 and 4 after sampling.



Significantly more larvae died in the *B. thuringiensis* plus Amino-Feed treatment than in the *B. thuringiensis* alone treatment at 2 days after sampling (χ^2 = 6.0074, 1 df, P<0.05), but both treatments resulted in 100% mortality by day 4. This indicates that the addition of Amino-Feed shortened the time to death.



A homogeneity test on the day 2 *B. thuringiensis* with and without Amino-Feed data, which showed the greatest differences, was not significant (χ^2 = 1.1334, 1 df, P>0.05) indicating that there are no significant differences between the *B. thuringiensis* treatments on any day after sampling.

(ii) Replicated bioassays

The results of the replicated Bioassays 11 and 12 are shown in Table H20, and the results for Bioassay 13 are in Table H22. In Bioassay 12 mortality also was assessed at 7 days after sampling. For day 0 the check had a mean of 0.75 dead larvae, the *B. thuringiensis* (1000g) +

Amino-Feed 1L treatment had 9.75 and the remaining treatments 10 dead larvae. On day 1 the check had a mean of 0.25 dead larvae, the *B. thuringiensis* (1000g) + Amino-Feed 1L and the *B. thuringiensis* (1000g) + Amino-Feed UV 4L treatment had 9.75, and the remaining treatments 10 dead larvae. These data have not been analysed as there clearly are significant differences between the check and the *B. thuringiensis* treatments but no differences between the *B. thuringiensis* treatments. Bioassay 12 was not sampled on day 2, but was sampled on day 3 and day 6 after spraying although a shortage of larvae meant that only one replicate was done. The results for this one replicate are given in Table H21.

Table H20
Mean number of dead larvae at 3 and 4 days after sampling in the various treatments in Bioassays 11 and 12. Sample days 0, 1 and 2 are the times after spraying that leaf samples were collected for the bioassay.

Treatment (rate/ha)	# No. dead larvae after 3 and 4 d at sample days 0, 1 and 2 day.					
	Sample Day 0		Sample Day 1		Sample Day 2	
	3 d	4 d	3 d	4 d	3 d	4 d
<u>*Bioassay 11*</u>	*	*	*	*	*	*
Untreated check	1.95 a	3.44 a	1.31 a	3.49 a	3.74 a	6.16 a
B. thuringiensis (1000g)	4.72 b	8.18 b	4.12 b	7.98 b	7.46 b	8.73 b
B. thuring. (1000g) + Amino-Feed 1L	6.16 bc	8.73 b	4.36 b	8.99 b	8.49 b	9.75 b
B. thuring. (1000g) + Amino-Feed 4L	5.39 bc	7.93 b	5.95 b	9.49 b	7.65 b	9.75 b
B. thuring. (1000g) + Amino-Feed UV 4L	6.87 c	8.67 b	5.46 b	8.73 b	8.99 b	10.00 b
<u>*Bioassay 12*</u>						
Untreated check	0.43 a	0.43 a	0.00 a	0 a	-	-
B. thuringiensis (1000g)	3.46 b	7.41 b	5.45 b	8.99 b	-	-
B. thuring. (1000g) + Amino-Feed 1L	4.37 b	7.48 b	4.87 b	7.86 b	-	-
B. thuring. (1000g) + Amino-Feed 4L	3.90 b	8.99 b	4.41 b	7.95 b	-	-
B. thuring. (1000g) + Amino-Feed UV 4L	4.24 b	8.21 b	4.07 b	6.92 b	-	-

Back-transformed means following $\sqrt{(x + 0.5)}$ transformation before analysis.
* In each column in each bioassay numbers followed by the same letter are not significantly different at the 5% level.

In both Bioassay 11 and Bioassay 12 on all sample days there were significantly more dead larvae in the *B. thuringiensis* treatments than in the untreated check. In Bioassay 11 on sample day 1, 3 days after sampling, there were significantly more dead larvae in the *B. thuringiensis* + Amino-Feed UV treatment than in the *B. thuringiensis* treatment, but this was the only significant difference between *B. thuringiensis* treatments recorded in either bioassay.

Table H21
Number of dead larvae in one replicate of Bioassay 12 on day 3 and day 6 after spraying at 3, 4 and 7 days after sampling.

Treatment (rate/ha)	No. dead larvae after 3, 4 and 7 d at sample days 3 and 6. Sample Day 3			Sample Day 6		
	3 d	4 d	7 d	3 d	4 d	7 d
Untreated check	1	3	4	0	0	0
B. thuringiensis (1000g)	0	1	6	2	2	2
B. thuring. (1000g) + Amino-Feed 1L	1	3	7	0	0	1
B. thuring. (1000g) + Amino-Feed 4L	0	4	6	5	5	6
B. thuring. (1000g) + Amino-Feed UV 4L	1	4	9	0	2	4

Table H22
Mean number of dead larvae in the various treatments at 4 and 7 days after sampling in Bioassays 13. Sample days 0, 2 and 4 are the times after spraying that leaf samples were collected for the bioassay.

Treatment (rate/ha)	# No. dead larvae after 3 and 4 d at sample days 0, 2 and 4 day. Sample Day 0		Sample Day 2		Sample Day 4	
	4 d	7 d	4 d	7 d	4 d	7 d
	*	*	*	*	*	*
Untreated check	1.68 a	4.92 a	2.17 a	4.88 a	0.62 a	2.39 a
B. thuringiensis (1000g)	9.48 b	9.75 b	6.14 b	9.75 b	2.64 bc	6.95 b
B. thuring. (1000g) + Amino-Feed 1L	8.73 b	10.00 b	6.22 b	9.75 b	4.24 c	7.25 b
B. thuring. (1000g) + Amino-Feed 4L	8.67 b	10.00 b	6.49 b	9.75 b	2.93 bc	8.20 b
B. thuring. (1000g) + Amino-Feed UV 4L	8.48 b	10.00 b	5.22 b	9.49 b	1.95 ab	7.25 b

Back-transformed means following $\sqrt{(x + 0.5)}$ transformation before analysis.
* In each column numbers followed by the same letter are not significantly different at the 5% level.

On all days there are significant differences between the check and the *B. thuringiensis* treatments, but there were no differences between the *B. thuringiensis* treatments. It had been planned to sample Bioassay 13 on day 7 but heavy rain the preceding night and all of day 7 prevented this.

(iii) Field trial

Heliothis activity, as measured by egg and larval counts, during the trial is shown in Table H23.

Table H23
Number of heliothis eggs and larvae on 30 leaves and number of infested leaves.

Date 2001	Eggs		Larvae	
	No. of eggs	No. infested leaves/30	No. of larvae	No. infested leaves/30
18 April	152	27	47	23
26 April	25	15	24	19
2 May	42	18	26	20
9 May	8	8	10	8
16 May	5	4	5	5
24 May	32	14	6	6
30 May	26	8	4	4
6 June	12	10	1	1
19 June	4	3	3	2
26 June	7	7	4	4
3 July	6	4	1	1

The percentages of collected larvae that were killed by NPV for each collection date are given in Table H24. (Percentages are used as a few larvae, a maximum of three from a plot, escaped from their containers. They have been excluded from the data.) On 16 May a search for larvae throughout the trial area found very few larvae but diseased larvae were noted in each replicate of the NPV plus Amino-Feed treatment.

Table H24
The percentages of field collected larvae that were killed by NPV. NPV had been applied to NPV treatment plots on 18 April, 25 April, and 2 May.

Treatment	Replicate	% larvae killed by NPV		
		19 April	27 April	4 May
Untreated check	1	0	5.0	0
	2	5.9	5.0	0
	3	0	0	10.0
	4	0	0	10.0
NPV	1	75.0		
	2	90.0		
	3	88.9		
	4	89.5		
NPV plus Amino-Feed	1	100.0		
	2	89.5		
	3	94.1		
	4	100.0		

A homogeneity test to test whether the proportion of larvae infected differed between the NPV treatment and the NPV + Amino-Feed treatment was not significant ($\chi^2 = 1.261$; 1 df).

Table H25 shows the yield and percentages of heliothis and cluster caterpillar damaged fruit in the trial. The results for all harvests combined and the results with the final harvest data omitted are shown.

