Development and Promotion of IPM Strategies for Silverleaf whitefly in Vegetables

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Department of Employment, Economic Development & Innovation

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FINAL REPORT

HAL Project VG05050

(22 July 2010)

Development and promotion of IPM strategies for Silverleaf whitefly in vegetables

Dr Siva Subramaniam et al.

Horticulture & Forestry Sciences
Agri-Science Queensland
Department of Employment, Economic Development and Innovation (DEEDI)

HAL project number VG05050

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Purpose of report: This final report 'Development and promotion of IPM strategies for silverleaf whitefly in vegetables' summarises the research and extension into development and implementation of IPM programs for silverleaf whitefly in vegetables.

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Media Summary

The control of Silverleaf whitefly is a major cost of production to vegetable growers in the Bowen, Burdekin, Bundaberg and Lockyer Valley growing areas of Queensland. This Horticulture Australia Limited funded project has delivered both economic and environmental benefits to the industry by encouraging growers to adopt an Integrated Pest Management (IPM) program.

This project integrated whitefly parasitoid releases with selective chemicals and best farm management practices. This provides growers with a sustainable and commercially viable IPM program for silverleaf whitefly and insecticide resistance management.

To date, three major Bowen-Burdekin growers have successfully adopted the whitefly IPM program developed by the project. These growers have 900 hectares of pumpkin, melons and eggplant under production, with a farmgate value of $24 million. On these farms, the project team released more than 400,000 parasitic wasps at an early stage of crop infestation. The wasps use the whiteflies to breed their own young, outcompeting the whitefly and ultimately reducing pest populations by 50 to 80 per cent.

A number of key regional growers have publically acknowledged the success of the project. In an interview with ABC Radio, Rapisarda Enterprise farm manager Mr Merv Mohr said: “We have seen the value of IPM in our farm and the parasitoid wasps worked well. We are negotiating with DPI for continuous availability of wasps for IPM program next season.” Cucurbit grower Donald Sproule said: “With the release of parasitic wasps, the costs of chemicals needed three years ago to try and control the whitefly has now been reduced to the normal spray program required for cucurbits.”

Gumlu melon, pumpkin and capsicum grower Des Chapman said he was very happy with the level of whitefly control he has been achieving since March 2008. “The wasp has done a fantastic job. We cut out the use of some chemicals entirely, and even then we didn’t need to spray as much. Now we’re back to having the crops we did before silverleaf whitefly became established,” Mr Chapman said.

Providing confidence to growers and obtaining their collaboration were key factors for the successful IPM implementation on-farm. "The project team achieved this through intensive on-farm extension work which included regular farm visits for sampling the crops, advising on pesticide selections, and establishing parasitoids early in the crops", project leader Dr Siva Subramaniam said.

A snapshot of other project achievements are:

- Establishment of parasitoid mass-rearing unit at Bowen research station which has supplied over 1.3 million wasps for over 30 farms. Consistent supply of parasitoids played a pivotal role for the implementation of IPM program in the Bowen – Burdekin region.

- Establishment of a resistance monitoring program over the 4 years, supported the industry with appropriate resistance management strategies, and detection of a new whitefly strain.

- The project has provided excellent support for chemical companies and regulators for approval of ‘softer’ chemicals such as Admiral®, Chess®, Synergy® and Movento® which were critically important for the biologically-based IPM program.

- In the Locker Valley, the project conducted a two year monitoring program to understand the whitefly and its parasitoids’ seasonal activity.

- Conducted over 50 technology transfer activities such as on-farm demonstrations, industry seminars, newsletters, website, farm-notes and media release to deliver project outcomes and facilitate adoption.

- The project impact was evaluated through a telephone survey of 50 growers and 30 agribusinesses across Queensland. Independent consultant Jeff Coutts who conducted the survey said, "We found that there was a perceived decrease in silverleaf whitefly damage in susceptible crops and an increased awareness and use of IPM strategies by growers and their consultants. DPI&F has played a key role in facilitating these changes”.

Continuous availability of parasitoids is critically important for growers to release at early pest infestation. As the project came to the end, a major concern for the growers is where to get the parasitoids?

Technical summary

Problem

Silverleaf whitefly (SLW), *Bemisia tabaci* biotype B is a major horticultural pest that costs producers millions of dollars in lost production and control measures. The pest has developed resistance to many insecticides, therefore an integrated strategy is essential for sustainable whitefly management.

Research undertaken

The project focussed on developing integrated management strategies for SLW and addressed key industry issues including effective biological control systems and insecticide resistance management. Emphasis was given to integrating the biological control agent with compatible pesticides and implementing a suitable integrated pest management (IPM) program at farm level. The project targeted the major Queensland vegetable production regions of Bowen, Burdekin, Bundaberg and Lockyer Valley.

Research outcomes

- A mass-rearing unit for the parasitoid *Eretmocerus hayati* was established at Bowen Research Station to provide parasitoid for release on vegetable farms and implementation of IPM on vegetable farms.

- Parasitoid releases were conducted over four seasons, from October 2006 until December 2009. During this period, the wasps were released on over 30 farms growing pumpkin, zucchini, tomato, beans, cucumber, eggplant, sweetpotato and melon crops.

- An estimated total of **1.3 million** parasitoids were released in Bowen, Gumlu, Burdekin, and Rockhampton regions.

- Parasitoid releases increase parasitism rates and improved control of SLW on most farms. Post-release evaluations showed between 50 and 80% whitefly control in pumpkin, melons and beans but less in tomatoes.

- A whitefly IPM program was implemented in three vegetable farms, covering over 900 ha of melons, pumpkins and eggplants. The farms were visited regularly and advice was provided to the growers on monitoring, spray threshold levels, parasitoid releases and selecting insecticides.

- Insecticide resistance levels were monitored in SLW populations for over four years in Bowen, Burdekin, Bundaberg and Lockyer Valley. Resistance to imidacloprid, pyrethroids and insect growth regulators (buprofezin and pyriproxyfen) increased in some locations of South-east and North Queensland.

- A new whitefly strain, the Q-biotype was indentified in the Bowen and Burdekin area in 2008. Bioassays showed high level resistance to the insect growth regulators pyriproxyfen and buprofezin and increased resistance to neonicotinoid insecticides.

- A new technique to overcome pyrethroid resistance in SLW was field tested in collaboration with Nufarm Ltd. This study demonstrated a high level of synergism when Talstar® was combined with synergists for controlling SLW. Data from this study were used to obtain an emergency APVMA Permit (permit no. 10105, exp date 30 Mar 2010). A report was submitted to Nufarm for registration purpose.

- The seasonal occurrence of SLW in the Lockyer Valley was monitored on crops and weeds on commercial farms from late 2006 to mid 2007. SLW was found from December to August, peaking in February to May on crops and from May to August on weeds. Monitoring of continuous plantings of unsprayed broccoli from January 2007 to May 2008 showed peaks of SLW occurrence from January 2007 to May 2007 and from December 2007 to April 2008, with parasitoid activity lagging by 6-8 weeks.

- Four varieties of Brassica crops were assessed for SLW oviposition preference and suitability for nymphal development. Oviposition preference (greatest to least) was for cauliflower, broccoli equal to cabbage, and Chinese cabbage. Nymphal survival was lower on Chinese cabbage than on the other varieties.

- Preliminary studies were undertaken in a protected cropping facility at Bundaberg. Parasitoids were released and assessed on cucumbers. The parasitoid release almost doubled the parasitism rate to 42%. These results were promising, suggesting that parasitoid releases would be useful in managing SLW infestations in the plant house.

- Over 50 technology transfer activities such as on-farm demonstrations, industry seminars, newsletters, a website, farm-notes and media releases were conducted to deliver project outcomes and facilitate adoption (Chapter 9).

- Independent consultants conducted a telephone survey with 30 agribusiness and 50 growers across growing regions in Queensland to evaluate the effectiveness of the project against project aims and to make recommendations for future work. The survey found that there was a perceived decrease in SLW damage in susceptible crops and an increased awareness and use of IPM strategies by growers and their consultants. Approximately 60% of growers indicated that they had made a recent change in relation to the management of SLW.

Industry benefits

- A rearing method for parasitoid has been developed that would be suitable for a semi-commercial production system.
- The farmers who adopted IPM strategies have achieved better whitefly control with minimal insecticide inputs where the parasitoids have contributed between 50 and 80% whitefly control.
- Establishment of parasitoids on several vegetable farms in the Bowen and Burdekin districts provided significant reduction in SLW numbers.
- Registration of Synergy® to manage pyrethroid resistance in vegetable crops.
- Database on the resistance status of both B and Q-biotypes, and guidelines and strategies to manage whitefly resistance were developed.

Recommendations for vegetable industry

It is recommended that an IPM system should be based on monitoring for both silverleaf whitefly and parasitism levels. The release of parasitoids during early crop growth stages, the judicial use of soft insecticides within a resistance management strategy, and a crop clean-up strategy should be used to manage SLW in vegetable crops.

Introduction

The silverleaf whitefly (SLW), *Bemisia tabaci* biotype B, also known as *Bemisia argentifoli*, is a widespread and difficult pest to control in Queensland. This polyphagous pest causes severe damage to vegetable crops through direct feeding, through honeydew contamination of product and by injecting a toxin into plants which causes physiological damage. The pest is also a vector of Gemini viruses, including tomato yellow leaf curl virus (TYLCV).

SLW is one of the major threats to the $900 million vegetable industry in Queensland as the pest not only reduces yields but also product quality, rendering fruit unsaleable. SLW has become a major problem in tomato, eggplant, melons, zucchini, pumpkin, squash, cucumber, and sweet potato, and recently in brassica crops and beans.

Over the past 10 years SLW control has relied largely on insecticides. Despite the continued spraying, crop losses due to SLW infestation remained. The repeated application of insecticides has increased whitefly resistance to them in many locations.

SLW is difficult to manage with insecticides solely because it has a high reproductive rate, a wide range of host plants and feeds on the undersides of leaves thereby avoiding spray deposits. The pest's adaptation to new crops, its migratory nature and ability to quickly develop resistance to insecticides are the major challenges for controlling the pest.

This project aims to build on the knowledge and expertise generated in the previous HAL project 'Improved management strategies for silverleaf whitefly in vegetable crops' (VG02016) through the development, validation and delivery of effective IPM strategies for cucurbits, brassicas, beans, eggplant and sweet potato. Research priorities for managing SLW whitefly effectively were agreed with industry. To address these industry needs this project has focussed on:

- IPM strategies for all crops in all production regions.
- Development of insecticide resistance management strategies (IRMS) for the vegetable production regions – Bowen, Burdekin and Locker Valley.
- Strategies to prevent mass migration of SLW between crops.
- Release and evaluation of the exotic parasitoid (*Eretmocerus hayati*) in the key vegetable production areas of Queensland.
- The initial steps in implementing and promoting the adoption of whitefly IPM at the farm level. These focussed on integrating biological control (augmentation of parasitoids) with selective chemicals and best farm practices.
- Effective technology transfer activities to facilitate the adoption processes.

This report has nine chapters which outline the research undertaken, the outcomes and the benefits to industry through their adoption, in addition to providing recommendations to industry and future research focus.

Chapter 1

Mass-rearing system for silverleaf whitefly parasitoid

1.1 Introduction

Silverleaf whitefly (SLW) *Bemisia tabaci* biotype B has become a major pest in the vegetable production regions of Queensland. Since 1996, field control has mainly depended on insecticide applications that have led to high levels of resistance to various insecticides (see Chapter 4). This has resulted in control failures and crop losses on several vegetable farms in Queensland, prompting the development of integrated pest management strategies in which biological control could potentially play a significant role.

The development of an efficient mass-rearing system is essential for the successful implementation of a biological control program. Efficient production systems for *Eretmocerus* depend on providing high-quality host plants that are free from pests, good environmental control, and careful control and monitoring of the whitefly host population (Simmons *et al* 2008).

The parasitoid rearing program was targeted at the production of good quality parasitoids in sufficient quantities for field releases and the implementation of whitefly IPM programs on several farms.

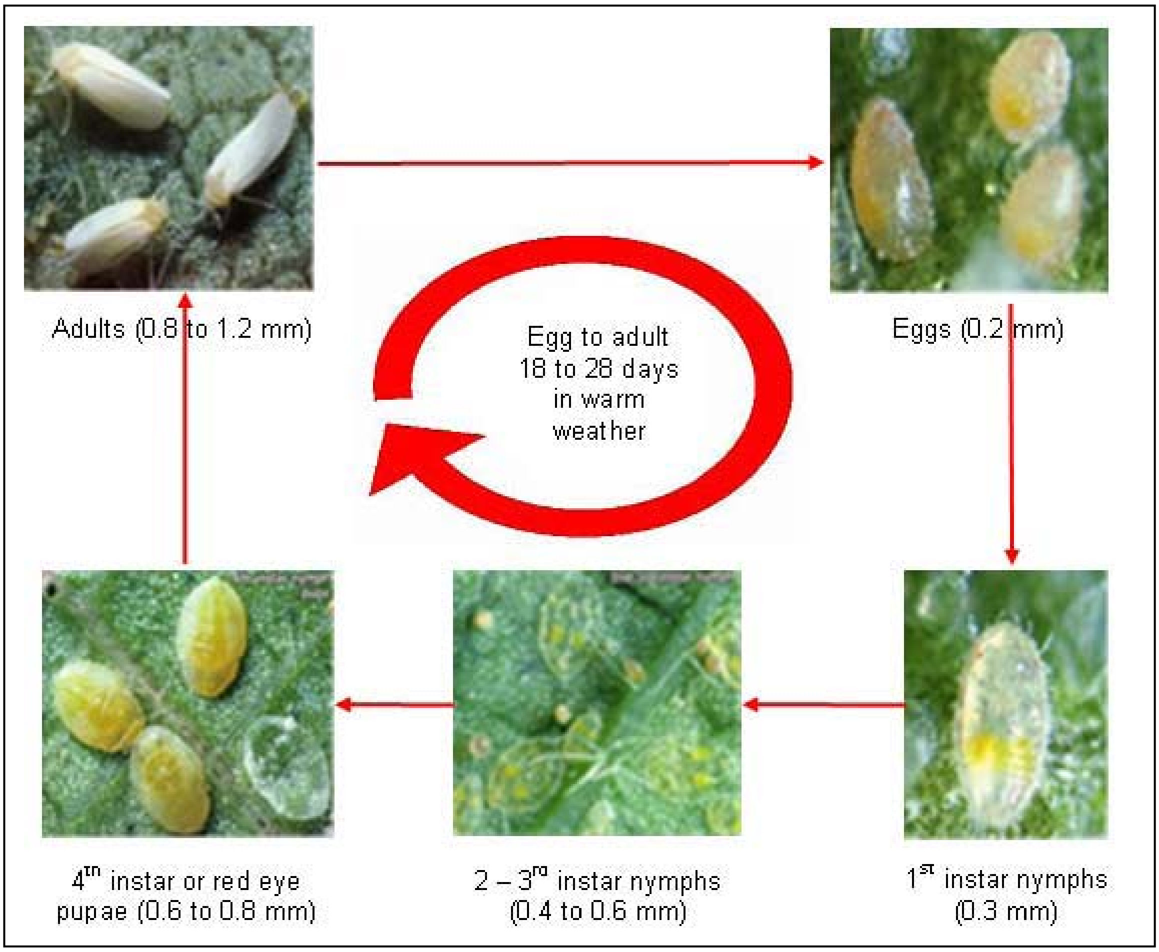
A thorough understanding of the biology of the parasitoid and its hosts are critically important for a successful breeding program. The Silverleaf whitefly and *Eretmocerus hayati* life cycles are briefly described below.

1.2 Silverleaf whitefly lifecycle

The life cycle of SLW consists of an egg stage, four nymphal stages, and an adult stage. The egg has a pointed end that is attached to the underside of the leaf surface, usually on the youngest leaves where the adults congregate. Each female lays between 50 and 300 eggs with egg production peaking in warmer weather. New eggs are whitish yellow. They turn brown and hatch within seven to 10 days.

Crawlers or first instar nymphs are greenish-yellow and flattened. They crawl a short distance until they tap into a sap source in the plant tissue. Second and third instar nymphs are attached to the leaf surface and suck sap from the plant. They are light yellow and the legs are not visible. Fourth instar nymphs are termed red-eyed nymphs or pupae and their bodies are dark yellow. Late in the fourth instar they stop feeding and develop into adults before emerging from their pupal cases. The empty white cases (exuviae) can be seen on leaf surfaces. It takes 18 to 28 days for the development from egg to adult in summer and 30 to 48 days in winter (Fig 1.1).

Fig 1.1 Silverleaf whitefly lifecycle



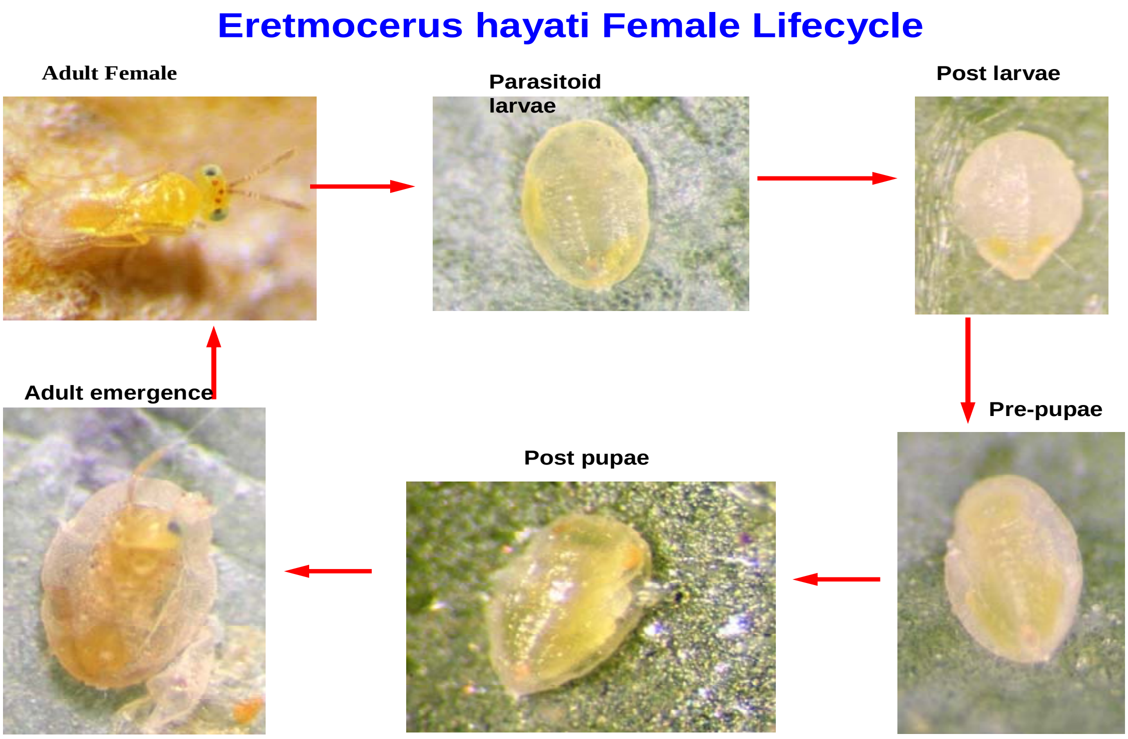
1.3 Parasitoid (*Eretmocerus hayati*) lifecycle

Eretmocerus hayati is a minute wasp, 0.8-1.0 mm long. Males have long antennae with black markings and are dark yellow-brown in colour. Females have bright yellow bodies with clubbed antennae. Males and females occur in almost equal numbers.

The parasitic wasp completes its development within the host SLW. Female wasps lay their eggs under the SLW nymphs. The larvae hatch from the eggs and penetrate into the whitefly nymphs. During early development the parasitised nymphs turns off-white, and their yellow internal bodies (mycetomes) displace to the edges. As they grow, parasitised nymphs become shiny yellow pupae. At a later stage, the yellow coloured wasp is clearly seen through the host's skin (Fig. 1.2). Unparasitised whitefly nymphs show symmetrical mycetomes.

After completing development, the adult wasps chew a round hole to emerge from the whitefly remains. The newly emerged wasps mate, and then the females begin to search for new whitefly nymphs to attack. During the warmer months, the wasps take around 13 to 20 days to complete their lifecycle.

Fig 1.2 Parasitoid *Eretmocerus hayati Life* Cycle



1.4 Establishment of parasitoid rearing unit

Media releases reported on the successful establishment of the SLW parasitoid *E. hayati* in Bundaberg (De Barro *et al* 2005) . This created interest from farmers in such areas as Bowen and the Burdekin who were experiencing whitefly problems in their crops, prompting requests for parasitoid releases on their farms.

Staff involved in the current project initiated efforts to establish a parasitoid rearing unit at Bowen Research Station (BRS) using existing resources. Although parasitoid rearing was not part of the original project proposal, it was included in the project activities at later stage to facilitate field releases as part of implementing a biologically-based IPM program.

The parasitoid rearing unit was established in April 2006 following modification and improvement to resources such as the plant house, polyhouse and insectaries, cages and irrigation system.

The rearing unit has five separate sub-units into-linked to each other to provide a continuous supply of host plants, whiteflies and parasitoids (Fig 1.4). These sub-units were:

1. Plant nursery for host plant production
2. Insectary for whitefly (*Bemisia tabaci* biotype B) stock colony
3. Insectary for parasitoid (*Eretmocerus hayati*) stock colony
4. Plant house for parasitoid mass production
5. Laboratory incubator set-up for quality control process.

This unit become fully functional from August 2006 and first parasitoids were harvested in October 2006 for field releases.

1.5 Host Plant Nursery

The SLW host plants hibiscus, eggplant and broccoli were grown in a shade house under natural light. This house was equipped with an automatic sprinkler and drip irrigation system and enclosed with nylon mesh as to minimise insect and wind damage.

Broccoli and eggplants were grown from seeds which were sown in 90–cell trays filled with seedling mixture. Once the seedlings reached the 4-5 leaf stage, they were transplanted to 15-cm pots filled with potting mixture. The seedling and potting mixtures were prepared at BRS and sterilised with steam to eliminate soil born diseases.

Hibiscus plants were propagated from stem cuttings taken from evergreen woody shrubs. The cuttings were dipped in rooting hormone, placed in 20-cm pots, and maintained under micro-sprinklers.

Plants were monitored 2 to 3 times a week for pests, diseases and disorders. Plants were fertilised with NPK, $MgSO_4$, $CaNO_3$ and micro-nutritients on a needs basis. Pesticides were not used at the seedling stage. If the plants had mites or aphids infestations the entire batch was sprayed with dimethoate or etoxazole before they were transferred into the whitefly and parasitoid colonies.

1.6 Silverleaf whitefly colony

Adult whiteflies were maintained continuously on broccoli in a polyhouse. Broccoli was selected as a host plant because it can tolerate high nymphal densities, tends to last for 2-3 months and is relatively free from pests and diseases. The polyhouse temperature was maintained at 25 to 30ºC, with a reverse cycle air-conditioner and external thermostat system.

A small culture of *Bemisia tabaci* biotype B was started in August 2005 from field collected material and maintained on hibiscus at BRS. This was used as the nursery colony to expand the whitefly rearing. Whitefly adults from the culture were collected and transferred to the broccoli rearing cages.

Each whitefly rearing cage (85 x 60 x 56 cm) contained between 4 and 6 broccoli plants. Cages consisted of an aluminium frame fitted with translucent mesh, designed to prevent the escape of the whitefly adults and the entry of other insects.

Each cage was inoculated with 200-300 adults (week 1). The colonies were then checked twice a week to ensure that there had been no whitefly parasitism. If parasitised nymphs were found they were removed with a dissection needle. Whitefly development was monitored and recorded as egg, small nymphs and large nymphs, red-eye pupae and exuviae.

When the cages reached 10-12 weeks old they were closed down and removed from the polyhouse. Two or three new whitefly cages were started at monthly intervals to ensure the continuous supply of whitefly adults for parasitoid breeding.

The polyhouse had around 4 to 6 cages under continuous production that yielded between 3,000 and 5,000 adults per week. The adults were collected using a battery-operated suction machine to supply parasitoid production unit.

1.7 Parasitoids (*Eretmocerus hayati*) colony

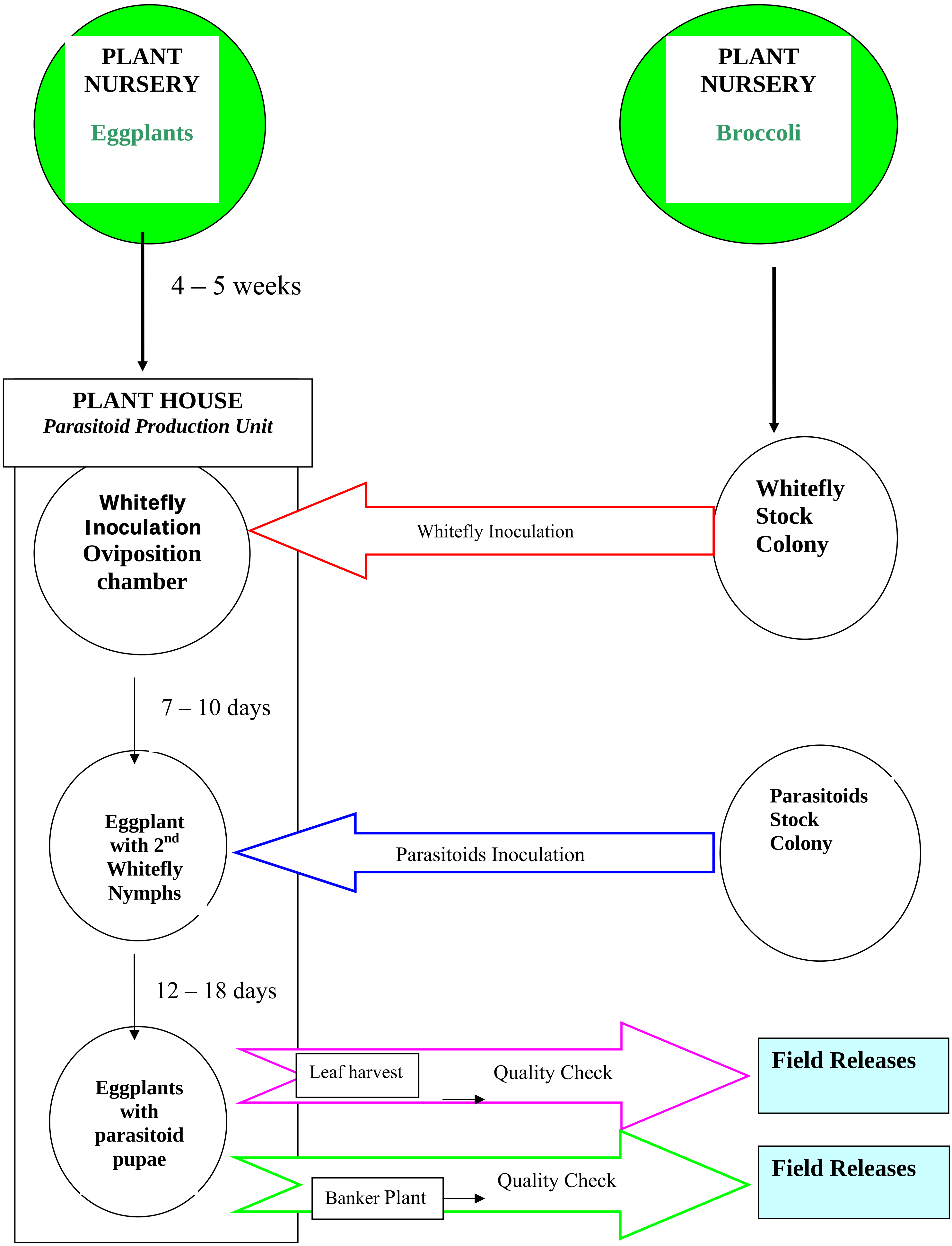
Hibiscus was the main host plant used for maintaining parasitoid stock cultures in a controlled temperature (CT) room under artificial light. The CT room was maintained at 26±2°C, 60±5% RH and a 14L:10D light cycle. Several hibiscus varieties were tested but the George Davis and Hot Pepper withstood the heaviest whitefly infestation. Hibiscus plants were exposed to SLW for 2-3 days by placing them individually in an oviposition cage (28 x 38 x 52 cm) containing more than 200 whiteflies (Fig 1.3). After 3 days these plants were inspected for egg density and transferred to 'rearing cages' (85 x 60 x 56 cm). When most whitefly nymphs had reached the 2nd instar stage, *E. hayati* adults were introduced into the rearing cages.

Parasitoid development was monitored by examining the nymphs with a 16x hand lens and comparing with a pictorial guide (Subramaniam *et al* 2008). The leaves with 60% or more parasitoid pupae were harvested into rearing containers and placed in incubators at 28 °C for adult emergence. The freshly emerged adults were used for inoculating the mass-rearing units.

Between 10 and 15 rearing cages with insects at different stages of maturity were maintained in the CT room to ensure a continuous and adequate supply of parasitoid adults or pupae for the mass production unit.

Fig 1.3 Oviposition cages for inoculating whitefly on hibiscus

Fig 1.4 Parasitoid Breeding Setup



1.8 Parasitoid production unit

A plant house was converted to a mass-rearing unit and operated under ambient temperature and natural light. The house's average temperatures fluctuated between 14 and 27 ºC during winter and 19 to 32 ºC during autumn and spring. The production was scale down during summer because the commercial crop season ended in November and the parasitoid releases were not required.

Five rectangular chambers (2.0 x 1.5 x 0.9 m) and 25 cylindrical cages (1.0 m x 0.85 m) consisted of aluminium frames fitted with insect mesh. The rectangular cages can accommodate up to 30 eggplants and the round cages had between 8 to 10 plants. All the cages were connected to an automatic drip irrigation system to water the plants twice a day.

Eggplants (variety Black Pearl) were used in the parasitoid production unit because of their fast growing, large leaves and tolerance of root diseases, apart from being good hosts for whiteflies. A fertiliser program with soluble fertilizers of NPK (21:12:15), $MgSO_4$ and urea were rotated at weekly intervals.

The potted eggplants with 4-6 fully-expanded leaves were selected from the nursery and arranged in the oviposition chamber inside the plant house (Fig 1.5). Freshly emerged adults from whitefly stock colony were released into oviposition chamber and allowed to oviposit for 3 to 4 days. Each cage with 25 to 30 plants received between 1200 and 1500 whitefly adults (approx 10 to 15 adults per leaf).

Fig 1.5 Whitefly Oviposition Chamber

After three days the plants were removed from the oviposition chamber and the egg densities checked. Any adult whiteflies found on the leaves were removed. Plants with high egg densities (approx 15 eggs per cm^2) were transferred to rearing cages and allowed to develop until the second nymph stage. When the majority of leaves contained 2^{nd} instar nymphs the cages were inoculated with freshly emerged *E. hayati* adults. The parasitoid release rate was based on the density of whitefly nymphs recorded on the eggplant leaves. Around 60 to 90 parasitoid adults per plant were released.

About 12-15 days after a whitefly nymph is parasitised it turns into shiny-yellow pupa. This indicates that the parasitoid has developed within the shell of the whitefly pupa. Adult parasitoid emergence took around 4 to 7 days from the pupal stage.

A week after the adult parasitoids were released with their hosts the development of the parasitoid progeny was monitored by examining the SLW nymphs with a 16x hand lens and comparing against a pictorial guide (Subramaniam *et al* 2008). Once the majority (over 70%) of nymphs were parasitised and the pupal stage had been reached, the leaves were detached and taken to the laboratory for incubation. The plants with over 80% parasitism were used as 'banker plants' for field release. Under optimum conditions each eggplant yielded between 2,500 and 6,000 parasitoid pupae.

Aphids and mites were the major pests of the colony host plants, and these were managed with the aphid parasitoid *Aphidius colemani* and the miticide Paramite®.

1.9 Quality control

Each batch of parasitoids undergoes a quality check before it released in the field. Harvested leaves with parasitoid pupae were placed in plastic containers fitted with ventilated lid. The containers were incubated for 1-2 days at 26 to 28 ºC as to allow unparasitised whitefly nymphs to emerge as adults (Fig 1.6). As the SLW lifecycle (Fig 1.1) is shorter than that of the parasitoid the whitefly adults emerge 3-5 days earlier than the parasitoids. SLW adults from the containers were removed and leaves with parasitoid pupae were used for field releases.

Fig 1.6 Parasitoid pupae ready for field releases

1.10 Outcomes

Establishment of the mass-rearing unit at Bowen Research Station has resulted in the supply of over 1.3 million wasps for over 30 farms. Consistent supply of parasitoids played a pivotal role in the implementation of IPM program in the Bowen – Burdekin region.

It was estimated that the rearing unit would need to supply between 60,000 and 80,000 parasitoids for the inoculative releases between October and December 2006. Thereafter, production capacity was expanded to produce around 100,000 parasitoids per month. The production was mainly focused on the period from April to November so as to target the vegetable growing season in Bowen and the Burdekin.

Parasitoid production at BRS commenced in August 2006 and continued until December 2009. Because of limited funding, it was established as a low-cost production system. Bowen's warm winter temperatures has allowed the production of adequate quantities of parasitoids without artificial heating or light.

This work has shown that eggplant (variety Black Pearl) is well suited for mass rearing the parasitoid under the dry tropical environment at Bowen. However, its suitability under different environmental conditions is not known.

One major challenge is obtaining the right balance between the whitefly nymph density and parasitoid numbers at release. If nymph densities increase to a high level (over 25 nymphs/cm^2) then honeydew deposits on the leaves can cause a reduction in parasitism and stress on the host plants. A regular monitoring program is very important so that egg and nymph densities can be estimated at an early stage. This facilitates adjustment of the parasitoid release rate.

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Chapter 2

Parasitoid releases in the Bowen and Burdekin production regions

2.1 Introduction

In the Bowen and Burdekin regions, the major cultivated host crops of silver whitefly (SLW) are tomatoes, melons, green beans, pumpkin, eggplant, squash and cucumbers which cover a total production area of 6500 ha.

SLW was first detected in Australia in 1994 (Gunning *et al* 1995) and had become well established in Queensland by 1996. Over the past 14 years it has become a major pest of vegetable crops. The new generation insecticides such as pyriproxyfen, imidacloprid and pymetrozine have been widely used in vegetable crops to manage the pest. SLW has developed resistance to many insecticides worldwide and a high level of resistance has been detected in field populations in Queensland (see Chapter 4).

Research in the USA indicates that augmentation of *Eretmocerus* parasitoids have led to their establishment and have provided a high level of parasitism of *Bemisia tabaci* in Texas (Goolsby and Ciomperlik 2008). *Eretmocerus hayati*, an effective SLW parasitoid, was imported to Australia in 2002 and released from quarantine in 2004 (De Barro *et al*. 2005). The successful establishment of the exotic parasitoid *Eretmocerus hayati* in vegetable crops has been reported in Bundaberg region (De Barro and Coombs 2009).

This component of the project was focused on establishing the parasitoid (*E. hayat*i) in the production locations in the Bowen- Burdekin district. In an attempt to facilitate the parasitoid releases in Bowen and Burdekin regions, a parasitoid mass-rearing unit was established at Bowen Research Station (BRS).

2.2 Release locations and methods

The vegetable planting season starts in February and sequential planting continues until September, and the harvest extends from May to December. Populations of silverleaf whitefly begin to increase from April and typically reach outbreak levels during the spring and summer months.

The release locations were selected on cropping patterns, whitefly infestation levels and the type of pesticides used in the crops. Tomatoes and melons are not part of the project (non-levy crops); however releases were conducted on both crops because they are highly preferred hosts of silverleaf whitefly and extensively cultivated in the region.

Four methods were adopted for release and establishment of parasitoids in the field;

- Adult releases: Freshly emerged parasitoid adults were released from plastic containers onto whitefly infested crops.

- Pupal releases: Eggplant or hibiscus leaves with parasitised whitefly nymphs were collected from the rearing cages and checked for parasitism levels. The leaves with parasitised pupae were placed under the crop canopy to minimise leaf desiccation and maximise parasitoid emergence (Fig 2.1).

- Banker plant method (Goolsby and Ciomperlik 1999): Eggplants were inoculated with whitefly in cages and held until eggs hatched and nymphs reached the 2nd instar stage. Then *E. hayati* were released into the cages and held until parasitoid reached the pupal stage. These banker plants with over 90% parasitised pupae were used for field releases.

- Field refuge crops: Eggplant, cucumber or lablab bean blocks were used to preserve parasitoid populations either on Bowen Research Station or commercial farms. Parasitoids as larvae or pupae on live potted plants were transplanted into insectary field plots.

In the insectaries, parasitoids were reared on eggplants or hibiscus for field releases. Once the parasitoid development reached the pupal stage, eggplant leaves were checked for parasitism levels. The leaves with over 90% parasitism were detached and placed in separate plastic containers for field releases. The remaining leaves were placed in plastic emergence containers and held in an incubator for 2 -3 days to allow whitefly emergence from unparasitised pupae. Emerged whiteflies were discarded and the leaves with parasitoid pupae were separated into other containers for field releases.

Releases were planned in discussion and collaboration with farmers to minimise pesticide sprays on the release crops. On most occasions parasitoids were released in minimally sprayed crops, and on two farms unsprayed blocks of cucumber and eggplant were maintained as refuges for parasitoid establishment.

Fig 2.1 Field releases of parasitoid in an organic pumpkin crop, Burdekin

2.3 Parasitoid releases in 2006

Parasitoid releases commenced in October 2006, and the initial releases targeted the Bowen production area. Pre-release sampling in tomatoes, eggplants, cucumbers, pumpkins and weeds determined the background level of parasitism. The pre-release leaf samples collected from tomatoes and cucumbers from Bowen recorded very low levels of parasitism, ranging from 0 to 3%.

During the establishment of the parasitoid rearing-unit production was limited to between 6,000 and 10,000 parasitoids per week; therefore more smaller releases were conducted on the farms. For each location between 3,000 and 10,000 parasitoids were released.

The parasitoids were released on 19 farms growing pumpkins, zucchini, tomatoes, cucumber, eggplants and melons crops. An estimated total of 55,000 parasitoids were released in Bowen and Gumlu. In addition, two inoculative releases were conducted in Burdekin. The 2006 release details are summarised in Table 2.1.

Table 2.1 SLW parasitoid releases in Bowen and Burdekin (Oct – Dec 2006)

Region	Locations	Number of farms	Number of releases	Crops	Number of parasitoids released
Bowen	Euri creek	3	8	Cucumber, Tomato, Eggplant	9,500
	Mt.Danga	1	2	Rockmelon	5,000
	Collinsville Rd	2	3	Tomato	10,500
	Delta Region	1	2	Cucumber	3,100
	Bowen Research station	1	3	Potato, Tomato, Eggplant, Pumpkin	5,100
	Lower Don	3	7	Melons,	7,800
	Bootaloo	2	3	Watermelon	5,500
	Guthalungra	1	1	Rockmelon	3,700
Gumlu	East	1	1	Pumpkin, Eggplant	1,000
	West	1	2	Zucchini, Pumpkin	4,200
Burdekin	Giru	2	2	Zucchini, Pumpkin	5,400
	Home Hill	1	1	Pumpkin	1,000
Total		**19**	**35**		**61,800**

2.4 Parasitoid releases in 2007

In 2007 parasitoid production capacity was expanded to facilitate wider releases. Releases were started in June and continued until November 2007. An estimated total of 381,000 parasitoids were released in Bowen, Gumlu, Burdekin and Rockhampton. There were 37 releases conducted on 22 farms growing pumpkin, zucchini, tomato, beans, sweetpotato, cucumber, eggplant and melon crops (Fig 2.2). The 2007 release details are summarised in Table 2.2.

During winter and spring, eggplant blocks were established at Bowen Research Station to provide continuous availability of whitefly for the reproduction of parasitoids. In summer, Dolicos lablab blocks were planted at BRS and on commercial farms to provide continuous availability of whitefly host plants. These crops were monitored for whitefly infestation and inoculated with *E. hayati*.

