IPM for greenhouse vegetables – research to industry

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NSW Department of Primary Industries

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IPM for Greenhouse Vegetables – Research to Industry

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Leigh Pilkington

HAL Project number VG05093: IPM for Greenhouse Vegetables – Research to Industry

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The purpose of this report is to summarise a series of trials that have developed management strategies for a variety of greenhouse vegetable pests and their associated diseases. These tools include an entomopathogenic fungus that is currently being developed by a commercial partner for registration and release to industry, the efficacy and side effects of several reduced-risk pesticides, and the development of several biological control agents. This research has demonstrated that there are several options available to growers aside from conventional pesticides and has worked towards providing a set of tools available to industry.

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Media Summary

Western flower thrips, *Frankliniella occidentalis* (WFT) is a key pest in many horticultural crops grown in Australia. They cause feeding damage, which is often minor in nature, and importantly are responsible for vectoring several tospovirus diseases. Many greenhouse horticultural growers have limited options for the management of WFT and there is often only a small number of conventional pesticides available for use in protected cropping for managing WFT. Due to the rapid development of pesticide resistance by WFT, there is an ongoing need to develop a variety of integrated pest management (IPM) strategies for this industry and effective tools in this process is the availability of reduced-risk pesticides, those pesticides that represent reduced risk to human health, the environment and pesticide resistance build-up, that are compatible with the use of biological control agents or that have an inherent minimised risk with respect to the development of pesticide resistance.

WFT is just one pest that poses a problem to industry – there are many more that require a clearly planned and executed integrated pest management (IPM) strategy in order to effectively manage pest numbers. These pests might include two-spotted mites, aphids or other thrips and also include emergency plant pests that might arrive in the future.

NSW Department of Primary Industries has identified a number of promising new reduced-risk pesticides and natural enemies with potential for inclusion into greenhouse IPM programs. The reduced-risk pesticides include new organisms such as entomopathogenic fungus as well as new products being developed for other industries and that currently do not have a focus on the greenhouse market. This HAL project aimed to accelerate their development to market uptake to ensure that the greenhouse industry gains access to the best of the new tools at the earliest opportunity. This research has added to the IPM arsenal through introductions of new biological control agents and new reduced risk chemicals compatible with them.

High temperatures in greenhouses often limit the ability for growers to use biological control agents and these high temperatures are often damaging to the crops being grown reducing yield and quality. This project also looked at methods to effectively, and cheaply, reduce the temperature in low-technology greenhouses to allow for more effective use of beneficial insects as well as making a better growing environment for the crops to grow in and farm staff to work in. The investment in research of this nature is producing benefits for the greenhouse industry with adoption of IPM techniques and increasing numbers of growers are now using biological control effectively.

The next step is for more of the industry to invest in the latest greenhouse technology to enable them to compete with other producers in Australia and overseas produce that is starting to appear on the supermarket shelves. Improving the level of technology in greenhouses will lead to more control of the growing environment, reducing temperatures for the effective use of biological control and manage humidity to mitigate the effects of disease. This project has provided low technology growers with a stepping-stone towards higher technology structures by offering modification systems that will allow them to effectively increase their control on the environmental

conditions within the greenhouse. By taking small steps like these for greater environmental control, growers will increase yield and reduce input costs and be able to make plans to further improve their infrastructure in the future.

The increase in the adoption of biocontrol in greenhouse pest management programs coupled with the replacement of synthetic chemicals with softer reduced-risk chemicals, plus the less frequent use of insecticides altogether, will mean a lower risk of residue violations and safer produce for Australian consumers. Greenhouse produced vegetables will quickly achieve a deserved reputation as clean, safe produce for families to consume. This HAL funded project has contributed to the body of knowledge to allow this to move forward. By presenting these findings to industry and continuing to offer personalised support in the application of these technologies, industry will be well placed in the future.

Technical Summary

NSW Department of Primary Industries (NSWDPI) has identified a number of promising new reduced-risk chemicals, those pesticides that represent reduced risk to human health, the environment and pesticide resistance build-up, and natural enemies with potential for inclusion into greenhouse integrated pest management (IPM) programs. This HAL project aimed to accelerate their development to market uptake to ensure that the greenhouse industry gains access to the best of the new tools at the earliest opportunity. The project collaborated with chemical companies to develop protocols for greenhouse trials to produce efficacy data. The data from this project was made available to the companies that produce reduced-risk pesticides for them to submit as registration applications to the Australian Pesticides and Veterinary Medicines Authority, Australia's registration authority for agricultural and veterinary chemicals.

A number of new biological control prospects were also targeted for development. These were studied in the laboratory before being trialled under greenhouse crop conditions to develop usage protocols for growers. Techniques for mass rearing were developed in conjunction with another HAL funded project and the predatory mite *Transeius montdorensis* is now in full production. This project developed data that shows industry this mite's utility for a number of pest insects and mites and has increased its value for industry. It is now known that this predatory mite is able to be used in conjunction with other predators, against western flower thrips as well as two-spotted mites and greenhouse whitefly, and they are being supplied to around 40 growers and several research organisations across Australia.

In addition to informing industry about the range of pests able to be managed by these new biological control agents, protocols were developed to examine the side effects of common synthetic pesticides and the role of reduced-risk pesticides in a management strategy that involves the organisms. Structural adaptations to low-technology greenhouses were also examined and it was shown that maximum temperatures can be brought down by as much as 12ºC and common pests excluded effectively by using very simple techniques. This information is crucial if greenhouse producers are to use biological control agents successfully as they must have information on the likely impact of chemicals on them.

We are adding to the IPM arsenal through introductions of new biological control agents and new reduced risk chemicals compatible with them. The investment in research of this nature is producing benefits for the greenhouse industry with adoption of IPM techniques and increasing numbers of growers now using biological control. This increase was highlighted in HAL project number VG03098.

The next step is for more of the industry to invest in the latest greenhouse structures and control gear to enable them to compete with other producers in Australia and overseas produce that is starting to appear on the Supermarket shelves. Better technology will also make it easier for growers to use biological control. This project has also provided low technology growers with a stepping-stone towards higher technology structures that will allow them to move forward with their capital investment in a stepwise fashion.

The knowledge regarding the entomopathogen, DPI9, was increased to a level where commercial uptake is highly likely and the breadth of knowledge regarding its application and efficacy has been covered in detail. Several other reduced-risk pesticides were shown to be highly effective against pests such as western flower thrips, greenhouse whitefly and green peach aphid. The onus is now upon those companies that are responsible for the registration of these promising pesticides to work towards this for industry.