Table H25
Yield and percent damaged fruit

Treatment	Yield		% heliothis damaged fruit			% cluster caterpillar damage
	No. fruit	Wt. (kg)	minor	major	total	
All harvests						
Untreated check	241.5 a	23.04 a	4.00 a	37.04 c	41.27 bc	2.50 bc
Standard insecticide	359.0 b	50.44 b	8.83 b	13.85 a	22.85 a	0.21 a
B. thuringiensis	344.5 b	49.35 b	16.74 d	38.14 c	55.09 d	1.00 ab
B. thuringiensis + Amino-Feed	350.0 b	53.08 b	17.53 d	33.39 bc	51.60 cd	0.08 a
NPV	344.5 b	49.99 b	13.40 c	22.94 ab	36.45 b	5.03 cd
NPV + Amino-Feed	348.8 b	52.43 b	12.56 c	23.39 ab	36.10 b	7.05 d
Omitting final harvest						
Untreated check	48.2 a	4.30 a	1.44 a	75.33 d	77.23 d	-
Standard insecticide	154.8 cd	25.80 b	15.48 b	28.62 a	44.43 a	-
B. thuringiensis	185.8 e	29.95 c	18.69 bcd	56.96 c	75.84 d	-
B. thuringiensis + Amino-Feed	169.5 de	29.92 c	22.12 d	53.45 bc	75.66 cd	-
NPV	125.7 b	21.99 b	21.06 cd	42.81 b	64.08 bc	-
NPV + Amino-Feed	134.5 bc	24.09 b	17.26 bc	40.35 ab	57.98 b	-

Discussion

The bioassays demonstrate that *B. thuringiensis* is effective against *H. armigera* larvae on both capsicums and tomatoes, with high mortalities recorded in most bioassays on sample day 0. NPV was not as effective, showing reasonable effectiveness on tomato in Bioassay 6 but

not in Bioassay 4a, and doing moderately well on capsicum in Bioassay 4b but quite poorly in Bioassay 9.

There is little evidence from these bioassays to show that the use of additives improved the performance of the biopesticides. Skim milk was tried in the first two bioassays and was similar to Amino-Feed. No further work was done with it. Adding Amino-Feed certainly did not reduce the effectiveness of the biopesticides.

For NPV on tomatoes, the data in Bioassay 4a and Bioassay 6 on both sample day 0 and sample day 1 showed small increases in mortality with the addition of Amino-Feed. However the differences were not statistically significant ($P>0.05$). On capsicums in Bioassay 4b the addition of Amino-Feed to NPV significantly increased the mortality of *H. armigera* larvae on sample day 0. However on sample day 1 the non-significant trend in the data shows lower mortality with the addition of Amino-Feed. In Bioassay 9 there is a trend to a slightly higher mortality with the addition of Amino-Feed, but the differences are not significant ($P>0.05$).

For *B. thuringiensis* there is some indication of a trend towards slightly higher levels of mortality with Amino-Feed, but in most cases these differences are not significant ($P>0.05$). In Bioassay 8, sample day 2, on day 3 and in Bioassay 10, sample day 1, on day 2 there are significant differences ($P<0.05$), but these differences are gone by the next day i.e. they perhaps indicate that larvae died faster with the addition of Amino-Feed but that the eventual total mortality was the same. The results of the replicated bioassays demonstrate that there was no increase in mortality with the addition of Amino-Feed at 1 L or 4 L or of Amino-Feed UV at 4 L to *B. thuringiensis* up to four days after treatment (Bioassay 13, sample day 4). (In Bioassay 12 the results from the single replicate sampled on day 6 indicate that possibly the higher rates of Amino-Feed and Amino-Feed UV resulted in higher mortality. It would be extremely risky to accept that was the case based on one replicate, but it would be interesting to repeat the bioassay and sample over longer periods.

In the field trial heliothis numbers were high from April to early May, fell to lower levels before rising again in late May, and then fell again through June and July. This pattern reflects that recorded in a nearby pheromone trap (Figure H3) but is different from that previously recorded in the district, which showed very low numbers of heliothis during June and July (Kay 1999). Hence the treatments in the trial were tested by reasonably high heliothis pressure for much of the trial's duration. The species occurring in the trial was not determined but it probably was exclusively *H. armigera* as this was the only species recorded in the pheromone traps, and normally is the only species present at that time of year (Kay 1999).

There were only low numbers of larvae infected by NPV in the check plots in the collection on 19 April and in subsequent collections showing that there was little spread of the virus from treated plots to untreated ones. Further sampling of larvae from the trial area was not possible because of low larval numbers but observations at other times showed little obvious virus spread to non-virus treated plots. This is important because if the virus had spread widely throughout the trial area it would have invalidated the trial.

High mortality rates were recorded in larvae collected from NPV treated plots on 19 April, which indicates that the NPV was effective in killing larvae. There was no significant difference ($P>0.05$) between the proportion of larvae infected between the two NPV

treatments indicating that the addition of Amino-Feed did not significantly increase the proportion of larvae infected.

The yield and damage results have been analysed including and excluding the final harvest. Comparisons of yield between the two show that a large proportion of fruit were harvested in the final pick, particularly in the check (about 80%), many of which were small fruit that had been set and had developed late in the trial when heliothis pressure was quite low. The levels of heliothis damage were high in all treatments, but similar in the check and standard insecticide plots to levels recorded in other trials (e. g. Kay 1993). Carbamate resistance levels are known to be quite high in *H. armigera* in the Bundaberg district (R. Gunning pers. comm.), which may explain the high damage levels, a lot of which was minor pinhole damage, in the standard insecticide treatment. (Damage by cluster caterpillar was scattered across the trial but was lowest in the standard insecticide and *B. thuringiensis* treatments, which would be expected to exert some control.)

Of particular interest and importance to the purpose of the trial is that there were no significant differences in yield (weight or number) or in the percentage of heliothis damaged fruit between *B. thuringiensis* alone and *B. thuringiensis* plus Amino-Feed or between NPV alone and NPV plus Amino-Feed. The addition of Amino-Feed did not improve the performance of either biopesticide in this season-long trial.

In conclusion, the bioassays and the field trial did not demonstrate any clear benefit from adding Amino-Feed to NPV or *B. thuringiensis* on tomatoes and capsicums. These results differ from those reported by Murray *et al.* (2000) on mungbeans and cotton where the addition of Amino-Feed to NPV significantly increased the mortality of *H. armigera* larvae, and on mungbean where the addition of Amino-Feed to *B. thuringiensis* increased larval mortality in bioassays. These differences may be due to the different crops with the solanaceous plants being less affected. No adverse effects of adding Amino-Feed were noted and growers may well consider that the possibility of slightly higher larval mortality (some small, non-significant trends were noted in bioassays) is worth the fairly low cost of Amino-Feed ($856 for 200 L, quoted Bundaberg, 14/08/2003).

Helicoverpa armigera oviposition sites on vegetables and melons

Introduction

Both *Helicoverpa armigera* and *H. punctigera*, both commonly known as heliothis, are pests of vegetables and melons, and many other crops, in Australia. They lay their eggs on the plants and the larvae feed on plant structures and cause damage, with the most important damage occurring when larvae feed on fruit. In many fruit and vegetable crops it is necessary to control heliothis at the very young larval stage or as eggs to prevent damage. Developing effective sampling plans for the pests depends on knowing where the eggs are laid. As well, if insecticides are targeting eggs then knowledge of where the eggs are laid is important.

Heliothis oviposition has been studied on a number of crops. Saour and Causse (1993) reported that in tomatoes *H. armigera* preferred to oviposit on leaflets in the upper half of the plant, particularly those near flowers or fruit clusters. The eggs were deposited equally on the upper and lower surfaces of the leaflets. Only 5% of eggs were found in open flowers, while buds, stems and fruit were minor sites. In the United States of America Snodderly and Lambdin (1982) reported that on processing tomatoes *Heliothis zea* preferred to lay eggs on the underside of leaves in the middle plant region, Alvarado-Rodriguez *et al.* (1982) reported a highly significant preference for oviposition on leaves over flowers, fruit or stems, with no difference between dorsal and ventral leaf surfaces, but with a strong relationship between the closeness of leaves to flowers and the presence of eggs, while Zalom *et al.* (1983) reported that *H. zea* deposited most of their eggs on leaves of the terminal half of the branches, with the majority on the ventral leaf surface. Nilakhe and Chalfant (1982) reported that both *Heliothis virescens* and *H. zea* preferred to oviposit on the upper third of the tomato plant, and that *H. zea* but not *H. virescens* preferred the lower surface of the leaf. On capsicums in Korea Hwang *et al.* (1987) reported that *Helicoverpa assulta* laid 45% of its eggs on the upper surface of leaves, with the remainder equally divided between the underside of the leaves and the fruit. There have a number of studies done on cotton. For example, Mabbett and Nachapong (1984) reported that the great majority of *H. armigera* eggs were laid on the flat plant surfaces such as leaves and bracts (97%) rather than on linear parts such as stems, petioles and peduncles (3%), and that 90% of leaf-laid eggs were on the first three leaves from the top of the stem, and that over 97% were on the upper leaf surface. On soybeans both *H. armigera* and *H. punctigera* laid the majority of their eggs on leaves in the top 20 cm of the crop canopy, with a strong preference for the lower surface of the leaves (Duffield and Chapple 2001).

There appear to be no published studies of the oviposition sites of heliothis eggs on tomatoes, capsicums, melons or zucchinis in Australia.

Materials and methods

Studies using natural egg lay and caged moths were done at Bundaberg Research Station to determine where *H. armigera* females lay their eggs on tomatoes, capsicums and zucchinis. Rockmelon plants in north Queensland were examined to find naturally laid eggs to determine oviposition sites.