Fig 2.2 Eggplant leaves with parasitoid pupae placed in a melon crop, Burdekin

Table 2.2 SLW parasitoid releases in Bowen, Burdekin and Rockhampton (Jun – Nov 2007)

Region	Locations	Number of farms	Number of releases	Crops	Number of parasitoids released
Bowen	Euri creek	2	2	Beans, Tomato, Eggplant, Zucchini,	11,000
	Dry creek	1	2	Tomato	10,700
	Mt.Danga	1	2	Beans, Pumpkin	27,000
	Collinsville Rd	4	3	Beans, Melon	72,200
	Bowen Research station	1	8	Pumpkin, Tomato, Zucchini, Eggplant	55,200
	Lower Don	1	1	Eggplant	2,450
	Bootaloo	1	3	Beans, Melon	36,600
	Guthalungra	1	1	Melon	4,000
Gumlu	East & West	3	7	Eggplant, Pumpkin, Melon	92,900
Burdekin	Giru	1	1	Zucchini	11,000
	Ayr	1	1	Eggplant, Pumpkin	7,000
	Clare	1	2	Cucumber, Pumpkin	22,000
Other Places	Rockhampton	4	4	Pumpkin, Sweetpotato, Zucchini	30,000
Total		**22**	**37**		**381,950**

2.5 Parasitoid releases in 2008

In early 2008, severe silverleaf whitefly infestations occurred on several farms in the Burdekin. Pumpkin, melons, zucchini and eggplants all had very high SLW infestations and the nymph densities increased over 10 fold the threshold limits.

In the Burdekin, over 250,000 parasitoids were released on the affected farms. There were 25 releases conducted on 12 farms producing pumpkins, eggplant and melon crops. These inundative releases had a significant impact on the whitefly populations and stabilised them within two months (details in Chapter 3).

In 2008, releases commenced in April and continued until December. The releases in Bowen reduced because of more required for the Burdekin. However, around 184,000 parasitoids were released on 22 farms in Bowen. The 2008 release details are summarised in Table 2.3.

Fig 2.3. 'Refuge' eggplants on a melon farm for the establishment and dispersal of parasitoids, Burdekin

Table 2.3 SLW parasitoid releases in Bowen and Burdekin (April – Dec 2008)

Region	Locations	Number of farms	Number of releases	Crops	Number of parasitoids released
Bowen	Euri creek	4	10	Tomato	57,300
	Dry creek	2	4	Tomato	7,300
	Mt.Danga	2	5	Eggplant, Melon, Pumpkin	17,300
	Collinsville Rd	3	5	Pumpkin, Tomato	7,700
	Delta Region	3	9	Tomato	20,100
	Bowen Research station	1	10	Sweet potato, Pumpkin, Tomato	25,500
	Lower Don	4	13	Eggplant, Pumpkin, Tomato	23,600
	Bootaloo	3	11	Melon, Pumpkin, Tomato	25,500
Gumlu	East & West	2	10	Melon Pumpkin	44,300
Burdekin	Ayr	2	3	Melon, Pumpkin	61,000
	Clare	6	8	Melon, Pumpkin	70,500
	Home Hill	2	4	Eggplant, Pumpkin	92,500
Other locations	Townsville	1	3	Cucumber, Tomato	8,300
	Mareeba	1	1	Pumpkin	2,000
	Bundaberg	1	1	Cucumber	12,000
	Gatton	1	1	Tomato	6,200
Total		**38**	**98**		**481,100**

2.6 Parasitoid releases in 2009

In 2009 three farms were selected in Bowen, Gumlu and the Burdekin for implementing an IPM program. Parasitoids were released at 2 or 3 week intervals, starting in March continuing through to December. Over 400,000 parasitoids were released on the three IPM farms (details in Chapter 6).

In addition, another 240,000 parasitoids were released on 15 farms in Bowen and in the Burdekin. These releases targeted farms with high whitefly infestations with suspected levels of insecticide resistance. The 2009 release details are summarised in Table 2.4.

Table 2.4 SLW parasitoid releases in Bowen and Burdekin (Mar – Dec 2009)

Region	Locations	Number of farms	Number of releases	Crops	Number of parasitoids released
Bowen	Euri creek	3	3	Tomato, Zucchini	3,500
	Dry creek	1	1	Tomato	500
	Mt.Danga	1	2	Melon	8,500
	Collinsville Rd	1	9	Beans, Melon, Pumpkin	44,300
	Delta Region	2	3	Tomato	7,000
	Bowen Research station	1	7	Tomato	39,500
	Lower Don	2	2	Eggplant	2,300
	Bootaloo	1	5	Melon	80,000
Gumlu	East & West	2	5	Eggplant, Pumpkin	93,000
Burdekin	Woodstock	1	1	Zucchini	27,000
	Ayr	1	1	Beans	2,000
	Clare (IPM farm)	4	20	Melon,Pumpkin	323,780
	Dalbeg	1	1	Zucchini	4,000
Other places	Townsville	1	1	Tomato	5,000
Total		**22**	**61**		**640,380**

The use of parasitoids to control whiteflies has become increasingly prevalent, perhaps in response to increasing resistance to insecticides. The purpose of augmentative biological control is to strategically release mass-reared agents to establish background parasitoid populations in vegetable production regions. In addition, inundative releases target heavy whitefly infestations so that the pest densities are suppressed below levels that cause economic damage. In 2008, for example, conducted several large-scale releases of parasitoids on Burdekin farms to contain whitefly populations.

2.7 Summary

Mass-rearing facilities for the SLW parasitoid (*Eretmocerus hayati*) were established at Bowen Research Station in August 2006 to support parasitoid releases and to implement IPM on vegetable farms. Parasitoid releases were conducted over four seasons, starting in October 2006 and continuing until December 2009. During this period, the parasitoid wasps were released on over 30 farms growing pumpkins, zucchinis, tomatoes, cucumbers, eggplants, sweetpotato and melons crops. An estimated total of 1.3 millions wasps were released in Bowen, Gumlu, Guthalungra, Homehill, Clare, Ayr, Rockhampton and Giru regions.

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Chapter 3

Post-release evaluation of silverleaf whitefly parasitoid

3.1 Introduction

In the Bowen and Burdekin regions, the major cultivated host crops of silverleaf whitefly (SLW) are tomatoes, melons, green beans, pumpkins, eggplants, zucchini and cucumbers which cover a total production area of approximately 6500 ha.

The vegetable planting season starts in February with sequential planting continuing until September, and the harvest extends from May to November. Populations of silverleaf whitefly begin to increase from April and typically reach outbreak levels during the spring months of September-November.

The previous HAL funded projects (VX99003 Integrated pest management of silverleaf whitefly and the geminiviruses it transmits and HG96016 Pre-emptive research into the biology and biological control of silver leaf whitefly, *Bemisia tabaci* biotype B) identified several endemic whitefly parasitoids in Queensland that contributed to only low levels of parasitism in SLW populations. The exotic parasitoid *Eretmocerus hayati*, originally from Pakistan and imported by CSIRO for SLW biological control in Australia, was reported to be an efficient parasitoid for SLW control in vegetable production system in Queensland (De Barro *et al* 2005).

During the period October 2006 to December 2009, a total of 1.3 million *E. hayati* wasps were released on farms in the Bowen and Burdekin districts. The releases were mainly on vegetable farms growing various vegetable crops (see Chapter 2).

This component of the project focused on evaluating the establishment and performance of the parasitoid released on vegetable farms in the regions.

3.2 Sampling and assessment methods

Commercial vegetable crops were sampled to measure parasitoid establishment and parasitism levels. Sampling was conducted on the cultivated crops from October 2006 to November 2009. As the production season ends in November, few whitefly host plants were available for sampling during the months of December and January. Therefore no evaluations were conducted on crops during the production-break.

The monsoon season that starts in January and continues to March stimulates weed growth throughout the district. Additional samples were collected from non-cultivated host plants such as broad-leaf weeds and volunteer crops during February and March. This allowed an estimate of the proportion of the parasitoid population that survived though the production-break and wet season into the next cropping season.

The sampling locations and host crops from 2006 to 2009 are summarised in Table 3.1 and Table 3.4.

In 2006, the host plants were sampled for whitefly and parasitism levels just before parasitoid release and 7-8 weeks after release. In 2007, 2008 and 2009 the post-release sampling was conducted at monthly intervals. Between 20 to 75 mature leaves from the base of the main stem of randomly selected plants were collected from each field or crop. On each leaf four $4cm^2$ areas (16 cm2) were selected and immature SLW stages were counted under the microscope (Fig 3.1), except in 2006 samples when 8 or 12 cm2 areas were examined. Immature stages of whitefly were categorised as small nymphs (1^{st} and 2^{nd} instar), large nymphs (3^{rd} and 4^{th} instar) and exuviae. Similarly, the parasitoid stages were recorded as larvae, pupae and exuviae (see Fig 1.2).

Parasitised nymphs can be distinguished at larval or pupal stages. A whitefly nymph parasitised by *Eretmocerus* turns turbid white, and its yellow internal bodies (mycetomes) displace to the edges. As they grow, parasitised nymphs become shiny yellow pupae. At a later stage, the yellow coloured wasp is clearly seen through the host's skin. Emerged wasps leave a distinctive round exit hole in the pupal case. Unparasitised nymphs show symmetrical mycetomes. Whitefly nymphs parasitised by *Encarsia* turn a dark brown or blackish colour (Subramaniam *et al* 2008).

For the 2006 samples, parasitoid adults were identified at genus level and categorised as *Eretmocerus* sp. or *Encarsia* sp. Later, with support from taxonomist Dr Greg Zolnerowich (USA), the *Eretmocerus* were identified to species level (Zolnerowich and Rose 1998). Post-pupae were placed in gelatine capsules until adults emerged. *Eretmocerus hayati* females have bright yellow bodies with clubbed antennae and males have long antennae with black markings and are a dark yellow brown. Males and females occur in almost equal numbers.

Fig. 3.1 Parasitoid assessment method – four $4cm^2$ leaf area with SLW and parasitoid stages

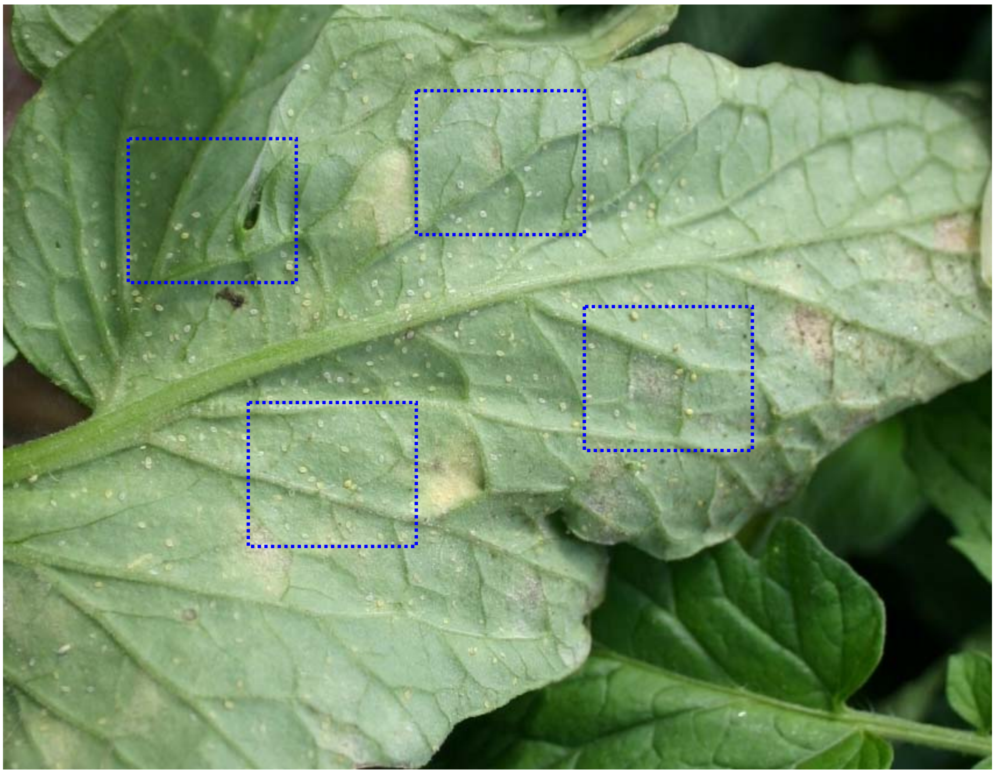


Table 3.1 Sampling details for Bowen and Burdekin 2006 and 2007

Year	Locations	No. farms	Crops	Total No. of Samples #
2006	Euri Creek	2	cucumber, tomato, eggplant	8
	Mt. Dangar	2	tomato, melon	4
	Delta	3	tomato, pumpkin, cucumber, melon	9
	Bootaloo	1	melon	1
	Gumlu	3	eggplant, melon, pumpkin	5
	Burdekin	2	zucchini	2
	Total	**13**		**29**
2007	Euri Creek	3	tomato, eggplant, melon	7
	Dry Creek	1	tomato	2
	Mt. Dangar	2	tomato, beans, melon	7
	Collinsville Rd	4	melon, beans, tomato	6
	Delta	4	tomato, cucumber, melon, eggplant	7
	Bootaloo	3	melon, beans, pumpkin	6
	Gumlu	5	eggplant, pumpkin, melon	12
	Burdekin	3	zucchini, pumpkin, eggplant	8
	Total	**25**		**55**

each sample consisted of between 15 and 75 leaves – higher number of leaves were collected from crops with low whitefly infestation.

3.3 Field evaluation in 2006

The first phase of parasitoid releases started in October 2006 and continued until December 2006. During this period, the parasitoid wasps were released on 19 farms covering a range of vegetable crops. An estimated total of 61,000 parasitoids were released on the crops in the Bowen, Gumlu, Burdekin locations (see Table 2.1 in Chapter 2).

During October to December 2006, pre-release leaf samples were collected prior to the release at the locations (Table 3.1). The samples were assessed for whitefly and background parasitism levels. Around 85% of the pre-release samples had very low parasitism (0 to 7%) and two samples had 11 to 13% parasitism. The pre-release sample results are summarised in Table 3.2.

Post-release evaluations were conducted in two farms in Bowen and one farm in Gumlu.

The first release was on a cucumber block (3 ha) at Euri Creek, Bowen, in October 2006, where around 10,000 *E. hayati* adults were released. Pre-release leaf samples were collected from the cucumber crop. After 8 weeks, the parasitoid establishment was assessed in cucumbers, tomatoes and weeds (nightshade) within a 500m radius from the release block. The parasitism levels reached 32% and 36% in cucumber and nightshade respectively, but were very low in tomato crops (Fig. 3.2). The low parasitism rate in tomato could be due to regular insecticide sprays applied to manage other pests and that adversely affected the wasps.

Fig. 3.2 Pre and post release parasitism levels in a cucumber and tomato farm, Euri Creek, Bowen, 2006

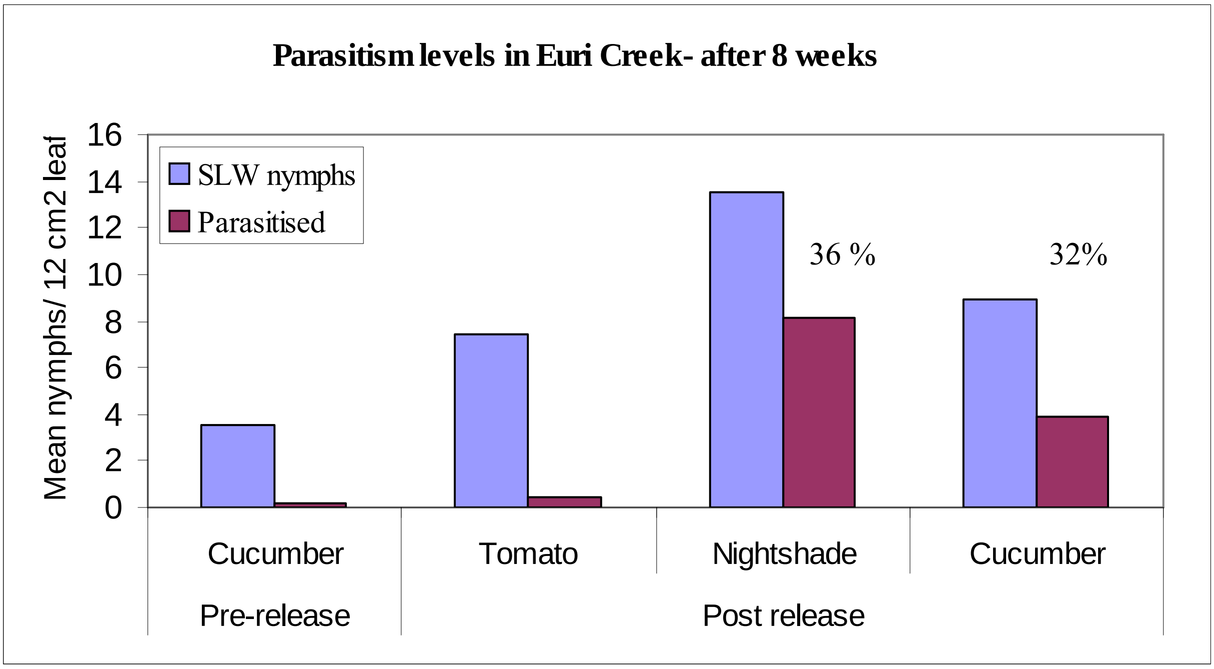
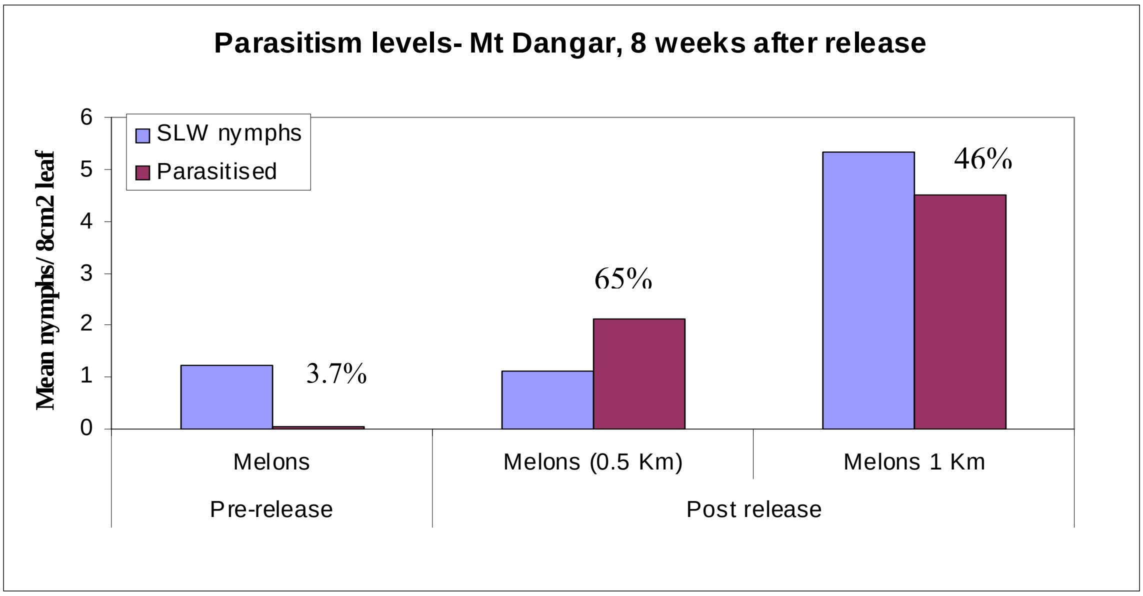


Table 3.2 Pre-release parasitism levels in Bowen, Burdekin and Rockhampton

Sampling date	Locations	Latitude	Longitude	Crops	whitefly nymphs/ sample	Parasitised nymphs	Parasitism %
2006							
12-Oct	Euri Creek	S 20.05194	E 148.05099	weeds	305	5	1.6
12-Oct	Euri Creek	S 20.02659	E 148.09097	Tomato	79	0	0.0
12-Oct	Euri Creek	S 20.05194	E 148.05099	Cucumber	264	14	5.0
20-Oct	Delta (DPI)	S 20.01015	E 148.19379	Pumpkin	1281	15	1.2
20-Oct	Delta (DPI)	S 20.01015	E 148.19379	Cucumber	5052	752	13.0
31-Oct	Mt Dangar	S 20.18077	E 148.14114	Melons	26	1	3.7
31-Oct	Mt Dangar	S 20.09898	E 148.13977	Tomato	144	2	1.4
2-Nov	Gumlu	S 19.88550	E. 147.68237	Thistle	1328	104	7.3
2-Nov	Gumlu	S 19.88548	E. 147.68235	Pumpkin	495	35	6.6
2-Nov	Gumlu	S 19.89289	E 147.69090	Eggplant	189	6	3.1
9-Nov	Home hill	S 19.65919	E 147.43665	Thistle	17	1	5.6
9-Nov	Giru	S 19.54088	E 147.11768	Thistle	1	0	0.0
17-Nov	Guthalungra	S 19.92123	E 147.84686	Melons	400	51	11.3
23-Nov	Bootooloo	S 20.03392	E 148.20329	Thistle	38	2	5.0
7-Dec	Lower Don	S 19.99837	E 148.20740	Watermelon	170	6	3.4
7-Dec	Lower Don	S 19.98045	E 148.20348	Weeds	188	1	0.5
7-Dec	Lower Don	S 19.98198	E 148.19950	Cucumber	129	0	0.0
8-Dec	Collinsville Rd	S 20.11344	E148.13423	Thistle	175	5	2.8
8-Jun-07	Rockhampton	S 23.02722	E 150.46692	Sweetpotato	1012	241	19.2

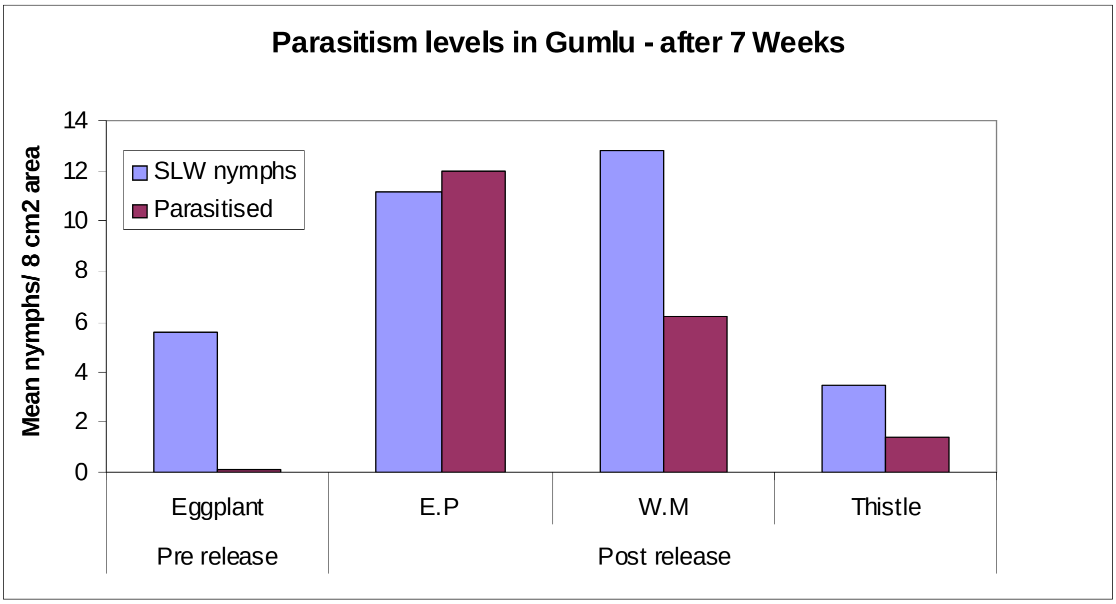
Approximately 5,000 parasitoids were released in melons on the second farm at Mt Dangar, Bowen. Leaf samples were collected before release and eight weeks after release at 500 m and 1000 m away from the release crops but within the farm. The parasitism levels ranged between 46% and 65%. (Fig. 3.3).

Fig. 3.3 Pre and post release parasitism levels in a melon farm Mt Dangar, Bowen 2006



The third farm was at Gumlu where parasitoids were released in an eggplant block (4 ha). After 7 weeks leaf samples were collected from the release block and from adjacent watermelons and weeds (thistle). In October 2006, prior to the release of *E. hayati*, the parasitism level was very low in eggplants (0.2 %) but at 7 weeks after release the parasitism level had increased to 55% (Fig. 3.4). During that period between the pre-release and post-release samples the density of SLW nymphs on eggplant increased to 25 nymphs/ $8cm^2$ leaf due to high adult migration from an adjacent slashed crop. Significant parasitism levels were also recorded on nearby watermelon plants (31%) and on weeds (22%). This farm has adopted 'softer' insecticides such as Gemstar® and Dipel® for heliothis control and sulphur for mite control.

Fig 3.4 Pre and post release parasitism levels in eggplant (E.P.), watermelon (W.M.) and weeds, Gumlu 2006



3.4 Field evaluation in 2007

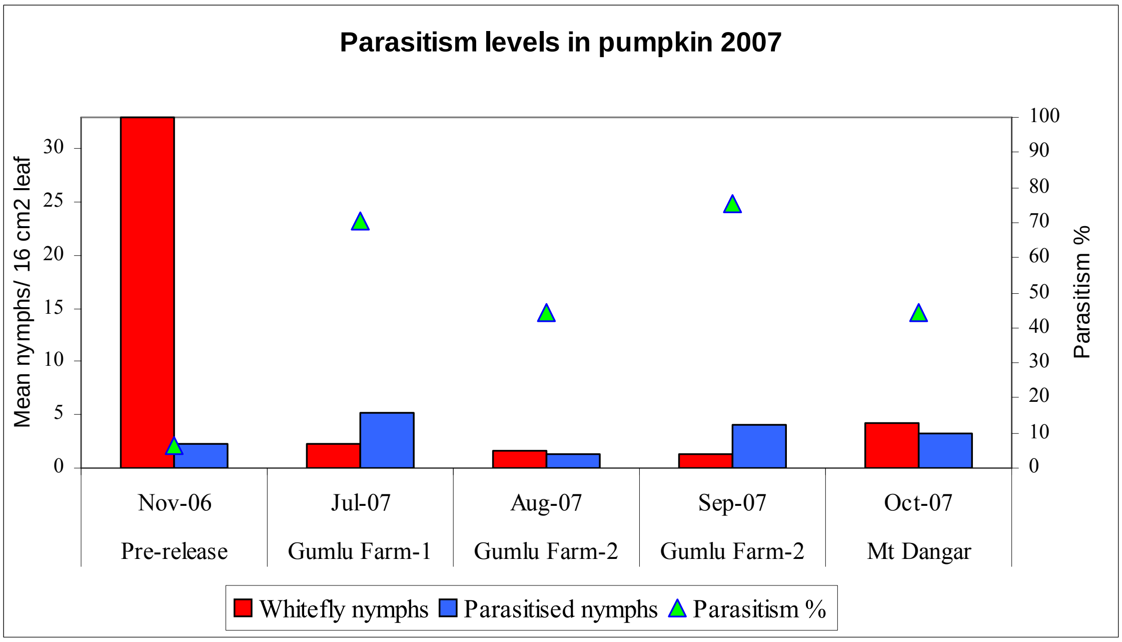
The second phase of parasitoid releases started in June 2007 and continued until November 2007. An estimated total of 381,000 wasps were released on 22 farms in the Bowen, Gumlu, Burdekin, and Rockhampton districts (see Chapter 2, Table 2.2).

Post-release samplings were conducted at eight locations covering 25 farms across the Bowen, Gumlu and Burdekin districts during June to November 2007 (Table 3.1). The results show that the parasitoid was established in all released locations with parasitism levels ranging from 24 to 87% (Table 3.3)

In tomatoes and eggplants, the parasitism levels varied between 29 and 70%. On a tomato farm at Euri Creek, the whitefly densities were decreased to 3.7 nymphs/ 16 cm2 of leaf while parasitism levels increased to 70%, and this farm had previous releases in 2006 and a second set of releases in June 2007. Even though most of the tomato farms had parasitism levels between 40 and 65%, the whitefly nymphal densities were high (over 4.5 nymphs/ 16 cm2 leaf) which was above the damage threshold level and can cause irregular ripening in the fruits (Table 3.3)

In pumpkins and beans, the direct parasitoid releases on the farms increased the parasitism levels to 87% where the whitefly nymphal densities declined to a lower level (Fig. 3. 5). The insecticide usage is generally low in pumpkin and beans that give better chance for wasps to establish.

Fig 3.5 Parasitism levels in pumpkin at Gumlu and Mt Dangar 2007



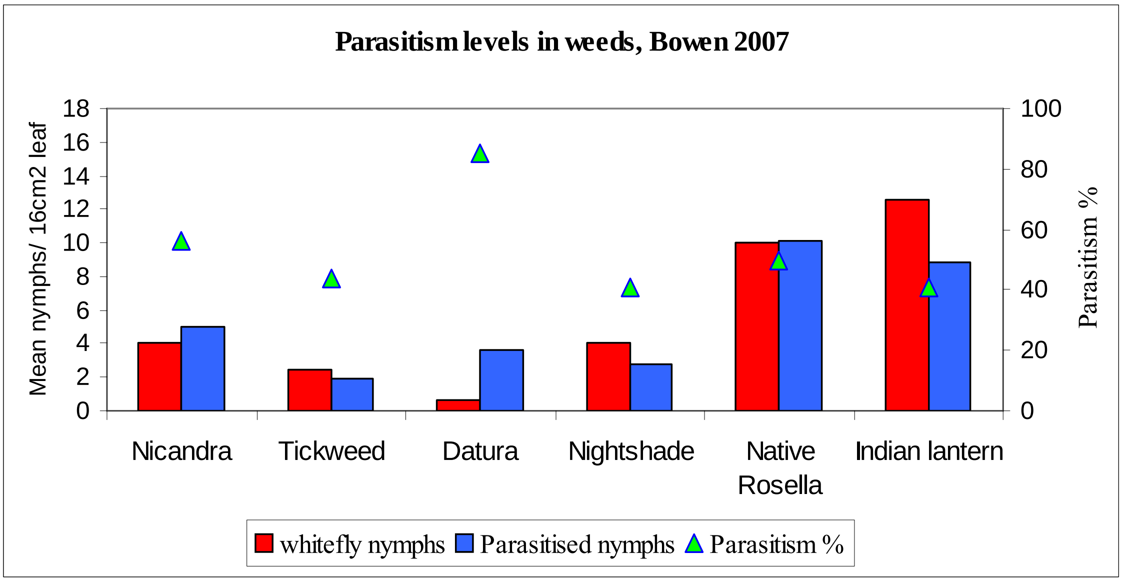
In most melon farms the parasitism levels ranged between 51 and 85%. One farm at Bootaloo had low parasitism (24 to 42%) during September and October because bifenthrin sprays used for mites and migrating whitefly adults affected the parasitoids. The grower was advised and later the crops were sprayed with pymetrozine. Subsequent monitoring results show that parasitism level increased to 61% (Table 3.3).

Table 3.3 Parasitism and whitefly levels in Bowen and Gumlu districts, Jul- Nov 2007

Crops	Locations	Months	Average numbers /16cm2		
			Whitefly nymphs	Parasitised nymphs	Parasitism %
Pumpkin	Pre-release	Nov-06	33	2.3	6.6
	Gumlu Farm-1	Jul-07	2.2	5.2	70.3
	Gumlu Farm-2	Aug-07	1.6	1.3	44.4
	Gumlu Farm-2	Sep-07	1.3	4.1	75.3
	Mt Dangar	Oct-07	4.2	3.3	44.3
Eggplant	Pre-release	Nov-06	10.8	0.34	3.1
	Euri Creek	Aug-07	2.8	1.4	33.6
	Delta	Sep-07	36.8	40	52.1
	Gumlu Farm-3	Aug-07	5.6	3.8	40.8
		Sep-07	9.9	7.1	42
Beans	Pre-release	Nov-06	8.8	0.25	2.8
	Bootaloo	Aug-07	12.6	4.3	25.3
	Collinsville Road	Oct-07	7.6	19.4	71.9
		Nov-07	2.5	16.3	86.9
Tomato	Pre-release	Oct-06	12.2	0	0
	Delta	Jun-07	9.6	9.5	49.8
		Jul-07	2.1	2.4	52.9
		Oct-07	1.5	0.6	29.2
	Sandy Creek	Jul-07	6.4	11.8	65
		Oct-07	5.2	5.4	51.3
		Nov-07	1.3	2.3	64.8
	Euri Creek	Aug-07	1.1	2.6	71.1
		Nov-07	2.7	3.1	53.3
	Collinsville Road	Oct-07	9.9	6.3	38.8
		Nov-07	4.5	8.6	65.7
Melons	Pre-release	Nov-06	8.5	0.3	3.4
	Delta	Jul-07	10.2	10.7	51.3
	Euri Creek	Jul-07	1.7	9.7	85.3
	Mt Dangar	Oct-07	0.8	1.9	70.5
	Bootaloo	Sep-07	13.8	4.5	24.6
		Oct-07	9.8	7.1	42
		Nov-07	5.9	9.4	61.3
	Gumlu Farm-2	Oct-07	6	8.8	57
	Gumlu Farm-3	Oct-07	15.6	32.9	67.9
	Guthalungra	Oct-07	5.5	21.3	79.6

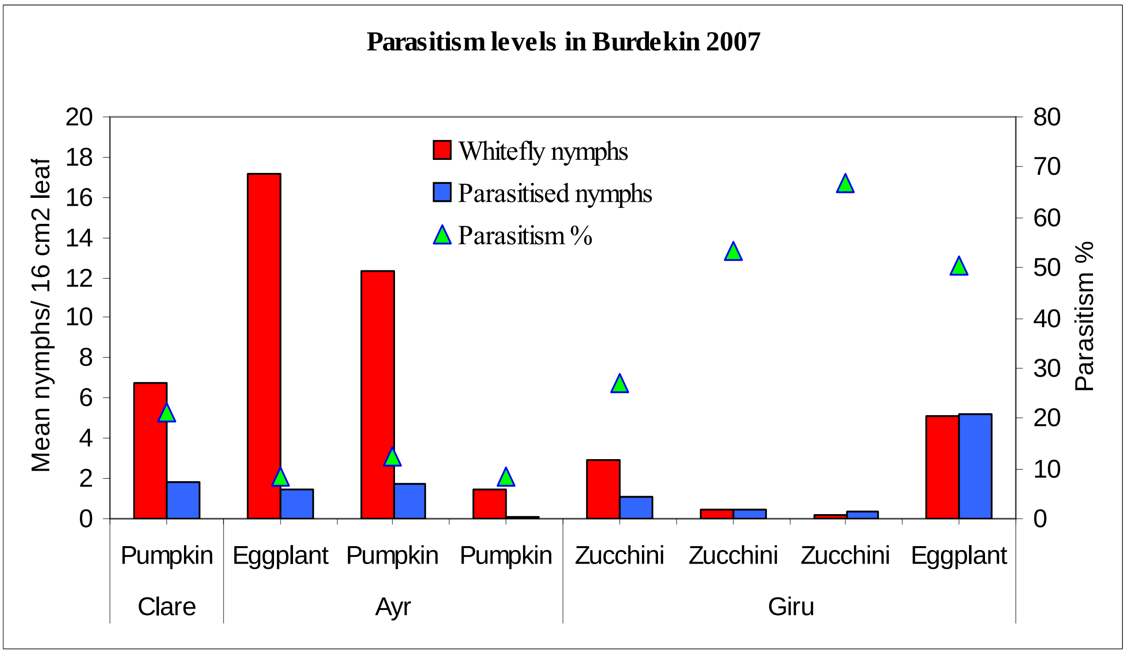
In addition, samples from weeds (known hosts of SLW), taken around the commercial farms, were assessed for parasitism levels. This was aimed at assessing parasitism levels without the impact of pesticide sprays. The parasitism levels ranged between 41% and 85%. Native rosella (*Hibiscus trionum)* had high parasitoid densities with an average 11 parasitised nymphs per 16 cm^2 leaf area (Fig 3.6).

Fig. 3.6 Parasitism and whitefly levels in weeds in Bowen, 2007



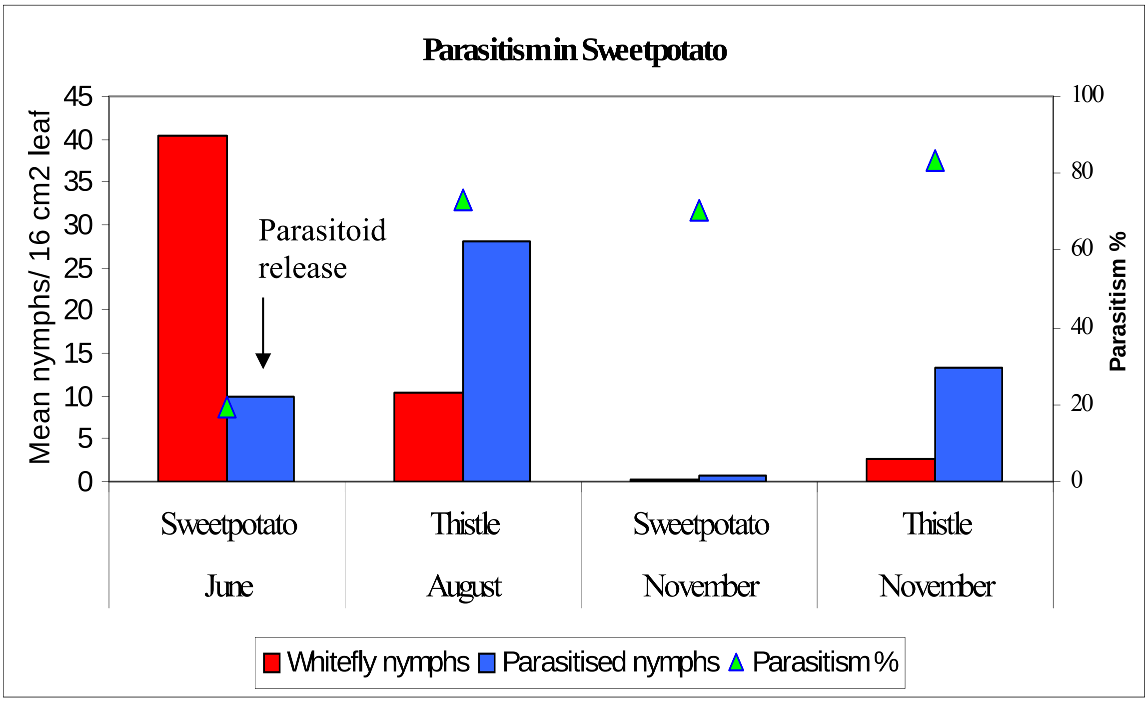
Burdekin had only three inoculative releases during 2007 and the three farms were assessed for parasitism levels after the releases. At the Ayr and Clare farms, the parasitism levels on eggplant and pumpkin were low (8% to 12%) after the initial releases. At Giru parasitism ranged from 27 - 67 % on zucchini and 50.5 % on eggplant (Fig 3.7).

Fig. 3.7 Parasitism and whitefly levels at three locations in Burdekin 2007



Four farms (sweetpotato, pumpkin and zucchini) in Rockhampton had a single release in June 2007. On one farm assessments were conducted two and five months after the release. In November 2007, the parasitism levels increased to 70% in sweetpotato and 83% thistle (Fig. 3.8).