The feeding rates of three biological control agents, and how they interact, were investigated and an understanding of their limitations and where they perform well will assist in the development of any management strategies.

The increase in the adoption of biological control in greenhouse pest management programs coupled with the replacement of synthetic chemicals with softer reduced-risk chemicals, plus the less frequent use of insecticides altogether, will mean a lower risk of residue violations for Australian consumers. Greenhouse produced vegetables will quickly achieve a deserved reputation as clean, safe produce for families to consume. This HAL funded project has contributed to the body of knowledge to allow this to move forward.

Introduction

A meeting of the AusVeg Greenhouse Vegetable Reference Group to determine priority issues facing this industry was held at Horticulture Australia Ltd on 14 December 2004. The meeting involved key people from the Australian greenhouse vegetable industry from around Australia. Integrated pest management (IPM) and chemical access were the two highest rated issues; specifically additional biological control agents and a greater variety of soft chemicals were identified as key priority research needs. This HAL funded project aimed to expand industry access to some important new biological control agents and soft chemicals that possess potential for industry success. It is important to get these new IPM tools to the stage of industry uptake at the earliest opportunity.

This project aimed to accelerate the development of these to commercial uptake through this project by producing efficacy data for reduced-risk chemicals, those pesticides that represent reduced risk to human health, the environment and pesticide resistance build-up, for registration purposes. Although many more data are required for full registration, the intent was to show the producers that their product was highly effective against certain pests and that their seeking registration would lead to a market with high demand. The project also aimed to undertake laboratory and greenhouse experiments and develop mass rearing methods for new biological control agents and to undertake side-effects trials to determine the compatibility of the selected new reduced-risk chemicals on targeted commercially-produced biological control agents.

The Sydney Region growers experience significant problems with insect vectors, such as thrips and aphids, insects that cause damage to produce and spread crop virus diseases. A wide range of vegetable crops grown in the region are affected by thrips and aphids, primarily lettuce, capsicum, cucumber, zucchini, and eggplant.

Key insect pests and the diseases they transmit (the insect as vector of the diseases) that affect the productivity and sustainability of vegetable growers in the Sydney Region were the focus of this project. Whilst any pest that was causing damage to the greenhouse vegetable industry was examined, there were several species that were of particular interest.

Western flower thrips, *Frankliniella occidentalis* (WFT), has become a key pest of lettuce in Australia, particularly in covered and hydroponic systems. Feeding by larvae and adults causes a scarring and deformation of the leaves. However, the pest's effective vectoring of tomato spotted wilt virus (TSWV) can cause even greater problems. A sporadic problem since it was first described in Australia in 1915, the arrival of WFT greatly increased the incidence and seriousness of TSWV. Thrips larvae feeding on an infected plant acquire the virus, which then multiplies inside the insect. When the larvae reaches adulthood it can fly to a new plant, which it infects with the virus as it feeds on the cell contents. Under warm conditions thrips populations can increase rapidly, efficiently spreading TSWV through a crop. The pest is particularly a problem in greenhouse and hydroponic systems and was a major focus of the IPM strategies developed by NSW Department of Primary Industries (NSWDPI).

WFT is an important pest of fruit, vegetable and ornamental crops. It damages plants by feeding, laying eggs in the plant tissue and vectoring diseases. A native of North America, it has spread to many parts of the world including Europe, South America, Japan, Africa and New Zealand. It was first detected in Australia in 1993 and was the major focus for this project. The ability of the pest to develop insecticide resistance as well as it's propensity to quickly populate a crop has made it a very important pest in the Sydney Basin.

Another pest that was focussed on in this project are aphids. Aphids are small (about 2 mm long), soft-bodied insects with characteristic tubular extensions to the abdomen. They feed on plant sap using their sucking mouthparts and have complex life cycles. Adults can be winged or un-winged and females can reproduce with or without mating. Aphids can build up large populations within a short period of time. Aphids are responsible for spreading mosaic viruses and transmit the disease in a non-persistent manner, meaning they are only infective for a few hours at a time. The aphid sucks on affected leaves, distorting plant tissues and moving around spreading disease to healthy plant tissue as it probes or feeds. Transmission may occur within a few minutes of feeding on a healthy host, making chemical control an unreliable management option.

Aphids may simultaneously be a vector for more than one type of virus. Crop protection from aphids is best managed through an IPM program that includes good farm hygiene, the use of resistant varieties, removal of crop residues, control of aphids in alternate hosts, introduction and preservation of beneficial insects as well as 'soft chemistry' insecticide applications when most necessary.

When growers are encouraged to undertake biological control in their crops, the control of fungus gnats (*Bradysia* sp.), is often the first target as they are easily controlled with predatory mites. Fungus gnats are a common problem in greenhouse crops, as they like high levels of organic matter and moisture. Adult fungus gnats can be found sitting on the surface of plastics and media, and flying around the bottom of plants. They are small (5 mm) black flies with long legs and antennae, with a single pair of wings. Under a microscope, a Y-shaped pattern can be seen in the veins on the end of the wings.

Providing greenhouse conditions are appropriate, low temperatures and no pesticide residues, greenhouse whitefly (GWF) *Trialeurodes vaporariorum* may be another easy success for adopters of biological control. *Encarsia formosa* is a highly effected parasitoid used to target greenhouse whitefly and growers can experience excellent successes. Greenhouse and silverleaf whitefly (SLWF) *Bemisia tabaci* Biotype B (also known as *Bemisia argentifolii*) are potentially major pests in greenhouse crops in the summer months or under dry warm conditions. Whiteflies are more commonly found in hot spots of greenhouses as higher temperatures suit their breeding cycle. This characteristic puts them at odds with biological control agents that nearly without fail prefer mild temperatures and their efficacy will be reduced in these hotter zones of the greenhouse.

Whiteflies suck the sap from plants. Affected plants may wilt, turn yellow, shed leaves and display reduced growth rates if infestations are severe. Whiteflies produce honeydew, encouraging sooty mould growth, which reduces photosynthesis and decreases plant vigour. Feeding by whiteflies can also cause deformed fruit and discoloration of tomatoes, through uneven ripening. Whiteflies can be vectors of plant viruses such as tomato yellow leaf curl virus (TYLCV), beet pseudo yellows virus (BPYV) and tomato torrado virus (ToTV).