(i) Capsicum
Cages made of a metal bar frame (0.75 m by 0.75 m and 1.1 m high) covered with mesh were placed over capsicum plants growing in the field on a number of occasions. Each cage covered three plants spaced 0.25 m apart in a row, so there was open space at the ends of the row and above the plants for moths to move.

H. armigera moths were sourced from a laboratory colony. Adults were paired two or three days after eclosion and held in a container and supplied with sugar solution for 24 hours before being released into a cage. Two or three pairs were released into each cage.

After three days the cages were removed. The height of each plant was measured and the plants were cut into 20 cm sections from the top down i.e. the first section was from the top to 20 cm down, the second from 20 – 40 cm from the top, and so on to the ground. The plant sections were taken to the laboratory, separated into the different plant structures, and carefully examined for eggs, which were counted. The plant parts were: terminals (end centimetre made up of the tip and tiny developing leaf buds; upper surface of leaves; lower surface of leaves; stems and petioles; flowers and flower buds; and fruit. The presence or absence of flowers and fruit was noted. The three plants were treated individually.

(ii) Tomato
Five young tomato plants growing in a field plot at Bundaberg Research Station were sampled for eggs naturally laid by wild *H. armigera* moths. The plants were just starting to flower and had not yet been trellised. The plants were measured, separated into 20 cm sections from the top down, and the number of eggs on the plant structures counted and recorded.

Cage studies were done on tall, fruiting plants. A cage with a crude wire frame covered with tuille was placed over two trellised tomato plants (variety Daniella) planted 0.5 m apart in a row, leaving space around and above the plants for moth movement.

H. armigera moths were reared, held and released using the same methods as used in the capsicum studies.

After three days the cages were removed, and the height of the plants measured. The two plants were treated as one as they were intertwined and to separate them would have risked dislodging eggs. Plants were cut into sections from the top down as follows: top to 20 cm; 20 – 40 cm; 40- 60 cm; and below 60 cm. Sections were taken to the laboratory where the plant parts were examined carefully for eggs and the eggs counted. The plants were separated into the following parts: terminals (1 –2 cm of tip growth); upper surface of leaflets; lower surface of leaflets; stems and petioles; flowers; and fruit.

(iii) Zucchini
The same cages used for capsicum studies were placed over single fruiting zucchini plants. One or two pairs of *H. armigera* moths that had been reared and held using the same methods as in the capsicum studies were released in each cage. One to three but usually two days later the cages were removed and the plants were cut at ground level and taken to the laboratory. Plants were separated into: terminal; leaf stalks; upper surface of leaves; lower surface of leaves; flower buds (very small buds in the terminals); female flowers; male flowers; fruit. Flowers, as compared to buds, were defined as having the petals extended and yellow coloured or open. The numbers of eggs on each part were counted.

(iv) Rockmelons
Twenty rockmelon plants grown at Ayr Research station were examined on five occasions from late February to mid March and the numbers and position of heliothis eggs on the plants recorded. Eggs were recorded as being on flowers or on leaves towards the base, middle or tips of runners. Most plants were budding or flowering on 28 February, and lowering and running by 5 March.

Results

The percentages of *H. armigera* eggs found on capsicums at each height and on each plant structure are shown in Table H26. The percentages of eggs found at each height and on each plant structure on small tomato plants are shown in Table H27, and those on tall, trellised plants in Table H28. The results for zucchini plants are given in Table H29. (The total percentage for the plant sections by height or structure may not total exactly 100% because of rounding-off approximations.) Table H30 shows where eggs were found on melon plants.

Discussion

(i) Capsicum
In capsicums most eggs were laid in the top 20 cm of the plant (82%) and the remainder in the 20 – 40 cm height section. On some plants, particularly those that were younger and hence smaller, there was a large proportion of eggs laid in the 20 – 40 cm height section. The majority of eggs were found on leaves (89%), with about twice as many on the upper surface as on the lower surface. Very few eggs were found on flowers or on fruit. The preference for ovipositing on the upper surface of leaves is similar to that reported for *H. assulta* but whereas *H. assulta* also oviposited substantially on fruit (Hwang *et al.* 1987), *H. armigera* did not in this study.

Hence to monitor for heliothis in capsicums sampling should be done on leaves in the top 20 cm of the plant. Sprays to control heliothis should be targeted at the top 40 cm of the plants and need to be applied to both leaf surfaces.

(ii) Tomato
On small tomato plants between 20 cm to 30 cm high obviously the majority of eggs were laid in the top 20 cm as there was little of the plant below that height. Eggs were laid predominately on leaflets and were equally divided between the upper and lower surfaces.

On tall, trellised, flowering and fruiting tomato plants eggs were laid mainly on leaflets (91%) in the top 40 cm of the plant (78%). While a greater proportion of eggs were laid in the top 20 cm (43%) than from 20 – 40 cm (35%) the proportion in the 20 – 40 cm section was high, and so important. Overall more eggs were laid on the upper surface of leaflets (52%) than on the lower (38%), but both were important oviposition sites. Some eggs were laid on flowers (2%) and on fruit (1%), and while the percentages are low larvae hatching from these eggs could directly damage the productive parts of the plants. The oviposition sites recorded in this study are very similar to those reported for *H. armigera* in France (Saour and Causse 1993).

Table H26
Percentages of *H. armigera* eggs on capsicum plants at each height and on each plant part.

Plant no. (height cm) Plant sections: cm from top down	(total no. of eggs on plant) % of eggs at each plant height	% of eggs on each plant structure terminal	upper leaf surface	lower leaf surface	stem and petiole	flower	fruit
Plant 1 (35)	(15)						
Top – 20 cm	93.3	6.7	53.3	33.3	0	-	-
20 – 40 cm	6.7	0	0	0	6.7	-	-
Plant 2 (39)	(16)						
Top – 20 cm	25.0	0	25.0	0	0	0	-
20 – 40 cm	75.0	6.3	56.3	6.3	6.3	0	-
Plant 3 (38)	(65)						
Top – 20 cm	41.5	1.5	32.3	6.2	1.5	0	-
20 – 40 cm	58.5	0	32.3	23.1	3.1	0	-
Plant 4 (35)	(22)						
Top – 20 cm	90.9	13.6	63.6	13.6	0	0	-
20 – 40 cm	9.1	0	4.5	4.5	0	-	-
Plant 5 (34)	(26)						
Top – 20 cm	100	0	88.5	11.5	0	0	-
20 – 40 cm	0	0	0	0	0	-	-
Plant 6 (35)	(35)						
Top – 20 cm	91.4	5.7	57.1	14.3	14.3	0	-
20 – 40 cm	8.6	2.9	2.9	0	2.9	-	-
Plant 7 (32)	(16)						
Top – 20 cm	93.75	6.25	31.25	43.75	12.5	0	-
20 – 40 cm	6.25	6.25	0	0	0	-	-
Plant 8 (37)	(3)						
Top – 20 cm	33.3	0	33.3	0	0	0	-
20 – 40 cm	66.7	0	66.7	0	0	-	-
Plant 9 (34)	(26)						
Top – 20 cm	100	3.8	50	46.2	0	0	-
20 – 40 cm	0	0	0	0	0	-	-

Table H26 continued

Plant 10 (35)	(33)						
Top – 20 cm	66.7	6.1	30.3	36.4	0	0	-
20 – 40 cm	33.3	0	3.0	24.2	6.1	-	-
Plant 11 (34)	(76)						
Top – 20 cm	97.4	6.6	63.2	26.3	1.3	0	-
20 – 40 cm	2.6	0	2.6	0	0	-	-
Plant 12 (40)	(119)						
Top – 20 cm	95.8	8.4	47.1	38.7	0.8	0	0.8
20 – 40 cm	4.2	0	4.2	0	0	-	-
Plant 13 (81)	(19)						
Top – 20 cm	57.9	0	42.1	15.8	0	0	0
20 – 40 cm	21.1	5.3	15.8	0	0	-	-
40 – 60 cm	21.1	0	15.8	0	5.2	-	0
below 60 cm	0	0	0	0	0	-	0
Plant 14 (74)	(5)						
Top – 20 cm	80	0	40	40	0	0	0
20 – 40 cm	0	0	0	0	0	0	0
40 – 60 cm	20	0	0	0	20	-	0
below 60 cm	0	-	0	0	0	-	0
Plant 15 (48)	(23)						
Top – 20 cm	91.3	0	60.9	30.4	0	0	0
20 – 40 cm	8.7	0	4.3	0	0	0	4.3
below 40 cm	0	-	-	-	-	-	-
Plant 16 (53)	(31)						
Top – 20 cm	74.2	0	51.6	19.4	0	3.2	0
20 – 40 cm	19.4	0	16.1	3.2	0	0	0
below 40 cm	6.5	-	6.5	0	0	-	-
Total	(530)						
Top – 20 cm	81.7	4.9	49.1	25.5	1.9	0.2	0.2
20 – 40 cm	17.0	0.8	9.6	5.1	1.3	0	0.2
40 – 60 cm	1.3	0	0.9	0	0.4	0	0
below 60 cm	0	0	0	0	0	0	0

For monitoring tomatoes leaves in the top 20 cm of the plant should be examined and both surfaces of the leaflets should be checked. We did not record the position of the leaves in relation to flowers or fruit clusters, but Saour and Causse (1993) and Alvarado-Rodriguez *et al.* (1982) with *H. zea* recorded that many eggs were laid on leaves close to flowers. It would be sensible then to monitor for eggs on leaves close to flowers, as recommended in processing tomatoes in Victoria (Smith *et al.* 1994).