Fig. 3.8 Parasitism and whitefly levels in sweetpotato farm in Rockhampton, 2007



3.5 Field evaluation in 2008

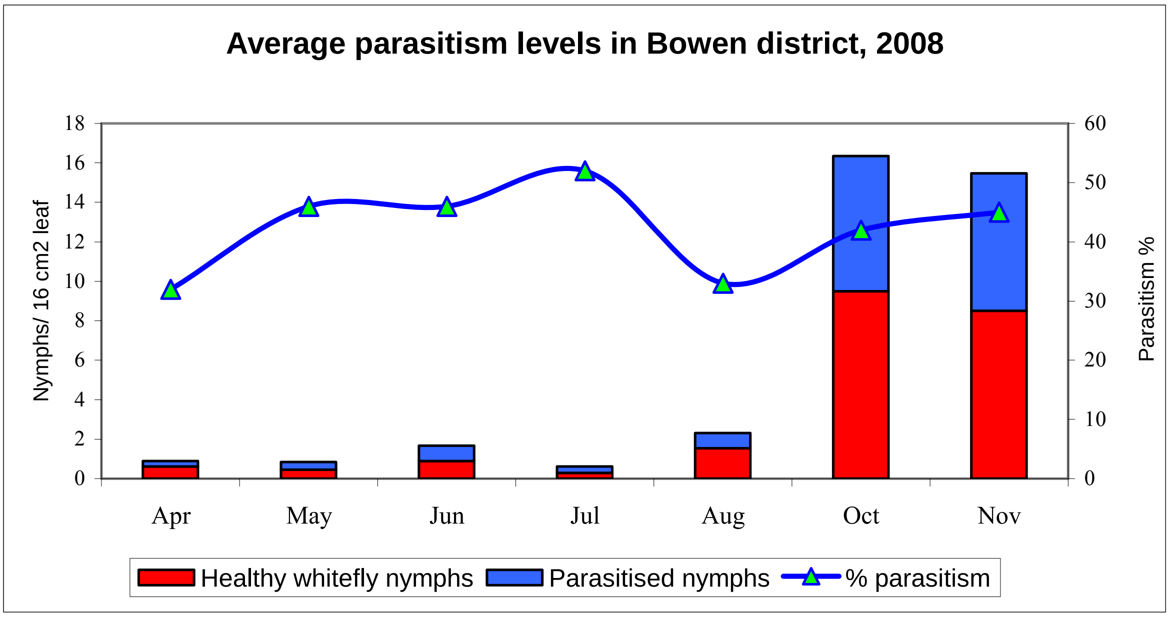
During the 2008 season over 450,000 parasitoid wasps were released on several vegetable farms in Burdekin, Bowen and Gumlu districts (Chapter 2, Table 2.3). More releases were conducted for Burdekin farms because of a severe whitefly outbreak during early 2008.

Post-release samplings were conducted on 35 farms across the Bowen, Gumlu and Burdekin regions from March to December 2008. Parasitism was recorded in various vegetable crops including tomatoes, melons, beans, eggplants and pumpkins and the details are given in Table 3.4.

Overall results indicated that the parasitoid was well established in all release locations with parasitism levels ranging between 12 and 80%.

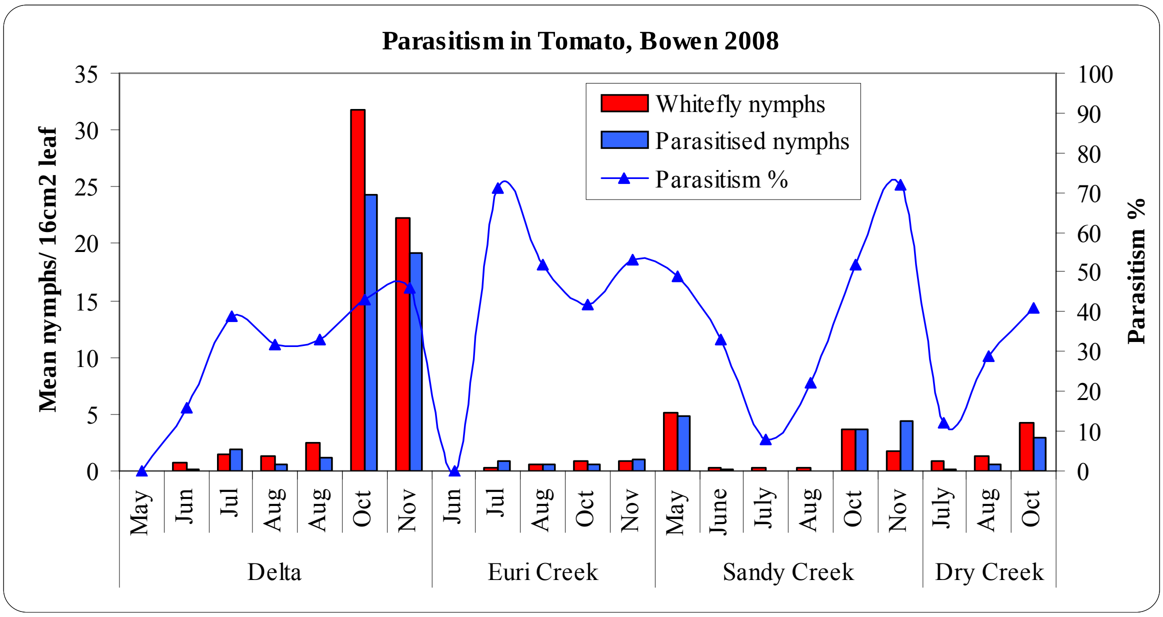
Bowen
In Bowen, whitefly populations on the crops in spring (Oct/ Nov) reached densities 15 times greater than in autumn and winter and parasitism density also equally increased with whitefly populations (Fig. 3.9). The average parasitism for the district ranged between 32% and 52% and varied with crops and locations.

Fig. 3.9 Average whitefly and parasitism levels across the locations in Bowen



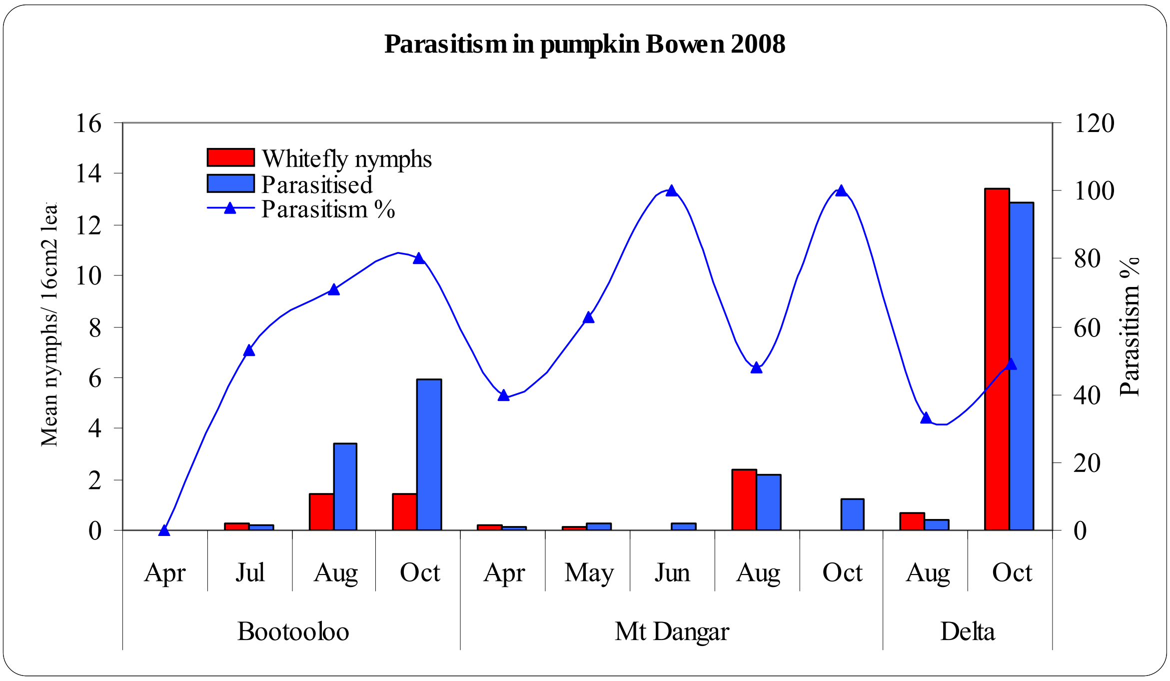
Tomato farms were sampled from May through November to determine the establishment of parasitoids and rate of parasitism at four locations in Bowen. The parasitism levels ranged between 16 and 72%. Whitefly and parasitism densities varied with locations. At Euri Creek the whitefly densities were well below damaging levels throughout the season. These farms had regular parasitoid releases during the 2007 and 2008 seasons. Whitefly densities in spring reached 55 nymphs per 16cm^2 of leaf in tomatoes at Delta and 10-fold lower than this at other locations (Fig. 3.10).

Fig. 3.10 Parasitism and whitefly levels in tomato farms at four locations in Bowen 2008



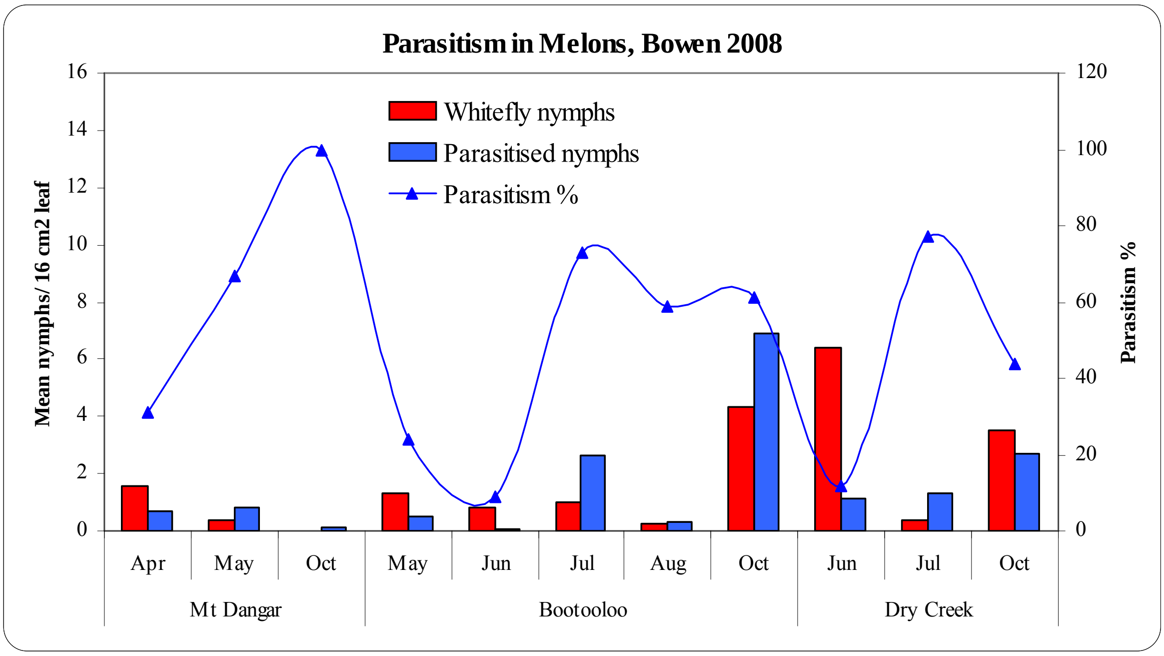
Four pumpkin farms were sampled from April through October at three locations in Bowen. The parasitism levels ranged between 33 and 100%. In most samples, mean whitefly nymphal (unparasitised) densities were below 2.0 nymphs per 16cm^2 leaf which was below the damage threshold level. Releasing parasitoids early in the crop's growth appears to stabilise the whitefly population in the crop (Fig. 3.11).

Fig. 3.11 Parasitism levels and whitefly densities in pumpkin farms in Bowen, 2008



The parasitism levels in melons were assessed at three locations. Overall parasitism levels ranged between 11 and 100% where whitefly nymphs densities varied between 0.1 – 12.0 nymphs per 16 cm^2 leaf. At Mt Dangar, the parasitism levels were high and the whitefly nymphal densities were below 3.0 nymphs per 16 cm^2 leaf. At Dry Creek, the whitefly density was high in June and two subsequent parasitoid releases in June caused reduction in whitefly densities by 94% and increased the parasitism level to 77% in July (Fig. 3.12).

Fig. 3.12 Parasitism levels and whitefly densities in melon farms in Bowen, 2008



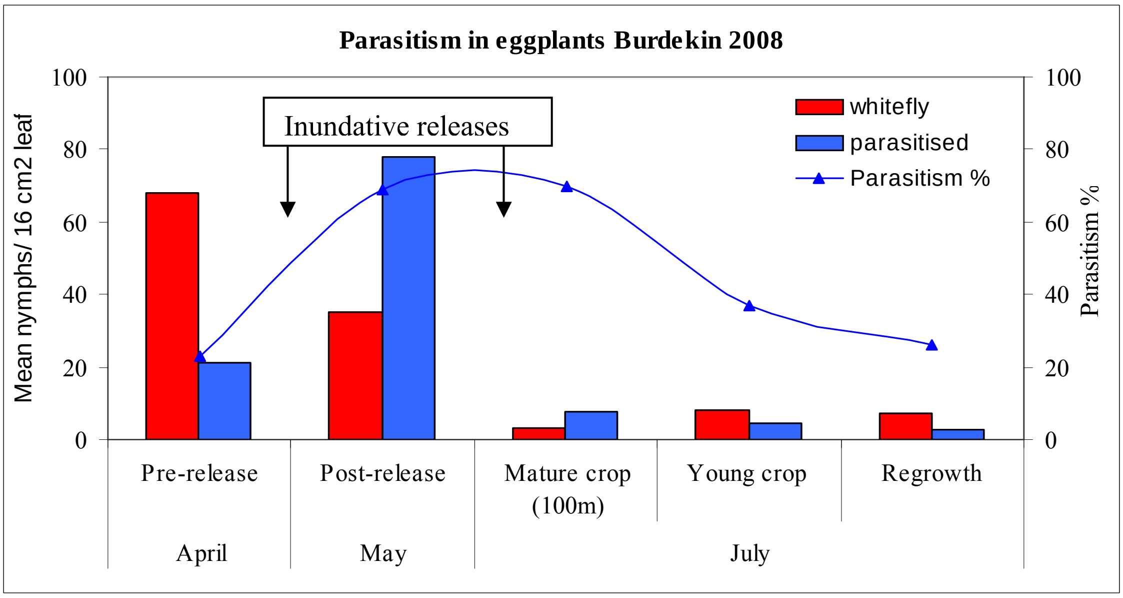
Burdekin

A severe outbreak of SLW in the Burdekin early in 2008 emphasised the need for more parasitoid releases on several farms. The outbreak caused very high infestations in the pumpkin, eggplant, zucchini and melon crops with nymphal densities ranging between 25 and 190 nymphs/ 16 cm^2 leaf, which was around 6 to 45 fold higher than the damage threshold. Over 200,000 parasitoids were released from May to August 2008 on three farms where the whitefly infestations were very high. In addition, smaller releases (around 25,000) were conducted for other farms with moderate SLW infestations (Chapter 2, Table 2.3).

In the outbreak location at Home Hill, Burdekin, an eggplant block (10 ha) with heavy whitefly infestation was selected for an inundative release and evaluation study. The grower applied five insecticide sprays (Admiral® x2, Chess® x2 and Confidor®) and did not find any significant reduction in whitefly numbers, so that he provided the block for this trial. Pre-release leaf samples results showed average whitefly densities of 87 nymphs/ 16cm^2 leaf with 23% parasitism (Fig 3.13). Around 75,000 *E. hayati* were released twice on the block. No insecticides were applied after the releases.

After 4 and 12 weeks, the parasitism rate was assessed in the release block and adjacent eggplant crops within 400m radius from the release block. The parasitism levels reached 70% in the release block and 37% in the adjacent young crop. At 12 weeks overall whitefly densities on the farm declined to below 8 nymphs/ 16cm^2 leaf (Fig. 3.13).

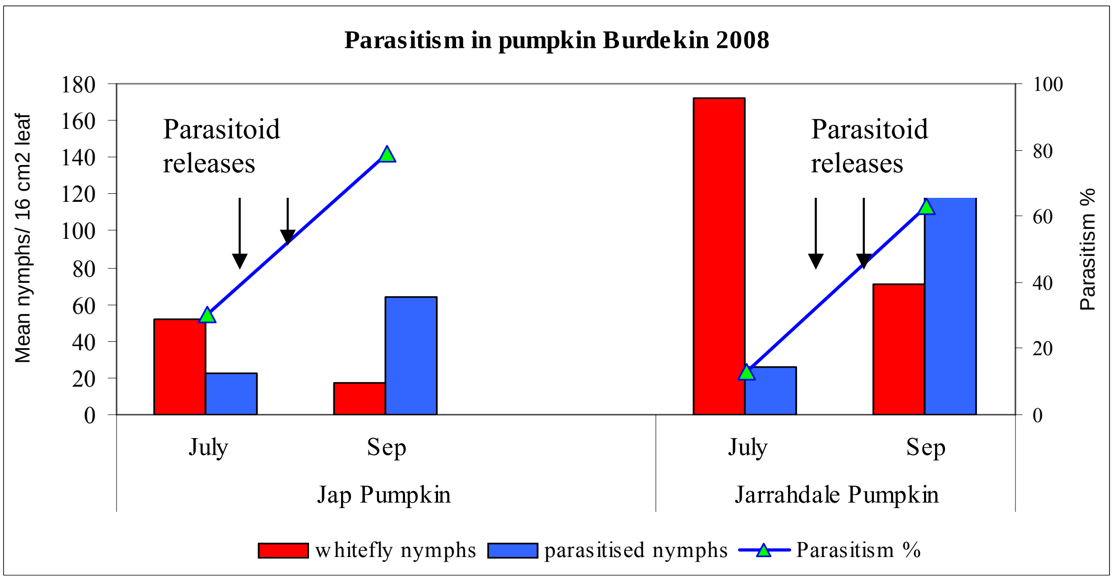
Fig. 3.13 Parasitism and whitefly levels on eggplant with inundative releases, Home Hill 2008



The second farm was at Clare where parasitoids were released on a heavily infested pumpkin farm (20 ha). There were two pumpkin plantings (Japs and Jarrahdale). The whitefly densities were very high (over 190 nymphs/ 16cm^2 leaf in Jarrahdale), which was 40-fold higher than the damage threshold level.

After 7 weeks, the parasitism and whitefly densities were assessed in the release blocks. The parasitism levels reached 79% in Jap pumpkin and 63% in Jarrahdale pumpkin, where overall whitefly densities on the farm declined by 67% and 59% (Fig. 3.14). Even though the inundative releases gave high parasitism levels the remaining unparasitised nymphs caused significant damage to the crops. The grower applied several insecticide sprays at weekly intervals but failed to achieve sufficient whitefly control. Later, resistance test results showed a very high level of resistance to pyriproxyfen (Resistance factor 3712) and imidacloprid (RF 1120).

Fig 3.14 Parasitism and whitefly levels on pumpkin farm at Clare, 2008

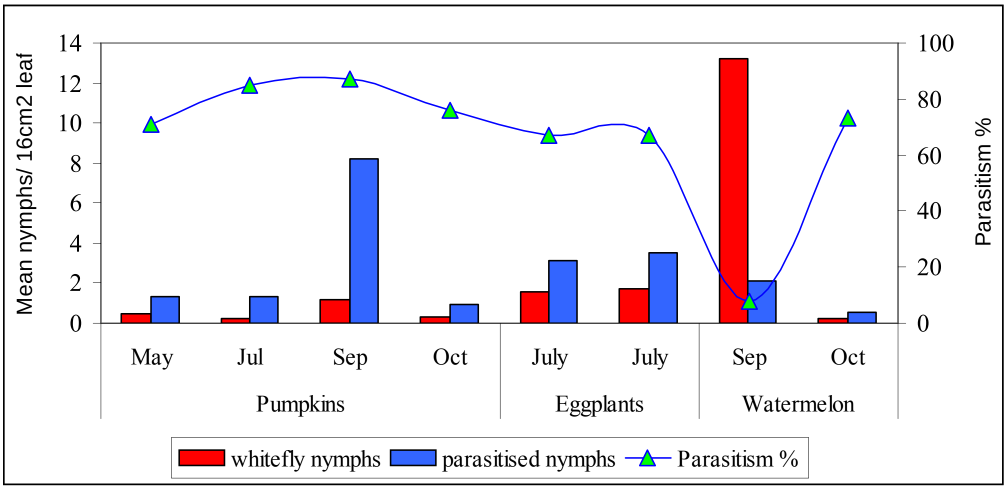


The third farm at Clare, a commercial pumpkin and melon farm extending over 200 ha, was selected for trialling parasitoid releases in combination with selective insecticides. An estimated total of 60,000 parasitoids were released during May/June and parasitism levels were assessed until October. The detail results are given in Chapter 6.

On the release blocks, the crop damage was high due to honeydew contamination at the early stage and only a proportion of fruit was harvested. However, this block served as a breeding source for the parasitoids that allow them breed and disperse into adjacent crops in the farm.

In addition, twelve samples from 8 farms were assessed for parasitism levels. The parasitism levels ranged between 5 and 85% and the results are given in Fig. 3.15.

Fig. 3.15 Parasitism and whitefly levels in Burdekin farms in 2008



Gumlu

Most of the releases were conducted on an IPM implementation farm at Gumlu and parasitism levels were assessed throughout the season. The details are given in Chapter 6.

Another three farms (pumpkin, cucumber, eggplant and melons) had one or two releases during June/ July and parasitism levels were assessed during the season. Post release evaluation has been conducted on the release and adjacent farms where parasitism levels ranged between 28 and 87% (Fig. 3.16).

Fig. 3.16 Parasitism and whitefly levels in Gumlu farms in 2008

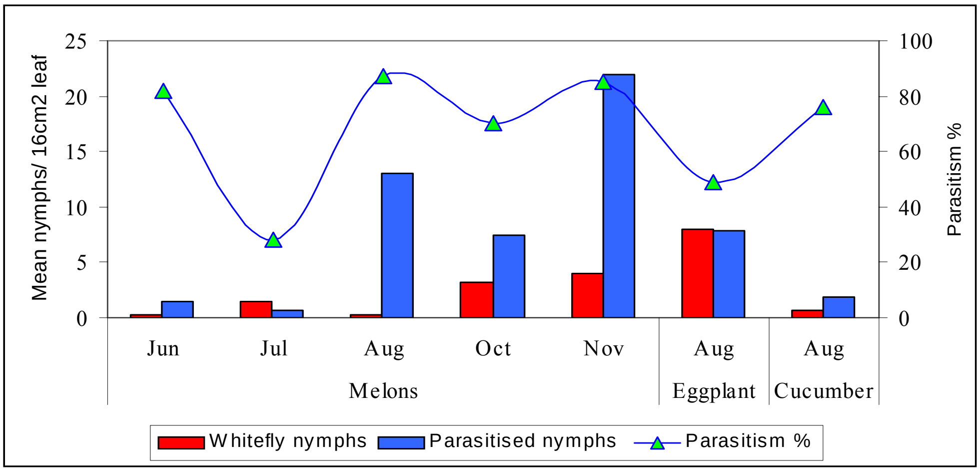


Table 3.4 Sampling details for Bowen and Burdekin 2008 and 2009

Year	Locations	Number of Farms	Crops	Number of samples collected
2008	Euri Creek	3	tomato, zucchini	12
	Dry Creek	2	tomato, melon	6
	Mt. Dangar	1	melon, pumpkin, eggplant	10
	Collinsville Rd	4	melon, beans, tomato, pumpkin	14
	Delta	3	tomato, melon, pumpkin	15
	Bootooloo	4	melon, beans, pumpkin	7
	Lower Don	3	cucumber, eggplant, pumpkin	4
	Gumlu	4	melon, eggplant, cucumber, pumpkin, zucchini	37
	Burdekin (3 locations)	11	melon, pumpkin, eggplant	33
	Total	**35**		**138**
2009	Euri Creek	2	tomato, cucumber, zucchini,	17
	Dry Creek	1	pumpkin, melon	6
	Mt. Dangar	1	melon, pumpkin, zucchini, eggplant	22
	Collinsville Rd	1	melon, beans, pumpkin	5
	Delta	2	tomato	11
	Lower Don	1	tomato, cucumber, eggplant	6
	Bootooloo	2	melon, beans, pumpkin	43
	Gumlu	2	pumpkin, eggplant, melons,	44
	Burdekin	3	melons, zucchini, pumpkin	134
	Total	**15**		**289**

3. 6 Evaluation in protected cropping in 2008 and 2009

Limited monitoring for parasitism in SLW was undertaken in a protected cropping facility at Bundaberg. The facility grows cucumbers and had an on-going problem with SLW in one of its plant houses.

In 2008 two samples, one before and one after a release of *Eretmocerus hayati*, were taken and assessed for parasitism levels. On each occasion, 20 infested leaves were collected from scattered locations throughout the plant house and forwarded to Bowen for assessment. Four $4cm^2$ areas on the underside of each leaf were examined under magnification and the numbers of live, dead and parasitised nymphs were counted. The facility was re-sampled on four occasions from February to April 2009, using the same sampling and similar assessment techniques described previously. Assessment was done locally and later instar nymphs only were counted. The leaves then were held in 10L plastic containers with fine mesh lids for five to six weeks to allow emergence and death of adult SLW and wasps, and numbers of adult SLW and wasps were counted.

Table 3.5 shows the results from the 2008 samples. The numbers of nymphs per unit area was lower in the second than the first collection, and the percentage of nymphs parasitised increased. The initial parasitism rate of 22.2% presumably was from "wild" parasites while the level of parasitism doubled following the release.

Table 3.5 Numbers of live, dead and parasitised nymphs in 2008 collections

Category	Average number nymphs per $16cm^2$	
	1st April 2008	28th April 2008
Live SLW nymphs	10.5	3.6
Parasitised nymphs	3	2.6
Fungal and dried nymphs	8.4	4.9
Total nymphs	21.9	11.1
Percentage parasitised	13.7	23.4
Percentage parasitised as percentage of live + parasitised (omitting dead from other causes)	22.2	41.9

Table 3.6 shows the results of the 2009 collections. No parasitised nymphs were recorded in the nymphal assessments but low levels of parasitism were recorded when adults were allowed to develop and emerge. There were many early instar nymphs, many of which were dead, on some leaves.

Table 3. 6 Numbers of live and parasitised nymphs and adult insects in 2009 collections

Category	Average number nymphs per 16cm^2			
	6th February 2009	24th February 2009	17th March 2009	28th April 2009
Live SLW nymphs	11.2	2.0	5.0	3.1
Parasitised nymphs	0	0	0	0
Total nymphs	11.2	2.0	5.0	3.1
Percentage parasitised	0	0	0	0
	Numbers of adults emerged			
SLW	341	223	992	317
Parasitoid wasps	12	0	1	0
Total adult insects	353	223	993	317
Percentage of wasps	3.4	0	0.1	0

The 2008 sampling showed that naturally occurring parasitism was occurring in the plant house, presumably by wasps that had entered from the outside. The parasitoid release almost doubled the parasitism rate to 42%. These results were promising, suggesting that parasitoid releases would be useful in managing SLW infestations in the plant house.

Very low levels of parasitism were recorded in the 2009 collections. Obviously the released parasitoids had not survived and nor had parasitoids that had entered naturally. The grower reported that pyriproxyfen had been used, probably accounting for the dead early instar nymphs, and other insecticides may have been applied as well. The grower reported that a broad spectrum insecticide had been used to comply with quarantine requirements for export to New Zealand and this certainly would have impacted on the parasitoids.

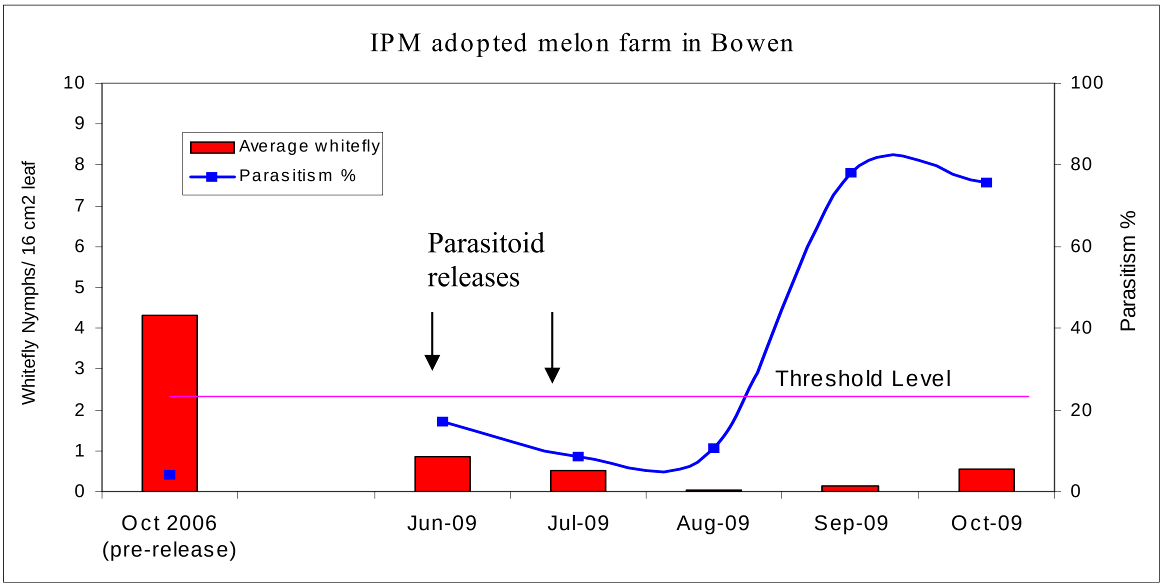
3.7 Field evaluation in 2009

In 2009, parasitoid releases and evaluations were conducted mainly on four farms adopting IPM in melons and pumpkins crops. In Gumlu and Burdekin, two large-scale farms (200 and 500 ha) were evaluated for parasitism and whitefly levels and the detail results are given in Chapter 6.

In Bowen, two medium-size farms (70 and 100 ha) were selected for the parasitoid release and evaluation study. The study focused on integrating the parasitoids with existing insecticide control strategies. The crops were sampled and assessed at 2 to 4 weeks intervals by trained entomologists. Data on SLW infestation and parasitism levels and insecticide sprays were collected to measure the benefit of the IPM. The sampling results were used for assisting the growers in making spray decisions and for parasitoid releases.

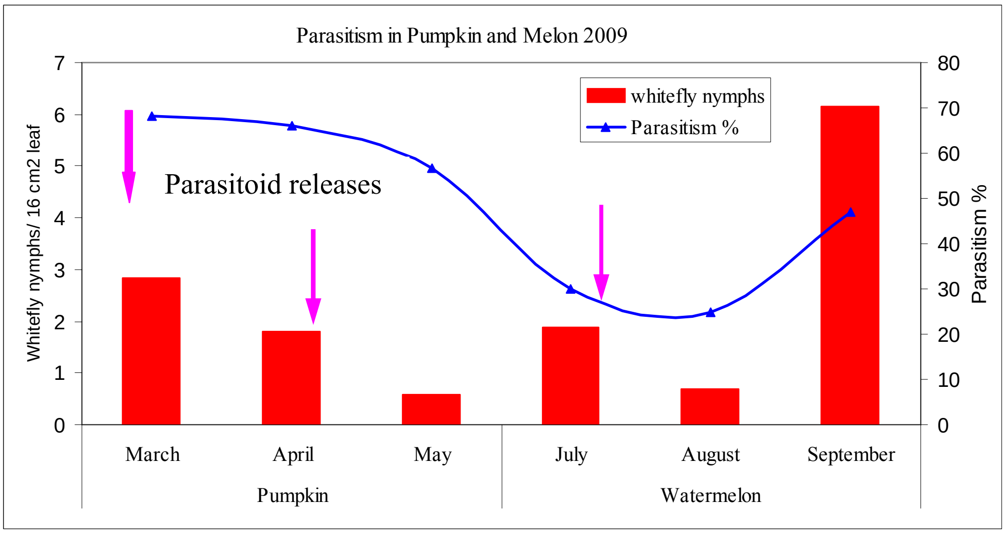
The first farm was at Mt Dangar (Bowen) where pumpkin, melons and cucumber were grown from March to November. The initial releases were started in November 2006 and more releases were conducted during 2007 and 2008. In 2009 the farm was sampled from June through October and two releases were conducted in June and July. The sampling results are summarised in Fig. 3.17. On the farm, the average parasitism levels increased from 18 to 76% while the whitefly nymphal densities remained below 2.0 nymphs per 16cm^2 leaf or below the damage threshold.

Fig. 3.17 Percentage of parasitism and density of whitefly in melons at Mt Dangar 2009



The second farm was at Bootooloo (Bowen) where pumpkin, melons and capsicum were grown from March to October. In 2009, the farm was sampled from March through October. Parasitoid releases started in March and continued until August. The sampling results are given in Fig. 3.18. On the pumpkin crops, the number of whitefly nymphs had declined from 2.8 to 0.6 nymphs per 16cm^2 leaf. The data show that the whitefly level has declined with releases during early growth stage of the crops. In watermelon the parasitism levels were between 30% and 47% and whitefly nymphal densities were below the damage threshold until August. However there was significant increase in whitefly nymphal densities in September because of high migration of whitefly adults from adjacent farms.

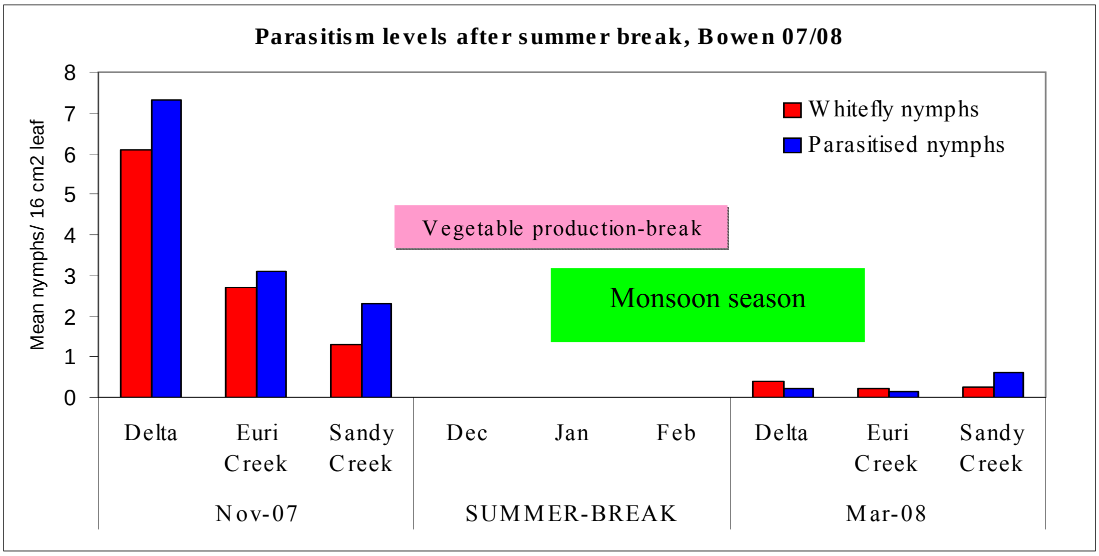
Fig. 3.18 Percentage of parasitism and density of whitefly in pumpkin and melons at Bootooloo, Bowen



3.8 Summer sampling 2008 and 2009

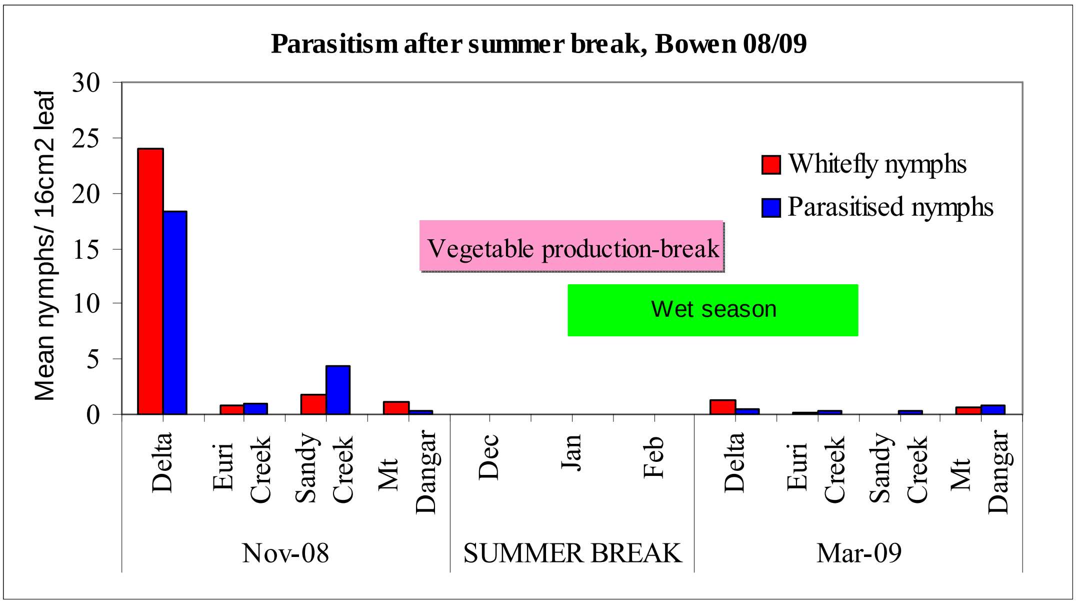
In March 2008 samples were collected from various weeds in three locations in Bowen. *E. hayati* was present in 12 of 16 weed samples collected from the Bowen locations. Whitefly and parasitism densities were lower in all samples compared to the previous season levels (Fig. 3.19).

Fig. 3.19 Parasitism and whitefly levels on crops before summer and on weeds after summer break (Mar 08) in Bowen.



In March 2009 around 38 weed samples were collected in Bowen and *E. hayati* was found in 10 samples. The samples had average of 0.5 nymphs per leaf, which was lot lower than the parasitoid densities found in the previous season (Fig. 3.20).

Fig. 3.20 Parasitism and whitefly levels on weeds before and after summer break in Bowen 2008/09



The parasitism levels dropped in February and March compared to the levels recorded at the end of the previous season, indicating poor survival during the production break (December to February) in Bowen. This is probably due to the lack of whitefly host plants during the break and unfavourable summer climatic conditions, including dry and hot conditions in December followed by extended rainfall in January and February.

Goolsby and Ciomperlik (2008) reported the successful establishment of *E. hayati* in Rio Grande Valley of Texas, which is a sub-tropical region with dry winter and most similar to the Indus River of Pakistan where *E. hayati* was collected. However, this species did not establish in Imperial Valley, California and Yuma, Arizona.

In Burdekin, a wide range of whitefly host plants such as soybeans, cotton and various broad-leaf weeds are present during summer. Preliminary sampling results showed a decline in parasitism levels in March, which indicates that weather conditions such as high rainfall and high temperature may have had an impact on the parasitoid and its host (SLW) populations.

3.9 Discussion

The project has taken three steps – parasitoid breeding, field releases and evaluations– for the whitefly IPM. The parasitoid was released at 40 Queensland sites at various times during 2006 to 2009.

Follow-up surveys found that the parasitoids had established at most sites, and even at some non-release sites indicating natural spread. Overall results from these 4 years of evaluation clearly demonstrated that the parasitoid releases played a significant role in SLW control. In most of the crops, parasitoids exerted between 30 and 80 % control. Even in regularly sprayed crops such as tomato and eggplant *E. hayati* was able to achieve an overall average parasitism of 45%.

The parasitism rate increased with the availability of whitefly nymphs, which was indicated by increasing parasitism in the later part of the season. The leaf sample data from several locations have indicated that the parasitoid population increased during the spring in Bowen and Burdekin locations.

There is a considerable lag between SLW infestation and the natural establishment of parasitoids in crops. It normally takes 3 to 6 weeks for parasitism levels to increase through natural colonisation, which is too long for some high value or sensitive crops in which damage, particularly physiological damage, can occur in a very short time.

Releasing parasitoids early in the crop's growth appears to stabilise the whitefly population in the crop. This has eliminated the need for applications of pyriproxyfen or bifenthrin which were often required to control the whiteflies. Rates of parasitism increased within 2 to 4 weeks of the initial release and up to 85% parasitism was recorded in the release crops. In most melon and pumpkin plantings, mean whitefly nymphal densities were below 2.0 nymphs per $16cm^2$ of leaf which was below the damage threshold level. Controlling whitefly nymphs during the vegetative stage in melons is very important to avoid honeydew or sooty mould contamination on the fruit.