Two-spotted mite (TSM), *Tetranychus urticae* Koch, is a pest of many vegetable crops. Feeding by all life stages of the mite from the under surface of the leaves can cause white or greyish spots on the leaves making leafy green crops unmarketable and reducing overall health in other crops. TSM is often an ‘induced’ or ‘secondary’ pest, which is a pest that is encouraged by insecticide sprays. This is because it can rapidly develop resistance to insecticides. The predators of TSM, such as ladybird beetles, are killed by the insecticides that in turn lead to TSM outbreaks. Routine insecticide applications can therefore assist TSM and lead to greater problems.

Materials and Methods

Reduced Risk Pesticides – External Effects on *Beauveria bassiana*

Effect of Application Rates of *Beauveria bassiana* Against Western Flower Thrips

Introduction

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), was detected in Australia in the early 1990's. Since this time, there has been increasing concern surrounding the feeding damage caused by this pest, its ability to vector diseases such as tomato spotted wilt virus, and its propensity to develop resistance to commonly used pesticides. Management of this pest, and many other pests, is largely restricted to a confined list of registered pesticides that may or may not be compatible with an integrated pest management system and may preclude the use of biological control agents. Growers in many industries, hydroponic lettuce for example, are eager to gain access to a greater number of management options and it is wise to provide pesticides that will have minimal side-effects on beneficial organisms.

Beauveria bassiana is a fungus that causes the death of insects after infecting them with the growth of its spores. When spores of this fungus are exposed to the cuticle of susceptible insect hosts, they germinate and grow directly through the cuticle to the inner body of their host. Inside the insect's body the fungus grows rapidly producing toxins and often drawing on the insects' stores of energy. The insect ultimately dies after a short growth period if given the right conditions.

The nature of the fungus and the fact it is effective after merely making contact with the insect host, sets it apart from other pathogenic pesticides such as virus or bacteria applications that require the insect to ingest the organism to become infected.

Once the fungus has killed the insect, its structure grows back out through the insect's cuticle, covering the insect with a layer of white, fluffy, fruiting bodies. This downy growth then produces millions of new infective spores that are released to the environment to make contact with additional hosts.

A local strain of *Beauveria bassiana* sourced on NSW DPI property in Gosford, NSW, was isolated and produced at levels that allow for experimentation of the organism against several insect pests. Commercial partners, Becker Underwood Pty Ltd, have been working with NSW DPI staff for some time to develop the entomopathogen as a commercially released pesticide available to growers.

This study aimed to address the required rates of application for DPI 9 in an attempt to lower the effective rate as far as possible. This would assist commercial partners in their consideration of taking the product on.

Methods

Nine treatments were applied – three rates (0.2195g DPI9 / l, 0.1097g DPI9 / l and 0.0548g DPI9 / l) of DPI9 and three different surfactants (0.5% oil, 0.25% oil and 0.5% Hasten oil) were combined to examine any individual or combination effects.

- 0.2195g DPI9 / l + 0.5% (5ml / L) oil
- 0.2195g DPI9 / l + 0.25% (2.5ml / L) oil
- 0.2195g DPI9 / l + 0.5% Hasten (Victorian Chemical Company Pty Ltd)
- 0.1097g DPI9 / l + 0.5% oil
- 0.1097g DPI9 / l + 0.25% oil
- 0.1097g DPI9 / l + 0.5% Hasten (Victorian Chemical Company Pty Ltd)
- 0.0548g DPI9 / l + 0.5% oil
- 0.0548g DPI9 / l + 0.25% oil
- 0.0548g DPI9 / l + 0.5% Hasten (Victorian Chemical Company Pty Ltd)

Control treatments include

- Water + 0.5% oil
- Water + 0.25% oil
- Water + 0.5% Hasten (Victorian Chemical Company Pty Ltd)

Experimental design

Treatments were applied in four replicates, each with 12 treatments consisting of the nine application rates and three controls. The experiment was run in two small greenhouse bays with replicates located on individual benches, four in total. Treatments were separated with suspended plastic curtains.

Effect of High Application Rates of *Beauveria bassiana* Against Greenhouse Whitefly

Introduction

The use of entomopathogenic fungal agents is not a novel idea in pest management and there are many products currently available for use in many crops. The majority of fungal agents available are *Metarrhizium* spp. with a few strains of *Beauveria* spp. being available. On paper, *Beauveria* has a greater pathogenicity but in practice suffers from an unreliable, and often more expensive, commercial production. The success of a biological control agent, entomopathogens included, are only as good as their capacity to be economically viable and their ability to be registered for use in target crops against important pests. Regardless of the ability of the entomopathogen to manage populations of pest insects, if these basic principals are not met then their success is limited.

This trial aimed to assist this process by producing data indicating the organisms efficacy against GWF, a new host as yet untested for use with the entomopathogen. By broadening the target pests that this strain can be used against, it is hoped that the commercial success of the product will lead to industry adopting this reduced-risk pesticide.

Methods

Preparation of Experimental Plant Material

48 "Cherry Elite" tomato seedlings purchased from an unspecified grower were transferred to pots and maintained in one of the two experimental greenhouse bays (4m x 4.5m double skinned roof, single skinned walls, heated by gas furnace and cooled by evaporative cooling pad). Two each of 3m x 1.2m benches were set up in each greenhouse bay, with each bench divided into 12 equal areas in a 2 x 6 configuration using plastic sheeting to minimise movement of pests. Each greenhouse bay was maintained at an average of 21-24°C. Each bench contained four replicates. Approximately 1500 adult GWF were released into a purpose-built cage containing all of the potted experimental plants, and allowed to lay eggs. After 48-72 hours, all adult whitefly were removed, and plants moved to individual plastic divisions. Plants were monitored until >75% of eggs had hatched.

Preparation of whitefly adults

Cages with 40-50cm tobacco plants were maintained in a greenhouse kept at 25˚C ±3˚C with plants and insects rotated as needed. Adults were collected from these cages and released into the experimental areas as described above.

Pesticide treatments

Two rates of DPI9 (1.0975g/l and 2.195g/l), and two controls (water only, and water + oil) were applied once a week for two weeks. A hand held sprayer was used and all treatments were applied to the point of incipient runoff. The water + oil control consisted of 5mL of vegetable oil + surfactant per litre of water.

Assessments

Assessments of the GWF population present on each assessment plant were made over 3 weeks. A single leaf containing 30-50 GWF larvae was marked at the initial count and the number of larvae present recorded. One week after the 2nd treatment application a final assessment was conducted, giving the number of emerged pupae, live pupae yet to emerge, dead pupae, and pupae parasitised by *Encarsia formosa* on the target leaf.