Sprays applied for heliothis control on tomatoes should be targeted at the top 60 cm of the plants, as very few eggs were oviposited below that level. Coverage of both leaf surfaces is needed.

Table H27
Percentages of *H. armigera* eggs laid by wild moths on tomato plants at each height and on each plant part.

Plant no. (plant height cm) Plant sections: cm from top down	(total no. of eggs on plant) % of eggs at each plant height	% of eggs on each plant structure					
		terminal	upper leaflet surface	lower leaflet surface	stem and petiole	flower	fruit
Plant 1 (26)	(14)						
Top – 20 cm	92.9	0	42.9	50.0	0	0	-
below 20 cm	7.1	0	0	7.1	0	-	-
Plant 2 (20)	(12)						
Top – 20 cm	100	0	50.0	41.7	8.3	-	-
Plant 3 (27)	(15)						
Top – 20 cm	86.7	0	60.0	13.3	13.3	0	-
below 20 cm	13.3	0	13.3	0	0	-	-
Plant 4 (22)	(12)						
Top – 20 cm	100	0	75	25	0	0	-
below 20 cm	0	0	0	0	0	-	-
Plant 5 (31)	(38)						
Top – 20 cm	65.8	5.3	23.7	36.8	0	0	-
below 20 cm	34.2	0	5.3	28.9	0	0	-
Total	(91)						
Top – 20 cm	82.4	2.2	42.6	34.1	3.3	0	-
below 20 cm	17.6	0	4.4	13.2	0	-	-

(iii) Zucchini

On zucchinis most eggs (95%) were laid on the leaves, with twice as many on the lower surface (66%) as on the upper (29%). Most of the remaining eggs were laid on the leaf stalk with very few laid on flower buds, flowers or fruit. Normally on zucchini very few larvae are seen on leaves while most flowers contain larvae (see zucchini insecticide trials report). Clearly the larvae move from the oviposition sites on leaves to feeding sites in flowers. The insecticide trials recorded little damage to fruit, with the most important type of damage being caused by a bite by a larva to the side of a young fruit. It seems possible that the larvae

responsible for this type of damage hatch from eggs laid on flower buds, with the low proportion of oviposition at that site explaining the low level of damage to fruit. It would be important then to include flower buds in sampling sites to determine whether or not to spray zucchinis for heliothis control.

Table H28
Percentages of *H. armigera* eggs laid by moths on caged tomato plants at each height and on each plant part.

Plant no. (plant height cm)	(total no. of eggs on plant)	% of eggs on each plant structure					
Plant sections: cm from top down	% of eggs at each plant height	terminal	upper leaflet surface	lower leaflet surface	stem and petiole	flower	fruit
Plant 6 (102)	(799)						
Top – 20 cm	21.0	0.3	5.6	14.5	0.6	0	-
20 – 40 cm	34.93	0.3	15.6	16.4	2.6	0	0
below 40 cm	44.1	-	23.6	15.0	4.8	0.1	0.5
Plant 7 (120)	(641)						
Top – 20 cm	62.1	0.5	33.9	21.7	4.2	1.9	-
20 – 40 cm	30.4	0	13.4	14.5	2.2	0	0.3
40 – 60 cm	5.1	0	3.6	1.2	0.2	0	0.2
below 60 cm	2.3	-	0.9	1.2	0	-	0.2
Plant 8 (130)	(979)						
Top – 20 cm	49.2	2.2	28.4	13.9	1.6	2.9	0.2
20 – 40 cm	37.7	0	24.4	11.6	0.9	0.7	0
40 – 60 cm	9.7	0	6.0	2.6	0.3	0.3	0.5
below 60 cm	3.4	-	2.2	0.8	0.1	-	0.2
Total *	(2419)						
Top – 20 cm	43.4	1.1	22.3	16.2	2.0	1.7	0.1
20 – 40 cm	34.8	0.1	18.6	14.0	1.8	0.3	0.1
below 40 cm	21.8	-	12.4	7.0	1.8	0.2	0.5

* The 40 – 60 cm and below 60 cm sections have been combined to form the below 40 cm section in the total as Plant 6 was separated into three sections only.

(iv) Rockmelons

On rockmelons most eggs were found on leaves (93%) while the remainder were found on flowers. Most eggs were found on leaves towards the tips of the runners (49%) and the middle section of the runners (34%), although the latter figure was boosted by an extraordinarily high count of eggs (18) on one leaf. These results clearly show that sampling for heliothis eggs on melons should be done on leaves towards the tips of runners. The species of eggs found were not determined. However usually *H. armigera* is the dominant

and often only species active in March in this region (Brown 2000, Kay 1989) so it is probable that all the eggs were *H. armigera*.

Table H29
Percentages of *H. armigera* eggs laid by moths on caged zucchini plants on each plant part.

Plant No. (total no. of eggs)	% of eggs on each plant structure							
	terminal	leaf stalk	upper leaf surface	lower leaf surface	flower bud	male flower	female flower	fruit
Plant 1								
(577)	0	5.0	23.9	69.8	0.5	0.7	0	0
Plant 2								
(565)	0	3.2	24.6	71.0	0.2	0.2	0.5	0.4
Plant 3								
(353)	0	4.8	46.5	46.2	0	1.4	1.1	0
Plant 4								
(910)	0	2.0	26.7	70.7	0.5	0	0	0.1
Plant 5								
(50)	2.0	0	10.0	88.0	0	0	0	0
Plant 6								
(202)	0	10.4	17.8	71.3	0	0.5	0	0
Plant 7								
(548)	0	4.4	37.4	54.9	0.2	2.0	1.1	0
Total								
(3205)	0.03	4.0	29.0	65.5	0.3	0.7	0.4	0.1

Summary of egg laying sites
On all four crops studied the majority of eggs were laid on leaves. Duffield and Chapple (2001) reported that the majority of *Helicoverpa* spp. eggs were laid on fully expanded leaves in the top 20 cm of canopy of soybeans, which they say reflects "a preference for leaves and the top of the canopy, combined with the dominance of leaves compared to other plant structures in terms of their surface area, and therefore the availability of oviposition sites." We did not measure the surface area of the plant structures, but obviously the leaf surfaces had a much greater surface area than the other plant structures and so provided more oviposition sites. On the taller crops (i.e. tomatoes and capsicums) *H. armigera* exhibited an ovipositional preference for height and leaves, while on zucchini and the prostrate melons there was a clear preference for leaves.

These studies have identified oviposition sites for *H. armigera* on capsicums, tomatoes, zucchinis and melons. This knowledge allows sections of the plants to be targeted for

monitoring for eggs and for insecticide application. More efficient and effective monitoring and insecticide use should result.

Table H30
The numbers of heliothis eggs on parts of rockmelon plants.

Date	Plant	Number of heliothis eggs on plant parts			
		leaves at base, middle or tip of plant/runners			flowers
		base	middle	tip	
28 Feb.		No eggs recorded			
5 March	3			1	
	4				2
	5			3	
	11			1	
	14			1	
8 March	3			2	
	7			1	
	11	1			
	12			1	
12 March	2		18	1	
	4			1	
	5			1	
	6			1	
	7			2	
	11			1	
	12	4		1	
	14		1	1	
	15			1	
	16			1	
	17			1	
	18			5	
	20			2	
15 March	1		1	1	
	2				3
	4		1		
	5	1	2	1	
	6			1	
	8				1
	10		1	1	
	11			3	
	12			1	
	13		1	2	
	15		3	2	
	19	3			
	20		2	3	
Total		9	30	44	6

Heliothis seasonal occurrence at Bundaberg

Introduction

Kay (1999) reported on studies of the seasonal occurrence and abundance of *Helicoverpa* spp. in the Bundaberg district. Those studies used pheromone traps and egg collections from tomatoes to determine the occurrence of the two major species, *H. armigera* and *H. punctigera*, in the district from 1996 to 1998. The occurrence and duration of diapause in *H. armigera* was determined in those years also. Those studies complemented information on heliothis seasonal occurrence in southern Queensland and northern New South Wales (Zalucki *et al.* 1986) and north Queensland (Kay 1989, Titmarsh *et al.* 1990).