Releases of parasitoids were also shown to be compatible with the use of selective pesticides in the crops. The data showed that integrating parasitoid releases with narrow-spectrum insecticides as part of an IPM program has maintained the whitefly population at its lowest levels, where the parasitoids have contributed between 50 and 70% of the whitefly control. Most melon and pumpkin plantings had around 1 to 2 insecticide sprays per crop, while late plantings (October to November) received between 2 and 4 sprays.

The parasitism level was generally low in tomato farms compared with pumpkins and melons. The possible reasons include:

- A range of other pests present in tomatoes require regular insecticide sprays, including broad-spectrum products such bifenthrin and methomyl.
- Interstate and export market access protocols require growers to spray with dimethoate or trichlorfon, which is highly detrimental to the parasitoid and to other natural enemies in the crop.
- The tomato industry doesn't have a levy, Ausveg / HAL funding is not available to enable researchers to make an attempt to implement IPM in this crop (see Chapter 6).

A variety of vegetable crops including tomato, capsicum, melon, eggplant, pumpkin and beans are grown during the production season and many of them are hosts for silverleaf whitefly. In addition to crops, a variety of weeds and ornamental plants are present around the farms and at rural home sites in the region. This provides a range of whitefly host plants throughout the season, and allows the host and the parasitoid to continue their development.

Because of limited funding and staff resources, the parasitoid releases were planned to target one production region per year. Because of this, intensive releases were conducted for Bowen/ Gumlu in 2007 and Burdekin in 2008. The releases in 2009 were mainly on the farms selected for IPM implementation program.

Based on the successful performance of parasitoid in the field, significant progress has been made on integrating the parasitoid with existing farm practices (discussed in detail in Chapter 6).

3.10 Reference

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Subramaniam S, Verni Subramaniam and Jackson K (2008). Parasitic wasps for silverleaf whitefly control in vegetable crops DPI & F Bowen, QLD.

Zolnerowich G and Rose M (1998) *Eretmocerus* Haldeman (Hymenoptera: Aphelinidae) imported and released in the United Sates for control of *Bemisia* (tabaci complex) (Homoptera: Aleyrodidae). Proceeding of the Entomological Society of Washington 100: 310-323.

Chapter 4

Insecticide resistance monitoring in *Bemisia tabaci*

4.1 Introduction

The cotton whitefly *Bemisia tabaci*, which is a serious pest of fibre, horticultural and ornamental crops world-wide, is comprised of a species complex or biotypes The most aggressive, damaging and insecticide resistant biotypes are the B and the Q-biotypes.

In Australia, there are two native biotypes of *B. tabaci* occurring in south-east Queensland and northern NSW and northern Australia respectively. Two exotic biotypes of *B. tabaci*, the B and Q-biotypes have been introduced to Australia. The B-biotype *B. tabaci* (Poinsettia or Silverleaf whitefly), which is thought to have come from the Middle East in the early 1990's, was first identified in the USA and has spread around the world via the world-wide trade in poinsettia cuttings. Q-biotype *B. tabaci*, thought to have originated in the Mediterranean region, is rapidly spreading around the world due to the international trade in ornamentals.

B-biotype *B. tabaci* (silverleaf whitefly) was detected for the first time in Australia in October 1994 (Gunning *et al*. 1995). Silverleaf whitefly is now widely distributed over eastern and inland Queensland and NSW and the Darwin area of the NT and is a major pest of horticultural crops. B-biotype *B. tabaci* has progressively increased its range in NSW and Queensland since 1995. Q-biotype *B. tabaci* was confirmed in Australia by Robin Gunning (NSW I&I) in 2008. Q-biotype records in Australia now range from southern NSW to north Queensland.

Insecticides are the major defence against the B and Q-biotypes in Australia, however, insecticide resistance is a major problem in the silverleaf whitefly. It is essential that the use of all chemicals is carefully managed to minimise or avoid resistance problems. This can only be achieved by establishing effective resistance detection and monitoring techniques and adapting insecticide management strategies to delay or avoid the evolution of resistance.

B-biotype *B. tabaci* came into Australia with insecticide resistance to most pyrethroids, organophosphates and carbamates. Explosion of the silverleaf whitefly into horticultural crops in north Queensland during the late 1990's ensured development of resistance to other insecticides (bifenthrin, endosulfan, amitraz and imidacloprid) to which they were initially susceptible. Field selection experiments in horticultural crops in north Queensland showed a very rapid rate in the selection of resistance to insecticides. Q-biotype *B. tabaci* arrived in Australia with high resistance to insect growth regulators and reduced susceptibility to neonicotinoid insecticides including thimethoxam. Extreme resistance to insect growth regulators is considered diagnostic of the Q-biotype.

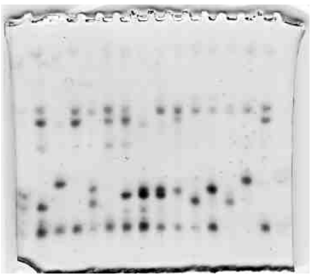
4.2 Methods and Materials

Whitefly samples were collected from vegetable crops in Bowen, Burdekin, Bundaberg and Lockyer Valley. The samples were sent to NSW DPI Tamworth as final instars on leaves and allowed to emerge. Cultures were established on young cotton plants (Sicot 71).

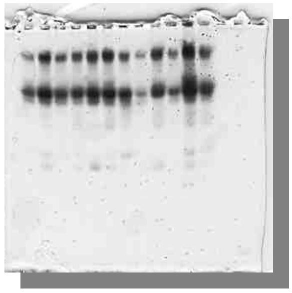
4.21 Distinguishing between whitefly biotypes

Identification uses established electrophoretic techniques to distinguish between *B. tabaci* biotypes. The method used here, exploits biotype distinctive esterase ectomorphs (Brown *et al* 1996). Esterase ectomorphs separated by polyacrylamide gel electrophoresis and visualised by traditional biochemical esterase staining methods. The detection of this esterase protein polymorphism has provided a valuable marker to facilitate tracking of *B. tabaci* biotype B as it spread round the world (Brown *et al* 1996) and was also used to confirm Q-biotype *B. tabaci* in the USA (Bethke et al 2009).

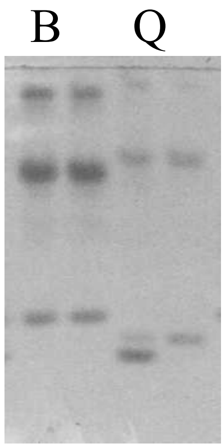
Biotypes of *B. tabaci* are morphologically indistinguishable and previously used biochemical techniques (esterase isoenzymes) to identify biotypes. Esterase iso-enzyme patterns are used overseas to identify *B. tabaci* to biotype. Individual adult whiteflies were homogenised in 20µL of 1.6% Triton X-100, containing 10% sucrose and a few grains of bromocresol purple. Aliquots (15µL, 0.75 insect equivalent) were pipetted into wells of polyacrylamide gels. Gels contained 7.5% polyacrylamide with 0.05% Triton X-100, but to achieve optimum resolution. Specially designed gel combs that cast wells with 4.5mm spacing in the stacking gel were used. Gels were run at 5°C, in barbitone buffer at 250V maximum current for 3 h. Gels were stained for esterase activity, using 0.5mM α-naphthyl butyrate and 0.2% Fast Blue RR, in 0.02M phosphate buffer pH 6.0. Gels were fixed in 5% acetic acid. Electrophoretic nobilities (R_m) of esterase bands were calculated. Typical gels showing esterase bands of B-biotype *B. tabaci* (silverleaf whitefly) and native, non-B biotype *B. tabaci* are shown in Fig 4.1a, b and c.



(a)



(b)



(c)

Figure 4.1 **Polyacrylamide gels showing esterase bands of adult *Bemisia tabaci* (a) native, non-B biotype *B. tabaci* , (b) B-biotype *B. tabaci* (silverleaf whitefly) and B-biotype and Q-biotype. Each track, represents of a single 0.75 whitefly**

4.22 Insecticide Resistance

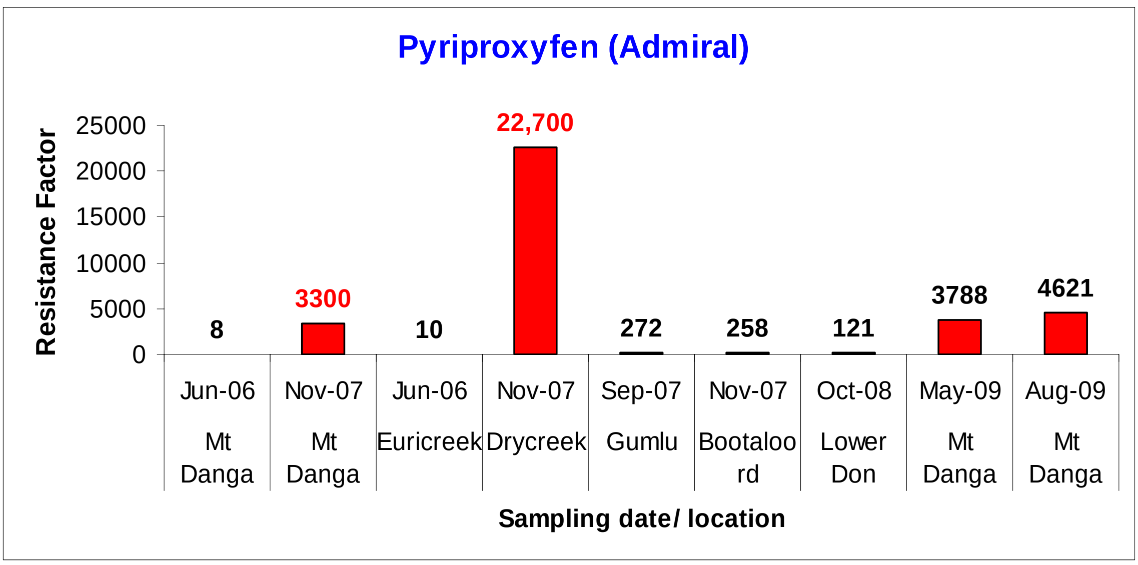
A leaf dip bioassay method was used to test contact insecticides against *B. tabaci*. Cotton plants (Sicot 189) were grown in the glasshouse without any exposure to insecticides. Leaf discs were cut and dipped into aqueous solutions of insecticide containing 0.01% Agral® surfactant and allowed to dry at 25ºC. Control leaves were dipped in Agral® and distilled water only. Leaf discs were placed adaxial side down in a small petri dish on a bed of agar. Female adult whiteflies of required strains were captured using an aspirator, temporarily anaesthetised with carbon dioxide and placed on the cotton leaf discs. Twenty whiteflies were placed on each cotton leaf disc and sealed into petri dishes. The whiteflies were allowed to feed on the leaf discs and were assessed at maximum mortality (48 hours).

The bioassay technique for insect growth regulators on immature whiteflies was more complex. Silverleaf whiteflies were allowed to oviposit on young cotton plants. The cotton plants were then removed from the whitefly cages so that no more eggs would be laid, thus ensuring that test whitefly nymphs were at the same developmental stage. Immature *B. tabaci* on the leaves were counted and then were dipped into formulated insecticide and Agral® solutions (to ensure wetting). Mortality was assessed 20 days after oviposition, by counting the number of living nymphs.

Standard toxicological statistics were used for the bioassay data. Bioassay data were analysed by Probit analysis. Control mortality was corrected for using Abbott's formula. The computer Probit program was P-A Mod (A. Woods, C. Orton & C. Virgona, University of NSW, for Macintosh microcomputers). Probit analysis is a transformation to facilitate computation, which converts the data to a straight line on probit graph paper. The method is to replace each percentage by its corresponding probit. The line which gives the best fit of the experimental data ($y = ax+b$) is computed from the transformed data, using a modified regression technique. In the equation $y = ax+b$, y represents the probit kill and x the log dosage. The calculations also give the slope of the line, 95% confidence limits for the estimated doses corresponding to percent mortality and a means for testing the homogeneity of the population used in the bioassay. Data was accumulated from north Queensland, Bundaberg and the Darling Downs.

4.3 Results

Fig 4.2 Pyiproxyfen (Admiral®) resistance in *B. tabaci*, Bowen (2006 to 2009)



4.31 Resistance testing results – Bowen/ Burdekin

Table 4.1 Response of *Bemisia tabaci* populations from vegetable crops in Bowen/ Burdekin (Queensland) to insecticides 2006-2009.

Insecticide	Year	Location (crops)	Biotype	Slope	LC 50 ppm (fiducial limits)	RF*
Imidacloprid		Susceptible (Darwin)		2.6	20 (17 – 29)	-
	2006	Euri Creek (tomato) 19/6/06		1.7	360 (230 – 550)	18
	2006	Mt Dangar (pumpkin) 21/6/06		2.0	50 (43 – 62)	2.5
	2007	Gumlu (egg plant) 18/9/07		1.9	370 (270 –560)	19
	2007	Dry Creek (tomato) 15/11/07	Q	1.1	2100 (450-4300)	105
	2007	Euri Creek (tomato) 14/11/07	Q	1.8	1800 (510 – 2600)	90
	2007	Bootaloo (melons) 7/11/2007	B	2.3	120 (78 – 140)	6
	2008	Clare (pumpkin) 4/08	Q	0.5	22400	1120
	2008	Clare (pumpkin)	Q	1.8	2050	103
	2008	Lower Don (eggplant) 24/10/08	B	13.	86	4.3
	2008	Clare (melons) 9/2008		2.0	97 (43- 110)	4.9
	2009	Clare (melons) 5/2009	B&Q	0.8	1206	60
	2009	Bowen 5/2009	B&Q	0.9	1309	65
	2009	Bowen 8/2009	B&Q	1.6	1950	98
Acetamiprid						
		susceptible		3.3	0.78 (0.62 – 0.99)	-
	2006	Emerald (cotton)		7.2	7.1 (6.1 – 8.2)	9
	2007	Dry Creek (tomato) 15/11/07	Q	1.1	20 (11 – 34)	26
	2007	Euri Creeek (tomato) 14/11/07	Q	1.5	15 (10 –22)	19
	2007	Bootaloo (melons) 7/11/2007	B	1.2	16 9 (11 – 23)	22
	2008	Clare (pumpkin) 4/2008	Q	2.4	4 (3.0 – 5.4)	5.1

*Resistance is expressed as resistance factor (ratio of field strain LC50 / LC50 susceptible strain).

Table 4.1 continue …

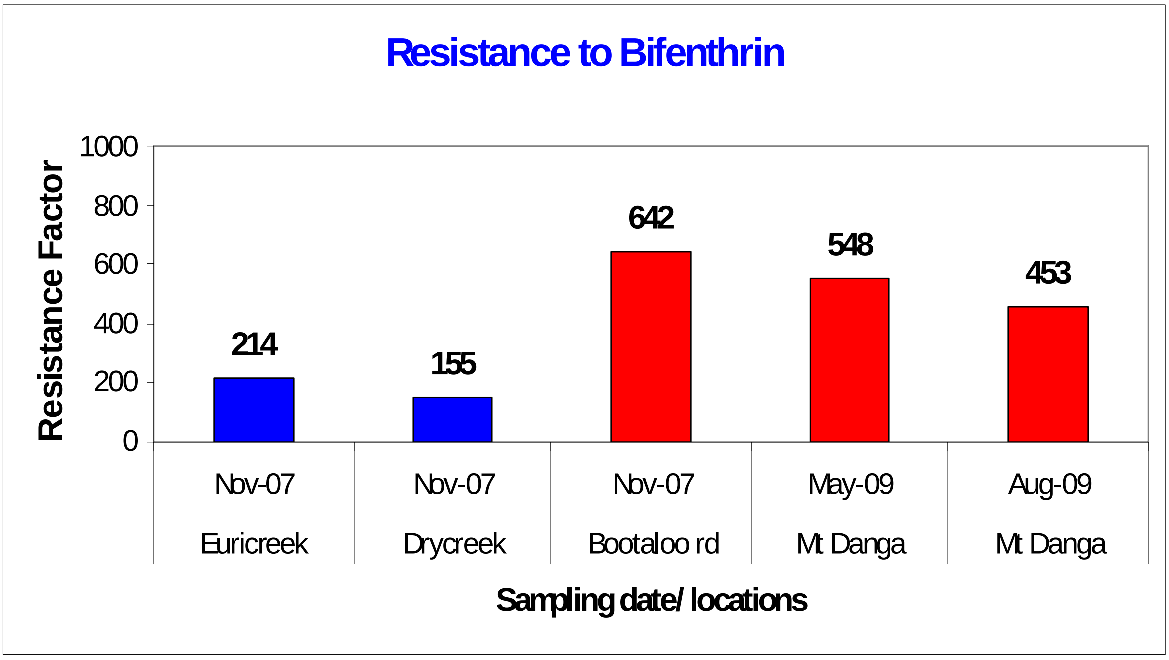
Insecticide	Year	Location (crops)	Biotype	Slope	LC 50 ppm (fiducial limits)	RF*
Diafenthiuron						-
		susceptible		2.5	36 (25 – 52)	
	2006	Mt Dangar (pumpkin)		1.6	300 (178 – 510)	8
	2006	Euri creek (tomato)		1.6	120 (60 – 240)	3
	2006	Emerald (cotton)		1.8	130 (50 – 350)	3.6
	2007	Dry Creek (tomato) 15/11/07	Q	2.5	30 (23 – 46)	1
	2008	Clare (pumpkin) 7/08	Q	1.2	4.6 (2.7 – 8.0)	0.1
Buprofezin						
		susceptible		2.5	0.26 (0.23 – 0.31)	-
	2006	Mt Dangar (pumpkin)		3.2	10 (8.3 – 14.0)	38
	2006	Euri Creek (tomato)		2.7	29 (13 – 61)	50
	2006	Emerald (Cotton)		2.1	766 (519 –1130)	2946
	2007	Dry Creek (tomato) 15/11/07	Q	5.1	1210(1000–1460)	4653
	2007	Euri Creek (tomato) 14/11/07	Q	2.1	802 (703 – 890)	3085
	2007	Bootaloo (melons) 7/11/2007	B	1.6	16 (11 – 24)	61
Pyriproxyfen						
		susceptible		4.9	0.066 (0.057–0.070)	-
	2006	Euri Creek (tomato)		1.8	0.68	10
	2006	Mt Dangar (pumpkin)		2.1	0.53	8
	2007	Gumlu (eggplant) 18/9/07		2.9	18 (15 –26)	272
	2007	Dry Creek (tomato) 15/11/07	Q	1.4	1500 (400 – 5600)	22700
	2007	Mt Dangar (beans) 7/11/07	Q	2.6	200	3300
	2007	Bootaboola (melons) 7/11/2007	B	1.8	17 (9.5 –25.6)	258

*Resistance is expressed as resistance factor (ratio of field strain LC50 / LC50 susceptible strain).

Table 4.1 continue..

Insecticide	Year	Location (crops)	Biotype	Slope	LC 50 ppm (fiducial limits)	RF*
Pyriproxyfen	2008	Clare (pumpkin) 8/7/08	Q	2.9	230 (140 – 350)	3485
	2008	Clare (pumpkin) 23/9/08	Q	25	245	3712
	2008	Clare (pumpkin) 4/2008	Q	1.6	95 (32- 240)	1439
	2008	Clare (pumpkin) 9/2008	Q	2.1	15 (8.7-25)	225
	2008	Lower Don (eggplant) 10/08	B	4.8	8 (5.6 – 12)	121
	2009	Clare (melons) 5/2009	B&Q	1.8	237	3590
	2009	Bowen (melons) 5/2009	B&Q	1.9	250	3788
	2009	Bowen (pumpkin) 8/2009	B&Q	1.4	305	4621
Bifenthrin		susceptible		3.5	0.084 (0 072 –0.099)	-
	2007	Euri Creek (tomato) 14/11/07	Q	2.5	18 (12 - 280	214
	2007	Dry Creek (tomato) 15/11/07	Q	1.4	13 (6 – 20)	155
	2007	Bootaloo (melons) 7/11/2007	B	2.0	54 (36 – 81)	642
	2008	Clare 2/2008	Q	2.0	101	1202
	2009	Clare (melons) 5/2009	B&Q	2.0	29 (23-37)	345
	2009	Bowen (melons) 5/2009	B&Q	1.7	46 (37-55)	548
	2009	Bowen (pumpkin) 8/2009	B&Q	1.5	38 (30-48)	453
Endosulfan						
		Susceptible		3.3	4.3 (3.5 – 5.4)	-
	2007	Dry Creek (tomato) 15/11/07		5.0	115 (90-114)	27
Pymetrozine						
	2007	Dry Creek (tomato) 15/11/07		2.0	43 (32 – 58)	
	2008	Clare (pumpkin) 7/2008	Q	1.1	95 (60 – 140)	

Fig 4.3 Bifenthrin resistance in *B. tabaci*, Bowen (2006 – 2009)



4.32 Resistance testing results – Bundaberg / Lockyer Valley

Table 4.2 Response of *Bemisia tabaci* populations from vegetable crops in Lockyer Valley/ Bundaberg to insecticides 2006-2009.

Insecticide	Year	Location (crops)	Biotype	Slope	LC 50 ppm (fiducial limits)	RF*
Imidacloprid		Susceptible (Darwin)		2.6	20 (17 – 29)	-
	2006	Lowood (cauliflower) 25/4/06		2.5	23. 9 (18 –29)	1
	2006	Laidley (cauliflower) 6/6/06		1.8	390 (270 – 560)	19.5
	2007	Tenthill (cauliflower) 1/5/07		1.8	1980(760 – 5100)	99
	2007	Gatton (broccoli) 1/5/07		2.4	25 (21 – 29)	1
	2007	Laidley (cabbage) 19//3/07		1.9	380 (270 – 551)	19
	2007	Bundaberg (eggplant) 15/3/07		1.0	80 (40-147)	4
	2007	Gatton 07/07		2.3	110 (80 – 140)	5.5
	2009	Bundaberg 1/5/09	B	1.8	312 (86-1128)	16
	2009	Gatton (cabbage) 14/5/09	Q	2.4	1578(1207-1895)	79
	2009	Gatton (broccoli) 14/5/09	Q	2.1	1700	85
Acetamiprid						
		susceptible		3.3	0.78 (0.62 – 0.99)	-
	2006	Darling Downs (cotton)		1.9	8.8 (4.2 –16)	11
	2006	Laidley (cauliflower)		2.6	144	187
	2007	Bundaberg (eggplant) 15/3/07		1.8	3.0 (1.3 – 6.9)	4.0
	2007	Tenthill (cauliflower) 1/5/07		3.2	0.77 (0.64 – 0.99)	1
Diafenthiuron		susceptible		2.5	36 (25 – 52)	
	2006	Laidley		1.1	2200 (740– 6300)	61
	2006	Lowood		2.2	1500(450 – 5000)	42
	2006	Darling Downs (cotton)		2.9	460 (250 – 980)	13
	2007	Tenthill (cauliflower) 1/5/07		2.1	25 (9.2 – 70)	1
	2007	Bundaberg (eggplant) 15/3/07		4.1	149 (82 – 192)	4
	2007	Gatton (broccoli) 1/5/07		2.5	36 (25 – 51)	1
	2007	Laidley (cabbage) 19//3/07		1.8	940 (850 – 5540)	26

*Resistance is expressed as resistance factor (ratio of field strain LC50 / LC50 susceptible strain).

Table 4.2 continue …

Insecticide	Year	Location (crops)	Biotype	Slope	LC 50 ppm (fiducial limits)	RF*
Buprofezin						
		susceptible		2.5	0.26 (0.23 –0.31)	-
	2006	Lowood		3.8	7.3 (5.9 – 9.0)	28
	2006	Laidley		2.7	5.3 (4.3 –6.8)	20
	2007	Gatton (broccoli) 1/5/07		2.7	5.4 (4.2 – 6.9)	21
	2007	Laidley (cabbage) 19//3/07		2.6	5.2 (4.0 –7.1)	20
	2007	Tenthill (cauliflower) 1/5/07		2.6	24 (13 – 40)	92
	2007	Bundaberg (eggplant) 15/3/07	B	2.8	26 (18 – 37)	100
	2007	Gatton 07/07	B	3.6	1300 (720- 2500)	5000
Pyriproxyfen						
		susceptible		4.9	0.066 (0.057–0.070)	-
	2007	Bundaberg (eggplant) 15/3/07		2.7	7.1 (4.8 – 10.6)	108
	2007	Gatton (broccoli) 1/5/07		4.0	0.3 (0.13 – 0.28)	4.5
	2007	Tenthill (cauliflower) 1/5/07		3.1	10 (7.9 – 15.3)	152
	2007	Laidley (cabbage) 19//3/07		1.9	0.7 (0.60 – 0.82)	11
	2007	Gatton 07/07		3.3	14 (11 – 17)	212
	2009	Bundaberg 1/5/09	B	2.4	3.4 (2.4 – 5.0)	48
	2009	Bundaberg 11/5/09	B	3.7	5.2 (3.4 – 7.0)	35
	2009	Gatton (cabbage) 14/5/09	Q		> 100	>1500
	2009	Gatton (broccoli) 14/5/09	Q		>100	> 1500
Deltamethrin						
		susceptible		2.7	0.13 (0.11 – 0.17)	-
	2006	Laidley		3.3	6,200(5000– 700)	47692
	2006	Lowood			>10,000	>70,000

Table 4.2 continue…

Insecticide	**Year**	**Location (crops)**	**Biotype**	**Slope**	**LC 50 ppm (fiducial limits)**	**RF***
Bifenthrin		susceptible		3.5	0.084 (0 072 –0.099)	-
	2007	Tenthill (cauliflower) 1/5/07		1.9	1.7 (1.2 – 2.4)	20
	2007	Gatton (broccoli) 1/5/07		1.8	21 (7.0 – 35)	250
	2007	Bundaberg (eggplant) 15/3/07	B	1.7	20 (6.2 – 36)	238
	2007	Gatton 07/07	B	5.0	9.9 (8- 12)	112
	2009	Gatton (cabbage) 14/5/09	Q	2,5	3.2 (2.7-3.9)	38
	2009	Gatton (broccoli) 14/5/09	Q	2.2	5.3 (4.8-5.9)	63
Endosulfan						
		Susceptible		3.3	4.3 (3.5 – 5.4)	-
	2006	Lowood 06		2.0	19 (9 – 40)	4.2
	2006	Laidley 06		1.9	100 (73 – 140)	23
	2007	Bundaberg (eggplant) 15/3/07		1.6	18 (13 – 25)	4.2
	2007	Tenthill (cauliflower) 1/5/07		3.2	59 (30 – 82)	13.8
Pymetrozine						
	2007	Tenthill (cauliflower) 1/5/07			62	
	2007	Bundaberg (eggplant) 15/3/07		1.3	15.5 (3.6 – 61)	

*Resistance is expressed as resistance factor (ratio of field strain LC50 / LC50 susceptible strain).

Insecticide resistance data for whitefly populations collected from horticultural crops in Queensland between 2006 and 2009 are shown in Tables 4.1 and 4.2. The resistance monitoring program was complicated by the detection of Q-biotype *B. tabaci* in north Queensland in 2007.

Two neonicotinoid insecticides were bioassayed, imidacloprid and acetamiprid. Resistance to imidacloprid increased during the course of this project (2006 – 2009), particularly in north Queensland. Resistance factors ranged from 1 to 1120. Imidacloprid resistance in populations of B-biotype *B. tabaci* (silverleaf whitefly) were low. Populations identified as Q-biotype *B. tabaci* showed greater resistance (85 – 1120 fold). In 2009, north Queensland populations comprising a mix of B and Q-biotype *B. tabaci* were between 60 and 98 fold resistant to imidacloprid. Resistance to acetamiprid in the silverleaf whitefly in Australia was detected for the first time on the Darling Downs in 2006. Acetamiprid resistance was also detected in Q-biotype *B. tabaci* populations in north Queensland in 2007.

Initially (2006), there were relatively low levels of silverleaf whitefly resistance to the insect growth regulators pyriproxyfen and buprofezin (Darling Downs and north Queensland). Later samples (2007-2009), showed a significant increase in resistance to both these growth regulators (Fig. 4.2). In particular, populations identified as Q-biotype *B. tabaci* were very highly resistant and resistance was at levels that would have compromised field performance. High-level resistance to pyriproxyfen is considered diagnostic of Q-biotype *B. tabaci*.

Resistance levels to diafenthiuron continue to remain low in silverleaf whitefly populations in Queensland horticultural crops. Resistance to diafenthiuron is not associated with Q-biotype *B. tabaci*

Two pyrethroids, bifenthrin and deltamethrin, were also bioassayed for resistance in whitefly populations. B-biotype *B. tabaci* (silverleaf whitefly) entered Australia with high levels of pyrethroid resistance, which has been exacerbated by pyrethroid use here. The current study has shown that whitefly populations identified as Q-biotype *B. tabaci* also have high levels of resistance to pyrethroids (Fig. 4.3).

Given that endosulfan is used against silverleaf whitefly on cotton, some data was also accumulated for populations in horticulture (Darling Downs and Bundaberg). Some resistance was detected, but the resistance factors were relatively low (4-23 fold).

Some baseline data for pymetrozine was also accumulated.

4.4 Conclusions

The outcomes of this research project have met the project objectives of monitoring insecticide resistance and providing the resistance information necessary for the management of silverleaf whitefly in horticultural crops. The capacity for accurate and cost effective identification of *B. tabaci* biotypes enabled the detection of the arrival of another exotic *B. tabaci* biotype, the Q-biotype, in Queensland horticulture. Although the management of insecticide resistance of silverleaf whitefly in vegetable and melon crops in Queensland has been complicated by the arrival of Q-biotype *B. tabaci* in Australia, this project has provided a valuable database on the resistance status of both B and Q-biotypes.

Without doubt, the greatest problem to resistance management has been the increased resistance to imidacloprid and insect growth regulators (buprofezin and pyriproxyfen). In the USA and Israel, effective control of silverleaf whitefly has been achieved through the use of insect growth regulators to prevent early season population build-up on horticultural and cotton crops. However, the finding that silverleaf whitefly (B-biotype) resistance is rapidly selected for, and that there is cross-resistance between buprofezin and pyriproxyfen, challenges the reliance on insect growth regulators against B-biotype *B. tabaci* Australia. Q-biotype *B. tabaci* arrived in Australia with high levels of resistance to insect growth regulators and reduced susceptibility to neonicotinoid insecticides. Extreme resistance to insect growth regulators is considered diagnostic of the Q-biotype and the high levels of resistance detected are consistent with observed field failures of these insecticides. Obviously, it will be essential to identify the biotype of *B. tabaci* prior to any management decision involving insect growth regulators. Recent research from the UK has demonstrated that neonicotinoid resistance is more highly expressed in adult *B. tabaci* than in juvenile whiteflies and use of soil drenches is highly recommended.

Anecdotal evidence of the failure of bifenthrin to control *B. tabaci* in north Queensland has been confirmed by the high levels of resistance detected in both B and Q-biotype *B. tabaci*. It is important that pyrethroids not be over-used against whiteflies and that use of synergists be considered.

4.5 Guidelines to manage insecticide resistance in B and Q-biotype *B. tabaci*

- Whitefly do not respect property boundaries and it is important to manage insecticide use against them on an area-wide basis and in cooperation with non-horticultural industries.

- Rotate insecticide groups, do not apply consecutive applications of any insecticide.

- Avoid the use of broad spectrum insecticides like organophosphates and pyrethroids against *B. tabaci*. Broad spectrum pesticides will destroy the natural enemies of whiteflies.

- Treat all insect growth regulators as one insecticide group.

- Do not re-apply an insecticide after a failure.

- Use petroleum oils (eg DC-Tron®) when whitefly pressure is low.

- Clean up infested crops before whitefly migration.

- Allow parasitic wasps to establish early in crops.

4.6 Resistance management strategy for silverleaf whitefly

Insect growth regulators (pyriproxyfen and buprofezin) have been used since 2003 in vegetable crops to manage silverleaf whitefly. Resistance to pyriproxyfen was detected after 4 years of use in vegetable crops in Bowen and field control failures have been reported in some locations. Resistance to IGRs threatens their effectiveness and continued use so a limit of one application during a defined window in the season is recommended.

Continued reliance on an increasing number of neonicotinoids (imidacloprid, acetamiprid and thiamethoxam) for controlling *B. tabaci* has led to resistance becoming increasingly potent and widespread. Continued exposure of successive generations of insects to these chemistries will select for resistance.

Resistance management is an important component of the whitefly IPM program. The insecticide resistance management strategy (IRMS) is critical for maintaining the efficacy of the selective insecticides that are crucial to the success of IPM in vegetables.

IRMS has been developed and promoted to the Bowen, Burdekin and Lockyer Valley regions. The strategy includes spraying only when economic thresholds are reached, using the most selective insecticides first to allow the natural enemies to contribute to the control of the SLW population, and then rotating between different insecticide classes.

The strategy window is somewhat varied between regions because of differences in SLW peak activity periods, cropping patterns and seasonal conditions. The IRMS for the three regions are given in Appendix 1.

4.7 Reference

Brown J.K, Bird J, Frohlich, D.R, Rosell R.C, Bedford I.D and Markham P.J. 1996. The relevance of variability within the *Bemisia tabaci* species complex to epidemics caused by subgroup III geminiviruses. In: D. Gerling and R.T. Mayer (eds), *Bemisia: 1995. Taxonomy, Biology, Damage, Control and Management*. Intercept, Andover. pp. 77–89.

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Gunning R.V, Byrne F.J, Conde B.D, Connelly M.I, Hergstrom K and Devonshire A.L (1995). First report of B-biotype *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) in Australia. *Journal of the Australian Entomological Society* 34, 116.

Chapter 5

Field evaluation of synergists to overcome pyrethroid resistance in silverleaf whitefly (*Bemisia tabaci* biotype B)

5.1 Introduction

Silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, also known as *Bemisia argentifoli*, is a serious and difficult to control pest of many vegetable crops in Queensland. Since 1995, SLW has become a major problem in tomato, eggplant, melons, zucchini, pumpkin, squash, cucumber, sweetpotato and, recently, in Brassica crops and beans.

This polyphagous pest causes severe damage to the crops through direct feeding, through honeydew contamination of product and by injecting a toxin into plants which causes physiological damage. SLW infestation of tomato plants is associated with irregular ripening in fruits. The external symptoms are characterised by green, yellow or orange streaks or blotches on the exterior surface of the fruit. Internally, the affected fruit exhibits white or yellow tissues.

SLW has demonstrated an outstanding capacity for developing resistance to insecticides, which further compounds the already difficult task of controlling this pest. Since 1996, pyrethroids especially bifenthrin (Talstar®) has been used to control this pest in vegetables. Whitefly control failures have been reported with applications of pyrethroid on several vegetable farms.

Pyrethroid resistance in *Bemisia tabaci* was primarily due to overproduction of esterase isoenzymes that metabolise pyrethroid insecticides (Bingham *et al* 2007). Piperonyl butoxide (PBO) is normally mixed with insecticides to block enzymes present in the insects that are capable of breaking down insecticides. PBO was considered for many years a specific inhibitor of microsomal oxidises, but recent research has revealed that it is also an inhibitor of enhanced esterase activity (Gunning *et al.* 1998).

The objective of this study was to evaluate the field efficacy of pyrethroids in combination with synergists (two piperonyl butoxide formulations) against SLW on tomatoes.

5.2 Materials and Methods

5.21 Experimental details

The trial was conducted at Bowen research station, Queensland, from July to October, when the pest pressure was very high. The experimental area consisted of 13 (80m long) polythene covered raised beds at 1.5 m row spacing. All experimental plots were grown with the trickle irrigation system (the commercial standard in Queensland) and irrigated at weekly intervals until final harvest. Commercial agronomic practices were followed to grow and maintain the experimental crops. Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result. Temperature and rainfall data recorded during the trial period are given in Table 5.6 and 5.7.

Tomato seedlings (Guardian, a ground-grown determinate variety) were transplanted 75 cm apart. Plots consisted of three rows 10m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with three replicates.

5.22 Treatments

Ten insecticide treatments and an untreated control were planned in the following manner (details in Table 5.3- 5.5):

Stand -alone pyrethroids – *applied as foliar spray at the recommended rate*
1. Talstar® (bifenthrin 100g ai/ L),
2. Astound® (alpha-cypermethrin 100 g ai/ L)

Tank mixtures of pyrethroid + Piperonyl butoxide (PBO)
3. Talstar® + Enervate® (piperonyl butoxide 800 g ai/ L)
4. Astound® + Enervate ®
5. Talstar® + NUQ 3313 (piperonyl butoxide -modified 800 g ai/ L)
6. Astound® + NUQ 3313

Split application (pre-spray with PBOs 3-5 hr prior to pyrethroid application)
7. Talstar® / Enervate®
8. Astound® / Enervate®
9. Talstar® / NUQ 3313
10. Astound® / NUQ 3313

Untreated control

5.23 Application methods

The insecticide applications were initiated when the whitefly threshold reached 1-2 adults per leaf. The first spray was started on 13 August (4 weeks after planting -WAP) and the second and third sprays were at 12 and 14 days intervals (Table 5.1). The treatments were applied using a motorised knapsack sprayer fitted with twin flat fan nozzles (Teejet DG80015).

Table 5.1 Details on the treatment application, time and spray volume

Applications	**Time applied**	**Temperature**	**Spray volume**
First spray	12 – 4.30 pm	23 – 26 ^{o}C	600- 625 L/ha
Second spray	8 - 11.30 am	24 – 27 ^{o}C	650 –700 L/ha
Third spray	12.30 – 5 pm	22 – 26 ^{o}C	800- 850 L/ha

Split applications: the PBO formulations, Enervate® and NUQ 3313, were applied as pre-treatment sprays and 3-5 hrs later the Talstar® and Astound® sprays were applied.

Tank-mixture treatments: both the PBOs and pyrethroids with their recommended rate were pre-mixed in the spray tank and were sprayed immediately onto the foliage.

5.24 Sampling Methods

The effects of the spray treatments were assessed on eggs and nymph populations by taking leaf samples. Tomato plants were sampled for whitefly stages at 14-day intervals. Four mature base leaflets (from the 6th or 7th main stem node position down from the terminal leaf) and four young leaflets (from the 3rd or 4th main stem node position) were collected from four random plants in each plot. Leaf samples were taken to the laboratory where 4 x 1 cm^2 areas were selected on each leaflet and immature stages were counted under the microscope. Immature stages on each leaflet were classified as eggs, small nymphs (1st and 2nd instar) and large nymphs (3rd instar and red-eye pupae).

To determine the residual activity of the treatments, whitefly adult populations were assessed at 2 to 14 days following each application. Whitefly adults were sampled from four random plants per plot using a modified vacuum sampling machine. The suction samples were taken from the top one-third of the plants, covering three leaves from each plant.

5.25 Fruit harvest and assessment

Tomato fruits were harvested 70 days after planting (DAP). Twenty-five to thirty mature green fruits were harvested from 10 plants in each plot and were placed in an ethylene gas room at 20 °C for ripening. Fully ripened fruits were assessed for external and internal irregular ripening using a 0 to 4 scoring system (Table 5.2).

Table 5.2 . Scoring system used for the assessment of SLW damage on tomato fruit

Score	External irregular ripening	Internal irregular ripening	Marketable grade
0	Full red colour	No white tissue inside	First grade
1	Slight blotches, but < 5% of fruit surface with uneven colour	< 5% internal area with slight white tissue	First grade
2	Moderate blotches, 6 to 20% of fruit surface with uneven colour	6 to 25% internal area with white or yellow tissue	Second grade
3	High uneven colours, 21 to 40% of fruit surface with uneven colour	26 to 50% internal area affected	Unmarketable
4	> 40% fruit surface with uneven colour	> 50% internal area affected	Unmarketable

5.3 Results and Discussion

5.31 Effect on Adult Population

SLW adult colonisation of seedlings started within two weeks of planting and increased gradually towards the end of the trial, especially in the untreated plots (Fig. 5.1). No significant differences in adult numbers were observed between treatments at the pre-treatment samplings.

After the first spray, all the PBO and pyrethroid combinations had significantly lower number adults than untreated control at 2 and 6 DAFS (days after first spray).