Effect of Low Application Rates of *Beauveria bassiana* against Greenhouse Whitefly

Introduction

One of the problems associated with *Beauveria bassiana* entomopathogen pesticides, and indeed all entomopathogens, is the need to reduce the rate of application to make it a more attractive option to commercial suppliers. The production of these entomopathogens is often unreliable and expensive, creating a considerable hurdle in moving towards commercialisation.

This study aimed to examine the lowest possible rate with which the use of *Beauveria bassiana* (DPI-9) is effective for the control of GWF. By reducing the application rate as much as possible, commercial producers will be more inclined to move through the expensive process of registration for use in commercial crops.

Methods

Preparation of Experimental Plant Material

Mature De Ruiter Tresco F1 hybrid tomato plants which had been utilised in previous experiments were used in this trial. Between each experiment a standard insecticide was applied to all plants, plants cut back, and the whitefly population built up again. Approximately 500 adult greenhouse whiteflies were released into each greenhouse to help numbers build up. It was assumed that there was no carry-over effect of treatments from one experiment to the next.

The experiment was conducted in two 6.1 m by 8.9 m double skinned poly greenhouses. Each greenhouse was set up with 3 rows of tomato plants, with 21 plants per row. There were 4 experimental units (row of 4 plants) per row, with a single buffer plant between each experimental unit. On each target plant, a terminal leaf from a branch 1/3 from the top of the plant (upper) and 1/3 from the bottom of the plant (lower) was scored for the number of 1) L1 and L2 stages, 2) L3 and L4 stages, and 3) pupae. Plastic sheeting was hung between the rows from the gutter to the floor to minimise movement of pests and fungal spores between the rows. Each greenhouse bay was maintained at an average of 20°C and 75% relative humidity.

Preparation of whitefly adults

Cages with 40-50cm tobacco plants were maintained in a greenhouse kept at 25˚C ±3˚C with plants and insects rotated as needed. Adults were collected from these cages and released into the experimental areas.

Pesticide treatments

Five rates of DPI9 (0.1829g/l, 0.5487g/l, 0.7317g/l, 0.9146g/l, and 1.0975g/l), and a control solution were applied once a week for three weeks. A knapsack sprayer was used and all treatments were applied to the point of incipient runoff. The control solution consisted of 5mL of vegetable oil + surfactant per litre of water.

Assessments

Assessments of the GWF population present on each assessment plant were made over four weeks. On each target plant, a terminal leaf from a branch 1/3 from the top of the plant (upper) or 1/3 from the bottom of the plant (lower) was scored for the number of 1) L1 and L2 stages, 2) L3 and L4 stages, and 3) pupae. Across the 4 plants that made up each experimental unit, 2 leaves were assessed from the upper part of the plant, and 2 leaves were assessed from the lower part. An assessment was made prior to each of the three treatment applications, and a final assessment made one week after the third treatment.

Effect of Humidity on *Beauveria bassiana*

Introduction

An entomopathogen is an organism that causes death in insects. Organisms such as these are routinely used in pest management around the world and include things like viruses, bacteria, protozoa or, as in this case, a fungal agent. *Beauveria bassiana* is a fungus that is found naturally in the environment all around the world. Sub-species of the organism are already being used as a biological control agent to manage a number of pests such as termites, beetles and plague locusts. Researchers at NSW DPI discovered a local sub-species of *B. bassiana* and have developed it to a stage where it is being tested for commercial release. This organism is labelled DPI-9.

A key element in the successful application of beneficial entomopathogenic fungi as a pesticide product for greenhouse crop use is tolerance to humidity. While there is some conflicting comment on this in the literature, it is generally held that fungal spores require a humid environment to germinate. However, for growers to successfully use a fungal biopesticide they need to know the conditions under which these products will perform and this apparent conflict needs to be investigated. It was determined in an initial experiment that fungal performance with DPI 9 was reduced at a constant humidity of 50 and 70% RH, but not at 90% RH.

Methods

Experiment 1 investigates the effect of short-term reduced humidity and long term high humidity on DPI9.

Experiment 2 investigates the effect of short-term high humidity and long term low humidity on DPI9.

Preparation of Western Flower Thrips

WFT are reared on fresh French beans in sealed vented containers. The WFT culture is maintained over 5 containers, with each container holding a discrete life-stage. Cultures are serviced twice weekly and are kept in two separate constant temperature rooms held at 25°C and between 75-85% RH (14h light, 10h dark). A 1.5-2cm layer of vermiculite covers the base of each container, with a sheet of paper towelling over the top. Mesh trays containing the beans are laid on top of the paper towel.

“French Flat” green beans are purchased and washed in a pyroneg solution to remove any insecticide residues, then in a dilute bleach solution to remove plant and insect pathogenic microbes, and dried thoroughly. The fresh beans are added to the container holding adult WFT, which then “egg” into the beans. At the next service the adults are removed, and pollen and honey are added as food for the emerging larvae. The young are maintained at each service until they reach adult stage, at which time fresh beans are added for the cycle to be repeated. Thrips to be utilised in trials are taken from the container holding the appropriate life-stage as required.

Pesticide treatments

A single rate of DPI9 (1.0975g/l), or a control solution were utilised in this experiment.

Preparation of Experimental Material

Saturated salt solutions were prepared giving the following relative humidities with the Vaisala HM70 sensor:
ZnNo3 – 50.61%
NaCl – 70.24%
KNO3 – 85.62%

Millipore dishes, 5cm in width, were set up with 1% agar, with 5ml of agar in each dish. French bean leaf discs were placed over cooling agar and allowed to set. The potter tower was calibrated and was calculated to spray 2.34mg/cm2. All leaf discs were then sprayed with 2ml of the appropriate solution, with negative control (NC's) dishes sprayed before DPI9 treated dishes.

WFT had previously been caught and placed into vials – about 15 thrips each vial. Once plates had been sprayed then dried, thrips were tapped out onto the plate, covered with the lid constructed with a fine mesh insert, dish edges sealed with parafilm, then placed into the appropriate humidity trays depending on the treatment. All trays were held at 22-25ºC throughout the experiment. At 1, 3, 7 and 9 hours, the dishes were moved between humidity trays as per experiment design.

Assessments

After 6 days, all dishes were removed from trays, opened, and each thrips assessed under the microscope. Thrips were scored as alive, dead due to DPI9 infection, or dead from other causes eg, drowning, age etc. This experiment was replicated 3 times.

Effect of Ultraviolet Light on *Beauveria bassiana*

Introduction

A key element in the successful application of beneficial entomopathogenic fungi as a pesticide product for greenhouse crop use is tolerance to UV light. UV wavelengths can have a damaging effect on conidial germination resulting in their failure to penetrate into the host insect body. For growers to successfully use a fungal biopesticide they need to know the conditions under which these products will perform.