The seasonal occurrence of insects such as *Helicoverpa* spp. is influenced by climatic factors and by the availability of hosts, and both of these influencing factors are variable. Long term records of insect abundance and occurrence may help explain the ecology of the insects (e.g. Maelzer *et al.* (1996) used long term light trap and weather data to determine the early season population dynamics of *H. punctigera*), while any such information may help in interpreting other studies on the insects. For example, Rochester and Zalucki (1998) used the pheromone trap and egg collection information from Kay (1999) to help explain possible migration by *H. armigera*. Such information may also help interpret microsatellite studies into the population structure, migration and recruitment of *H. armigera* in local areas (K. Scott, pers. comm.). Locally, information on the occurrence of the two heliothis species can assist growers manage the pests in their crops by alerting them to large increases in numbers, such as occurs in spring and in autumn.

For these reasons monitoring of heliothis pheromone traps has continued at Bundaberg for the duration of this project.

Materials and methods

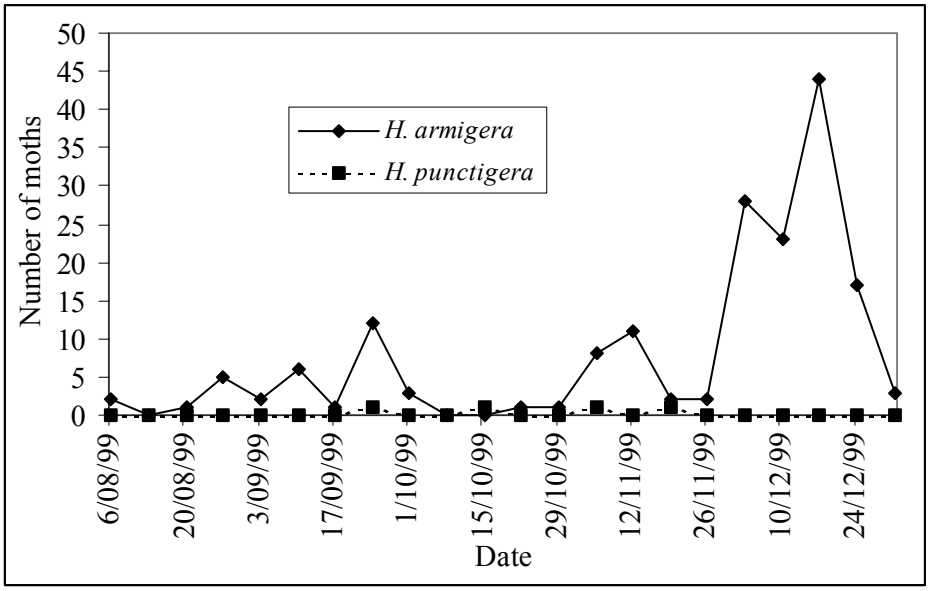
Pheromone traps were used to monitor the occurrence of *Helicoverpa* species at Bundaberg Research Station from August 1999 to September 2003.

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, melons, peanuts, sweet potatoes, pumpkins, and forage sorghum and legumes for green mulch, and sugar cane). 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 commercial pest strip (Shelltox Ministrips from August 1999 to March 2003 and then Mortein Moth and Insect Strips), which contains dichlorvos, was placed in the bucket of each trap to kill trapped moths. Pest strips were replaced with new ones every eight weeks. The traps were cleared every seven days and the numbers of moths counted and recorded.

Results

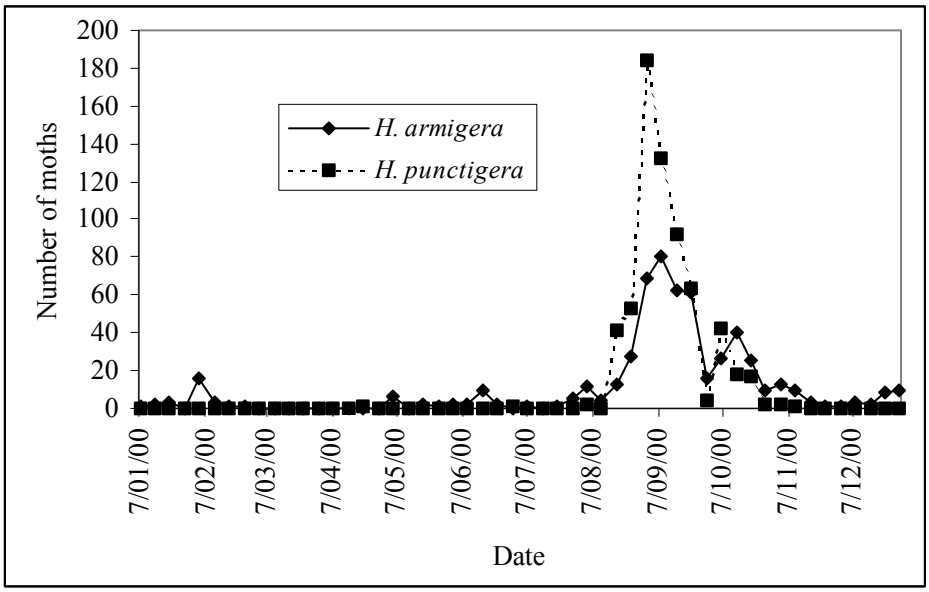
The numbers of *H. armigera* and *H. punctigera* moths caught in the pheromone traps each week in 1999, 2000, 2001, 2002,and 2003 are shown in Figures H1 to H5 respectively.

Figure H1
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research Station in 1999.



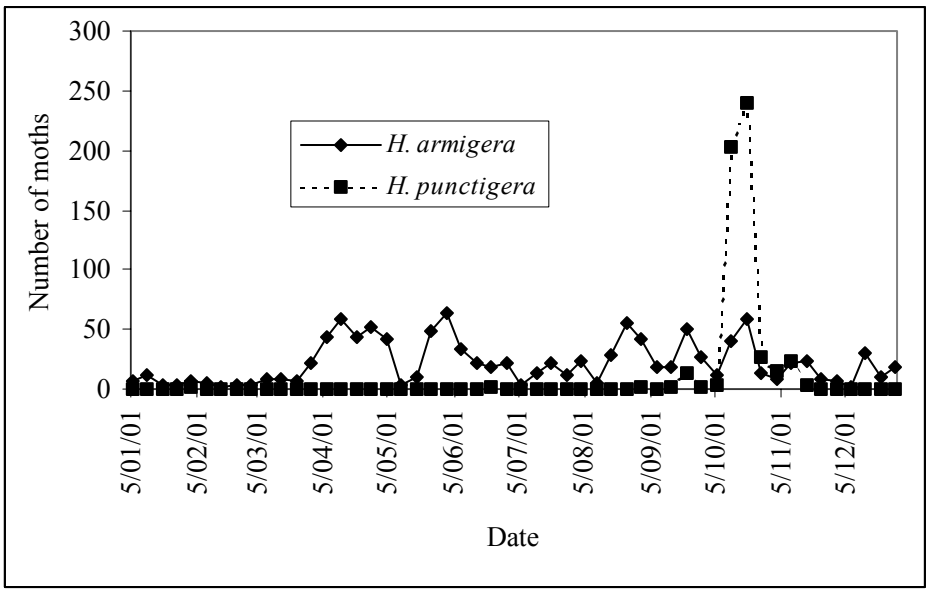
Numbers of *H. punctigera* were low throughout the trapping period. *H. armigera* was present but the numbers were quite low through August to October and in November and numbers increased in December.

Figure H2
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research Station in 2000.



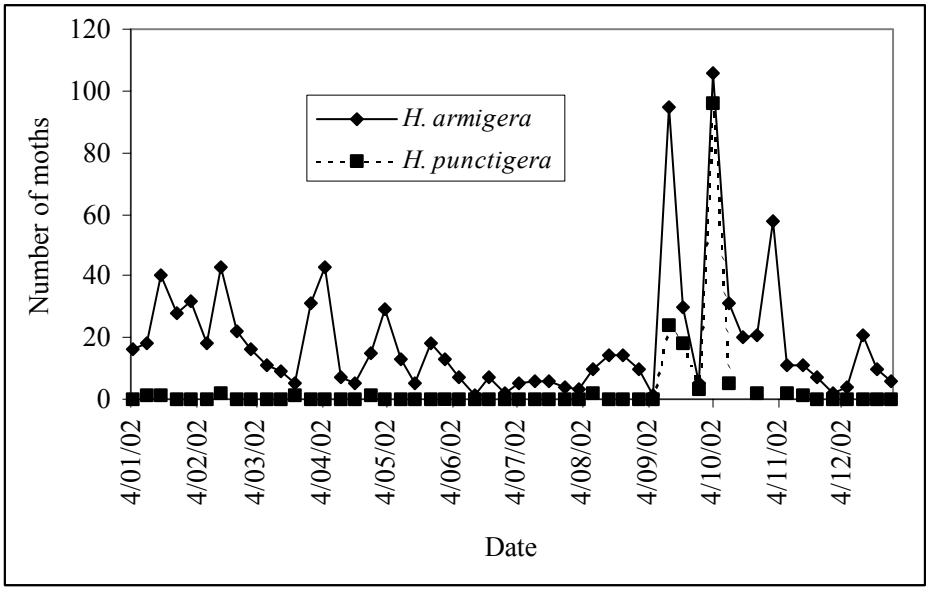
Numbers of both species were very low during 2000 until both increased in mid September. Both were caught through November but numbers fell again in December.