However, this was not the case at 12 DAFS. Only the split application of Talstar®/ Enervate® and Talstar®/ NUQ 3313 gave significant levels of control up to 12 days. No significant reduction in adult numbers was found between plots treated with pyrethroid only (Talstar® or Astound®) or the untreated control at any sampling dates (Table 5.3).

Table 5.3. Effect of PBO and pyrethroid combinations on SLW adults, after the first spray (4 weeks after planting)

Treatments	Product Rate (ml/ ha) [a]	Mean number of Adults/ Sample *			
		Pre-spray	2 DAFS	6 DAFS	12 DAFS
Untreated control	NA	22.7 a	22.7 a	60.7 a	173.7 a
Talstar®	375	22.7 a	20.3 a	36.3 ab	137.7 ab
Astound®	378	22.0 a	17.0 ac	35.0 ab	125.7 ab
Tank-mixture					
Enervate® + Talstar®	243 + 362	20.7 a	6.3 b	27.6 bc	140.0 ab
Enervate+® Astound®	255 + 375	21.7 a	10.3 bc	14.3 b	125.0 ab
NUQ3313 + Talstar®	247 + 367	17.0 a	5.3 b	12.0 c	130.0 ab
NUQ3313+Astound®	237 + 355	15.7 a	8.7 b	15.3 b	199.3 ab
Split Application #					
Enervate® / Talstar®	252/ 410	15.7 a	5.3 b	14.7 b	93.3 b
Enervate/® Astound®	252/ 370	27.7 a	5.0 b	20.7 b	113.3 a
NUQ3313/ Talstar®	256/ 410	19.0 a	6.3 b	8.7 c	49.7 b
NUQ3313/ Astound®	256/ 370	20.0 a	10.3 bc	17.0 b	121.7 ab

* Suction sampling covering approximately 12 leaves per plot
\# Split application – PBO applied as pre-treatment spray and 3-4 hrs later pyrethroids applied. DAFS = days after first spray
[a] Product rate based on the label recommendation of 40 to 60 ml/ 100L, and back calculated to ha rate
Means within a column followed by the same letter did not differ significantly at P = 0.05

At 3 and 7 DASS (days after second spray), whitefly numbers were significantly lower in PBO/ pyrethroid combination treatments than the untreated control. Most of pyrethroid/ PBO combinations provided better protection against whitefly adults compared with the pyrethroid only treatments. However, the residual control levels varied between the tank mixture and split application methods (Table 5.4).

Split application of Enervate® or NUQ3313 with Talstar® maintained adult numbers at a significantly lower level than the pyrethroids alone and the untreated control, and the reduction ranged from 72 to 98% (Table 3). The plots pre-treated with PBOs (Enervate® and NUQ-3313) and then sprayed with Talstar® within 3-4 hours had significantly lower number of adults up to 14 DASS.

Tank-mixture of Talstar®+PBOs provided shorter protection than the same treatments with split application. After 7 days, adult numbers in all tank–mixture treatments had increased to higher levels than the split application treatments with Talstar® (Table 5.4).

No significant reduction in adult numbers was found between untreated and pyrethroid only treated plots, except for Talstar® which gave a significant reduction only at 3 DASS.

Table 5.4. Effect of PBO and pyrethroid combinations on SLW adults, after the second spray (6 weeks after planting)

Treatments	Product Rate (ml/ ha) [a]	**Mean number of Adults/ Sample ***		
		3 DASS	7 DASS	14 DASS
Untreated control	NA	133.3 a	232.0 a	482.0 a
Talstar®	365	56.3 b	147.0abc	409.7 ab
Astound®	380	128.0 a	184.0ab	359.3 a
Tank-mixture				
Enervate® + Talstar®	260 + 385	25.0 b	119.7 bc	354.0 ab
Enervate®+ Astound®	280 + 425	25.7 b	94.7 bcd	334.0 ab
NUQ3313 + Talstar®	275 + 407	11.3 b	74.3 cd	253.7 ab
NUQ3313+ Astound®	260 + 385	39.7 b	135.7 bc	380.3 ab
Split Application #				
Enervate® / Talstar®	308/ 440	9.7 b	34.7 d	137.0 b
Enervate®/ Astound®	308/ 450	8.0 b	75.0 cd	272.0 ab
NUQ3313/ Talstar®	300/ 460	3.7 b	37.0 d	115.3 b
NUQ3313/ Astound®	300/ 450	17.7 b	80.0 cd	257.3 ab

* Suction sampling covering approximately 12 leaves per plot
# Split application – PBO applied as pre-treatment spray and 3-4 hrs later pyrethroids applied. DASS = days after second spray
[a] Product rate based on the label recommendation of 40 to 60 ml/ 100L, and back calculated to ha rate
Means within a column followed by the same letter did not differ significantly at P = 0.05

Six days after the third spray (DATS), Talstar® with PBO combinations resulted in over 93% adult control compared with the untreated plots, whereas the Talstar® or Astound® only treatments had more adults than the untreated control (Table 5.5). After three applications, SLW numbers were approximately 8 to 34 fold higher in the plots treated with Talstar® and Astound® alone than in the plots treated with PBO/ pyrethroid combinations.

Within the tank mixture combinations, Talstar®+Enervate® and Talstar®+NQU-3313 provided moderately better adult control than the same combinations of Astound®. However, there were no significant differences between the tank mixture and split applications for any combination treatment (Table 5.5).

Table 5.5. Effect of PBO and pyrethroid combinations on SLW adults, after the third spray (8 weeks after planting).

Treatments	Product Rate (ml/ ha) [a]	**Mean number of Adults/ Sample ***		
		Pre- spray	3 DATS	6 DATS
Untreated control	NA	482.0	490.0 a	511.7 a
Talstar	540	409.7	437.7a	546.3 a
Astound®	545	359.3	250.3a	512.7 a
Tank-mixture				
Enervate®+ Talstar®	367 + 533	354.0	17.3 b	23.0 bd
Enervate® + Astound®	370 + 535	334.0	52.3 c	60.3 c
NUQ3313 + Talstar®	360 + 525	253.7	29.7 bc	16.3 d
NUQ3313+ Astound®	360 + 525	380.3	39.0 bc	57.0 c
Split Application #				
Enervate®/ Talstar®	348/ 500	137.0	10.3 b	36.3 bcd
Enervate®/ Astound®	360/ 500	272.0	32.7 bc	60.7 c
NUQ3313/ Talstar®	360/ 500	115.3	11.3 b	16.0 d
NUQ3313/ Astound®	353/ 530	257.3	48.0 bc	49.7 bc

* Suction sampling covering approximately 12 leaves per plot
# Split application – PBO applied as pre-treatment spray and 3-4 hrs later pyrethroids applied.
DATS = days after third spray
[a] Product rate based on the label recommendation of 40 to 60 ml/ 100L, and back calculated to ha rate
Means within a column followed by the same letter did not differ significantly at P = 0.05

Overall, both pyrethroids with PBOs provided good knockdown effect compared with the pyrethroid alone. However, the clear trend in adult suppression was not seen until the second and third applications. After three applications, Talstar® combined with Enervate and NUQ3313 provided slightly better adult control than Astound® combinations. In the split application, both PBOs with Talstar® appeared to be fast acting on adults and provided better residual control for up to 14 days.

The split application of pyrethroid/PBOs provided better adult suppression by the second application, but after the third spray the reduction in adult numbers was not significantly different for the two application methods (tank-mixture or split application).

The adult numbers increased steadily on untreated plots 12 days after the first spray (DAFS). Similarly, the adult numbers increased in the Talstar® and Astound® only plots. This sudden increase was mainly due to the completion of generations within the crops. In the untreated plots the plants were less attractive to adults due to high honeydew contamination, especially toward end of the experiment. This may have increased adult movement from the untreated plots to the adjacent plots.

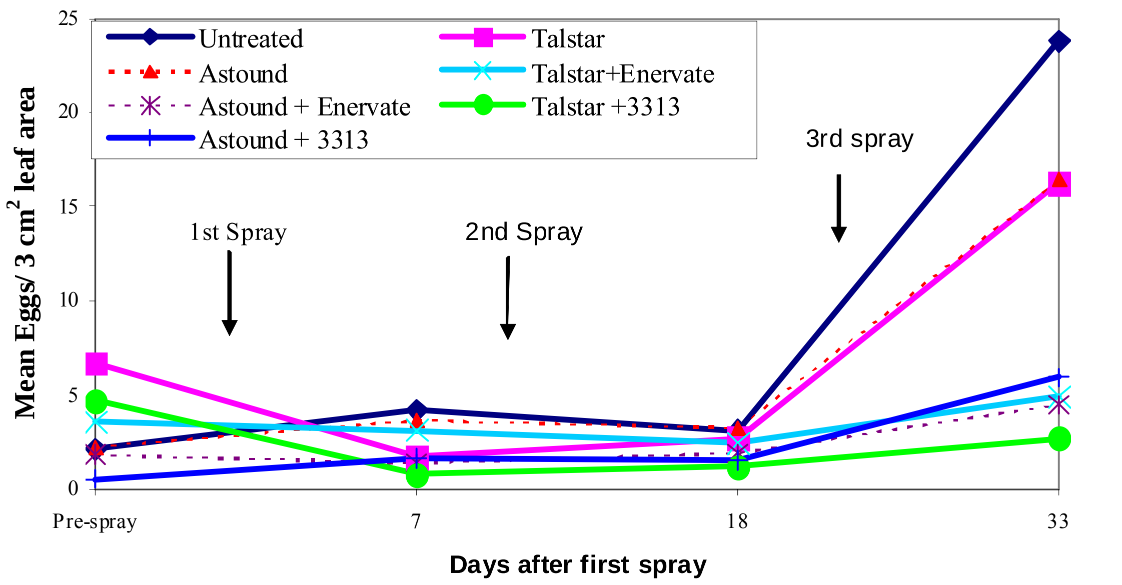
5.32 Effect on Oviposition

The effect of treatments on the oviposition and egg densities of SLW are shown in Figure 5.1 and 5.2. At the pre-treatment sampling, the egg depositions were high in the Talstar® plots, but the numbers were low in Astound®+NUQ-3313 plots. All other treatments had similar levels of egg densities.

Most of the pyrethroid/PBO combination treatments provided significant reductions in egg deposition compared with pyrethroid only treatments and untreated control. This trend was particularly more apparent after the third application (Figs. 5.1 and 5.2).

Among the tank-mixture treatments, Talstar®+ NUQ3313 performed better than any other treatment. After three applications, the egg densities in the pyrethroid+PBO combinations were significantly lower than in the pyrethroid only treatment and untreated control (Fig. 5.1).

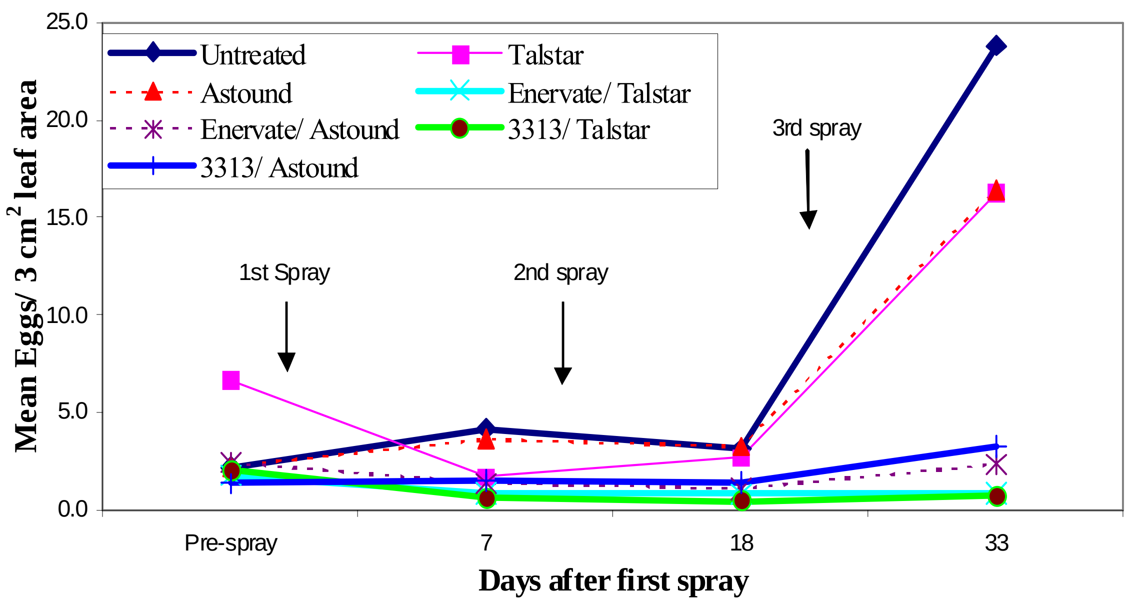
Fig 5.1. Effect of pyrethroid + PBO mixtures on whitefly oviposition



The split application of Enervate® or NUQ-3313 with Talstar® had significantly lower egg densities than the pyrethroids alone and untreated control at all sampling dates, and the reduction ranged from 74 to 97% (Fig. 2). However, the split application of Astound®/ PBO combination treatments had more eggs than the Talstar®/PBO treatments.

The NUQ-3313/ Talstar® combinations had significantly lower number of eggs than NUQ-3313 /Astound® treatments irrespective of application method. Similar differences were recorded for the adult populations in these treatments. The first two sprays of NUQ3313/Talstar® provided good adult control, resulting in constant reduction in egg numbers on the treated plants.

Fig 5.2. Effect of pyrethroid/ PBO split applications on whitefly oviposition



5.33 Effect on the Nymph Population

Small nymph stage (1st and 2nd instar) establishment was detected from the pre-treatment sampling date (4 WAP) and the numbers gradually increased towards the end of the trial (Fig. 5.3).

In the tank-mixture applications, both the Talstar®+Enervate® and Talstar®+NUQ3313 combinations had significantly lower numbers of nymphs than the pyrethroid only treatment and untreated control at last sampling date (Fig. 5.3). Mixing PBOs with Astound® did not give significant reduction in nymph population at last sampling date (Fig. 5.3).

With the split application, all four PBO/ pyrethroid combinations had significantly lower numbers of nymphs compared with the pyrethroid only treatment and untreated control at the last sampling dates (Fig 5.4). The NUQ3313/Talstar® combination resulted in fewer nymphs compared with the other combinations at the last sampling date. These nymphal densities were around 1.3 nymphs /3cm^2 leaf area which was just below the damage threshold level. Previous studies indicated that a damage threshold exceeding 0.5 nymphs / cm^2 can cause up to 40 % fruit damage (irregular ripening) at harvest (Subramaniam, HAL report 2001).

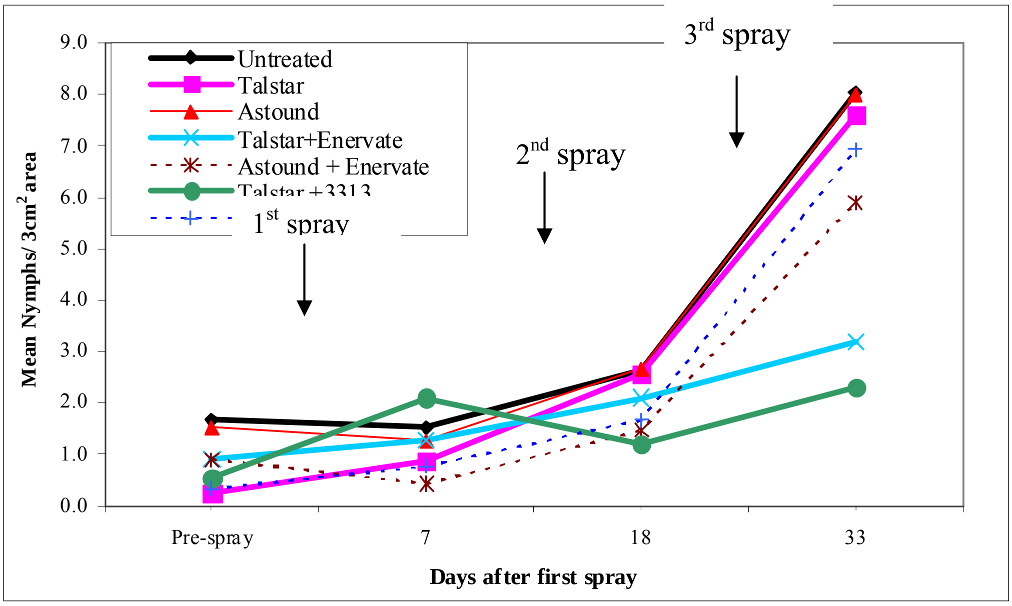


Fig. 5.3. Effect of pyrethroid + PBO tank mixtures on whitefly nymph populations

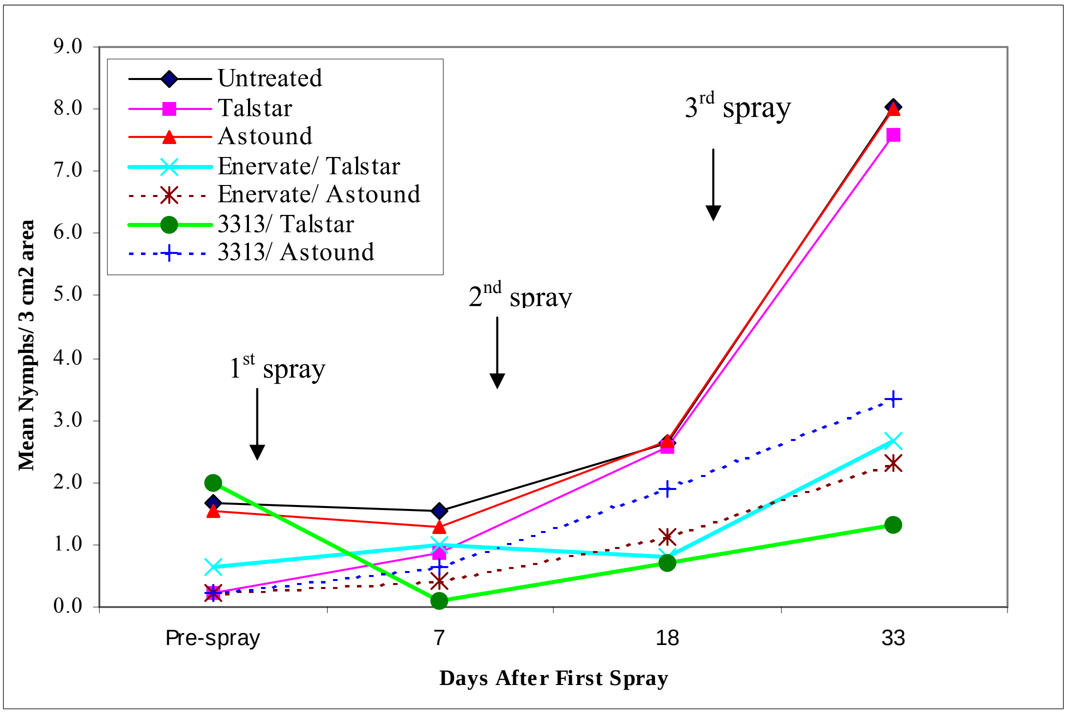
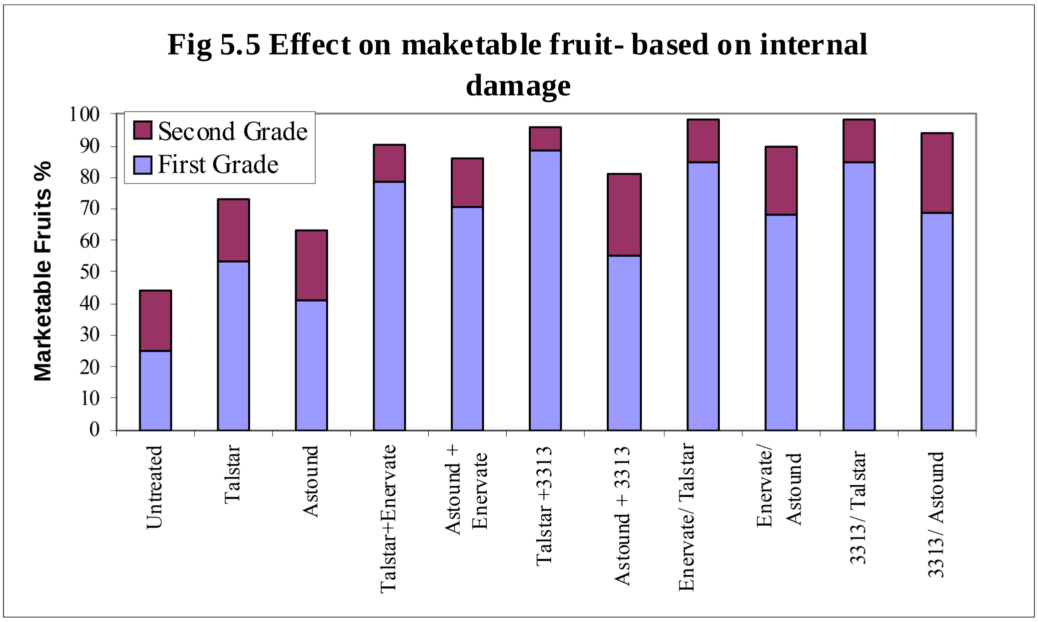
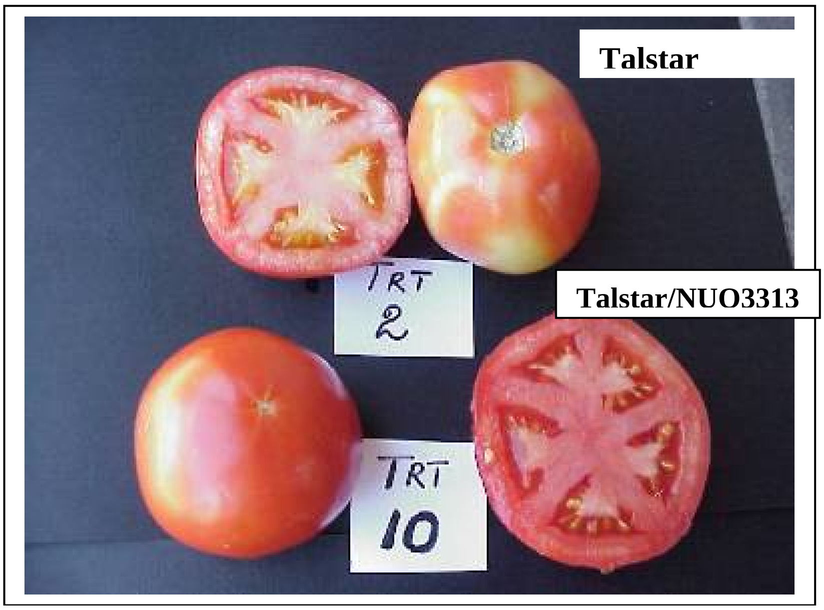


Fig. 5.4. Effect of pyrethroid / PBO split application on whitefly nymph populations

5.34 Effect on Fruit Quality and Marketable Yield

Fruits harvested from the plots treated with pyrethroid/PBO combinations had lower levels of irregular ripening damage than fruits from the Talstar® and Astound® only treatments (Fig. 5.6). The unmarketable fruit due to internal symptoms (white tissue) was reduced from 56 % in the untreated control to 1.5 -10% in the Talstar®/PBO treatments (Fig. 5.5).





5.6 Tomato irregular ripening symptoms – Talstar®/ NUQ3313 vs Talstar® alone

A higher percentage (79 to 88%) of first-grade fruits was harvested from Talstar®/PBO combination treatments where the crop was protected from SLW colonisation. The percentage of internally damaged fruit (white tissue) was higher in the Astound®/PBO treatments where around 55- 70% of fruit were at first grade quality.

The untreated control, and the Talstar® and Astound® only treatments had lower percentages of first-grade marketable fruits (25 to 53%) and fruit rejection was mainly due to severe internal damage and sooty mould contamination. In Queensland, SLW populations have been exposed to pyrethroid insecticides for over ten years. Control failures with pyrethroids have been reported since 2003. High levels of resistance to pyrethroid insecticides has been reported in field populations of SLW in various regions of Queensland (see Chapter 4 in this report).

This study found that the combination of PBOs (Enervate or NUQ 3313) with Talstar® provided better control of SLW than the pyrethroid alone. The results showed that pre-treatment with PBO three to five hours before pyrethroid application was better than the same combinations as tank-mixtures. Previous research in cotton has demonstrated that pre-treating with PBO, followed by an appropriately timed pyrethroid spray, produced better control compared to a pyrethroid alone or a pyrethroid plus PBO tank mix (Young *et al,* 2006). In cotton, over 75% whitefly mortality was achieved by pre-spraying crops with PBO and five hours later with alpha-cypermethrin (Gunning *et al*, 2004).

Field trial results have shown that the timing of PBO application is criticial in whitefly control. Pyrethroids penetrate the insect cuticle and are metabolised by esterase more rapidly than the action of PBO in the whitefly (Gunning *et al* 2004). Therefore, PBO should be applied several hours prior to the pyrethroid as to maximise the esterase inhibition in resistance whitefly population.

Even though split applications (spraying PBO a few hours prior to the pyrethroid application) performed better than tank mixtures of PBO + pyrethroid, it may not be adopted by large-scale growers because of additional spray cost and time. However, research by NSW DPI in collaboration with Rothamsted Research UK has explored the use of microencapsulated pyrethroid and PBO to produce a suitable time delay between PBO application and pyrethroid release onto the insect pests (Gunning per. com.). This microencapsulated techniques works by giving a quick release of PBO soon after application, and delayed release of the pyrethroid.

Controlling whitefly adult populations before they establish in the crops is critically important for successful whitefly management. If the adults colonise in large numbers and oviposit on leaves, it becomes more difficult to control the nymphs and subsequent generations. Therefore, quick knockdown products such as Talstar®/PBO mixtures will play an important role in SLW management programs. A recent SLW study in melons also demonstrated that a Talstar® +Enervate® mixture provided better adult control than Talstar® alone (Kay & Subramaniam 2005).

APVMA approval of the PBO product NQU-3313 (Synergy ®) has provided additional support for the resistance management program (Subramaniam and Heisswolf 2006) that has been widely used to overcome pyrethroid resistance in SLW populations. PBO in combination with bifenthrin is very useful for adult control when rotated with pyriproxyfen (Admiral®) and imidacloprid (Confidor®) to manage SLW in vegetables.

5.4 Conclusion

This study clearly shows the synergistic effect of PBO/ pyrethroid combinations against SLW. When compared to pyrethroid only treatments, Talstar® in combination with PBOs was significantly more efficacious and provided better whitefly control.

- Among the combinations tested, the split application of Talstar® with NQU-3313 or Enervate® provided the most effective control of SLW adults, the greatest reduction in egg numbers, low nymph populations and more marketable fruit.
- Talstar® with Enervate® and NUQ-3313 provided better SLW control than the equivalent Astound® combinations.
- Occasionally, NQU-3313 with Talstar® provided better synergism than the Enervate/ Talstar® combination.
- Tank mixtures of Talstar® and NQU-3313 or Enervate® may be better options for the vegetable industry because of lower costs than split applications.

5.5 Summary

This study examined the synergism of bifenthrin (Talstar®) and alpha-cypermethrin (Astound®) with two piperonyl butoxides (PBO- Enervate and NUQ-3313) against silverleaf whitefly (SLW). Two pyrethroid only treatments, eight PBO/pyrethroid combinations and an untreated control were evaluated against SLW (*Bemisia tabaci* Biotype B) on tomato. The treatments were applied three times at 12 to 14 days intervals. Systematic leaf and suction sampling to assess the egg, nymph and adult stages were undertaken within treatments and the control plots until harvest. The effect of treatments on fruit quality was also evaluated at harvest.

Most of the PBO/pyrethroid combination treatments resulted in a significant reduction in adult populations and egg densities, compared to pyrethroid only treatments. Talstar® with PBO (Enervate® and NUQ 3313) combinations showed higher efficacy than the Astound combinations against SLW in the field.

Split application of PBO/ Talstar® provided better synergism and consistently resulted in fewer adults, eggs and nymphs and lower irregular ripening damage on fruits. Among tank-mixture combinations, NUQ3313+ Talstar® performed better than others. Among the PBOs, the improved formulation of NUQ3313 performed somewhat better than Enervate when they were combined with Talstar®.

Even after three applications, Talstar® or Astound® treatments did not give a significant level of control above the untreated control. The percentage of marketable fruits was higher in the Talstar®/PBO treatments than in the pyrethroid alone and untreated control plots.

This study demonstrated a high level of synergism when Talstar® was combined with PBOs for controlling SLW. Data from this trial was used to obtain a APVMA permit (PER9569, expiry date 31/12/07) in 2006. Nufarm used the report for the registration of Synergy® (piperonyl butoxide) in tomato and cucurbit crops. This tool has provided additional benefits for the insecticide resistance management program promoted for the vegetable industry.

5. 4 References

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5.6 Temperature and Rainfall data for the month of July/ August 2003

For July

Date	Temperature (°C) Maximum	Minimum	Evaporation (mm)	Rainfall (mm)
1	27.2	15.7		
2	28.7	16.4		
3	24.5	13.4		
4	22.3	9.6		
5	22.5	8.4		
6	24.5	16.9		
7	25.4	16.9	31.0	1.4
8	25.3	17.6		
9	25.2	17.9		
10	24.8	18.1		
11	25.5	18.4		
12	25.7	18.7		
13	25.5	19.2		
14	24.4	17.7	32.0	
15	24.3	17.3	**Trial started**	
16	24.1	17.6		
17	25.9	17.6		
18	25.0	18.7		
19	25.4	18.6		
20	24.3	17.7		1.0
21	24.4	17.3	40.0	
22	25.4	17.2		
23	25.6	16.1		
24	28.3	15.6		
25	22.9	11.4		
26	24.5	8.6		
27	22.5	8.4		
28	23.4	10.2	31.0	
29	24.6	10.4		
30	24.1	11.4		
31	24.3	9.4		

For August

Date	Temperature (°C) Maximum	Minimum	Mean	Evaporation (mm)	Rainfall (mm)
1	20.7	4.1	13.0		
2	22.7	4.2	14.9		
3	24.6	10.2	17.8		
4	24.3	16.3	19.0	36.0	
5	25.7	13.9	19.6		
6	26.4	13.7	19.3		
7	26.4	13.3	19.6		
8	26.2	13.3	19.8		
9	26.8	13.9	20.0		
10	26.4	14.6	20.5		
11	26.6	17.7	21.7	27.0	
12	26.2	17.3	21.2		
13	26.1	14.1	19.7	**First spray**	
14	26.6	13.7			
15	26.3	14.1	20.3		
16	26.0	15.9	20.7		
17	25.6	15.4	20.2		
18	25.0	12.3	18.6	30.0	
19	26.9	12.4	19.6		
20	26.6	14.1	20.7		
21	25.6	18.2	21.8		
22	26.5	19.7	22.5		
23	26.6	20.9	23.6		
24	28.1	20.0	23.4		
25	26.9	17.9	22.0	**Second spray**	
26	26.4	13.4	20.2	36.0	
27	26.2	13.8	20.3		
28	24.6	17.9	20.5		
29	25.2	18.4	20.6		
30	25.7	17.5	21.2		
31	26.4	16.0	21.8		

5.7 Temperature and Rainfall data for September 2003

For September

Date	Temperature (°C) Maximum	Minimum	Mean	Evaporation (mm)	Rainfall (mm)
1	27.9	17.3	22.0	38.0	
2	28.1	13.1	21.1		
3	26.8	13.2	19.5		
4	24.4	9.3	18.0		
5	26.4	14.6	20.7		
6	26.6	13.2	19.8		
7	26.6	13.3	20.1		
8	25.7	11.9	19.3	40.0	
9	25.7	12.9	19.7	**Third spray**	
10	27.2	13.8	20.5		
11	28.1	13.8	20.4		
12	27.0	13.5	20.7		
13	27.5	15.6	22.4		
14	28.4	21.6	24.5		
15	36.4	18.3	27.0	43.0	
16	33.6	13.2	22.4		
17	29.4	11.7	20.6		
18	29.0	15.1	22.0		
19	28.4	16.0	22.3		
20	27.3	17.1	22.3		
21	27.7	16.9	22.4		
22	27.4	15.1	22.1	49.0	
23	27.6	19.8	23.4		
24	27.6	15.3	22.2		
25	27.7	16.0	22.6		
26	27.8	17.3	23.0		
27	28.7	17.1	22.9		
28	29.1	17.9	23.5		
29	29.1	22.9	24.9	47.0	
30	27.9	20.3	24.1		

Chapter 6

Implementation of IPM for silverleaf whitefly in commercial farms

6.1 Background and commercial practices

Silverleaf whitefly (SLW) has been the major pest of vegetable crops for many years. In early 2008, severe outbreaks of SLW on several Burdekin farms resulted in crop losses of more than one million dollars. The heavy populations of whitefly caused damage to melons, pumpkins and eggplant through direct feeding which leads to the contamination of fruits with honeydew and sooty mould.

In the Bowen and Burdekin regions, the planting season which starts in February and continues through to September maintains the continuity of host plants for the pest. The standard practice for SLW control on farms included Confidor Guard® injection at planting followed by 5-8 foliar insecticides at weekly intervals. A sample spray program with a summary of the insecticides used for SLW control is listed in Appendix 1.

These frequent applications of insecticides led to the development of resistance to a degree that caused control failures in the field (see Chapter 4). Factors such as overlapping crop cycles, insecticide resistance and extensive crop losses have necessitated improved IPM practices in the region.

When the releases of the parasitoid *Eretmocerus hayati* started in 2006 most farms largely relied on insecticides to control SLW (Chapter 2). Growers had limited understanding of biological control, and were unaware how the parasitoid could potentially be incorporated into their existing pest management programs. A severe outbreak of SLW in the Burdekin early in 2008 further emphasised the need to integrate parasitoid releases with selective chemical control strategies.

This section reports on the outcomes of IPM programs that were implemented on three vegetable farms in Bowen and the Burdekin during 2008 and 2009.

6.2 Implementation of IPM methods

The principal objective of this work was to demonstrate to growers that the parasitoid could be used as one component of IPM in SLW control. Consequently, commercial farms were used to measure the contribution and interaction of biological control within melon and pumpkin pest management systems for silverleaf whitefly. This program included parasitoid (*Eretmocercus hayati)* releases in combination with crop monitoring, selective insecticides and best farm practices.

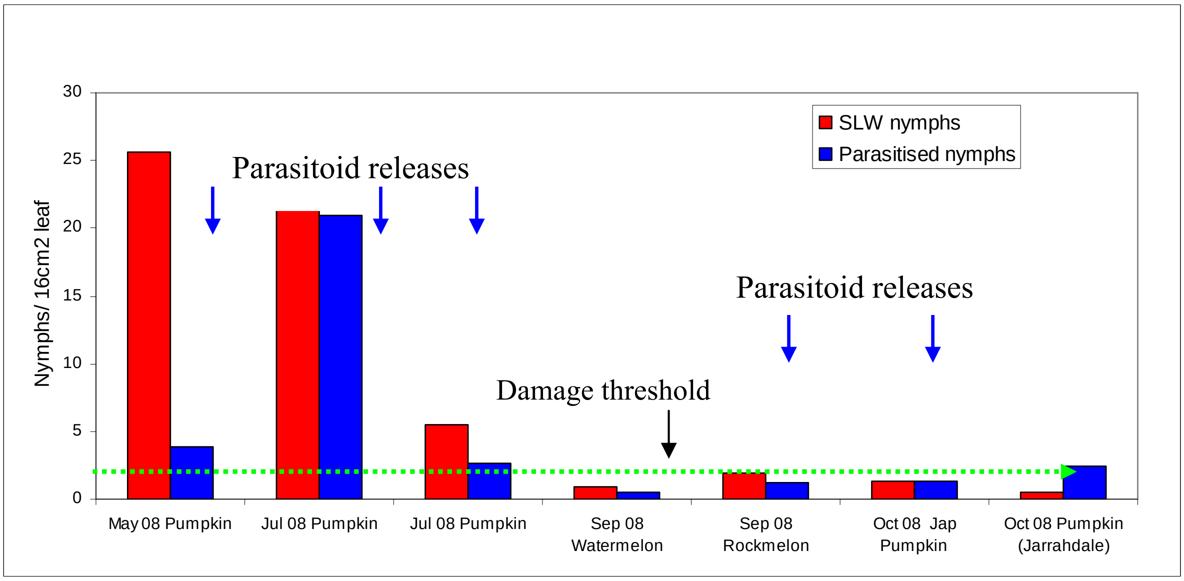
6.3 Pilot study: Pumpkin and melons in the Burdekin - 2008

In 2008, part of a commercial pumpkin and melon farm extending over 200 ha was selected for trialling parasitoid releases in combination with selective insecticides. This was to determine how well the parasitoids established and the level of control they could achieve, so that growers could observe the outcomes directly on farm. Project staff put extensive effort into demonstrating that whitefly control was more effective when growers used IPM strategies rather than more frequent calendar sprays of insecticides.

The severe SLW outbreak in March and April 2008 caused very high infestations in the pumpkin and melons crops. The mean nymph densities were 25 nymphs/ 16 cm^2 leaf which was around 10 fold higher than the damage threshold. Therefore, around 60,000 parasitoids were released during May/ June to contain the whitefly populations. Smaller releases followed to maintain the parasitoid and whitefly balance (Fig. 6.1).

The sampling results are summarised in Fig. 6.1. In the parasitoid-release blocks, the parasitism levels increased from 13 to 53% while the whitefly nymph densities declined from 25 to 6 nymphs/ $16cm^2$ leaf within 6 weeks of the initial release. Thereafter, the whitefly nymphs densities remained below 2.0 nymphs per $16cm^2$ leaf or below the damage threshold.

Fig 6.1 Integration of parasitoids with insecticides in melon and pumpkin crops, Burdekin 2008



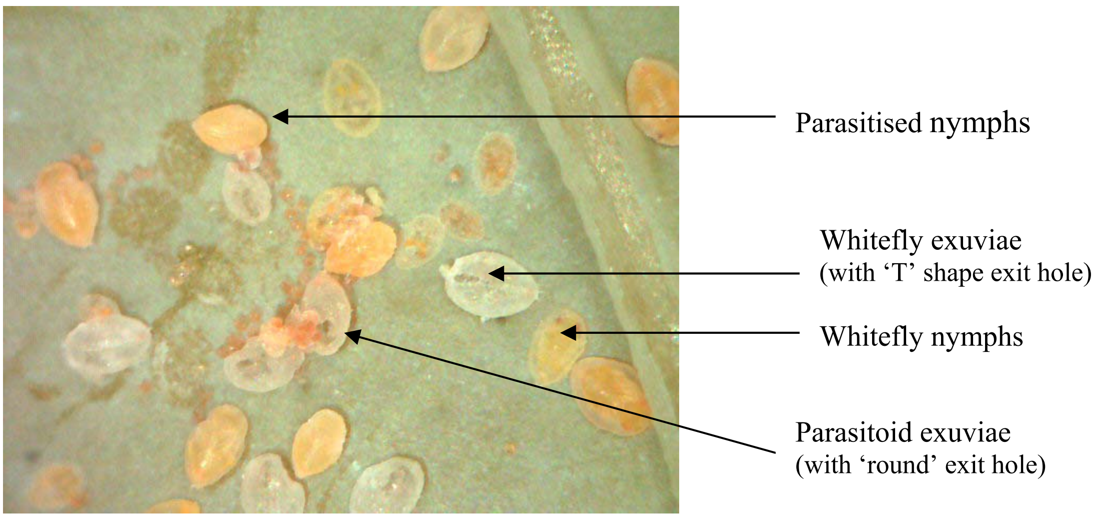
6.4 IPM implementation in pumpkin and melons in the Burdekin - 2009

Based on the success of the pilot study in 2008, the grower agreed to implement an IPM program over his entire farming enterprise for the 2009 season. The program was designed in consultation with the farm manager to ensure its compatibility with existing management practices. Some changes were made to the spray schedule based on the sampling results of the previous season.

The pumpkin and melon crops were grown on 12 farms located within 10km of the packhouse. The farm sizes ranged 30 to 60 ha, and each had 5 to 8 blocks. Pumpkin and melons are short duration crops (3 to 4 months) that are planted in sequence at weekly intervals. The planting starts in February and continues until October to ensure continuous supply for markets.