An initial experiment will be conducted to measure the adverse influence of set periods of UV light in a greenhouse on cucumber leaves previously treated with an aqueous suspension of DPI 9. At the conclusion of each exposure period leaf discs will be cut and presented to WFT adults for 6 days in a bioassay unit previously described, after which they will be assessed for mortality of the WFT.

Methods

Preparation of WFT

WFT are reared on fresh French beans in sealed vented containers. The WFT culture is maintained over 5 containers, with each container holding a discrete life-stage. Cultures are serviced twice weekly and are kept in two separate constant temperature rooms held at 25°C and between 75-85%RH (14h light, 10h dark). A 1.5-2cm layer of vermiculite covers the base of each container, with a sheet of paper towelling over the top. Mesh trays containing the beans are laid on top of the paper towel.

"French Flat" green beans are purchased and washed in a pyroneg solution to remove any insecticide residues, then in a dilute bleach solution to remove plant and insect pathogenic microbes, and dried thoroughly. The fresh beans are added to the container holding adult WFT, which then "egg" into the beans. At the next service the adults are removed, and pollen and honey are added as food for the emerging larvae. The young are maintained at each service until they reach adult stage, at which time fresh beans are added for the cycle to be repeated. Thrips to be utilised in trials are taken from the container holding the appropriate life-stage as required.

Pesticide treatments

A single rate of DPI9 (1.0975g/100ml), or a control solution were utilised in this experiment. . The solution for the control was 5ml /L of Vegetable oil + surfactant (Becker Underwood) in water, while the DPI9 solution was 5ml of DPI9 stock solution (0.54875g of spores into 50ml vegetable oil + surfactant) in 1L of H2O.

Preparation of Experimental Material

A large rectangular frame was constructed over which a polycarbonate sheet and shadecloth were attached side by side. The polycarbonate sheet had previously been assessed as providing 100% UV blockout, and the shadecloth when placed in a triple layer was assessed to provide 50% UV blockout (Environdata WeatherOne data logger). A temperature and humidity datalogger was suspended from the frame, and the UV levels (W/m2) were also recorded throughout the experiment.

At time = 0 (T0) mature cucumber plants were placed either in 100% UV light (full sun), 50% UV light (under shadecloth), or no UV (under the polycarbonate sheet), then sprayed with either a control solution or a DPI9 spore solution until the point of incipient runoff. One control and one DPI9 treated plant were removed to the laboratory immediately, and once completely dry, leaf discs were made and placed over 5ml of 1% agar in 5cm petri dishes.

Adult WFT had previously been caught and placed into vials – about 15 thrips each vial. Once plates had cooled, thrips were tapped out onto the plate, covered with the lid containing a fine mesh insert, and dish edges sealed with parafilm. Saturated salt solutions had previously been prepared giving a relative humidity of 70-75%. The dishes were suspended in trays containing the salt solution and held at 25ºC until assessment.

At time = 90 minutes (T90) a further control plant and DPI9-treated plant were removed to the laboratory, and leaf discs were made. Thrips were released onto each plate, dish sealed and incubated until assessment. This process was repeated a third time at time = 180 minutes (T180).

Assessments

After 6 days, all dishes were removed from trays, opened, and each thrips assessed under the microscope. Thrips were scored as alive, dead due to DPI9 infection, or dead from other causes eg, drowning, age etc. This experiment was replicated twice.

Reduced Risk Pesticides – Efficacy Trials

Efficacy of Multiple Reduced-Risk Pesticides

Introduction

A reduction in the routine use of conventional pesticide applications is needed to avoid pesticide resistance build-up in key pest groups and retain the efficacy of those pesticides for future strategic use. A key component to a successful integrated pest management program, a strategy used to reduce pesticide use, is the use of effective biocontrol agents in a cropping system. Many biocontrol agents are highly susceptible to the effects of conventional pesticide residues. These effects are often not limited to longevity but also sub-lethal effects such as reduced fecundity and efficacy.

A reduced-risk pesticide is generally derived from biological sources such as bacteria, viruses, fungi and protozoa, as well as chemical analogues of naturally occurring biochemicals. These pesticides are often considerably different to conventional, broad-spectrum products in the sense that they are typically highly target-specific and have little to no impact on non-target organisms. This trait is particularly important in order to protect beneficial insects that may be operating in a system as part of an integrated pest management strategy.

Several prospective reduced-risk resources are available to manage WFT, GWF and green peach aphid. The performance of these products required evaluation prior to the pursuing of commercial use permits and registrations.

Experiment 1: Evaluate the performance of the following products and their application rates against WFT populations on cucumber.

1. Cyazypyr (DuPont) - 0.05gai/L
2. Cyazypyr (DuPont) - 0.075gai/L
3. Pyris (Sumitomo) – 0.02gai/L (stock is 500gai/l)
4. Symphony (Sumitomo) – 0.02gai/L (stock is 100gai/L)
5. DPI9 – 1.0974g/100ml
6. Agri50NF (rate) + 0.1% eco oil (Sumitomo)
7. Agri50NF (Cal Agri) – 1.5ml/L
8. Agri50NF (Cal Agri) – 3ml/L
9. Abrade (Grow Choice.) – 5ml/L
10. Abrade (Grow Choice) – 2.5ml/L
11. PestOff (Holland 3) – 25ml/L
12. Bio-cover (Agnova) – 1%
13. Bio-cover (Agnove) – 2%
14. Spinosad – 0.096gai/L (0.4ml/L)
15. Control – water only treatment

Experiment 2: Evaluate the performance of the following products and their application rates against GWF populations on tomato.

1. Cyazypyr (DuPont) - 0.05gai/L
2. Cyazypyr (DuPont) - 0.075gai/L
3. Abrade (Grow Choice) – 5ml/L

4. Abrade (Grow Choice) – 2.5ml/L
5. PestOff (Holland 3) – 25ml/L
6. Bio-cover (Agnova) – 1%
7. Bio-cover (Agnova) – 2%
8. Natrasoap Label Rate
9. Bifrenthrin label rate
10. SB Plant Invigorator (SB Products) 2ml/L
11. Eco-Oil (OCP) – Label Rate
12. DPI-9 1.0974g/100ml
13. DPI-9 2.195g/100ml
14. E2Y45 (DuPont) - 0.125g/L
15. Control – water only treatment

Experiment 3: Evaluate the performance of the following products and their application rates against green peach aphid populations on cucumbers.