Figure H3
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research Station in 2001.



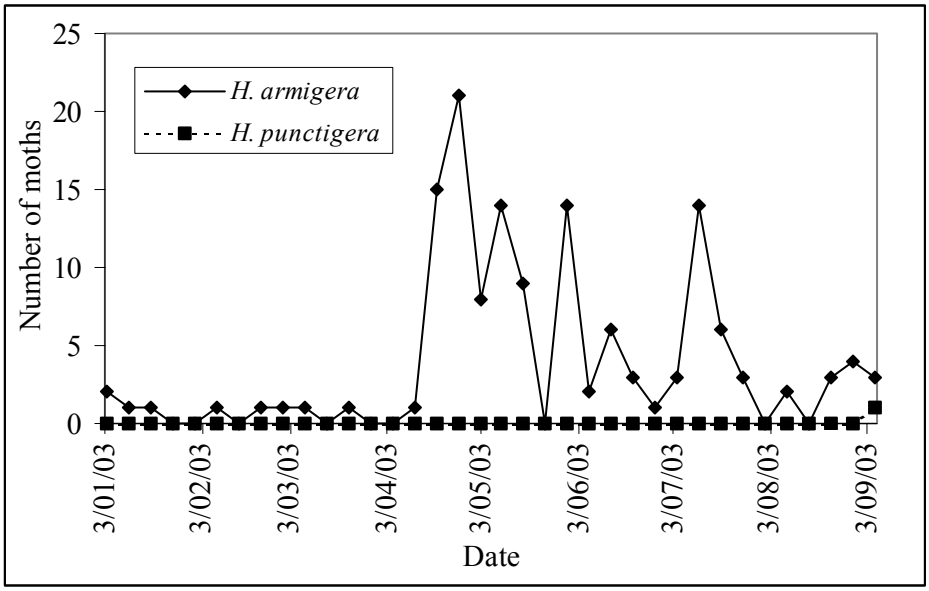
In 2001 *H. punctigera* was absent until early October when the number of moths caught increased rapidly, but then fell again by December. *H. armigera* numbers were low during the first part of the year but then increased in April and continued to be present for the remainder of the year.

Figure H4
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research Station in 2002.



H. punctigera was virtually absent during 2002 until mid September and early October when its numbers increased to high levels. *H. armigera* was present in moderate numbers from January until June when they fell, but they increased again in September. It was present in November and December in low numbers.

Figure H5
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research Station in 2003.



H. armigera numbers were low in 2003 until mid April, when they increased to moderate levels. *H. punctigera* were not trapped until early September.

Discussion

The seasonal abundance and occurrence patterns for the two *Helicoverpa* species over the years reported here differed to some extent from those recorded from 1996 to 1998 (Kay 1999). In those years *H. punctigera* were rarely caught from January to September. They appeared in the traps in September to mid October. In each year they were trapped only from about September to December, and were rarely caught from January on. *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.

It is important to remember that pheromone traps provide information on the presence or absence of the two species (i.e. their temporal occurrence) but they do not provide good information on the relative abundance of the two species (Fitt *et al.* 1984).

H. punctigera migrates into eastern areas each spring from breeding areas in inland Australia (Gregg *et al.* 1995). This migration did not occur, or was not recorded, at Bundaberg in 1999. Presumably conditions in the western early-season breeding areas were poor so numbers of moths in the migrating generation were low. The normal migration patterns were recorded in 2000, 2001 and 2002. *H. punctigera* generally were not trapped from January to about September in any year, which is the standard pattern.

The pattern of *H. armigera* occurrence has been quite variable from year to year, although the underlying pattern still is discernible. In 1999 numbers were low, and unusually so until December when they increased, only to fall to unusually low levels from January to September 2000. The increase in numbers in September 2000 followed the standard pattern and probably was due to local emergence from diapause (Kay 1999) and possibly some migration. The very low numbers during December 2000 through to late March 2001 were unusual. An increase, but with low numbers, occurred as usual in April, and this level of activity continued during winter, indicating perhaps that a low proportion of the population only entered diapause, and for the remainder of the year and until mid May 2002. Numbers fell in the cooler months of June-August 2002, and then rose significantly in September-October, before falling to low levels again in early 2003. The usual rise, albeit at low levels, occurred in April 2003.

Overall, *H. armigera* numbers have been very low during the period of this study. Similarly low population levels have been recorded on the Darling Downs during this time (D. Murray pers. comm.).

The differences from the "standard" pattern of *H. armigera* and *H. punctigera* occurrence and abundance reported by Kay (1999) are probably due to natural variation in climatic conditions, both in the Bundaberg area and in areas from which migrants may originate. A mild to warm autumn may mean a lower proportion of the *H. armigera* population will enter diapause; a lack of rain at a suitable time in western breeding areas may result in a low migrating population of *H. punctigera*; excessively hot temperatures may increase egg and larval mortality; drought may reduce the availability and abundance of host plants. Local

conditions such as the presence or absence of host crops close to the traps may have influenced numbers caught.

The differences in the pattens of occurrence, particularly for *H. armigera*, over the eight years of pheromone trapping reported in Kay (1999) and here emphasises the need for long-term studies in such matters. It is planned to continue running the pheromone traps so that this useful information continues to be collected.

Protocols for conducting trials with bio-pesticides

Protocols to guide the conduct of field trials using bio-pesticides and to minimise the risk of cross-contamination when using preparations of heliothis nuclear polyhedrosis virus were written at the start of the project. They have provided guidance in all the work done with bio-pesticides in the project (i.e. insecticide trials on various crops, and the experiments with Amino Feed as an additive).

The protocols are presented below.

PROTOCOL

Protocols for conducting field screening trials including biopesticides against *Helicoverpa* spp.

The principal aim of this protocol is to document the principles and procedures that should be followed when conducting pesticide screening trials with biopesticides or other insecticides against heliothis (*Helicoverpa* spp.) in this project.

This protocol does not claim to include all the methods needed to conduct such trials but rather documents the general principles that should be followed.

This protocol should be read in conjunction with the **Protocol to minimise cross-contamination when using heliothis nuclear polyhedrosis virus (and other biopesticides)**.

Protocols

The following procedures should be followed when conducting field screening trials, or the field component of bioassays, including biopesticides in this project.

- The trial should be designed carefully with adequate numbers of treatments and replicates to allow statistical analyses of data. Use a minimum of three replicates.

- Plots should be large enough to allow treatments to be applied accurately, and to allow necessary sampling (eg of heliothis eggs and/or larvae, of other insects such as predators, parasites, secondary pests) to be conducted, and to allow fruit to be harvested to determine damage levels and yield. Fruit samples for yield and damage assessment and insect samples should be taken from separate plants or sections of row as the two are not mutually independent.

- Adequate untreated guard areas should be left around plots.

- Care must be taken that other treatments (eg fungicides, miticides, insecticides for other pests) will not interfere with the primary purpose of the trial. For example, oils may affect heliothis oviposition, avamectin may kill *H. punctigera*.

- Spray equipment must be calibrated before treatments are applied. Calibration should include checking nozzles for wear and even output, as well as determining spray output per unit time, area or length of row.

- Separate measuring equipment (eg pipettes, measuring cylinders) should be used for each treatment. They must be washed thoroughly after use, and must be soaked in and washed with bleach (0.5% solution) if they have been used for virus treatments.

- Spray equipment must be emptied and washed thoroughly between treatments, including spraying clean water to wash out spray lines and nozzles. Bleach should be used if the equipment has been used to spray virus. Left over spray and washings must be disposed of responsibly.

- If several rates of the one pesticide are to be used they should be applied in order of ascending rate or concentration. The spray tank and lines should be emptied between treatments but need not be washed.

- Staff mixing and applying spray treatments must wear all necessary protective clothing. This should include: plasticised or other spray resistant overalls; chemical resistant gloves; waterproof chemical resistant boots (eg gumboots); eye protection; respirator fitted with the correct filters. All other relevant safety procedures must be obeyed.

- If biopesticides, particularly the heliothis nuclear polyhedrosis virus, are included in the trial then the procedures in the **Protocol to minimise cross-contamination when using heliothis nuclear polyhedrosis virus (and other biopesticides)** should be followed.

- The abundance of heliothis during the trial should be monitored by regular scouting or sampling using a consistent technique applicable to the particular crop.

- The species composition of heliothis present should be monitored on several occasions during the trial either by collecting eggs and/or larvae and rearing them to adults for identification, or by testing eggs using a Lepton kit.

- Weather conditions at the time of spray application should be recorded.

PROTOCOL

Protocols to minimise cross-contamination when using heliothis nuclear polyhedrosis virus (and other biopesticides)

The principal aim of this protocol is to document the procedures that need to be considered and carried out to minimise the risk of contamination when conducting trials with biopesticides, particularly with nuclear polyhedrosis virus (NPV), in this project.