To provide the grower with more confidence in the IPM program regular farm visits were undertaken by project staff to undertake sampling and to pass on information on the status of the crops. The crops were sampled and assessed at fortnightly intervals by trained entomologists. Whitefly nymphs and parasitoid stages were counted on 2-3 leaves per plant from 20 to 40 plants systematically sampled from each planting. Leaves were selected from the lower and middle part of the vine to target various life stages. All samples were examined under a dissecting microscope when parasitised nymphs were recorded as a proportion of total whitefly nymphs to evaluate the changes in parasitism levels (Fig. 6. 2).

Fig. 6.2. Whitefly and parasitoid stages on a leaf (4 cm^2 leaf area)



The sample results were used to make decisions based on the relative levels of whiteflies to parasitoids. Actions were triggered by tentative threshold levels which were adjusted with crop phenology and changes in parasitism levels. Selective insecticides such as Admiral®, Chess® and Movento® were used, but only when necessary. The parasitoid releases were used as the main control strategy in this IPM program.

Parasitoid releases commenced during early SLW infestation of the crop to allow the parasitoids to attack the first generation of whitefly present and to increase the parasitoid population. Three release methods (as listed in Chapter 2) were used to establish the parasitoids in the field (Fig. 6.9).

SLW resistance to imidacloprid, pyriproxyfen and bifenthrin has already been documented (see Chapter 4) and these results were used to support the choice of effective insecticides when required.

Best farm practices also played a supporting role, and these included location of plantings, spray application and crop residue management at harvest. A key farm practice that was emphasised was a ‘crop cleanup’ strategy to prevent adult migration from declining crops to adjacent crops.

6.41 Results

The releases of *E. hayati* during early infestation of the crop by whiteflies was effective in achieving high levels of parasitism level before the crop reached the fruiting stage. Controlling whitefly nymphs during the vegetative stage in melons is very important to avoid honeydew or sooty mould contamination of the fruits (Fig. 6.3).

Fig. 6.3 Sooty mould on melon fruits due to whitefly infestation

Rates of parasitism increased within 2 to 4 weeks of the initial release when up to 85% parasitism was recorded in the released crops (Fig. 6.8). In most plantings, mean whitefly nymph densities were below 2.0 nymphs per 16cm^2 leaf which was below the damage threshold level. Releasing parasitoids early in the crop's growth appears to stabilise the whitefly population in the crop. This has eliminated the need for applications of pyriproxyfen or bifenthrin which are often required to control the whiteflies (Fig 6.4 and 6.5).

Fig. 6.4 Percentage parasitism and density of whitefly nymphs in early season melons in the Burdekin, 2009

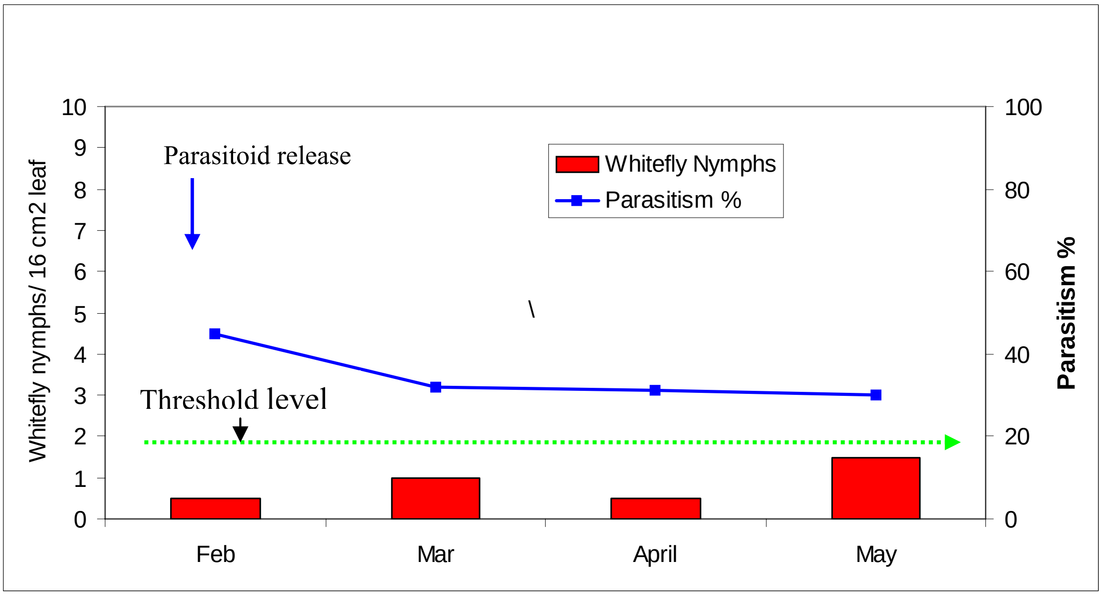
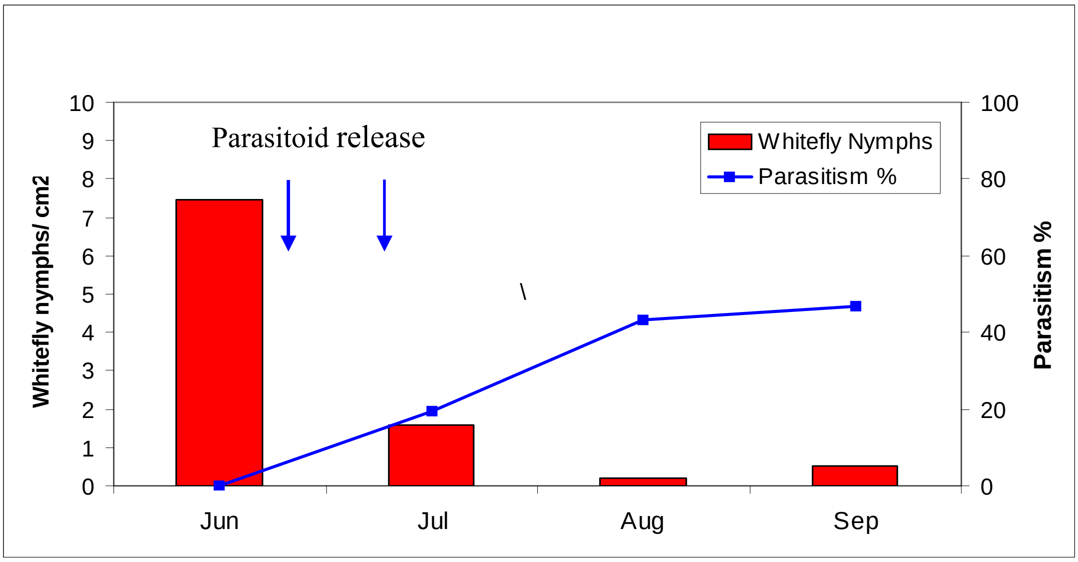
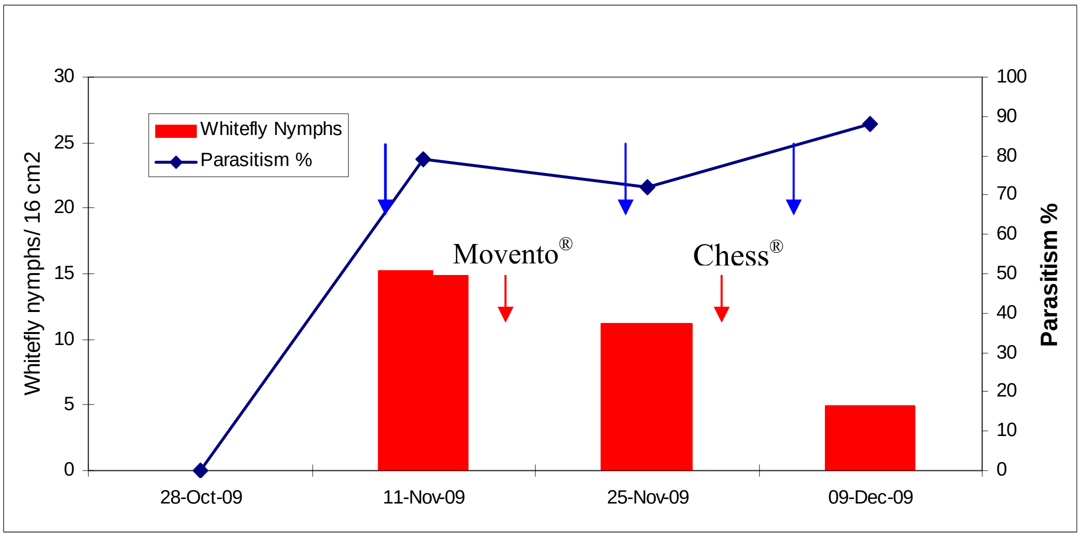


Fig. 6.5 Percentage .parasitism and density of whitefly nymphs in mid-season pumpkins in the Burdekin, 2009



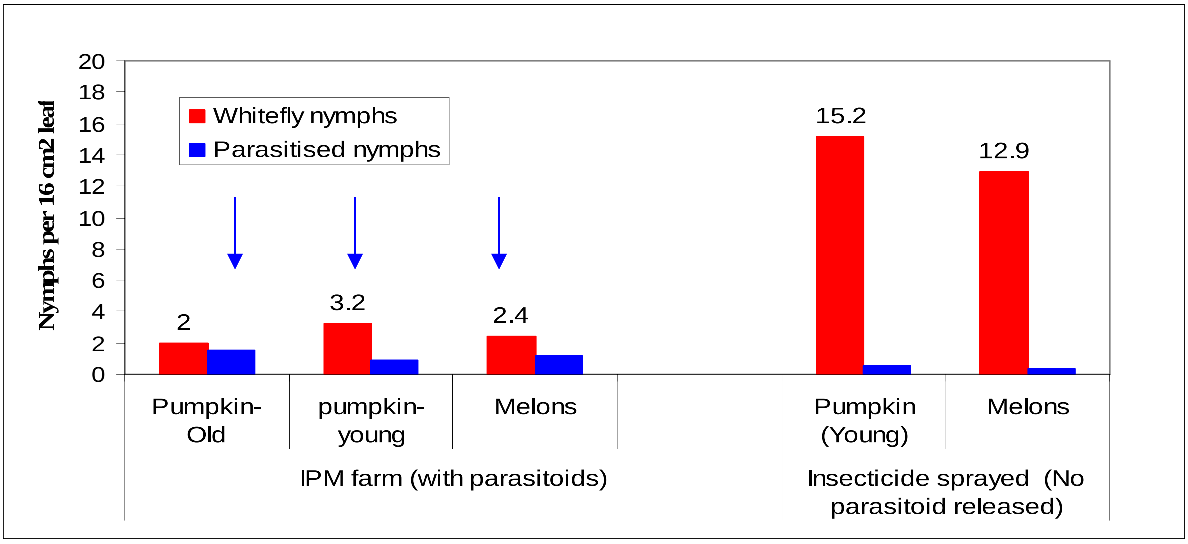
The late season crops planted in September and October had high whitefly infestation levels because of migration from adjacent declining crops. These had received two or three parasitoid releases per crop which were followed by applications of Chess® and Movento® to control adults and nymphs, respectively. During this period the whitefly density increased to 15 nymphs/ 16 cm^2 leaf area while parasitism gradually increased to 90%. This ultimately resulted in a reduction in whitefly density to below 5.0 nymphs/ 16cm^2 leaf area (Fig. 6. 6). However, more parasitoid releases were required for late season crops due to more rapid whitefly population growth on such crops.

Fig. 6.6 Percentage parasitism and density of whitefly nymphs in late season melons in the Burdekin, 2009



The proportion of parasitised nymphs in IPM crops averaged 60% compared to below 10% for conventional farms. Also, whitefly populations in IPM crops tended to decrease as the crops matured. This decrease was not seen on conventional farms where whitefly nymphs densities increased to 13 nymphs per 16 cm^2 leaf towards the end of the growing season (Fig. 6. 7).

Fig 6.7 Comparison of IPM and conventional farms in Burdekin, Aug 2009



Using conventional methods, growers spent between $390 and $600 per ha for whitefly control but still had 10 to 40% of fruit lost due to honeydew contamination. For the IPM program which included the parasitoid releases combined with selective insecticides, the control cost was reduced by an average of $300 per ha. The main economic benefit was the reduction of contaminated fruits which was below 5% in the IPM blocks.

This commercial implementation study has demonstrated that parasitoid releases exerted control pressure on SLW. To clearly show this 2 or 3 consecutive releases at fortnightly intervals showed growers the rapid decline in whitefly levels in their crops. This encouraged them to make changes to the routine application of insecticides, which allowed the establishment of the parasitoids on farm.

Fig. 6.8 Overall parasitism and whitefly levels on a farm practising IPM.
(average of sample data of all melons planted from Mar to Dec 2009)

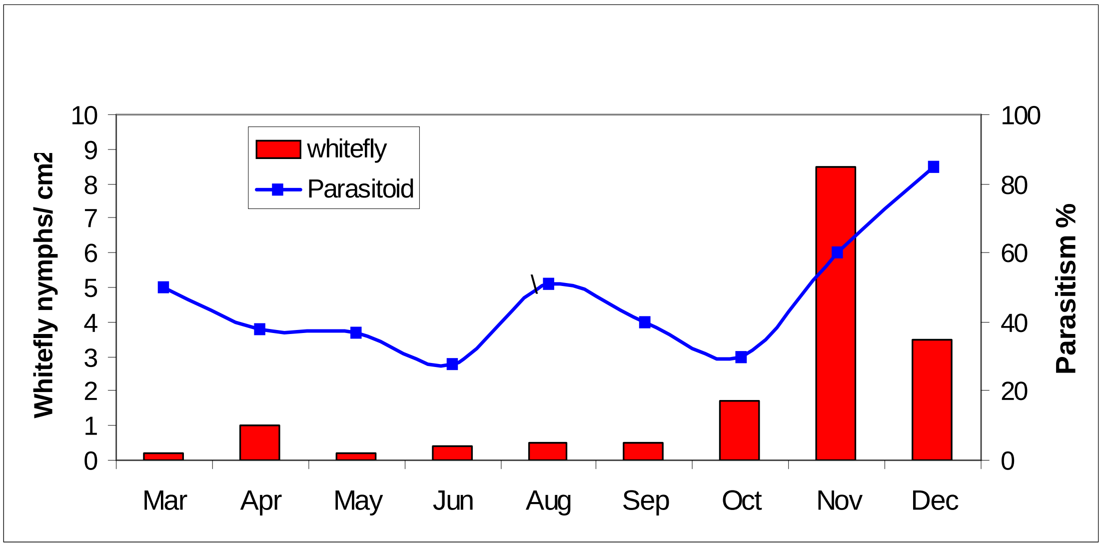


Fig. 6.9 An IPM melon farm with 'Banker plants' for parasitoid release, Burdekin

Banker plants
for parasitoid
dispersal

6.5 Implementation of IPM in Gumlu 2008

In 2008, a 210 ha commercial melon and pumpkin farm at Gumlu was selected for implementing an IPM program for SLW (Fig 6.11). The farm was visited on a regular basis throughout the season to release parasitoids and to provide support to the grower with pest management decisions such as monitoring, spray threshold levels, parasitoid releases and selecting insecticides. Data were collected on SLW infestation and parasitism levels, as well as the insecticide sprays used, to measure the economic benefit from the IPM program.

The data indicated that the IPM strategies maintained the whitefly population at very low levels with the parasitoids contributing between 60 and 80% to the whitefly control (Fig. 6.10). Most of melon and pumpkin plantings had only 1 or 2 insecticide sprays per crop, while the late plantings (October to November) received between 2 to 4 sprays but this was 60 to 75% less than the previous seasons. In dollar terms, the grower had a saving over $60,000 on insecticides for the 2008 season compared with previous seasons.

Fig. 6.10 SLW control and Parasitism levels in 2008
(Melon farm adopted IPM practices)

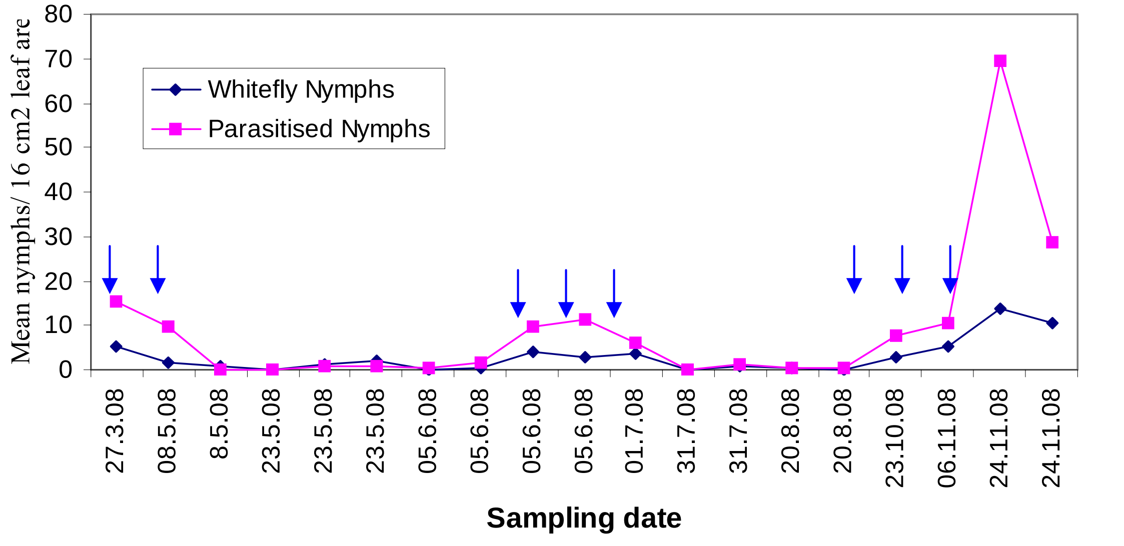


Fig. 6.11 A successful pumpkin farm adopted IPM program in Gumlu

6.6 Discussion

One-on-one extension between project staff and growers has been critical to the adoption of the IPM programs. This has enhanced grower confidence and limited the uncertainty over spraying decisions. On-farm demonstrations, regular field visits and communicating the results to growers have all been essential to the success of these programs. The outcomes of the 2008 and 2009 studies show that for IPM to be effective crops need to be monitored regularly and the right decisions made at appropriate times. The perception that IPM involves greater risk can be attributed to inadequate monitoring which can lead to increased pest problems.

IPM helps to manage insecticide resistance by reducing overall use of insecticides and hence selection pressure on SLW and other pests. Traditionally, growers have used from six to ten insecticide applications for SLW control. Since the permit approval of imidacloprid (Confidor®) in 2003, its use as a soil application became the standard whitefly control practice for some vegetable crops. Imidacloprid applied at planting normally gave control for 4 to 5 weeks (Subramaniam 2003). However, both efficacy and the duration of residual control have declined in the last 2 years. Admiral® and Movento® are more selective than imidacloprid and appeared to be less toxic to the parasitoids. This was viewed as a favourable factor in implementing a parasitoid release program in vegetables. While the insect growth regulators (Applaud® and Admiral®) were confirmed as highly selective, a commercial-scale study demonstrated that Movento® is equally selective as the IGRs but that its selectivity is dosage dependent (Naranjo and Ellsworth, 2008). The insecticide resistance management strategy (IRMS) is critical for conserving the effectiveness of the selective insecticides that are important for IPM.

In high value crops such as melons and pumpkins, growers are mainly concerned about crop losses. Therefore, main focus was on maintaining whitefly and parasitoid equilibrium so that the fruit contamination was minimised. However, used the reduction of insecticide sprays as a 'measure of success' rather than an economic benefit.

Feed back from the participating growers showed a high level of satisfaction with the IPM program. Evidence for this was their continued collaboration and ongoing contribution (financial and in-kind) to the program during the 2010 season.

The cost benefit of an IPM program has not been fully calculated yet, as data from 2010 is required for a meaningful outcome. A conservative estimate based on the reduction in insecticide sprays and the increased proportion of marketable fruits would see a benefit of around $2000/ ha.

6.7 Summary

In 2008 and 2009, three farms in Bowen and the Burdekin implemented IPM programs with the extensive support of DEEDI staff. This has involved regular field visits, monitoring and sampling crops, parasitoid releases and assistance with decision making for pest management. Adoption of IPM strategies has resulted in improved whitefly control, with parasitoids contributing between 50 and 80% of the control. Most of melon and pumpkin plantings had around 1 to 2 insecticide sprays per crop, while late plantings (October to November) received between 2 and 4 sprays. Spray records from IPM crops show an average saving of 40% in insecticide use compared with non-IPM crops. When insecticides were used they were selective. Broad-spectrum insecticides, such as pyrethroids and organophosphates, should be avoided as foliar sprays as they are too disruptive to the beneficials.

The parasitoids do not eliminate the whitefly populations, but maintain a balance with them so that damage is generally held below thresholds. When pest densities exceed the thresholds, selective insecticide treatments or additional parasitoid releases are required. Accurate monitoring is essential for taking appropriate decisions. Insecticide intervention is considered vital in some situations to control high infestations of whitefly nymphs, so as to reduce economic damage and spread to other crops.

There were four major reasons for the success of IPM implementation in these farms:

- Crisis – pest outbreak and field control failures with insecticide applications which led to crop losses. This encouraged growers to consider alternative options.
- Availability of alternative option – establishment of parasitoid breeding facilities at Bowen Research Station provided regular supply of parasitoids. Availability of selective insecticides to integrate with parasitoids is major advantage.
- Expert service – availability of expert entomologists to provide advise and assisting growers on decision making.
- Growers collaboration – growers continuous collaboration, in-kind support and adopted the recommendations.

6.8 Reference

Naranjo, S.E and Ellsworth, P.C (2008) Conservation of Natural Enemies Through use of Selective Insecticides: Recent Developments. Fourth International Bemisia Workshop International Whitefly Genomics Workshop. 53pp. *Journal of Insect Science* 8.

Subramaniam, S (2003). Evaluation of Confidor® soil applications against silverleaf whitefly (*Bemisia tabaci* Biotype B) on zucchini. Research report to Bayer Crop Science.19 pp.

Chapter 7

Whitefly Management in the Lockyer Valley

7.1 Introduction

The Lockyer Valley is a major vegetable production district in south-east Queensland, based around the town of Gatton (27^{o} 56' S, 152^{o} 28' E). Vegetable crops grown include brassicas and crucifers, cucurbits, potatoes, sweet corn, carrots, beans, capsicums, tomatoes and lettuce, and there are large areas of lucerne.

Silverleaf whitefly, *Bemisia tabaci* (Gennadius) B-biotype (SLW), was first detected in the Lockyer Valley in 2002. It rapidly became a severe problem for the region with damaging outbreaks occurring between 2002 and 2005. Since then observations indicate that populations in the Lockyer Valley generally have been significantly lower than previous seasons. While the general population trend was low, a few hot spots were observed where SLW numbers were moderate to high. The reason for the lowering of population numbers is unclear, but may be due to factors such as weather (e.g. rainfall), reduced crop hosts (due to drought), beneficial insects (e.g. especially by *Eretmocerus hayati*, an exotic wasp species introduced by CSIRO in 2005), and improved management practices by growers.

Investigations on SLW in the Lockyer Valley focussed on two issues:
1. The seasonal occurrence of SLW and its parasitoids
2. Testing best management options to use against SLW.

The results of these investigations are reported here.

7. 2 Seasonal Occurrence of Silverleaf whitefly

7.21 Materials and Methods

Two studies were done to monitor and determine the seasonal occurrence and activity of SLW and its parasitoids in the Lockyer Valley. The first (Study A) monitored levels on commercial farms and the second (Study B) monitored SLW in plantings of broccoli at Gatton Research Station.

<u>*Study A*</u>
Three commercial vegetable properties located in the central Lockyer Valley were sampled weekly between October 2006 and October 2007.

Each property was assigned a reference number (e.g. Property 1, Property 2, Property 3). On each property both a weed and a crop host (Table 7.1) were sampled for SLW activity. Sampling consisted of selecting approximately the 5th mature leaf from each of 20 randomly selected plants. Each leaf was then excised from the plant and placed into a large paper bag. Bags were labelled with date, property reference number, GPS location and the host plant (i.e. weed or crop) and stored in a cool esky.

Samples were taken back to the laboratory and examined under a stereo-microscope and all eggs and nymphs were recorded. For each sample whitefly species were identified and recorded (i.e. SLW or greenhouse whitefly, *Trialeurodes vaporariorum*), and the number of unparasitised pupal cases and parasitised pupal cases were recorded.

Any later instar nymphs (i.e. 3rd - 4th instar nymphs) and exuviae observed on crop hosts during the microscopic examination were collected for evidence of parasitism. Third and 4th instar nymphs will stay alive sufficiently long for parasitoids to develop and emerge as adults and as parasitism occurs during the 1st – 2nd instar stages this gives a reasonable estimate of parasitism levels.

Nymphs collected from leaf samples were placed into emergence containers to capture parasitoids for later identification. The containers were observed every 2 - 3 days for 2 weeks for evidence of parasitism. Wasps were collected and preserved in 70% ethanol.

Attempts were made to obtain the spray records for each crop. Each property applied imidacloprid to crops pre-plant and made weekly applications of insecticides against a range of pests. However records of the actual insecticides used were not made available.

Table 7.1 List of host weeds and crops used to sample for SLW

	Property 1	Property 2	Property 3
Weed	Sowthistle and bellvine	Sowthistle and bellvine	Sowthistle and bellvine
Crop	Cabbage	Cabbage	Tomato and broccoli

Study B

A trial was established at the Department of Primary Industries and Fisheries, Gatton Research Station (GRS) in late 2006 to monitor SLW and parasitoid populations over 2 seasons in a continuously planted broccoli crop. The crop was sprayed only with *Bacillus thuringiensis* products to control caterpillar pests.

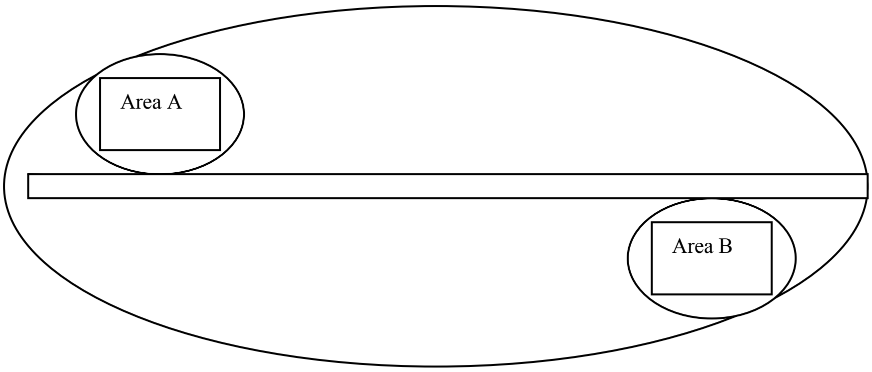
Every 6 weeks a bed of broccoli seedlings 50m long was planted within a block of three beds. Seedlings were given 2-3 weeks to establish and were then sampled for approximately 10 weeks. They were then removed and replaced by a new set of seedlings. At any one sampling two beds of plants were being used, an older established planting and a younger planting.

SLW adults, eggs and nymphs and the level of parasitism were monitored regularly in the crop from January 2007 until May 2008.

Two methods were used to sample SLW adults in the experimental plot. In the first yellow sticky cards (YSC) (6cm x 4cm) were attached to the top of plastic stakes and positioned just below the crop canopy, 2 per plot, for the duration of the trial. YSCs were collected and replaced weekly until December and fortnightly thereafter. Collected YSCs were taken to the laboratory and the number of SLW adults and parasitoid wasps on the 6cm x 4 cm card were recorded. The second method involved visual field sampling. Each week the 3rd youngest leaf of 20 randomly selected plants (10 from the new planting and 10 from the established planting) was assessed. The selected leaf was gently turned over and the number of adult SLW recorded.

The crop was sampled weekly to determine SLW egg and nymph numbers and parasitism activity. Ten plants were randomly selected in each bed (total of 20 plants). On each selected plant, the 3rd and 8th youngest leaf was excised. Leaves were placed into individual plastic bags, labelled for identification, taken back to the laboratory and examined under a stereomicroscope. Two 4.2cm diameter circles were marked on the underside of each leaf, one at the top immediately right of the mid-vein and one at the bottom immediately left of the mid-vein (Figure 7.1). All eggs and nymphs located inside each circle were recorded.

Fig. 7.1 Diagram of broccoli leaf showing two sampling areas.



Parasitism levels were monitored by collecting the oldest healthy leaf from each of 20- 25 plants. Leaves were taken back to the laboratory. Two 4th instar nymphs were randomly selected from each leaf and placed into emergence containers to capture parasitoids. The collection was observed every week for up to 4 weeks for evidence of parasitism, and wasps were collected. Wasps were identified to genus from January to May 2008.

7.22 Results

Study A

Figures 7.2 and 7.3 show the mean numbers of SLW nymphs per leaf for crops and weeds respectively for each Property.

SLW activity on crops and weeds was observed between December 2006 and August 2007. SLW populations on crops were greatest during February and May, peaking at approximately 8 nymphs per leaf. On weeds, SLW populations were greatest during July and August, peaking at approximately 30 nymphs per leaf.

Population fluctuations were observed during the survey. Periods of very low activity were observed between October to December 2006, and between August and October 2007 in both crop and weed hosts. A period of decline was also observed during March on crop hosts.

Parasitism levels in crop hosts are shown in Figure 7.4. The level of parasitism followed the activity of SLW, with levels fluctuating between zero and 60 percent.

In July-early August 2007, crops that had high SLW populations were harvested. SLW populations on weeds increased in August-early September 2007. Weeds on properties were sprayed with herbicide during late August 2007.

Fig. 7.2 Mean number of SLW nymphs on leaves of crop hosts on three Lockyer Valley Properties 2006-2007

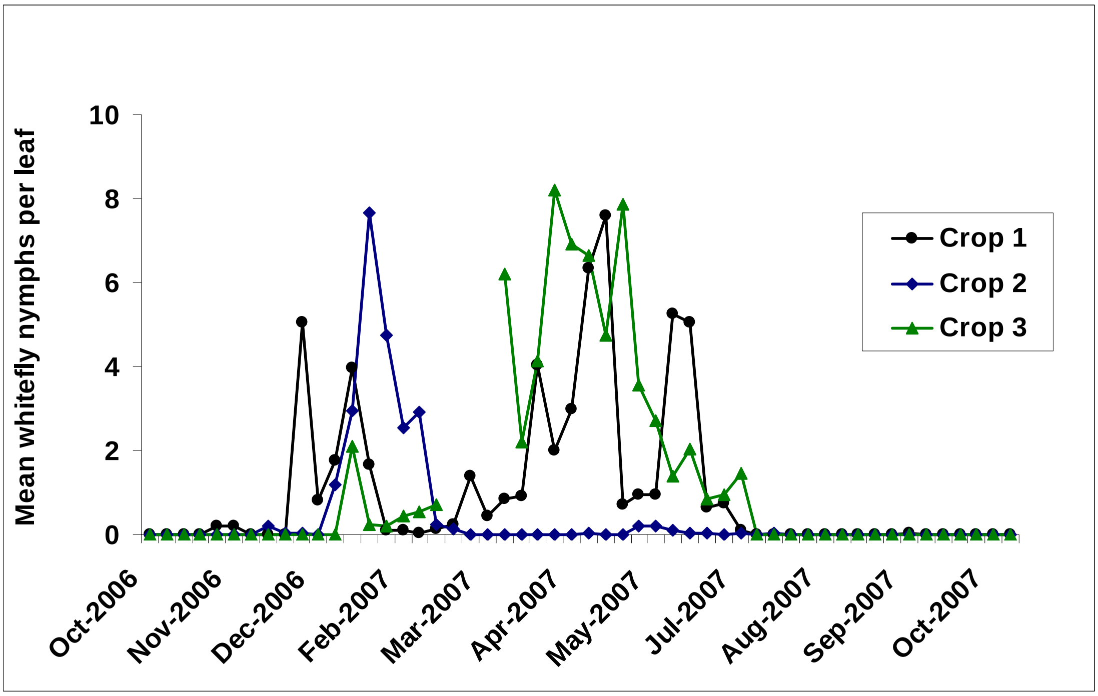


Fig 7.3 Mean number of SLW nymphs on leaves of weed hosts on three Lockyer Valley Properties 2006-2007

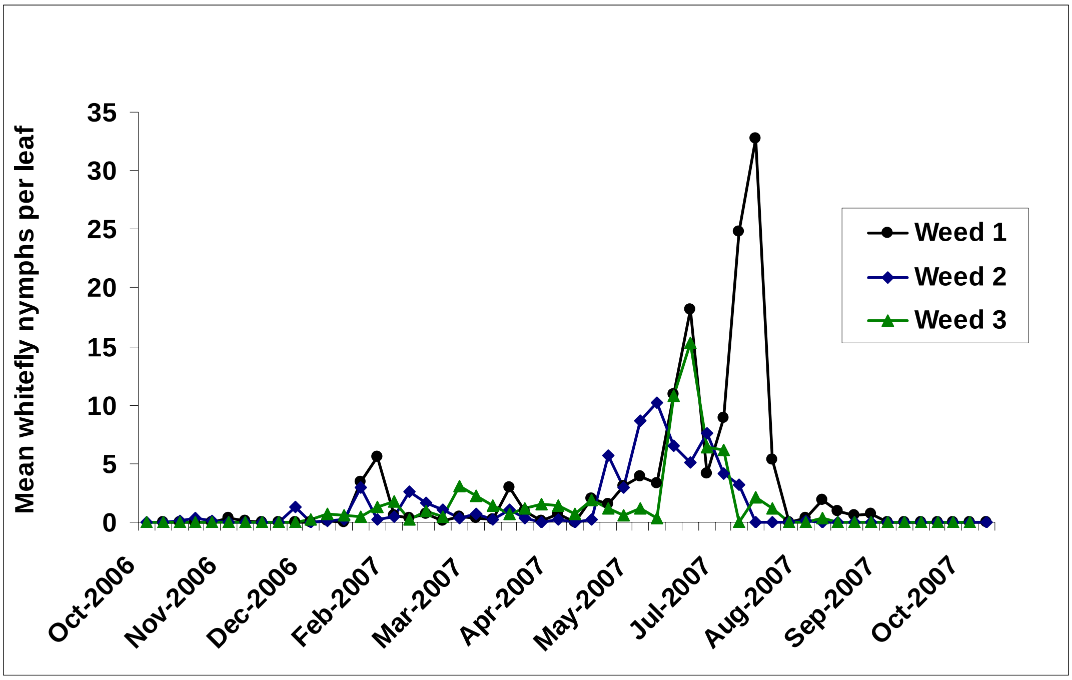
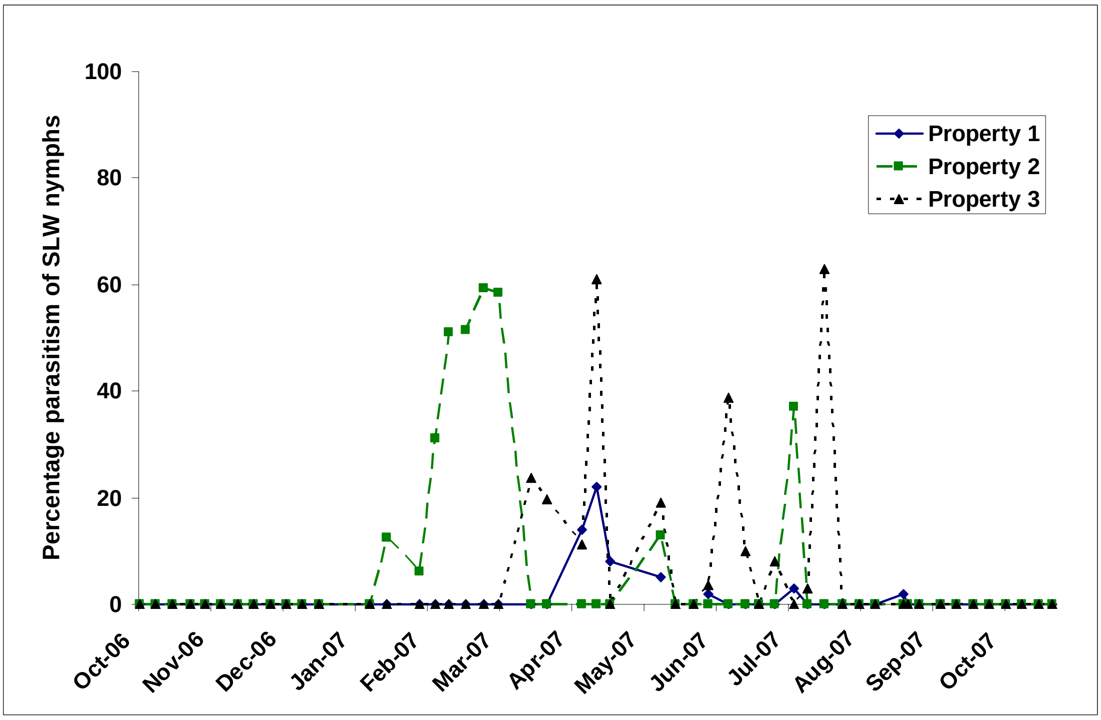


Fig 7.4 Percentage parasitism of SLW nymphs on leaves of crop hosts on three Lockyer Valley Properties 2006-2007



Study B

Figure 7.5 shows the numbers of SLW adults, eggs and nymphs recorded in the visual monitoring. The results show SLW was active from January to June 2007 and November to April 2008 with peak times for adult activity from early March to late April in 2007 and January to March in 2008. SLW activity was negligible in the crop from early July to early November and the overall activity was lower in summer 2008 compared to summer 2007.

Fig. 7.5 Numbers of SLW adults, eggs and nymphs recorded by visual monitoring.