1. Agri50NF 1.5ml/L
2. Agri50NF 3.0ml/L
3. Cyazypyr (DuPont) 0.05ml/L
4. Cyazypyr (DuPont) 0.075ml/L
5. DPI9 1.0974g/100ml
6. DPI9 2.195g/100ml%
7. Pirimicarb – label rate
8. Control – water only treatment

Methods:

The greenhouses were planted with three rows of cucumbers (or tomatoes for GWF experiment), in slabs, separated with plastic sheets running between the rows for the length of the house. Treatment plots will be separated by using a buffer plant between each treatment plot. Each row had seven slabs with three plants each for a total of 21 plants per row. This allowed for 10 treatment plants in each row.

Each house will allow two replicates of each treatment with a leaf being taken from the plant, bagged and returned to the lab for counting.

Distribution of WFT population

Adult thrips were distributed on the floor of the house to allow for dispersal. Nymph WFT were distributed onto individual leaves of each plant.

Distribution of GWF population

Adult whitefly were released in the house for a period of one week to allow a population to establish.

Application of treatments

Three, weekly applications of each treatment occurred with pre-treatment counts being undertaken prior to the first application. One week after the third application, a leaf will be taken from the plant, bagged and thrips counted in the lab.

Efficacy of Cyazypyr on Western Flower Thrips on Cucumbers

Introduction

The development of pesticide resistance is one of the greatest concerns surrounding the management of WFT in many crops. Effective pesticides are required to be rotated regularly with several different active ingredients and modes of action. In greenhouses, the paucity of available conventional, or reduced-risk, pesticides make this rotation difficult.

In addition to resistance management strategies, the application of reduced-risk pesticides will allow growers to consider other management options such as biological control. Without these options, the efficacy of existing pesticides will diminish quickly and there will be nothing available for effective use in times of crisis. This trial aimed to examine an unreleased reduced-risk pesticide with the view to develop efficacy data for the producer to use to pursue registration for commercial use. This first step in building data is critical in the establishment of new reduced-risk chemistries that are accessible by industry.

Methods

Preparation of Experimental Plant Material

60 Rijk Zwaan Khassib F1 hybrid cucumber seeds (Lot #100308044/3) were seeded into trays, then transferred to pots 9 days later and maintained in the three experimental greenhouse bays (4m x 4.5m double skinned roof, single skinned walls, heated by gas furnace and cooled by evaporative cooling pad). Two each of 3m x 1.2m benches were set up in each greenhouse bay, with each bench divided into 12 equal areas in a 2 x 6 configuration using plastic sheeting to minimise movement of pests. Each greenhouse bay was maintained at an average of 21-24°C. Each bench contained 3 replicates.

Approximately 1500 adult WFT were released across each greenhouse bay on day 20 and again on day 21 after seeding. On day 22 post-seeding 10 WFT larvae were released onto three leaves of each cucumber plant. A pre-treatment count was undertaken on all plants on day 29 to ensure a uniform population across the greenhouse.

Preparation of Western Flower Thrips

WFT were reared on fresh French beans in sealed vented containers. The WFT culture was maintained over five containers, with each container holding a discrete life-stage. Cultures are serviced twice weekly and are kept in two separate constant temperature rooms held at 25°C and between 75-85% RH (14h light, 10h dark). A 1.5-2cm layer of vermiculite covers the base of each container, with a sheet of paper towelling over the top. Mesh trays containing the beans are laid on top of the paper towel.

“French Flat” green beans are purchased and washed in a pyroneg solution to remove any insecticide residues, then in a dilute bleach solution to remove plant and insect pathogenic microbes, and dried thoroughly. The fresh beans are added to the container holding adult WFT, which then “egg” into the beans. At the next service the adults are removed, and pollen and honey are added as food for the emerging larvae. The young are maintained at each service until they reach adult stage, at which time fresh beans are added for the cycle to be repeated. Thrips to be utilised in trials are taken from the container holding the appropriate life-stage, adults in the vermiculite mix, and larvae gently brushed off of the beans used a fine paintbrush.

Pesticide treatments

Two rates of Cyazypyr (0.05ml/L and 0.075ml/L), a single rate of spinosad (0.8ml/L), and a control treatment of water were applied once a week for three weeks. A hand held sprayer was used and all treatments were applied to the point of incipient runoff.

Assessments

Assessments of the WFT population present on each assessment plant were made weekly for four weeks, with the first three counts performed just prior to the application of the pesticide treatments and the final count performed a week after the final pesticide treatment. On each plant, four leaves were marked. All four leaves were scored individually for the number of adult and larvae/pupae at the first and last count, while a single marked leaf was assessed at the second and third counts.

Efficacy of Agri50NF against Western Flower Thrips, Greenhouse Whitefly and Two-spotted Mites on Cucumbers

Introduction

Agri-50NF is based on the properties of natural plant extracts to form a sticky layer able to trap small insect pests. The product was a focus in this project due to its compatibility with IPM and biological control strategies. The pesticide does not have any residual effects and its physical mode of action is an excellent resistance management tool.

The product is known to target **a**phids, scale, whitefly, psyllids and mites. It is most effective against the juvenile stages of pest outbreaks and monitoring of crops for early detection of pests is essential for effective pest management. It is not yet registered for use in Australia and the development of local efficacy data is imperative to this process. This trial aimed to develop efficacy data for the local distributors in an attempt to expedite the registration process of this valuable reduced-risk pesticide in Australian crops.

Methods

The following methods were repeated for each of the three pests tested. Pests included WFT, GWF and twopostted mites, all tested on cucumber crops.

Preparation of Experimental Plant Material

60 Rijk Zwaan Khassib F1 hybrid cucumber seeds (Lot #100308044/3) were seeded into trays, then transferred to pots 9 days later and maintained in the three experimental greenhouse bays (4m x 4.5m double skinned roof, single skinned walls, heated by gas furnace and cooled by evaporative cooling pad). Two each of 3m x 1.2m benches were set up in each greenhouse bay, with each bench divided into 12 equal areas in a 2 x 6 configuration using plastic sheeting to minimise movement of pests. Each greenhouse bay was maintained at an average of 21-24°C. Each bench contained three replicates.

Approximately 1500 adult WFT were released across each greenhouse bay. A pre-treatment count was undertaken on all plants on day 29 to ensure a uniform population across the greenhouse.

Pesticide treatments

Two rates of Agri50NF (1.5% and 3%), a single rate of bifrenthrin (0.5 ml/L), and a control treatment of water were applied once a week for three weeks. A hand held sprayer was used and all treatments were applied to the point of incipient runoff.