The protocol does not detail all the methods needed to conduct trials with biopesticides (eg plot size, number of replicates, calibration, method of application, type of data to be gathered, sampling methods). Many of these methods are common to trials using standard insecticides, while some will pertain to the particular trial.

The risk of spreading NPV from virus treated areas to non-treated areas, and of infecting non-treated larvae by exposing them to virus contaminated plants, equipment or surfaces is high unless adequate precautions are taken. Such virus contamination could result in the failure of the particular trial and so waste time, money and effort. This risk can be reduced by taking the proper precautions.

The risk of cross-contamination when using other biopesticides such as the *Bacillus thuringiensis* preparations is considered to be much less. However reasonable care still should be taken when using these products.

Field Protocols

The following procedures should be followed when conducting field trials with NPV.

- Adequate untreated guard areas should be left between virus treated plots and other plots.

- Staff should not walk from virus treated plots through other plots. Safe walkways should be left if at all possible so that virus plots can be accessed without passing through non-virus plots, and vice versa.

- The passage of farm equipment through the trial area should be minimised to reduce the risk of it spreading NPV from virus plots to non-virus plots. Some access may be essential, for example to apply necessary fungicides to the crop. In these cases the tractor should travel along non-treated guard tracks, spray droppers should be correctly aligned so they hang between rows and do not touch the plants rather than to one side where they may brush along plants, and the time between the previous virus spray and the other operation should be maximised.

- When applying treatment sprays to the trial all non-virus treatments should be applied before the NPV treatment. The NPV treatment must be applied last. If several rates of virus are to be used they should be applied in order of ascending rate or concentration.

- When sampling after virus applications samples should be taken from non-virus treated plots first and from the virus treated plots last.

- All equipment used in the trial should be washed carefully and sterilised with bleach (sodium hypochlorite) (0.5% solution) after each use. Heavily contaminated equipment should be soaked overnight. Clothing should be washed.

Laboratory Protocols

Care must be taken in the laboratory so that the risk of contamination is minimised. The following procedures should be followed.

- Bench areas should be washed with bleach (0.5% solution) before and after use.

- Work areas should be covered with brown paper when samples are being processed. The paper should be replaced between treatments and disposed off carefully.

- Wear disposable gloves when handling samples. Use a new pair of gloves for each treatment.

- Use a separate set of instruments (eg forceps, brushes) for each treatment, or sterilise the equipment thoroughly in bleach (0.5% solution) between treatments.

- Do not reuse disposable items. Dispose of them carefully.

- All equipment should be sterilised in bleach (0.5% solution) after use (or autoclaved if that option is available). Heavily contaminated equipment should be soaked overnight.

Caution

Bleach can corrode some metals such as stainless steel so bleach solutions should not be left standing in stainless steel sinks for any length of time. Use plastic buckets or basins to soak equipment in bleach.

Acknowledgments
Staff of the FSI Heliothis team contributed their experience and knowledge to the preparation of these protocols.

Bio-pesticides meeting report

A meeting to discuss the use of and the registration of bio-pesticides in vegetables was held in Bowen in 2000 as a project activity. A report on the meeting was prepared at the time, submitted to HRDC and circulated to meeting participants and other interested parties. That report is copied below.

Report on the Biopesticides Meeting Held at Bowen Research Station, 21 June 2000.

I R Kay, Senior Entomologist, Queensland Horticulture Institute, Bundaberg Research Station, 49 Ashfield Road, Bundaberg Q 4670

Summary

The main points from the meeting were:

1. Chemical industry support for further development or registration of the currently available biopesticides (Gemstar, *Bacillus thuringiensis* products) is not guaranteed in vegetables.
2. Data protection legislation would protect the companies' investment in obtaining registrations.
3. The use and benefits of additives should be evaluated carefully, particularly in the field. Registration of their use by the NRA would be advantageous.
4. Vegetable industries should be prepared to lobby chemical companies to obtain registrations, and the industries need to be prepared to provide support in obtaining efficacy and residue data.

While discussions during the meeting were generally open, frank and positive obviously there were some restraints of a commercial-in-confidence nature in discussing products in development.

Introduction:

The meeting was held following a suggestion by Dr M Smith, then HRDC Program Manager, that I organise a meeting of researchers and biopesticide producers and sellers to discuss the progress of trials and registrations of biopesticides in vegetables. It was decided to hold the meeting in conjunction with the "Insect Pest Management in Sweet Corn" Project Workshop at Bowen from 19th to 22nd June 2000 as many of the people involved with biopesticides in vegetables would be at the workshop.

Invitations to the meeting were sent specifically to chemical companies, to groups known to be developing biopesticides, to State Department of Agriculture/Primary Industries vegetable entomologists, and generally to all sweet corn project stakeholders. The Appendix gives a list of those who attended.

For the purpose of the meeting biopesticides were defined as pesticides that cause diseases in insects. Those currently commercially available or potentially available for use in vegetables include a heliothis nuclear polyhedrosis virus (Gemstar) and several products based on *Bacillus thuringiensis* subsp. *kurstaki* (eg DiPel, MVP, Delfin) and on *B. thuringiensis* subsp. *aizawai* (eg XenTari). However the discussions also included references to a broader range of compounds including the insect growth regulators. Vegetables were defined as including fresh market tomatoes but sweet corn generally was excluded from the discussions as considerable discussions on the uses of biopesticides on sweet corn were held during the remainder of the workshop.

The meeting agenda was a brief introduction, a 'keynote' address from Dr Caroline Hauxwell, talks on work in progress by Iain Kay, Dr Sandra McDougall, Bronwyn Walsh, John Duff and Pat English, interspersed with and followed by discussions on a range of issues.

Notes on talks:

1. Dr Caroline Hauxwell (QDPI FSI) gave a comprehensive, understandable review of insect pathogens and their commercial potential. The talk was informative, interesting and provided everyone with an excellent overview of the subject.

2. Iain Kay (QDPI QHI) spoke about the biopesticide work being done in the heliothis (*Helicoverpa* spp.) component of an HRDC funded project in tomatoes, melons and vegetables. XenTari has been trialed against heliothis in tomatoes to develop data for registration. Products of both *Bt* subspecies are included among insecticides being trialed against heliothis in capsicums at present, and Gemstar will be included in trials later this year. XenTari, MVP and Gemstar were included in trials against heliothis in melons at Ayr. Planned work in the future includes further field trials and bioassays of biopesticides plus additives.

3. Dr Sandra McDougall (NSW Dept. Agric) spoke of trials of Gemstar against heliothis on processing tomatoes and on lettuce, and of *Bt* on tomatoes and lettuce. Field trials with Gemstar plus several additives indicated that additives did not increase yield. The importance of biopesticides to organic growers was noted.

4. Bronwyn Walsh (QDPI QHI) discussed the use of biopesticides on brassica crops, and mentioned concern about the development of resistance to *Bt* in diamondback moth (*Plutella xylostella*).

5. John Duff (QDPI QHI) talked briefly about current and proposed work with biopesticides in lettuce.

6. Pat English (Bayer) spoke about a new product, methoxyfenoxide (Prodigy), an insect growth regulator that is nearing registration for use against heliothis on some vegetable crops. While not strictly a biopesticide, Bayer considers that it has many of the advantages of a biopesticide, and that it has commercial advantages over biopesticides. It will compete against the *Bt* products.

Discussions:

Major issues raised during discussions in the meeting were:

1. Additives

The addition of additives of various sorts (eg skim milk powder, Denkavit, Amino-Feed) is touted as improving the efficacy of biopesticides. Some of the results of bioassays using heliothis larvae conducted by Dr D Murray (QDPI FSI) with Gemstar plus additives and with *Bt* plus additives on field crops were shown. These demonstrated increased mortality of larvae when some additives were added to Gemstar and to *Bt* (not as great an effect).

Discussion ranged over the hype surrounding the use of additives; the potential benefits of additives; the wide range of compounds that could be used as additives and the need to consider each one separately (i.e. it is not possible to generalise on the topic); the need to properly assess the benefits or otherwise of additives, using bioassays, and more importantly, field trials to test whether there are benefits of improved control, improved yield and reduced damage in real field situations. There was concern that a wide range of compounds are being or could be promoted as additives with little or no testing of their effects, and with little or no regulation of their use. There is a need for NRA regulation/registration of additives to manage their use.

2. Registration status of *Bt* products

There currently are full registrations of *Bt* products on only a few vegetable crops (tomatoes, brassicas) or, for that matter, other crops. There are numerous off-label permits. NRA off-label permits have expiry dates, which means that permits have to be renewed regularly or full registrations obtained so the *Bt* can continue to be used legally for the particular purposes.

Renewing permits requires that someone be responsible for it, takes a degree of work and effort, and it needs the NRA to be agreeable to the renewal, which is not guaranteed. Full registration would be the best option.