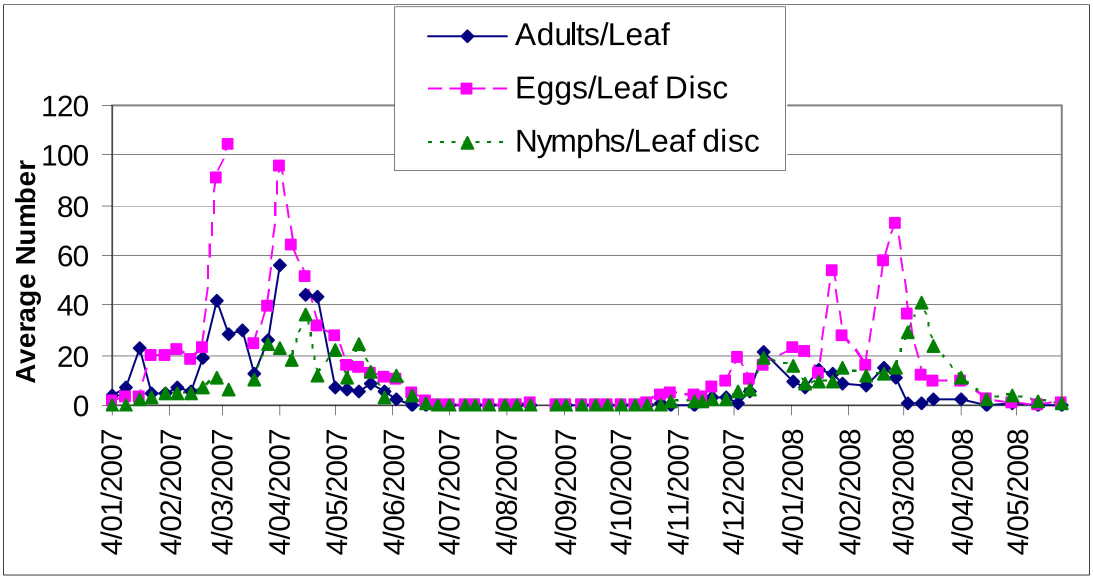
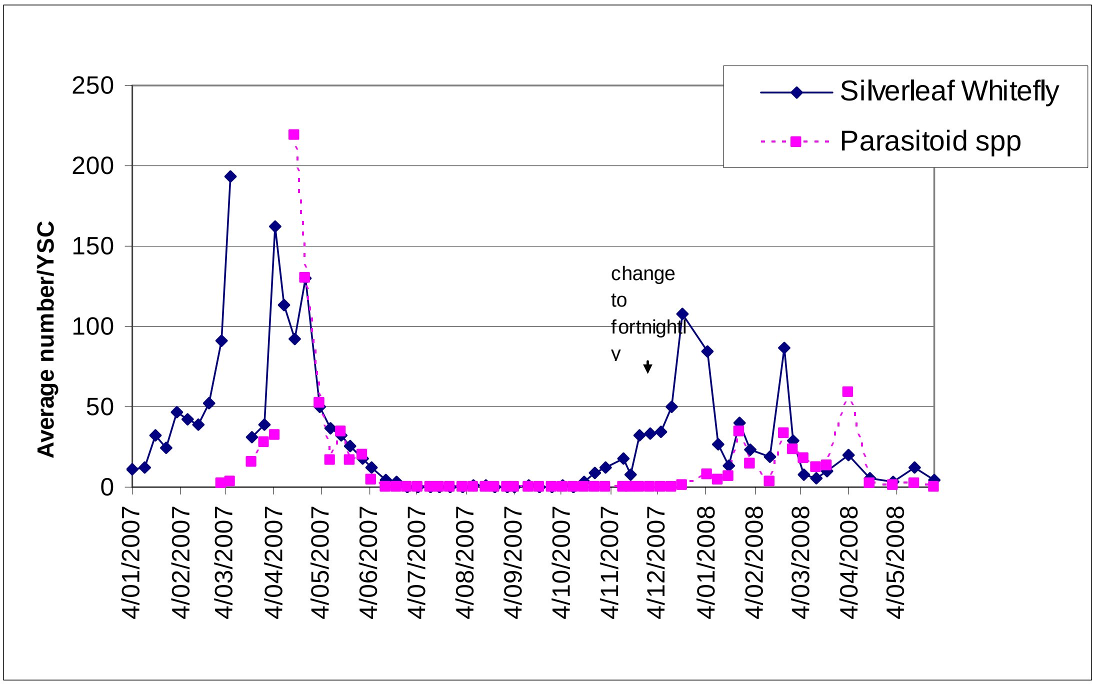


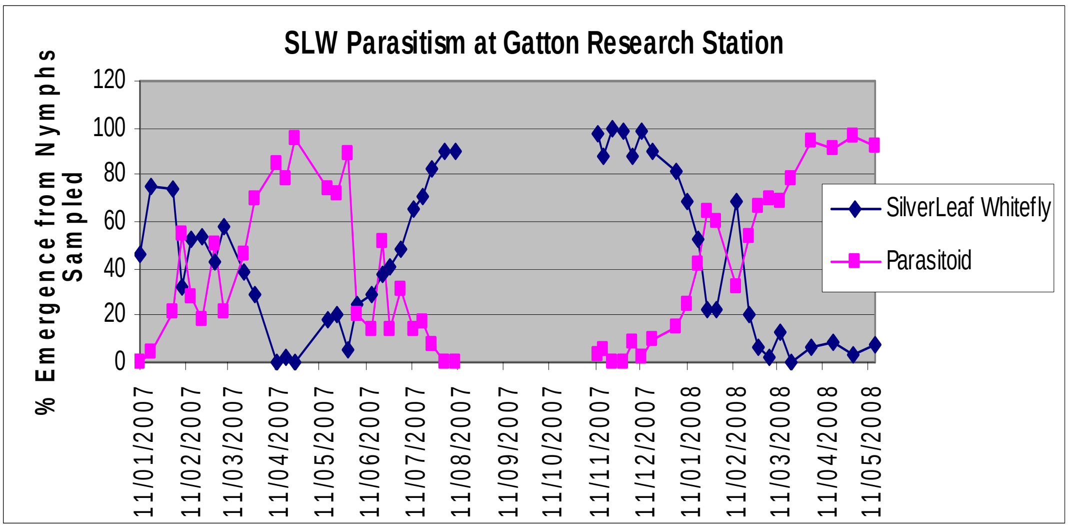
Figure 7.6 illustrates the counts of SLW and parasitoid wasps recorded on the yellow sticky cards. Adult SLW numbers began to build rapidly after spring and in March 2007 the YSCs were trapping an average, of > 100 adults/card. The parasitoid numbers increased in March 2007 and after a peak in activity in April both SLW and parasitoid numbers rapidly declined. Only very low numbers of SLW and no parasitoids were recorded until October-November when numbers again started to increase. During the 2008 season, peak activity of SLW was observed on YSCs in December with an increase in the parasitoid population observed from January.

Fig 7.6 SLW and parasitoid catches on yellow sticky cards.



Emergence results (Figure 7.7) from nymphs collected to determine parasitism levels indicate parasitoid activity from late January 2007 and from December 2008. Fluctuating levels of parasitism, between 20-55%, were recorded from January to March 2007. By late March the parasitoids had become well established within the crop and levels of 70- 100% parasitism of collected SLW nymphs were recorded. Parasitism levels declined sharply in June and were then recorded at lower levels until July when insufficient numbers of nymphs were able to be collected. SLW became active again in the crop in November 2007 with parasitoid numbers remaining low until December. Increasing levels of parasitism in January 2008 began to significantly impact on the SLW population, with levels of 80 -100% parasitism recorded from March to May 2008.

Fig 7.7 Proportions of SLW and parasitoids emerging from collected nymphs.



Eretmocerus and *Encarsia* were the two genera of parasitoids that emerged from collected nymphs. Eretmocerus comprised 85-100% of the emerged wasps from January to mid March 2008. Their proportion then fell rapidly to almost zero by mid April. *Encarsia* made up over 95% of the reared parasitoids until the survey finished in late May.

7.23 Discussion

The results of monitoring from crops and weeds on commercial farms in 2006-2007 indicated that SLW was active from December to August. Decline in SLW numbers in August coincided with crop harvesting. SLW populations appeared to then move from crop to weeds. However, these populations crashed when weeds were sprayed with herbicides. Insecticide applications may also have affected SLW populations in crop hosts as SLW densities were on average lower on crop hosts compared with weeds. Low parasitism levels of SLW observed during the survey suggest there may be a lag phase or growers' management practices are disruptive. Insecticide applications probably negatively impacted on parasitism by disrupting wasp populations in crop hosts.

In comparison, SLW activity in 2007-2008 in the continuous broccoli planting was confined to the warmer times of year, from November to May, with almost no activity from June to October. This pattern, with higher numbers in summer and little activity in winter, would seem more likely and it is similar to that reported from other areas in southern Queensland such as the Bundaberg district. Parasitoids were more active from January to June.

High egg densities observed during March-April 2007 and January - March 2008 in the broccoli plantings (Figure 7.5) did not result in high SLW adult numbers. Emergence results (Figure 7.7) and YSC trapping (Figure 7.6) from these periods showed high levels of parasitism, indicating the parasitoid was highly active in the crop and impacted significantly on the SLW population.

The parasitoids appear to take longer than SLW to establish after winter as there is a lag time of approximately 2 months between SLW and *Eretmocerus* becoming active in the crop (Figure 7.6). During this period of parasitoid establishment, growers need to resist using insecticides to control SLW as these chemicals can impact on the parasitoid population.

Both studies indicate that populations of SLW continue to remain low, compared with populations the Lockyer Valley experienced between 2002 – 2005, with the Study B showing a decline in numbers from 2007 to 2008. The reasons for this decline are unclear but could be attributable to a combination of the following factors:

- Use of the systemic insecticide imidacloprid as a pre-plant seedling drench.
- Releases of the introduced parasitic wasp *Eretmocerus hayati*.
- Adoption of IPM friendly strategies including good cultural practices, crop monitoring and application of insecticides only when necessary, use of narrow spectrum insecticides and implementation of Insecticide Resistance Management Strategies by growers in the Lockyer Valley.

The results from this seasonal occurrence study serve as a baseline for understanding SLW and parasitoid population dynamics in Brassica crop production in the Lockyer Valley. This provides management opportunities, such as use of production breaks, crop rotation, and strategic insecticide applications, that have significant implications for successful IPM and area wide management programs.

7. 3 Best Management Options for silverleaf whitefly

The integrated pest management (IPM) strategies employed against a variety of mainly lepidopteran pests by brassica growers in Australia included "soft chemical" approaches to manage the insect pests and reduce damage. SLW has the potential to disrupt this IPM approach because some disruptive insecticides are part of management plans designed for SLW control in vegetable crops.

It was therefore important that management tools be assessed to find the best management practice that will deliver effective management of SLW, but also maintain the IPM strategies designed for other brassica insect pests.

The experiment reported here investigated the effectiveness of a best management strategy for SLW and compared it with the current standard industry practice that included applications of bifenthrin.

7.31 Materials and Methods

A 0.2 ha block of broccoli, consisting of three bays of broccoli 12 rows wide and 100m long with bays separated by a 3m laneway, was sown at Gatton Research Station in March 2007. The crop was grown with standard fertiliser and irrigation practices but insecticide applications were restricted to the trial treatments.

The trial was a replicated design with three treatments and four replicates. Plots were a 20m length of bay with a 5m buffer of broccoli separating plots along the bay.

There were three treatments. The Control treatment had no insecticides applied at all. The best management option (BMO) treatment had imidacloprid (Confidor® 200SC) applied as a seedling dressing in the nursery to seedlings just before planting out The Standard treatment had the seedling drench with imidacloprid and two applications of bifenthrin at 40 gai/ha (Talstar®100 at 400mL/ha) to the plants in the field. The bifenthrin sprays were applied using a Hardy hydraulic air-assisted boom applying 435 L/ha of spray mix.

A yellow sticky card (YSC) ($5cm^2$) was attached to the top of bamboo stake and positioned at crop canopy height in each plot for the duration of experiment. YSCs were collected weekly and the number of SLW adults on each card counted and recorded.

A total of 40 leaves in each treatment (10 per plot) were randomly sampled at weekly intervals. Leaves were carefully examined and numbers of adult SLW counted. Leaves were excised, bagged and returned to the laboratory. In the laboratory two 4.2cm diameter circles were marked on the underside of each leaf, one at the top immediately right of the mid-vein and one at the bottom immediately left of the mid-vein (Figure 7.1). The marked portions of each leaf were examined under a dissecting microscope and the number and location of SLW eggs and nymphs were recorded. Nymphs were classified as small (1^{st}, 2^{nd} and 3^{rd} instar) or large (red-eye pupae and exuviae).

Any later instar nymphs (i.e. 3^{rd} - 4^{th} instar nymphs) observed during above procedure were collected to assess parasitism. Nymphs collected from leaf samples were placed into emergence containers to capture parasitoids. Collections were observed every 2 - 3 days for 2 weeks and any wasps that emerged were preserved in 70% ethanol.

At harvest 10 plants per plot were assessed for quality and the presence of the physiological disorder white stem.

Average minimum and maximum field temperatures experienced during experiment were 10^0C and 25^0C, respectively.

7.32 Results

Numbers of SLW were very low during the trial. Numbers of SLW adults, eggs and nymphs recorded in each treatment are shown in Figures 7.8 to 7.11. The control treatment had considerably higher number of all SLW life-stages compared with the BMO and Standard treatments. No appreciable difference was observed in numbers of SLW in any stage between the BMO and Standard treatments.

No differences in population of SLW adults sampled on YSC were seen between treatments in the first 2-3 weeks of the crops life (Figure 7.12). Differences between the levels of adult SLW seen on YSC compared with on leaves were observed in the BMP and the Standard Treatments.

Results presented in Figures 7.8 to 7.11 also indicate that two generations of SLW developed in the crop. This is particularly evident in the graphs of small and large nymphs where two distinct peaks can be seen.

Harvest damage assessments showed no differences between treatments in plant vigour or quality, such as the physiological disorder 'white stem' caused by SLW feeding.

Parasitism levels were hard to determine as very few large nymphs (4^{th} instar) were recorded during the experiment. No parasitism was observed in the small number of nymphs collected from the control plots.

Fig. 7.8 Mean number of SLW adults observed on leaves in each treatment

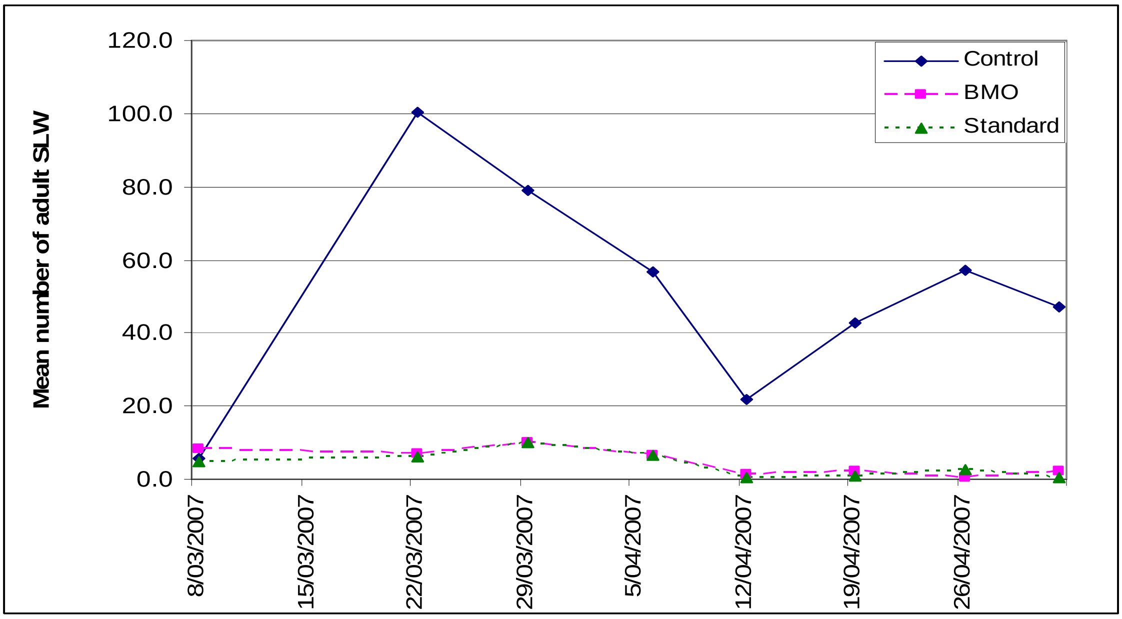


Fig. 7.9 Mean number of SLW eggs observed on leaves in each treatment

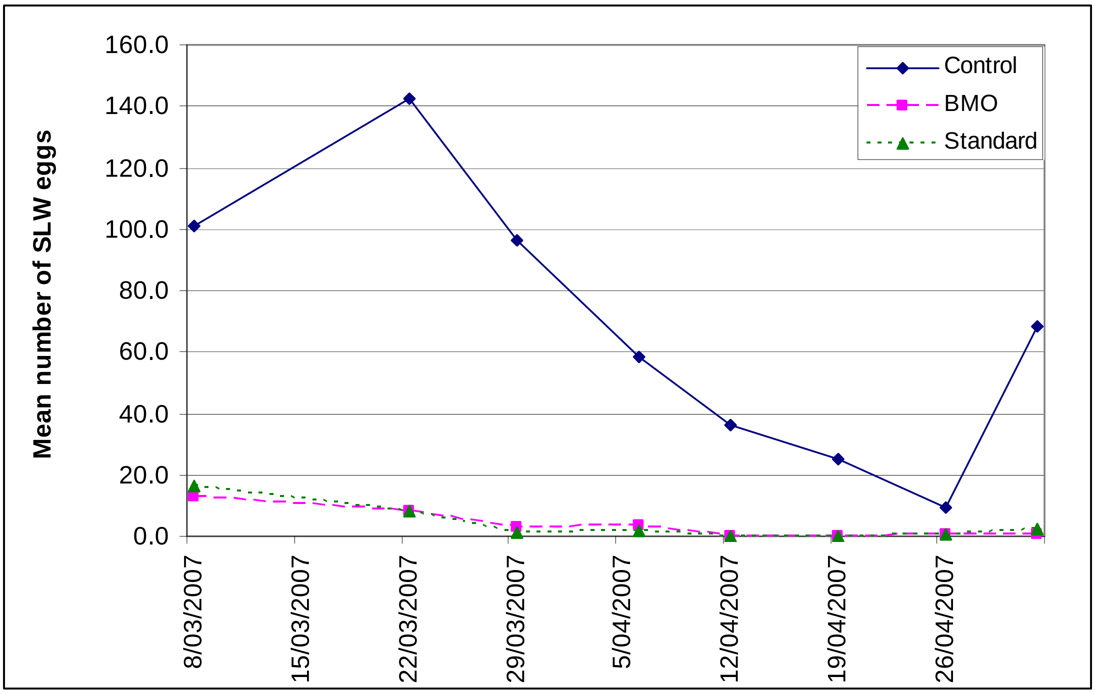


Fig 7.10 Mean number of SLW small nymphs observed on leaves in each treatment

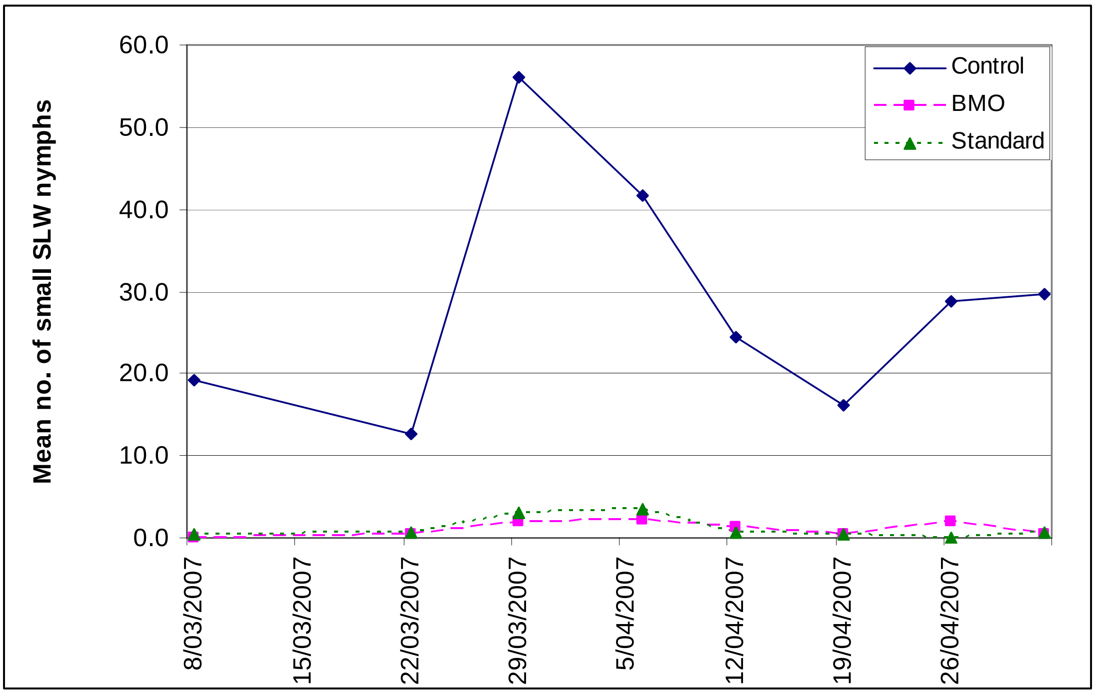


Fig. 7.11 Mean number of SLW large nymphs observed on leaves in each treatment

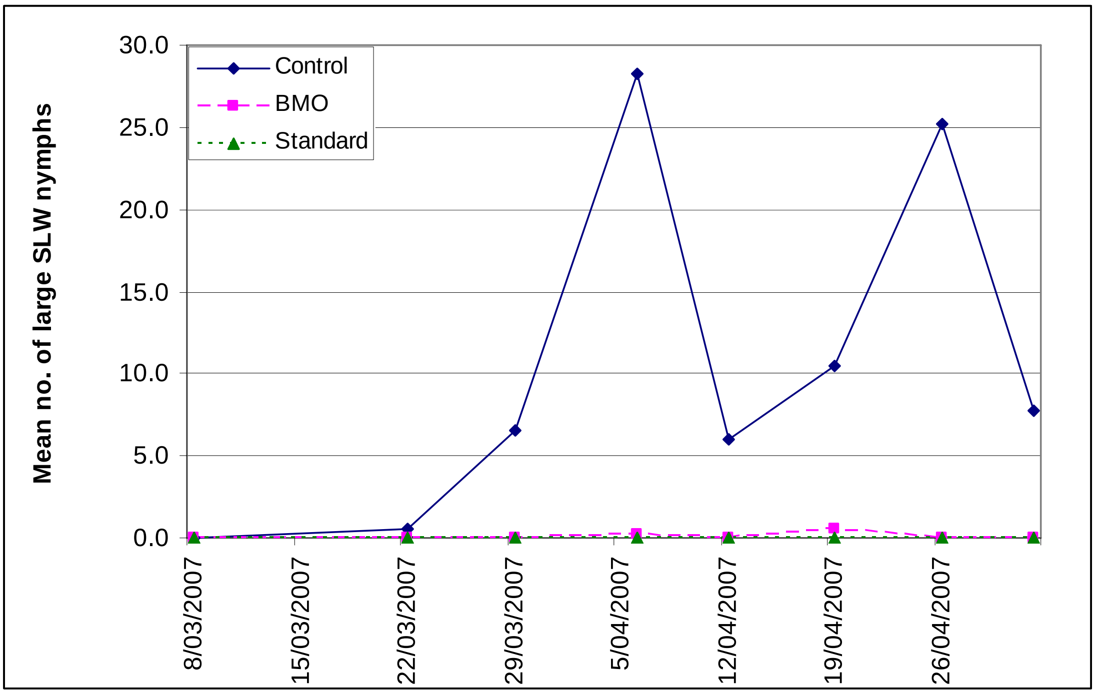
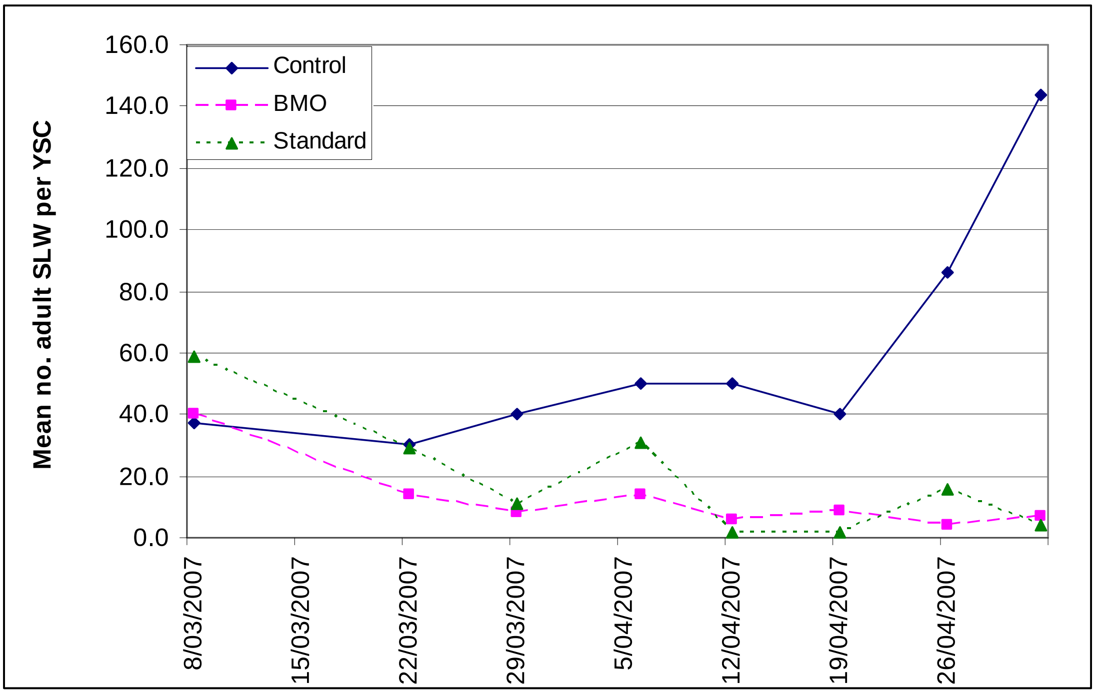


Fig 7.12 Mean number of SLW adults collected on yellow sticky cards.



7. 33 Discussion

Very low numbers of SLW were present in the trial area during this experiment, although seasonal occurrence studies suggested SLW should be present. Because of this low field population of SLW much of the planned management options were not able to be implemented. For example the use of monitoring to determine insecticides applications was not utilised. It is suggested that future trials could be inoculated with whitefly prior to transplanting.

The low levels of SLW activity in the BMO and Standard Treatments compared to the Control was clearly due to the use of the insecticide imidacloprid pre-plant.
The result indicates that the use of this insecticide is a very effective strategy in reducing SLW activity in the crop. However, the continued sole reliance on this insecticide may lead to resistance issues. Therefore, additional tools need to be tested for their effectiveness against SLW. This was not achievable during this trial due to the low field population of SLW.

Monitoring during this experiment identified SLW immigration and establishment into the experimental site. The results have significant implications for the management of SLW in broccoli. Accurate information about SLW activity allows effective timing of narrow spectrum insecticides and the protection of beneficial insect activity, such as parasitic wasps. Improved control and reduction in the use of broad spectrum insecticides will enable brassica growers to reduce the impact synthetic insecticides have on the environment. Food safety issues such as chemical residues on the crop may also be reduced for the consumer.

7.4 Silverleaf whitefly oviposition preference and survivorship on brassica varieties

Silverleaf whitefly, *Bemisia tabaci* biotype B (SLW) was first detected in the Lockyer Valley in 2002 and has become a major problem for the region. Many biological characteristics, including multivoltisim, a wide host range, high reproductive rate, ability to migrate, adaptation to high temperatures and an ability to rapidly develop insecticide resistance (Naranjo, 2001) underlie SLW's pest potential to the region's production of vegetables. These characteristics have contributed worldwide to the difficulty of developing robust and sustainable management systems.

Brassica crops are economically important for vegetable industry in the Lockyer Valley, contributing 10 million dollars to Queensland's economy (ABS 2008). Brassica crop varieties such as broccoli (*Brassica oleracea* - Italica group), cabbage (*B. oleracea* - Capitata group), cauliflower (*B. oleracea* - Botrytis group) and Chinese cabbage (*B. rapa*) are grown between February and October. SLW infestations severely impact on early season brassica crops through direct feeding, while a phytotoxin produced by the insect can cause white stem disorder (Brown *et al.*, 1995, Lima *et al.*, 2000).

Host plant suitability has been identified as an important component of SLW's population dynamics. SLW does not pass through a resting stage (Butler *et al.*, 1986). Therefore, survival from season to season depends greatly on the suitability of host plants for feeding and development.

SLW is highly polyphagous, having over 500 plant species documented as suitable hosts (Cock, 1993, Greathead, 1986), including *B. oleracea* and *B. rapa* (Simmons, 1999, Patel & Jhala, 1992). Kennedy (1965) found insects use a sequence of behavioural responses in host plant selection including habitat location, host location, host acceptance, and host use. Various studies have shown differences in SLW populations on different plant species suggesting host plant behavioural responses exist (Chu *et al.*, 1995, WeiHong *et al.*, 2003).

On brassicas, Ying *et al.* (2003) found SLW populations were higher on Chinese cabbage compared to common cabbage. Elsey and Farnham (1994) observed cabbage and broccoli were less infested by SLW than other brassica crops such as kale, collard and Brussels sprouts. Anecdotal evidence from the Lockyer Valley suggests broccoli and cauliflower have higher populations of SLW than do common cabbage and Chinese cabbage.

To understand the role host-plant suitability has on SLW oviposition and survivorship, project has investigated:

- Which of the common varieties of brassica crop grown in the Lockyer Valley does SLW prefer to oviposit on ?
- What proportion of SLW nymphs are able to complete development on these varieties?

7. 41 Materials and Methods

A field experiment and laboratory bioassay were conducted at the Gatton Research Station, Queensland, between April and May 2005.

Seeds from four varieties of brassica crops (broccoli cv ‘Babylon’, cabbage cv ‘Kamaroon’, cauliflower cv ‘Discovery’ and Chinese cabbage cv ‘Matilda’) were sown in peat trays on the 19^{th} April. Plants were transplanted to plastic pots when the seedlings had 3 to 4 leaves. Treatments consisted of the four varieties with 16 potted plants to each treatment.

On the 30^{th} of April, the 4 treatments were positioned in a randomised complete block design, with four replications, inside an established field-grown mature crop of cabbage (Fig 7.13). The plot size of each replicate was 4m wide x 3m long. Spacing between potted plants was 0.7m. A two meter buffer existed between replicate plots.

Figure 7. 13 Field-grown mature crop of cabbage.

The field-grown crop of cabbage was heavily infested with SLW adults (Fig 7.14). The potted plants were left in the field for a period of 4 days to allow time for field populations of female SLW adults to oviposit. Average minimum and maximum field temperatures experienced during experiment were 10^0C and 25^0C, respectively.

On day four, 10 potted plants were randomly selected from each plot and transferred to an insect-proof controlled environment room (CER) to keep the plants free from new adults. The CER was maintained at 28^0C, 60% humidity and 12 hrs light. Plants were kept in the insect-proof room for 3 weeks.

Figure 7.14 Field population of SLW adults observed on lower leaf surface of a cabbage located within the trial site.

All leaves, except the 3rd oldest and 7th youngest leaves below the terminal, were removed from each potted plant. Eggs of *B. tabaci* are deposited in various proportions on both leaf surfaces of many hosts, but are generally on the lower leaf surface (Lynch & Simmons, 1993, Simmons, 1994). A sample unit, consisting of a circle 2cm^2, was marked on the underside of each remaining leaf between the central and 2nd right lateral leaf vein (Fig 7.15).

Each sample unit was observed at 1, 9 and 18 days after field removal (AFR) using a stereo-microscope and immature stages of SLW recorded. SLW immature stages were classified as eggs, small nymphs (1st, 2nd and 3rd instar), large nymphs (red-eye pupae and exuviae). Exuviae are enclosed pupal cases.
The 1st nymphal instar is capable of limited movement and is called the crawler. Simmons (2002) found crawlers on brassica plants ceased travelling ≈2 mm from where they hatched. Eggs, small nymphs and large nymphs were also observed for parasitism.

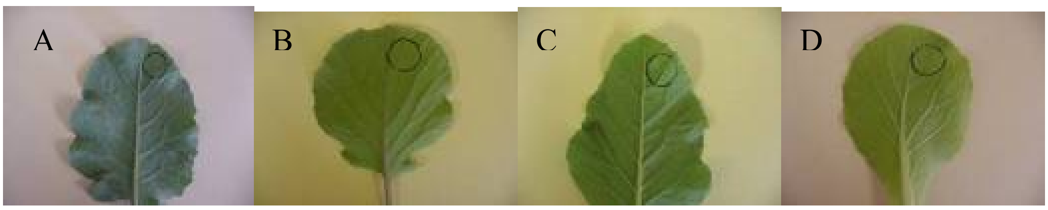


Figure 7.15 Location of 'sample unit' circle (20mm in diameter) on each variety (A – Broccoli; B – Cabbage; C – Cauliflower; D – Chinese cabbage).

Two yellow sticky cards (YSC), a visual trap for whitefly were placed in each replicated plot during the 4 days the treatments were in the field to monitor SLW adult populations (Fig

7.16). At day 4 all YSC were removed from the field and a 2cm^2 sub-sample was assessed for SLW adult populations on each trap per plot per treatment and number of adults recorded.

Figure 7.16 YSC's located within the trial site.

All data were analysed with Genstat® (Version 5). Oviposition and survivorship between plant cultivars were analysed using analysis of variance (ANOVA). Adult numbers recorded on YSC were transformed by Log(x+0.5). A 'Transition Index' (TI) was used to calculate the proportion of a SLW life stage to survive to the next stage and was computed as a means of comparing host plant suitability for SLW development (Moore *et al.*, 2002). Two 'Transition indexes' were calculated: - 1. Egg TI (defined as the ratio of small nymphs to eggs); and 2. Nymph TI (defined as the ratio of large nymphs to small nymphs). A TI score of 1 = 100% survival; Score of 0 = 0% survival. The TI was calculated before being subjected to ANOVA. Least significant difference (LSD) tests were conducted to assess differences in oviposition and survivorship among host plants. All data were expressed as mean numbers per sample unit per treatment.

7.42 Results

Mean density of SLW immature stages in each treatment is displayed in Table 7.2. At one day AFR eggs were the only immature stage observed. Potted plants were exposed to SLW adults for 3 days therefore no nymphs were recorded during the initial observation (1 day AFR). At 9 days AFR only small nymphs were observed and at 18 days AFR only large nymphs were observed. Mean density of SLW immature stages on all treatments declined as their age increased (e.g. egg to small nymph to large nymph).

Mean number of SLW adults per treatment were monitored using YSC (Fig 7.16). No significant different (ANOVA, $P > 0.05$) in the number of SLW adults between each treatment was observed (Fig 7.17).

Table 7.2 Mean (± SD) density of SLW eggs, small nymphs and large nymphs recorded per 2cm^2 circle in each treatment.

Treatment	*Eggs*	Small nymphs	Large nymphs
Broccoli	27.3 (19.9)	24.6 (17.3)	20.5 (12.3)
Cabbage	23.4 (12.2)	22.2 (11.8)	18.1 (11.8)
Cauliflower	43.9 (16.8)	38.9 (15.2)	31.5 (11.8)
Chinese cabbage	1.70 (0.80)	1.50 (0.40)	0.60 (0.50)

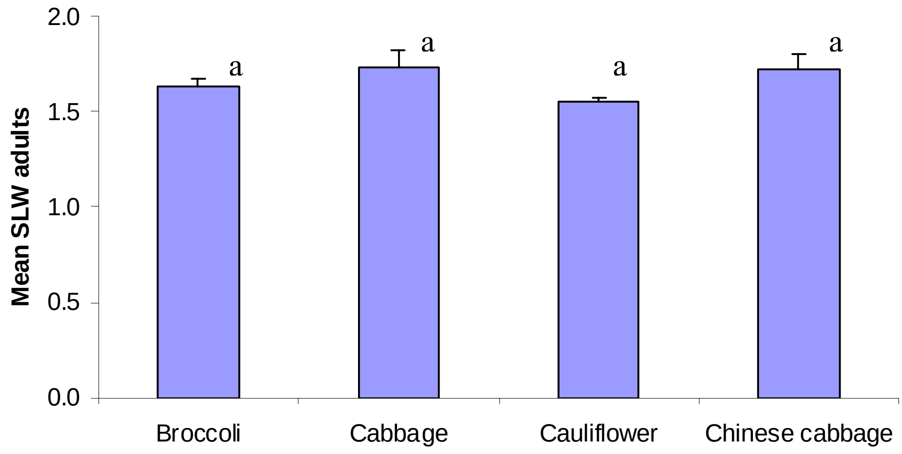


Figure 7.17 Mean number of SLW adults trapped on YSC in each treatment. Means that do not share a common letter are significantly different (P < 0.05, LSD). Error bars represent standard errors.

Significant differences (P < 0.05, ANOVA) in the number of SLW eggs laid were observed (Fig 7.18). Chinese cabbage had considerably fewer eggs lay on it than all other treatments. A greater number of eggs were laid on cauliflower compared to both broccoli and cabbage. No difference in egg lay occurred between broccoli and cabbage.

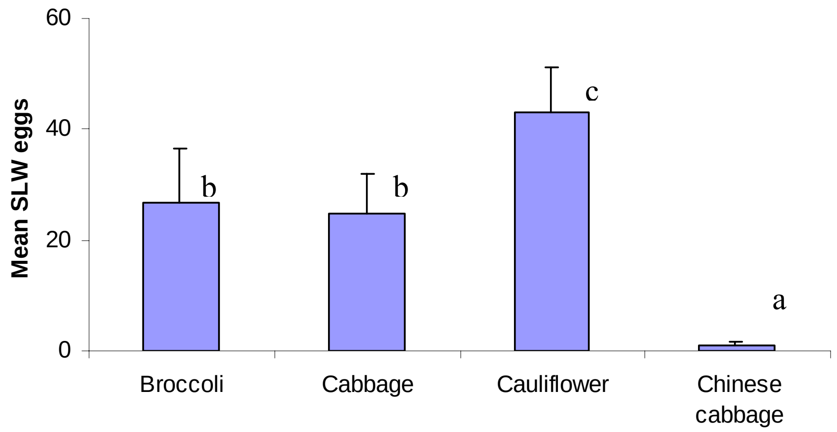


Figure 7.18 Mean SLW eggs recorded in each treatment.
(Means that do not share a common letter are significantly different P < 0.05, LSD. Error bars represent standard errors).

During the experiment, temperature and humidity were constant across treatments and no mortality of immature stages due to parasitism was observed, suggesting oviposition variation and nymph survivorship was not influenced by these abiotic and biotic variables.

Life stage survivorship calculated by the Egg and Nymph Transitional Index (Score of 1 = 100% survival; Score of 0 = 0% survival) is displayed in Table 7.3.

Egg transitional index - survivorship from egg to small nymph was very high (> 81%) in all treatments. No significance difference ($P > 0.05$, ANOVA) between treatments was observed.
Nymph transitional index - survivorship from small nymph to large nymph was very high in broccoli (90%), cabbage (76%) and cauliflower (84%), but was significantly lower ($P < 0.05$, ANOVA) on Chinese cabbage (43%). All treatments except Chinese cabbage appear highly suitable for nymphal development to adult.

Table 7.3. Mean (± SE) Transitional Index comparing host plant suitability for SLW development
(Score of 1 = 100% survival; Score of 0 = 0% survival. Means that do not share a common letter are significantly different $P < 0.05$, LSD).

	Mean Transitional index	
Treatment	*Egg to small nymph*	**Small to large nymph**
Broccoli	0.97 (0.025) a	0.90 (0.026) a
Cabbage	0.90 (0.028) a	0.75 (0.065) a
Cauliflower	0.88 (0.025) a	0.84 (0.047) a
Chinese cabbage	0.81 (0.060) a	0.42 (0.100) b

7.43 Discussion

The results from this study indicate that SLW females preferentially lay their eggs on some brassicas crops over others. Order of oviposition preference was cauliflower (most preferred), broccoli, cabbage, and then Chinese cabbage (least preferred). Adult SLW population densities were similar in all treatments suggesting host plant behavioural responses, such as host plant learning, plant defence characteristics or plant chemical cues may be influencing oviposition.

Various authors (Cunningham *et al.*, 1998, Landolt & Molina, 1996, Papaj & Prokopy, 1989) have found that previous experience of a host plant by a herbivore can lead to an increased preference for that host species, even after one generation. It is assumed that SLW females were feeding and ovipositing on the mature field grown cabbage crop for at least 2 or 3 generations prior to the commencement of this experiment. If host learning behaviour was influencing the oviposition preference of SLW females, egg laying would be highest on plants from the cabbage treatment. However, the results identified plants from the cauliflower treatment as receiving the greatest numbers of eggs.

Previous studies suggest some plant characteristics can negatively affect SLW performance. For example, plants devoid of leaf hairs (glaborous) had lower oviposition and reduced numbers of nymphs (Navon *et al.*, 1991, Butler *et al.*, 1992, Riley *et al.*, 2001). Waxy foliage in broccoli was found to lower adult and nymph densities (Farnham & Elsey, 1995). Broccoli, cabbage and cauliflower are all sub groups of the same species (*B. oleracea*), and have similar plant characteristics, such as glaborous and waxy leaves. Therefore, the assumption would be for broccoli, cabbage and cauliflower to have similar egg and nymph densities. This study showed differences exist. Chinese cabbage (*B. rapa*) is a different species to the other 3 treatments. Its leaves are very hairy. Chinese cabbage had the lowest egg and nymph densities, which is contrary to findings of previous studies.