Assessments

Assessments of the WFT population present on each assessment plant were made weekly for four weeks, with the first three counts performed just prior to the application of the pesticide treatments and the final count performed a week after the final pesticide treatment. The entire plant was assessed and was scored individually for the number of adult and larvae/pupae.

Biological Control Agents – Feeding Trials

Transieus montdorensis – Greenhouse Whitefly and Western Flower Thrips Feeding Rate

Introduction

The utility of *T. montdorensis* against WFT has been shown to be an effective tool for managing this pest. Trials were conducted to then assess the predatory mites ability to manage numbers of GWF. These two pests commonly appear in the same crop and management strategies for the two organisms will overlap. GWF and WFT are different sizes and would have different nutritional value. It is possible that the *T. montdorensis* will eat different numbers of each pest and a comparison of numbers eaten (or proportion eaten) should be taken into account.

This trial aimed to answer the question as to whether there is an interaction between the two preys and if *T. montdorensis* prefers one of the prey in a two-choice experiment. The aim was to compare the predatory performance of the predator *T. montdorensis* against GWF and WFT where predatory performance is defined as the number of pests eaten per day and the number of eggs produced by the *T. montdorensis*.

This information is valuable for growers because if the predatory mite preferentially controls one pest, it may lead to a secondary pest outbreak of the other if a complementary management strategy is not put in place.

Methods

A single *T. montdorensis* was placed on a Petri dish containing agar and a cucumber leaf disc. The leaf disc will have had GWF eggs laid onto it previously, WFT larvae will be added. The initial number of GWF (10-15) and WFT (20) was known.

5 treatments – GWF + *T. montdorensis*
WFT + *T. montdorensis*
GWF + WFT + *T. montdorensis*
GWF control
WFT control

Each day for four days the number of pests eaten in each dish was recorded and the dish topped up with a known number of pest larvae. Proportion eaten was calculated. Natural mortality was estimated by counting the number of dead pests in the control dishes.

For each dish, the number of *T. montdorensis* eggs produced over the four day period was recorded.

The effect of the three treatments on fecundity was tested using the number of eggs produced for each of the 15 *T. montdorensis*.

Hypoaspis aculeifer, *Hypoaspis* sp., and *Stratiolaelaps scimitus* Feeding Rates

Introduction

A reduction in the routine use of conventional pesticide applications is needed to avoid pesticide resistance build-up in key pest groups and retain the efficacy of those pesticides for future strategic use. A key component to a successful integrated pest management program, a strategy used to reduce pesticide use, is the identification and use of efficacious biological control agents in a cropping system. A biological control agent's efficacy can be measured by quantifying the number of pest individuals the biocontrol agent consumes over a given period of time.

One undescribed species of Laelapid mite (*Hypoaspis* sp.), a mite shown to be effective in the management of thrips pests internationally (*Hypoaspis aculeifer*), and a mite currently used in biological control programs in Australia (*Stratiolaelaps scimitus*), were evaluated, comparatively, in their biology and predatory performance against WFT pupae.

Methods

Preparation of arena:

The floor of the arena was prepared by mixing, by volume, one part activated charcoal with seven parts plaster of Paris (POP) in a zip lock bag. Water, 70ml, was then added per 100g of POP mix in a large beaker. The POP mix was slowly added to water and allowed to sit for 30 seconds before being mixed quickly by hand. The mixture was then spooned to individual cells that were to be used in the experiment. The surface of the POP, when set, was smeared with label rate captan.

Obtaining uniform mite ages for evaluation

Approximately 100 pre-adult mite stages for each species were removed from the colony. Mites were placed in large arena with small amounts of yeast and thrips pupae. These individuals were monitored daily for moult to adult stages.

When 20 female mites moulted to adult stage, they were removed to separate arena with males for 24 hours. After 24 hours when mating was assumed, the males were removed.

Predation evaluation – prey consumption

Arenas were prepared for each species of predatory mite. Adding a drop of water onto the surface until it darkened moistened the POP while care was taken not to allow the water to pool. A single female was placed in each arena with 40 WFT pupae. The lid was closed and sealed with parafilm, placed in a darkened container and placed in a controlled environment room at 23°C. The pupae were counted every 24 hours for five days. During the counts, numbers of pupae were refreshed up to 40.

Biological Control Agents – Side Effects

Transieus montdorensis – Pesticide Side-Effects

Introduction

The utility of predatory mites, or any beneficial insect, can be limited by a number of factors. The environment that they are placed in, their access to prey and alternate food sources, the host plant and the size of the host prey all have an impact. One of the greatest impacts for beneficial insects and mites is the presence of residues from pesticide applications or the direct impact of spray applications.

For growers to be able to effectively manage the pests within their crops using biological control, the first and possibly the most important step is to clean all surfaces of pesticide residues. These residues may have direct mortality effects, or indirect impacts on the biology of the beneficial organisms. Growers need to be able to make informed decisions about the pesticides they are going to apply and what impact they will have on the biological management practices they are using within their greenhouses.

In order to make side effect data available to other projects, this project aimed to develop the protocols that are necessary to successfully complete pesticide side effect work.

Toxic Standards

The toxic standard needs to be run for each predator at least once per year. Obtain each life stage of target insect, and expose all life stages to the required standard for use as a positive control in the following manner:

1) Place a Filtech glass microfibre filter paper disc in both the top and the bottom sections of a 60mm Schott soda glass Petri dish.
2) In clean sterile test tubes/conical flasks, make up pesticide solution using deionised water at the following concentrations: 0 (neg ctrl), 1/8 recommended rate (RR), 1/4RR, 1/2RR, full RR, and double the RR. Make the solutions up separately for each replicate.
3) Pipette 500µl of deionised water or aqueous pesticide solution of the appropriate concentration onto each filter paper disc using a calibrated pipettor.
4) Immediately place a single insect or group of five eggs into each dish, and replace lid + filter paper.
5) Seal with parafilm so that no insects escape, then place into an incubator at 25ºC ±1 ºC and a photo period of 16:8 (D:L) hours.

Treatment No. 1 = Negative control (deionised water)
Treatment No. 2 = Double the Recommended Rate (RR)
Treatment No. 3 = RR
Treatment No. 4 = One Half (1/2) of RR
Treatment No. 5 = One Quarter (1/4) of RR
Treatment No. 6 = One Eighth (1/8) of RR

Evaluate mortality effect of the toxic standard after 24 hours of exposure at the increasing rates of Active Ingredient (AI) per m-2 by observing under a microscope. If insects did not respond when touched with a fine paint-brush, they were considered to be dead. For eggs – monitor every 24 hours until hatching. If eggs had not hatched after five days, they were considered to be dead.