However chemical company representatives stated that their companies had little incentive for commercial reasons to work towards full registration of *Bt*. Registration applications require considerable expensive trial work to show efficacy and involve costs in preparing and submitting the applications, yet after the initial registration other companies can simply mirror the application for minimal cost and enter the market and compete. The representatives said that data protection rules were needed so that their investments in obtaining registration could be protected. It was implied that without such data protection the companies would not be pursuing registration for *Bt* products, particularly on minor crops or minor pests.

As well, new products, protected by patent, that the companies regard as direct competitors to *Bt* are being developed, and the companies are likely to support those products over *Bt* for commercial reasons.

3. Efficacy data for permits

Applications for off-label permits should be supported by efficacy data. Such data should be collected whenever possible, particularly for minor pests so that it is available when needed.

4. Gemstar availability

Most discussion on this occurred during sweet corn workshop sessions but comments from Aventis regarding this matter were raised during the meeting. Aventis declined to present a

talk to the meeting but commented that they are dealing with other issues regarding Gemstar (presumably quality and supply issues) and at present have no definite policy regarding its use in vegetables.

5. Chemical company priorities

There is a great need for the vegetable industry to provide arguments and input to influence the chemical companies' priorities for obtaining registrations, particularly for what are perceived as minor crops. Representatives of the three companies stated that the companies were more likely to consider obtaining registration of a product for a particular use if they received approaches/lobbying from industry. Such approaches should be supported by data on the importance of the pest, the size of the crop, the number of applications to be used etc., and, if possible, indications of industry support in obtaining efficacy and residue data. This matter is pertinent to all insecticides and not just the biopesticides.

There was a suggestion that the Vegetable Industry Development Officers could further this matter.

Appendix

Attendance

The meeting was attended by most of the people at the Sweet Corn Workshop (about 55 people attended) and a few others who were present specifically for the meeting. The following list gives names and affiliations of those particularly pertinent to the meeting.

Chemical Industry

(a) Bayer Australia: Pat English, R&D Officer; Jeff Harrison, Area Manager.
(b) Dow AgroSciences: Paul Downard, Development Manager, Crop Insecticides; Geoff Messer, Senior Sales Agronomist.
(c) Aventis CropScience: Tim Murphy, Sales Agronomist.

Apologies for being unable to attend were received from Mr R Winten, Novartis Crop Protection, and from Dr J Riechelt, Genesearch.

State Departments of Agriculture/Primary Industries

Entomologists involved in vegetable research:
Lionel Hill, Tasmania
Dr Peter Ridland, Victoria
Dr Sandra McDougall, NSW
John Duff, Qld
Bronwyn Walsh, Qld
Iain Kay, Qld
John Brown, Qld
Dr Caroline Hauxwell, Qld (Insect Pathologist)
Departmental horticulturalists, development officers, and extension officers also were present.

Crop Consultants

Dale Abbott and Dr Chris Monsour, Bowen Crop Monitoring Services.

Horticultural Research and Development Corporation
John Tyas, Program Manager.

Queensland Fruit and Vegetable Growers
Samantha Bray, Vegetable Industry Development Officer.

Technology Transfer

The main efforts in the project have been aimed at conducting research into the management of fruit flies and heliothis in a number of vegetable crops. As well, considerable effort has been made to inform growers and the agricultural industry about the project, its activities and results, outputs and outcomes so that information from the project is used for the benefit of vegetable growers.

Technology transfer activities undertaken as part of the project have included:

1. A press release in early 2000 provided information on the project's aims and the people and organisations involved (both as researchers and funders). This resulted in articles on the project being published in: "Vege Patch", issue 2, February 2000, a newsletter produced for and distributed to vegetable growers in the Dry Tropics region of north Queensland; Bundaberg Region Horticultural Newsletter Number 45, March 2000 (Kay, I. (2000). New Research Projects –Heliothis and fruit fly management strategies in IPM for tomato, vegetable and melon crops. *Bundaberg Region Horticultural Newsletter*, Number 45, p.4.); Queensland Fruit and Vegetable News, 13th April 2000; and an interview on ABC Rural Radio.

2. A project team member presented a talk on the project's purpose and progress, particularly in respect to heliothis, to cucurbit growers and industry representatives at a field day at Rockhampton on 7th September 2000. Approximately 40 growers attended.

3. A project team member attended the "Growing for Profit" field day organised by QFVG at Gympie on 15th November 2000 and manned a poster display and handed out information. The field day was attended by many growers from throughout south-east Queensland.

4. A project team member presented a talk on the project's progress to growers and industry representatives at a 'Tomato breeding and insect pest management' field day at Bundaberg research Station on 22nd November 2000.

5. Two articles resulting from project activities were published in the Bundaberg Fruit and Vegetable Growers Association newsletter in 2001. They were: Kay, I. (2001).Heliothis Resistance Results. *Bundaberg Region Horticultural Newsletter*, Number 60, pp. 4, 6.; and Kay, I. (2001). So Many Heliothis! *Bundaberg Region Horticultural Newsletter*, Number 58, p. 4.

6. Project team members attended the "Growing for Profit 2" seminar day organised by QFVG at Gatton on 4th September 2001 and presented a talk on the fruit fly aspects of the project.

7. A project team member presented a talk on the project's progress at the "Growing for Profit 2" seminar day organised by QFVG at Bundaberg on 11th September 2001.

8. A project team member presented a talk on the project's progress and results at a 'Capsicum Information Session' extension activity for growers at Bundaberg Research Station on 16th May 2002.

9. A project team member presented a talk on the project's progress and results, particularly with regard to capsicums, at a 'Grower Information Meeting' at Gumlu on 26th February 2003. Approximately 20 growers and industry representatives attended the meeting.

10. A project team member presented a talk on the project's progress and results in tomatoes and capsicums at a 'Grower Information Meeting' at Bowen, attended by approximately 30 growers and crop consultants on 27th February 2003.

11. Methoxyfenozide has been registered for use against heliothis in tomatoes. A trial in the project provided data to support the registration.

12. Copies of a report on the heliothis insecticidal control trials on capsicums were sent to all chemical companies whose products were included in the trials. As a result, DuPont have registered indoxacarb (as Avatar) for use against heliothis on capsicums using the efficacy data from these trials and their residue data. This is a good outcome for growers. Dow AgroSciences, which now owns methoxyfenozide, is expressing an interest in registering it in capsicums and related crops.

13. Copies of a report on the heliothis insecticidal control trials on zucchini were sent to all chemical companies whose products were included in the trials, and to extension staff and entomologists working in vegetables in Queensland.

14. Information on fruit fly infestation levels in commercial capsicum crops has been supplied to the growers who cooperated in the surveys. (Growers received the results for their own crop only, to preserve their privacy.) This has resulted in a grower modifying his management activities to improve management of fruit flies in the crop in at least one case.

15. As well as the formal activities reported above, information on the project, its purpose, progress and results has been disseminated widely to growers, extension staff, crop consultants, and scientific and agricultural industry colleagues through informal personal contact.

Recommendations

The development of IPM systems for insect pests in any crop is a large task, and it is a task that is continual. This project has made some advances in the development of IPM systems for fruit flies in tomatoes and capsicums and for heliothis in tomatoes, vegetables and melons, but a lot more detailed work is needed. The required work can only be done and advances made if the difficult, detailed and complex nature of such work is understood by industry and if it is supported by industry and the funding bodies. The fresh market tomato and the melon industries, through QFVG, withdrew their funding support part way through this project, and they no longer collect levies for or provide funding support for research and development in their industries.

The project failed to demonstrate the efficacy of protein baiting for fruit fly management in vegetables. However it is probable that baiting is effective, or effective enough to contribute significantly to a systems approach to fruit fly management.

The project determined the effectiveness of biopesticides and insecticides against heliothis in a range of vegetable crops, resulting in the registration of several products and much useful information, and investigated some aspects of the pest's biology with respect to the crops.

Recommendations from the project include:

1. The tomato, melon and vegetable industries should be encouraged to contribute to the long term support of research, development and extension activities related to the development of IPM programs for pests of their crops.

2. Further studies to demonstrate the effectiveness of baiting for fruit fly management at a level acceptable to export markets are needed. These may need to be broad scale trials. Integration of baiting in a systems approach should be pursued.

3. The effectiveness against fruit flies of insecticides used against other pests, especially heliothis, on these crops should be determined, and registrations for use against fruit flies be pursued for any that are effective.

4. Registrations for the use of insecticides effective against heliothis, particularly those with specific IPM benefits, should be pursued in a range of vegetables.

5. Ways of integrating the use of currently available heliothis biopesticides (*B. thuringiensis* products and the nuclear polyhedrosis virus) into tomato, vegetable and melon production systems should be investigated.

6. The tomato industry and the vegetable industry should develop and actively maintain strong links with other industries affected by heliothis, in particular the cotton and grain industries, and they should strive to manage the pest cooperatively.

7. There are many pests in tomato, vegetable and melon crops and research, development and extension work is needed to develop management systems for them individually and, more importantly, together. Such work should be encouraged and supported.

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