Plant chemistry (taste and olfaction) is a fundamental factor in the process of individual herbivores accepting or rejecting a plant (Holmgren & Getz, 2000). Some of these chemicals are volatile odours detectable at some distances, while non-volatiles (e.g. waxes) are detected by contact chemoreception or taste. Most olfactory receptors are located on the antennae (Visser, 1986). When SLW adults make contact with the potential host, its acceptability must be established by checking the targets suitability for growth and development (Gullan & Cranston, 1994). Volatile odours or the nutritional value may vary among the brassica varieties tested in this experiment. These differences may have been detected by SLW female's, influencing their oviposition choice.

Nymph mortality was low on broccoli, cabbage and cauliflower treatments, suggesting these varieties are highly suitable host plants for development of SLW nymphs. In contrast, Chinese cabbage had a low small nymph to large nymph transition index value. Combined with low oviposition, Chinese cabbage is not preferred by adult SLW females and is less suitable for nymphal development than the other hosts evaluated.

The results clearly implicate plant chemistry, through volatile and non-volatile odours, as influencing the oviposition behaviour of SLW females. Apart from Chinese cabbage, brassica varieties tested appear to be highly suitable for developing and sustaining SLW populations. The results provide important implications for growers and pest managers. Firstly, cauliflower is a high risk crop, while Chinese cabbage appears to have a tolerance to SLW infestations. Secondly, even though the base population of SLW varies among broccoli, cabbage and cauliflower, very low mortality in immature stages suggests these host plants may contribute to rapid population growth. Thirdly, brassica varieties are very suitable hosts for SLW and are most likely contributing to their survival through the winter period in the Lockyer Valley. Understanding these implications will greatly improve the capacity of pest managers to implement effective pest management strategies for brassica vegetable production in the Lockyer Valley.

Four varieties of Brassica crops were assessed for *B. tabaci* oviposition preference and suitability for nymphal development. Oviposition preference (greatest to least) was for cauliflower, broccoli = cabbage, and Chinese cabbage. Nymphal survival was lower on Chinese cabbage than on the other varieties.

7.44 Reference

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Chapter 8

Silverleaf whitefly project evaluation

8.1 Introduction

From May July 2008, independent consultants Coutts J&R conducted a statewide telephone survey relating to SLW with 30 agribusiness and 50 grower respondents taken from a stratified sample of growers and service providers across growing regions in Queensland. The purpose of the survey was to evaluate the effectiveness of the project against project aims and to make recommendations for future work.

The project team developed a series of key questions with the evaluation team from which the survey instrument was developed.

The full survey report is available via HAL:

- Summary of surveys of Agribusiness and Vegetable Growers for "Development and promotion of IPM strategies for silverleaf whitefly in vegetables" (VG05050). Kerry Bell, Amy Samson and Jeff Coutts, September 2008, Coutts J&R.

The summary from the full report is provided below.

During the life of the SLW project, there has been a perceived decrease in damage by SLW across susceptible horticultural crops in Queensland and an increase in the awareness and use of IPM strategies by growers and their consultants. DPI&F has played a key role in facilitating these changes.

8. 2 Key messages

- ➢ While SLW remains a pest concern for most (86%) industry respondents across Queensland, there was a majority view that the level of damage was noticeably less than it was in previous years.

- ➢ There has been an increase in the influence of crop monitoring consultants. DPI&F remains as a significant source of information (well ahead of other sources).

- ➢ While rating lower than other information sources, newsletters were well received by growers and consultants and would appear to be an important communication mechanism. It is clear that many growers continue to prefer to receive newsletters by post while agribusiness is content with e-mail.

- ➢ Just over half of the randomly selected respondents had been to one or more pest and disease management seminars. These would appear to be a key part of the information and skill landscape for growers and agribusiness.

- ➢ Consistent with similar rural studies, the SLW website is not commonly used by growers or agribusiness (85% not having visited it) as an information source. The website, however does provide an on-going source of collated and updated information useful for information providers.

- ➢ The information and promotion strategy relating to the use of beneficial (83% awareness) and insecticide resistance strategies (60% awareness) appears to be working well – with less awareness (50%) of clean up strategies. Use of insecticides remained the main insect management strategy growers were aware of – with an emphasis on softer chemicals. The results indicated that 66% use Confidor soil applied compared to 15% foliar applied.

- ➢ There has been a high level of adoption of improved SLW management practices. Approximately 60% of growers indicate that they have made a recent change in relation to the management of SLW – mainly in the area of using softer chemicals to protect parasitoids (27%), monitoring pest levels (16%) and improving farm hygiene (14%).

- ➢ The analysis shows that people attribute the full range of information sources – as it ties in with their own experience – as contributing to their decision-making process.

8. 3 Recommendations

1. The silverleaf whitefly (SLW) project team should be congratulated on the significant inroads they have made to the development, validation and promotion of integrated pest management (IPM) strategies for silverleaf whitefly in brassicas, beans, sweetpotato and pumpkin (Other crops such as tomatoes & melons also benefited).

2. Growers and agribusiness highly value their own experience and research. Extension strategies that promote on farm research and local demonstration trials should be strengthened. Likewise, workshops should highlight local experiences.

3. There is a strong argument for DPI&F to work directly with agribusiness such as resellers and crop consultancy firms as much as possible as a strategic way to impact on grower practice.

4. A focus should be on reinforcing key messages through a range of information and advisory mechanisms.

5. Email should be seen as a key medium for communication with agribusiness and paper mail (faxes were a low rated option) for communicating with growers.

6. The website should not be relied on as a general information medium at this time. Efforts should be made to creatively provide ‘reasons’ for industry individuals to access the website – videos, links, chat rooms, pod-casts, competitions, user-friendly information.

8. 4 Purpose

This survey report is part of the summative evaluation of the project: Development and promotion of IPM strategies for silverleaf whitefly in vegetables (HAL project number – VG05050) referred to in the report as the silverleaf whitefly (SLW) project. The SLW and Western Flower Thrips (WFT) projects were evaluated at the same time. This report deals specifically with SLW.

A telephone survey (from 234 contact names randomly stratified across regions in Queensland) was undertaken with 35 agribusiness and 72 grower respondents relating to questions on SLW.

8. 5 Background of survey respondents

- On average the grower respondents reported that they used 155 ha to grow vegetables either generally per year or last season.
- The Lockyer valley (30.2%) and north Queensland (30.2%) were the two regions with the most respondents. The Bundaberg response rate was 27.6%. The North Queensland location includes Bowen, Burdekin (including Clare, Giru and Ayr), Mareeba (including Tableland), Gumlu and Home Hill. The Bundaberg area includes Childers and Gin Gin. Respondents tended to be involved in both SLW and WFT vulnerable crops.
- Silverleaf whitefly is an issue for the crops that the majority of respondents (86.1%) grow or deal with in their work. There was a significant difference across localities with other areas in Queensland and interstate stating that silverleaf whitefly was less of an issue than in Bundaberg, north Queensland and the Lockyer Valley.
- Nearly half (48.2%) of the grower and agribusiness respondents (relevant to the SLW project) said that western flower thrips was an issue for the crops they grow or deal with in their work. The agribusiness respondents thought western flower thrips was more of an issue (65.8%) than the grower respondents (39.2%).

8. 6 Findings

Overall 86.9% of the respondents were aware of the SLW project run by DPI&F

8.61 Information sources

- *Sources of information:* Agribusiness respondents found DPI&F officers (51.3% of respondents mentioned), chemical companies (15.4%), Bowen Crop Monitoring Services (10.3%), Websites/Internet (10.3%), and their own experience (10.3%) as the top four sources of information about managing pests and diseases. Growers rated their own experience, Crop Tech (now T Systems) at Bundaberg, Bowen Crop Monitoring Services and other crop consultants as the top four sources of information.

- *Newsletters and leaflets:* Agribusiness respondents preferred to receive the colour newsletters and leaflets via emails (51.3%) whereas growers mostly preferred delivery by post (72.7%). Similarly more than three-quarters (76.9%) of agribusiness respondents preferred to be notified about seminars and workshops by email, while the main preference by growers was to be notified by post (50.6%) – with e-mail as the next preference (there appeared to be a higher preference for fax in North Queensland compared to other regions).

- *Pest and disease management seminars and meetings:* Over three-quarters (77.6%) of the respondents (relevant to SLW project) were aware of the pest and disease management seminars and meetings run by DPI&F. Of these, approximately three-quarters (76.7%) had attended at least one of them. Overall, respondents indicated that the seminars and meetings were moderately useful with an average rating of 6.1 out of

10. These results were not significantly different between grower and agribusiness respondents.

- *Newsletter:* Three-quarters of the respondents (75.7%) had seen the newsletter the *SLW Update* and a further 4.7% were unsure whether they had seen it. On average, respondents rated the newsletter as moderately useful / relevant with a rating of 6.0 out of 10.

- *Website:* Over three-quarters of the grower and agribusiness respondents (84.9%) had never visited the silverleaf whitefly website (growers 88.7%, agribusiness 77.1%), 12.3% had visited it once or twice (growers 9.9%, agribusiness 17.1%) and 2.8% had visited 2 to 5 times (growers 1.4%, agribusiness 5.7%), while no respondents indicated they had visited more than 5 times. Those who had visited the website indicated that it was moderately useful and relevant giving an average rating of 5.1 out of 10.

8.62 Awareness and use of management strategies

- The top three strategies most often identified by respondents as important for slowing down movement of silverleaf whitefly were spraying with insecticide (53.3%), monitoring/checking crops on a regular basis (37.4%) and getting rid of/slash off/chop in crop straight after harvest (34.6%).

- *Silverleaf whitefly clean up strategy:* Nearly half the grower and agribusiness respondents (44.3%) were aware of the silverleaf whitefly clean up strategy, 5.7% where unsure and 50% were not aware. Respondents from North Queensland (69.7%) had a significantly higher awareness than other locations. The three most frequent descriptions of the clean up strategy were getting rid off/slashing off/ploughing or discing in crop straight after harvest (20.6%); spraying out old crop with insecticide (19.6%); and spraying and cleaning up old crops straight after harvest (16.8%).

- The top two insecticide treatments considered most important to the grower and agribusiness respondents for controlling silverleaf whitefly (last season) were Confidor® (on soil) with trickle (26.2%) and Confidor (on soil) in plant hole drench (26.2%). Chess® (pymetrozine) (15.9%), Confidor® (imidacloprid) - (foliar) (15.0%), Talstar® / Synergy® mixture (15.0%), Admiral® (pyriproxyfen) (14.0%) and Confidor® (on soil) in furrow (14.0%) were the next most important.

- *Insecticide resistance management strategy:* Sixty percent (60.0%) of respondents said they were aware of the insecticide resistance management strategy for silverleaf whitefly in their district. The top four descriptions of the insecticide resistance management strategy for silverleaf whitefly by respondents were: rotate chemicals according to the windows (60.3%); using only chemicals allowed at different times of the season (34.9%); only using Confidor® in the later part of the season (NQ winter/spring; SE summer/autumn) (33.3%); and avoiding broad spectrum insecticides (to protect beneficials) (31.7%). Over half (56.1%) of respondents said that nothing might prevent them from using the resistance management strategy and 12.1% said that it was too expensive.

- *Parasitic wasps/parasitoids (Eretmocerus hayati) release program:* Overall 83.0% of grower and agribusiness respondents had heard or are aware of a program to release parasitic wasps/parasitoids (*Eretmocerus hayati*) that attack silverleaf whitefly in their district. The top three respondent descriptions of how they would recommend protecting or preserving them were: avoiding use of broad-spectrum/toxic chemicals (55.7%); only spraying at-risk plantings rather than the whole crop (economic damage) (16.0%); and planting a small 'refuge area' for them to breed and disperse within the farm (14.2%).

- On average the grower and agribusiness respondents thought there was a reduction of damage to crops due to silverleaf whitefly over the last few years, giving an overall average of 7.1 (where 0=much more damage, 5=same amount of damage and 10=a lot less damage). However this average rating was significantly different between growers (7.5) and agribusiness (6.1) respondents, and between localities with North Queensland (5.9) showing less of an impact than the Bundaberg area (7.2) and Lockyer Valley (7.9). For agribusiness respondents when North Queensland is separated into the Burdekin area (1.8) and the rest (6.0) to explore a SLW outbreak there was a significant difference. However there wasn't a significant difference in grower ratings between the Burdekin area (6.4) and the rest of North Queensland (7.0).

8.63 Practice change

- The top four ways that the grower and agribusiness respondents have changed the way they recommend or manage silverleaf whitefly is shown below:
  1. Use softer chemicals to protect parasitoids (27.1%)
  2. Monitor crops for SLW levels/employ a consultant to do this for me (16.8%)
  3. Injecting or drenching Confidor® at planting (as preventive approach) (15.9%)
  4. Good farm hygiene: Control weeds around the farm (14.0%)

  Only 42.1% of respondents indicated that they had not made any practice change.

- On average, years of experience (agribusiness 7.8, growers 7.8) was the most important factor given by respondents in prompting or convincing them to change practices for recommending or managing silverleaf whitefly. Agribusiness respondents were also prompted to change by information about SLW that arrived on the farm from DPI& F (7.4) and their own research / information seeking (7.2). Growers own research/information seeking (7.4) and discussions with crop consultants (7.3) prompted practice change.

Chapter 9

Technology Transfer and Extension

9.1 Needs analysis

A needs analysis was conducted early in the life of the project to help shape project plans and the extension strategy for the project.

Needs analysis surveys were established for Bowen/Burdekin, Bundaberg and Lockyer Valley (LV) regions. A questionnaire was developed based on series of closed and open-ended questions. The purpose of this survey was to identify major issues impacting on SLW management and industry needs for further improving management of this pest. Surveys targeted vegetable growers (brassicas, beans, pumpkins, eggplant and zucchini), farm advisers and agribusinesses. The grower questionnaire was adapted to cater for the service provider group.

The Bowen-Gumlu-Burdekin survey was completed by May 2006 while the Bundaberg and LV regions survey was completed by June 2006. Analysis of the data indicates the following:

Crop losses due to SLW in some instances had reached 50% with the range generally 5-30%. Overall losses in the Burdekin area are estimated at some 20%, much of this being due to downgrading in quality of produce. Some main points from the needs analysis are:

- heavy reliance on Confidor® as the pivotal chemical in SLW management
- limited use of IGRs in grower's management strategy with some *Admiral* and almost no *Applaud* utilised – use of this chemical group is largely restricted to growers employing crop consultants
- better crop hygiene, particularly in relation to the accumulation of weeds in fallow areas and limited use of cover crops in the off-season, is seen as an area requiring considerable attention.

LV region results show that farmers were keen to know more about what alternatives to pesticides were available, as well as more detail on the current pesticides they were using. They were also interested in information on natural enemies for SLW, whether the SLW populations can be predicted and anything else new that would help them with their SLW management.

9.2 Newsletters

Three issues of the 'Silverleaf whitefly project update' newsletter have been published, with another in progress and a further two planned to complete the series.

The newsletters have each been sent to over 600 people, including growers and agri-business staff, across Australia. Around 200 of each issue have been emailed as PDF's and over 400 hard copies sent by mail. Further copies were made available as handouts.

A PDF copy of each Update has been attached to the project web site.

Silverleaf whitefly project update Issue 1: December 2006
This newsletter:

- introduced and described the project
- introduced the project team
- described the Silverleaf whitefly life cycle
- provided information on Tomato yellow leaf curl virus (TYLCV)
- provided a Regional roundup of activity in the north Queensland, Bundaberg and Lockyer Valley regions
- provided a Chemical update listing registered chemicals and all APVMA Permits for silverleaf whitefly management.

Silverleaf whitefly project update Issue 2: November 2007
This newsletter:

- provided information on 'Biological control of silverleaf whitefly
- provided information on the Bowen IPM field trials
- provided information on Insecticide resistance management in silverleaf whitefly
- provided a Regional roundup of activity in the north Queensland, Bundaberg and Lockyer Valley regions
- provided a Chemical update with detailed information on new chemical registrations, and new APVMA Permits, and links to registered chemicals and APVMA Permits for silverleaf whitefly management.

Silverleaf whitefly project update Issue 3: May 2009
This newsletter:

- provided information on the new whitefly Q-biotype
- provided information on how insecticides work
- provided a Regional roundup of activity in the north Queensland, Bundaberg and Lockyer Valley regions
- provided a Chemical update with chemical registrations, detailed information on new APVMA Permits, and links to APVMA Permits for silverleaf whitefly management.

9.3 Project website

A project web site was developed and is available on the DEEDI website, it is regularly reviewed and updated.

The website: 'Silverleaf whitefly in Queensland - Project VG05050' link is: http://www2.dpi.qld.gov.au/horticultureresearch/18362.html.
This website is set up so that additional information is only 'one click' away from the home page.

The website provides:

- A brief overview of project information and a link http://www2.dpi.qld.gov.au/horticultureresearch/18363.html to 'Development and promotion of IPM strategies for silverleaf whitefly in vegetables (VG05050)', a detailed summary of the project showing its objectives; description; activities; outputs and outcomes, and lists the project team.
- A link to PDF versions of the SLW Update produced by the team.
- Descriptions of SLW including a life cycle diagram and eight life stage photos.
- Descriptions of SLW crop damage with eight photos.
- A link, http://www2.dpi.qld.gov.au/horticulture/18512.html, to the DPI&F Note 'Silverleaf whitefly management in vegetable crops' that has been developed by the team and others.
- A link, http://www2.dpi.qld.gov.au/horticulture/18522.html, to the DPI&F Note 'Tomato yellow leaf curl virus' developed by the team and others and a link, http://www2.dpi.qld.gov.au/health/4250.html, to the DPI&F Note 'Tomato leaf curl virus' which was updated by the team and others.
- A link to the Fact sheet on the Q-biotype whitefly.
- A number of links to external sources of information on SLW.

9.4 Industry meetings

A series of seminars and workshops were held during the life of the project. The needs analysis conducted at the start of the project indicated that meetings and workshops were not a primary source of information for busy vegetable growers, they were nevertheless identified as an important avenue for disseminating information to growers, consultants and other agribusiness people.

Tables 9.1 and 9.2 lists the workshops, seminars and field days held, their topics and where they were held, e.g. Bowen, Burdekin, Bundaberg and the Lockyer Valley regions.

Seminars and workshops were well attended by growers, consultants and agricultural distributors (number of attendees varied between 10 and 45). Some larger growers who did not attend were represented by their consultants or in-house agronomists. Results from the project evaluation indicate that these extension activities were well received. Presentations were often supported with displays (e.g. parasitoids), posters and take-home printed material. Questions were encouraged and time was allowed for informal discussions.

In North Queensland, the early Pest and Disease Management Seminars in March or April have become a regular feature for updating the vegetable industry on progress and outcomes from SLW as well as other relevant HAL projects (e.g. powdery mildew). The usefulness of this approach is illustrated by the increasing coverage the seminars are achieving. For the last round of seminars in March 2009 obtained coverage of 80% for Bowen and 50% for Gumlu and the Burdekin. This is due to excellent representation from all major crop consultancy firms in the region, most of the main agricultural distributors, a number of in-house agronomists, the Bowen District Growers Association, chemical company staff as well as growers particularly in the Burdekin.

Table 9.1 Seminars and workshops in the North Queensland regions

Date	Workshop topics
15-17 Mar 2005 (Bowen, Gumlu, Ayr)	Pest and Disease Management Seminar • The latest on managing Silverleaf whitefly and more
19 Jun 2005 Mareeba	Growers meeting • IPM strategies for whitefly in cucurbits
1-2 Mar 2006 (Bowen, Gumlu, Ayr)	Pest and Disease Management Seminar • Update on silverleaf whitefly project & resistance management • Weed host survey results
27-29 Mar 2007 (Bowen, Gumlu, Ayr)	Pest and Disease Management Seminar • Natural enemy *Eretmocerus hayati* release program • Spray programs & insecticide resistance management • Overcoming whitefly resistance with synergist • Tomato yellow leaf curl virus update
20 Sep 2007 (Bowen)	Zucchini Field day • Demonstrate IPM options for whitefly
11-13 Mar 2008 (Bowen, Gumlu, Ayr)	Pest and Disease Management Seminar • Update on parasitoid release and evaluations • Update on insecticide resistance levels in silverleaf whitefly • Pumpkin IPM trial results and recommendations
02 Jul 2008 (Ayr)	Silverleaf whitefly outbreak in Burdekin • Expanding parasitoid releases for outbreak location • Managing whitefly migration
5 Sep 08	Project Team meeting • Update on project progress and planning for next season
31 Mar & 01 Apr 2009 Bowen, Ayr	Pest and Disease Management Seminar • Q biotype detection and resistance levels • Update of parasitoid releases and IPM strategies

Table 9.2 Seminars and workshops in the Bundaberg and Lockyer valley regions

Date	Workshop topics
Bundaberg Regions	
6 Apr 2006	Growers' TYLCV awareness meeting Sweetpotato growers' meeting
26 April 2006	Melon growers' meeting
13 Mar 2007	Project Team Meeting • Update on project progress and planning for next season
14 Mar 2007	Industry meeting • IPM trials results • Insecticide resistance management • Weeds host of whitefly and management
Lockyer valley	
16 Nov 2005 Indooroopilly	Project Team Meeting • Project planning and identify industry issues
17 Nov 2005 Gatton	Industry meeting • Current silverleaf whitefly issues in Locker valley • Project overview and priorities • Insecticide resistance management
14 May 2006 Gatton	Industry Seminar • Update project results and management options
23 Apr 2008 Gatton	Industry meeting • IPM strategies for silverleaf whitefly • Insecticide resistance management
26 Oct 2006 Laidley	Industry meeting • Whitefly and resistance management strategies
2-16 Nov 2006 Lowood, Tenthill, Glenore Grove	Industry meeting • Whitefly and resistance management strategies
13 Oct 2009 Brisbane	Bayer Movento registration workshop • Movento use strategies for whitefly • Resistance management strategies

9.5 Media Releases

A communication and promotion plan was an integral part of stakeholder engagement and industry and community awareness.

Media releases were written throughout the life of the project. A distribution list that incorporated local media outlets and industry publications was developed.

The main media targets were those that could inform growers of the benefits of IPM. These were:

- Bowen Independent newspaper 02 August 2006 - update on project activities
- Bowen Independent 01 Nov 2006 – information SLW parasitoid and field releases
- ABC Rural Radio – country hours
- Ayr Advocate newspaper 20 Feb 2009 – grower success story
- Queensland country life - 12 Jul 2007 Rockhampton parasitoid releases
- North Queensland Grower and Grazier Annual 24 Jul 2008- IPM story
- Gatton star newspaper 22 March 2006 - describing project objectives.
- Gatton Star newspaper 18 October 2006 - update on project activities
- Good fruit and vegetable magazine Nov 2009 – IPM implementation story
- Bundaberg News Mail Rural section 20 Mar 2007 – Seminar update
- Bundaberg Fruit & Vegetables Growers newsletter 'Fresh Pickings'

Photographs and articles appeared in all targeted media publications throughout the life of the project. ABC Rural Radio featured the research on a number of occasions.

An essential part of the media releases was to incorporate comments from growers involved in the adoption of IPM models, as an example to others that these initiatives were commercially viable.

Pest and Disease Management seminars held regularly throughout the project were also promoted in the media. These gave the opportunity to further profile IPM techniques to the wider industry group.

Selected recent media highlights:

- ABC radio News hours 18 Nov 2009 - media reporter interviewed three Burdekin farmers, Merv Mohr who is farm manger of Rapisarda Enterprise adopted IPM program, Ken Duncan is a conventional melon grower, and Steve Ahern an organic farmer. Project leader Dr Siva Subramaniam also interviewed.

- Media release (9 October 2009) – 'Clean, mean and green – NQ veg producers win the battle against whitefly'. Media officer Andrea Corby interviewed two Bowen and Burdekin farmers and project leader on the success on IPM adoption. The release was published in several local and national media.

- Media release (29 June 2008) – 'Silverleaf whitefly battle being won in Bowen'. Based on success story of Rockpond farm that adopted biologically-based IPM for whitefly. The release was published in several local and state media.

- Vegetable Australia (Vol 3.4 Jan 2008)- 'Adaptive pest meets its match'

9.6 Publications and information

Whitefly information packages including SLW management notes, spray programs, insecticide guide and weed hosts management were distributed at the industry meetings and posted to growers, consultants and agri-business staff.

Farm notes and Fact sheets have been published, reviewed and updated as required. The Fact sheets are available on the project web site. The project publication list is given below:

1. **Biological control**
   - Parasitic wasps for silverleaf whitefly control in vegetables
   - Parasitoid *Eretmocerus hayati* lifecycle – picture guide
   - Post release Evaluations – Bowen and Gumlu

2. **Integrated management strategies**
   - SLW lifecycle – picture guide
   - Field sampling method to assess whitefly infestation
   - Action threshold levels for insecticide application
   - List of resistance varieties – Pumpkin
   - List of resistance varieties – Zucchini
   - Crop clean-up strategy
   - Weed hosts of silverleaf whitefly
   - Key tactics to manage silverleaf whitefly

3. **Chemical control**
   - Guide to choose insecticides for silverleaf whitefly
   - Spray program for silverleaf whitefly – pumpkin
   - Spray program for silverleaf whitefly – early season tomato
   - Spray program for silverleaf whitefly – late season tomato
   - Spray program for silverleaf whitefly – melons
   - Soil application methods for Confidor®
   - Best use of IGR against silverleaf whitefly in vegetables
   - Tank mixtures for silverleaf whitefly control
   - Admiral® Technical Information

4. **Silverleaf Whitefly Resistance Management**
   - Insecticide resistance monitoring results 2006 - 2009
   - Insecticide resistance management guidelines for SLW for Lockyer Valley
   - Area wide management strategy for silverleaf whitefly – Bowen
   - Area wide management strategy for silverleaf whitefly – Burdekin
   - Area wide management strategy for silverleaf whitefly – Gumlu

5. **Farm notes, Factsheets and Articles**
   - Silverleaf whitefly management in vegetable crops – DPI&F Farm notes
   - Silverleaf whitefly management – Vegenotes AusVeg 2006
   - IPM strategies for silverleaf whitefly in vegetables - Vegenotes (16) AusVeg 2010
   - Silverleaf whitefly management in melons
   - Insect growth regulators for managing silverleaf whitefly in melons
   - Guidelines for managing silverleaf whitefly in tomato

- Tomato yellow leaf curl virus – DPI&F Farm notes
- Tomato leaf curl virus - DPI&F Farm notes
- What is Q-biotype whitefly – Factsheet
- Q- biotype whitefly prepare for invasion – winter 2009 Gro Magazine Syngenta

6. **Project Reports**

- HAL Milestone Report 1 (May 2006)
- HAL Milestone Report 2 (Feb 2007)
- HAL Milestone Report 3 (Jul 2007)
- HAL Milestone Report 4 (Mar 2008)
- HAL Milestone Report 5 (Oct 2009)

Recommendations

1. The promising silverleaf whitefly biocontrol agent *Eretmocerus hayati* needs to be further evaluated to provide information on field release rates, suitable release techniques and field compatibility with insecticides.

2. *E. hayati* should be considered for commercialisation and a suitable pathway is being developed. DEEDI staff are in negotiations with major vegetable growers, Bayer Crop Science and Bugs for Bugs for a collaborative project proposal to develop an economically viable commercial production and supply system. Some growers have expressed their interest in the project and are willing to provide financial and in-kind support.

3. The current project has developed a low-cost parasitoid production system for local releases and on-farm trials. Further research should focus on methods to improve the efficiency and quality control that are suitable for a commercial production system.

4. A high quality IPM program includes best farm management practices adopted on a regional basis. An emphasis should be placed on host plant sanitation, crop residue management and intensive monitoring to assist in good decision making.

5. Success of silverleaf whitefly IPM is dependent upon resistance management and industry collaboration. Pesticide tools, particularly the use of the IPM friendly products, are an integral part of the whitefly management program. To prolong the life and efficacy of these insecticides, a coordinated resistance management strategy should be put in place and promoted to industry.

6. The registration of IPM friendly insecticides for SLW affected crops should be supported to overcome the shortage of selective chemicals. Implementation of biologically-based IPM depends on the availability of 'softer' insecticides which are less harmful to beneficials.

7. On-farm extension should be emphasised to promote or implement IPM. Field trials or on-farm demonstrations are more effective by allowing growers to gain confidence in the pest management programs.

8. Whitefly movement between farms is still a major issue for all vegetable production regions. The mass migration of whiteflies from adjacent crops has hindered control measures adopted in the region. Movement of adults from older crops and crop residues is the primary source of infestation for young crops. Workable and practical SLW dispersal control strategies are needed to tackle this issue. These could be combined with the existing "clean-up strategy" employed by north Queensland vegetable growers, which has been critical for containing SLW migration within farms.

9. The new chemistry spirotetramat (Movento®) and pyriproxyfen (Admiral®) are effective 'softer' tools to integrate with parasitoids for SLW IPM in vegetables. However, timing of application and effective crop monitoring are essential to maximise their effect. Therefore, extension should be focused on providing adequate training and skill in the spray decision making process.

Acknowledgements

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- Horticulture Australia Ltd and vegetable industry for funding the project.
- Nufarm Australia Ltd provided funds for the synergy field trial and support for the temporary permits from the APVMA.
- Bob William, former Science Leader DPI & F, who provided guidance and direction throughout the project.
- Dr Harry Fay provided comments on and review of this report.
- Many Bowen and Burdekin growers collaborated in and supported the parasitoid releases.
- Many growers and service providers responded to the needs analysis and to the project evaluation.
- Rapisarda Enterprise Burdekin, Rockypond farm Gumlu and Elphinstone farm Bowen collaborated by providing in-kind support for the IPM implementation program on their farms. Eden Farms allowed sampling from their plant house crops.
- Bowen and Gatton Research Station staff helped support the field trials.
- Andrea Corby, DPI & F media officer, conducted grower interviews and media releases.
- Kerry Bell, Amy Samson and Jeff Coutts conducted the project evaluation.
- Technical and field staff including Kevin Jackson, Ron Hermann, Ian Walker and Jennell Glover provided laboratory and field support.
- Eric Coleman, DPI & F, supported the parasitoid releases in Rockhampton.

Appendix 1

Area wide management strategy for silverleaf whitefly (SLW) – Burdekin

This strategy is an area-wide guideline. It is voluntary and flexible and should be seen as an ideal to aim for.

If you need to go outside the strategy to control a SLW outbreak, please return to the strategy once you have overcome the problem.

1. Use an integrated approach

- Summer production break and non-host cover crops (eg sorghum)
- Control broadleaf weed hosts and volunteer crops
- Improve farm planning – consider wind direction when planting, avoid planting young crops next to old crops, talk with your neighbours about their plans for the season
- Check transplants before planting out
- Avoid sensitive cucurbit varieties during peak whitefly periods (July to September plantings)
- Monitor crops regularly and spray on thresholds
- Ensure the spray rig is achieving good crop coverage
  - calibrate regularly, check water volumes used and chemical rates applied
- Timely spray out of finished crops before slashing to reduce mass migration of SLW into young crops

2. Rotate use of insecticides according to your local strategy

(see the diagram on the next page)

Window I – Autumn

- Use Admiral or Applaud - one spray/ crop early in crop growth
- Use Chess – 1 or 2 sprays based on adult threshold levels
- Rotate with DC tron oils as required - use as a clean up spray after harvest if needed
- From April onwards, use Confidor Guard as a soil application at planting if you expect high migration of SLW from adjacent crops.

Window II – Winter

- Do not use Admiral or Applaud
- Use Confidor Guard as a soil application at planting if you expect high migration of SLW adults from adjacent crops
- Use DC tron oils if required – use as a clean up spray after harvest if needed
- Use bifenthrin (Talstar or equivalent) to control adults. In cucurbit crops, consider impact on bees when spraying.

Window III - Spring

- Stop using Confidor Guard soil applications by the end of September
- Use Admiral or Applaud – 1 or 2 sprays per crop. If two sprays are required use Admiral first, then Applaud two weeks later
- Use Chess to control adults in the early part of crop growth
- Use bifenthrin mixtures to clean up crops after harvest if high SLW populations are present. For low populations, use 1% DC tron.

Summer window

- Vegetable crop production break
- bifenthrin for adult knockdown in seedling nurseries

3. Supporting best practices for managing insecticide resistance

- Avoid using OP's and SP's early in the crop's growth, as they are broad-spectrum insecticides that reduce natural enemy numbers, reduce pollination and increase the chance pest outbreaks.
- Avoid continuous use of an insecticide from any one chemical group
- Any one product should not be used more than twice within a window period
- Do not to respray with an SP if you suspect that a SP spray has failed
- If established whitefly populations are present, avoid using OP chemicals to control other pests as this can lead to whitefly flare-ups.

Insecticide Resistance Management Strategy for silverleaf whitefly in vegetable crops

Burdekin – 2009 (Version 5)

Comments and suggestions welcome – please contact Siva Subramaniam or Sue Heisswolf at Bowen DPI&F on 4761 4000

<table>
<tr><th>Summer</th><th>Window I
Mid February to May</th><th>Window II
June to mid August</th><th colspan="4">Window III
Mid August to mid December</th><th>Summer</th></tr>
<tr><td rowspan="5">Summer break

Field:
Recommend crop free period</td><td>IGR’s – Admiral, Applaud</td><td>IGR’s free period</td><td colspan="2">IGR’s – Admiral, Applaud</td><td colspan="2">No IGR’s</td><td rowspan="6">Summer break

Put in place recommended cultural practices</td></tr>
<tr><td colspan="6">Petroleum oils (DC Tron Plus)</td></tr>
<tr><td>Movento</td><td></td><td colspan="3">Movento</td><td></td></tr>
<tr><td>No Confidor</td><td colspan="2">Confidor Guard soil application
(May to end September)</td><td colspan="3">No Confidor</td></tr>
<tr><td>Chess</td><td>No Chess</td><td colspan="4">Chess</td></tr>
<tr><td>bifenthrin*
Seedling nurseries only</td><td>No bifenthrin*</td><td>bifenthrin*</td><td colspan="4">bifenthrin* mixtures for field clean up</td></tr>
</table>

*bifenthrin – Talstar or equivalent – a synthetic pyrethroid (SP)

Insecticide Resistance Management Strategy for silverleaf whitefly in vegetable crops

Bowen - 2006 season

Comments and suggestions welcome – please contact Siva Subramaniam or Sue Heisswolf at Bowen DPI&F on 4761 4000

Summer	Window I Mid February to May	Window II June to mid August	Window III Mid August to mid December		Summer
Summer break **Field:** Recommend crop free period	**IGR's –** Admiral, Applaud	**IGR's free period**	**IGR's –** Admiral, Applaud	**No IGR's**	**Summer break** Put in place recommended cultural practices
	Petroleum oils (DC Tron Plus)				
	No Confidor	**Confidor Guard soil application**		**No Confidor**	
	Chess	**No Chess**	**Chess**		
bifenthrin* Seedling nurseries only	**No bifenthrin***	**bifenthrin***	**bifenthrin* mixtures for field clean up**		

*bifenthrin - Talstar or equivalent
a synthetic pyrethroid (SP)

Change over times between windows dependent on prevailing temperature and pest pressure

Disclaimer: Information in this leaflet is based on the current best information available and is provided solely on the basis that the reader will be responsible for making his/her own assessment of the content and seek professional advice as needed. Chemical registrations and APVMA permits for silverleaf whitefly control do not apply to all vegetable crops.

Insecticide resistance management guidelines for silverleaf whitefly (SLW) for Lockyer Valley Vegetable crops, 2007

Use an integrated approach! ▪ Plant non-host cover crops over summer ▪ Control broadleaf weed hosts and volunteer crops ▪ Don't plant young crops next to old crops ▪ Check transplants before planting out ▪ Monitor crops regularly and spray only on thresholds ▪ Calibrate the spray rig regularly, replace worn nozzles ▪ Ensure water volumes give adequate crop coverage ▪ Spray only at risk plantings ▪ Clean up harvested crops promptly **Encourage natural enemies (beneficials)** – let parasitoids and predators do the job for you. Spray only when necessary	**Use insecticides wisely** ▪ Avoid broad spectrum insecticide sprays. These will kill natural enemies, interfere with pollination and increase the chance of pest outbreaks. ▪ If you must use an OP or pyrethroid restrict their use to late in the crop ▪ Do not use an OP to control other pests when SLW populations are present in the crop **Alternate insecticides** ▪ No consecutive applications of an insecticide from any one chemical group. ▪ Treat the IGRs as one insecticide

The **area wide strategy** shown below is a guideline only and should be seen as an ideal to aim for. It does not mean that you must apply the chemicals listed to the crop at that time of year. Sprays should still only be applied as necessary, according to monitoring counts and thresholds.
However to help manage resistance, we encourage you to use only those insecticides listed in any particular window for the situations described. If you need to go outside the strategy to control a severe SLW outbreak, please return to the strategy once you have overcome the problem.

December & January	February to April	May to August	September to November
For winter vegetables Production break Non-host crop eg. sorghum Green manure crops **Summer vegetables** 1. DC tron oil for low pressure 2. Confidor Guard only if high pest pressure is expected 3. On spray of IGR per crop for high pressure and if registered in crop 4. Chess for adults early in crop if adult pressure is high End of crop spray out with pyrethroid/synergist/OP/DC tron at high water volume	1. DC tron oil for low pressure 2. DC tron for end of crop clean up spray if needed 3. Chess for adults early in crop 4. One spray of IGR per crop for high pressure if registered in crop 5. Avoid Confidor Guard use especially as the weather cools and pest pressure decreases End of crop spray out with DC tron ?? at high rate and high water volume if pest pressure if high – slash three days laster	1. DC tron oil for low pressure 2. No Confidor Guard until August and then only if pest pressure is high 3. Pyrethroid+Synergist as a last resort when pest pressure is high – remember it will kill natural enemies that may have been building up End of crop spray out with DC tron?? at high rate and high water volume if pest pressure if high	1. DC tron oil for low pressure 2. Confidor Guard only if high pest pressure is expected 3. Avoid IGRs – use only when nymph pressure is high and if registered in crop. Limit to one spray per crop. 4. Pyrethroid+Synergist as a last resort when pest pressure is high – remember it will kill natural enemies that may have been building up over winter End of crop spray out with pyrethroid/syngergist/OP/DC tron mix?? at high water volume if pest pressure is high

A SAMPLE SPRAY PROGRAMME FOR SILVERLEAF WHITEFLY – Pumpkin

(For late season crops planted from Aug to October 2007)

Crop stage (weeks after planting)	**When to spray (Spray threshold)**	**Insecticide**	**Rate**	**Spray Volume**	**WHP (days)**	**Comments**
1st week	High risk of whitefly migration	Confidor Guard (Soil application)	14 ml/ 100 m row	See Label	See Label	Crops planted after August at high risk of whitefly infestation. Spray older crop before slashing down
5 – 6 th week	If 1-2 flies/ leaf	DC-Tron	500ml/100L	300 – 500L	1	Don't mix DC-Tron with soap, sulphur, Benlate, Bravo or Morestan
	If more than 4 flies /leaf	Chess	200g/ha		3	Chess works mainly against adult whiteflies and safe to bees
6- 8th week	2-3 nymphs/ leaf	Admiral	500ml/ha	400-600L	1	Admiral should be sprayed when crop are at active growth stage. Don't spray on older or stressed plants.
9-10th week	More than 5 flies/leaf	Chess	200g/ha	500 -700L	3	High spray volume or good coverage is essential for better adult control
	Less than 5 flies/leaf	DC-Tron	500ml/ 100 L		1	
11- 12th week	For low adult numbers	DC-Tron	500ml/ 100 L	500-700L	1	Good coverage is essentials
13-15 weeks	For high adult numbers (above 10 flies/leaf)	Talstar and Synergy	600ml/ ha 300 ml/ ha	500-700L	7	For whitefly and mites control.
Clean-up spray (After final harvest)	If high number of adults flies present	Talstar + Chlorpyrifos	60ml/100L 1L/ha	500-800L	Do not pick fruit or feed animals	Important to control adult flies before they move into young crops. Spray after last harvest and plough down within 2-3 days.

This is only a sample program and may be used as a guide to develop your own spray program. Crop must be monitored to take proper decision. Care must be taken before mixing fungicides with DC tron. Young crops are more sensitive for SLW damage, therefore good control needed at early stage (up to 6 weeks). Must check the product or permit label before use