Estimate a 24h - LD50 for each life stage. Based on these data, determine which life stage represents the worst case. The most susceptible life stage is what should be used for further testing, and the LD50 value for that particular life-stage is what will be used as a positive control.

IOBC Laboratory Testing Procedure

Place approximately 25-30 gravid females in a dish containing a leaf disc over agar with a food source. Allow females to lay eggs. Remove adults after 24hours, and label dish with date of egg lay. Monitor dish daily for hatching. Ensure that ages are uniform and within a 24 hour age-range by removing any eggs that have not hatched from the dish. Label each dish with date of hatching. Once hatching occurs, ensure predators have sufficient appropriate food. All life stages must be <24 hours old when used in experiments, except adults that must be used within 48 hours.

Time egg lay so that the required life stage is reached within 24 hours of the day of testing, eg two days before testing for juvenile stages. Provide individuals of *Carpoglyphus lactis* as food for the predatory mites.

Laboratory testing test unit set-up:
Biopesticides tested include Agri50NF, Cyazypyr, and DPI9 at 1.0974g/100ml.

A Test unit comprises a 6cm petri dish containing a French bean leaf disc over 1% agar gel. The dish is sealed with cling wrap stretched tight over the top of the dish and held in place with an elastic band. 100 holes are pricked through the cling wrap using an insect-mounting pin to aid ventilation.

Day 0 – The test units are set up, sprayed, (test for approximate runoff –ie 1ml or 2ml) and then left to dry for about 15 minutes. 1.5-2mg fluid/cm2 is used at the highest recommended dose, with an equivalent number of dishes sprayed with demineralised water as a control. Immediately after drying, 60 adult gravid female DFM are placed on each dish to establish a colony. Once all dishes have a food source, the predator mites can be transferred to each dish. 5 mites per dish may be sufficient.
Day 1 – No counting was done, however dishes were examined to ensure that there was sufficient food for the predators, and topped up if required. Also, if the prey mites were dead because of the treatment, extra prey was added.
Day 2 – By this day the first adults of the predator were possibly emerging. At least one male predator was required on each dish to allow mating to occur. If none were present, a male was transferred from one of the other dishes of similar treatment. Any predator eggs that were produced were counted and removed. Extra food was added if required.
Hereafter, the dish was checked every day and the number of predator male, female and eggs were counted, and food was added to excess.

Incubation
All test units were kept in a controlled temperature cabinet 25±3˚C, 75±10% RH, photoperiod of 16:8 (L:D). Cabinet was aired at regular intervals 1-2 times daily, to prevent pesticide buildup.

Spraying:
The Potter spray tower was calibrated before each assay. The spray volume required to achieve the runoff point using distilled water was determined. This was defined as the first point of droplets merging along leaf veins, as per Bernard et al, 2004. The pesticides to be sprayed should be sprayed at the highest registered field concentration (note our chemicals are not yet registered) and made using distilled water, with no spreaders/adjuvants. The insects, along with their initial food and the entire water supply are sprayed to the point of runoff using the potter spray tower. Control to be sprayed with distilled water. Treatments are replicated three times, and randomised after spraying. Test units were dried for 10-15 minutes after spraying at room temperature, before being sealed and incubated.

Assessment:
1) Evaluate the lethal effects of the selected pesticides:
The lethal effects of each pesticide will be assessed at 24, 48, 72 hours and seven days post-spray. After each observation time, insects are designated as either dead or alive after probing with a soft-bristled brush. Note this is by indirect contact. Monitor egg lay and hatching.
2) Evaluate the sublethal effects of the selected pesticides:
Egg lay and longevity of the mites are monitored over the period at 24, 48, 72 hours and seven days.

Greenhouse Modification Trials

Introduction

Greenhouse structures across NSW ranges from extremely high technology enterprises to very basic structures. At the high technology end, growers enjoy high levels of environmental control, pest exclusion and attain optimum plant growth conditions that favour the retention of biological agents and assist in pest management. The utility of biological control agents is often compromised in low technology greenhouses that encompass the majority of the greenhouse industry in Australia.

Low technology greenhouses are characterised by single skinned walls, low ceilings, minimal ventilation and no pest exclusion infrastructure. These features lead to summer temperatures that, at times, will exceed 50°C during the day and to ambient temperatures at night, often close to freezing. Conditions such as these do nothing to improve crop production and severely damage plant health reducing plant vigour, yield and fruit and vegetable production. Conditions such as these also favour insect and mite pests that are able to thrive in adverse conditions while beneficial insects and mites have been shown to fail quickly in these temperatures.

Capital investment by many growers in Australia is a difficult task and small steps are often needed to improve their growing structures and move forward. This trial aimed to provide low technology options to growers that have low technology greenhouses. By providing maximum ventilation through large side and roof openings that are screened, installing circulation fans and using biological control techniques, an economically feasible set of improvements is presented to industry.

Methods

A grower in Western Sydney supplied four low technology greenhouses for use in this trial. Two greenhouses were left unmodified and were managed by the grower using conventional practices and pesticide applications. Two greenhouses had their structures modified and pest management followed standard IPM strategies including the use of biological control agents.

Modifications included four ridge openings that were opened, like a large slit, across the width of the greenhouse. Plastic was pulled back exposing whitefly grade mesh with thrips deterrent optic threads woven into the fabric. A mechanism allowed the grower to open and close these openings up to two to three metres in width, and to close them in times of rain or cold weather.

Both sides of the greenhouses were converted into openings with plastic being able to be rolled up from the ground to the gutter exposing the entire length to ventilation. This length was screened with the same mesh as the roof vents and the grower was able to open and close this ventilation depending on conditions.

Two circulation fans were installed inside each of the modified greenhouses. One fan was hung from the ceiling approximately 10 metres from the entry facing the rear wall, and the second was installed approximately two thirds of the length, facing in the same direction. The fans were activated at all times to maximise airflow and assist cooling. The fans also reduced humidity on the plants in an effort to prevent foliar diseases.

Biological control agents were released (Table 1) through the life of the crops in the modified houses, and no conventional pesticide applications were conducted during this time. These biological control agents were released as prophylactic applications prior to the establishment of pests. When pests were seen to be arriving in the crop, application rates increased slightly to compensate for the extra load.

Table 1: Biological control applications in modified greenhouses for the duration of the trial.

Pest	Bio-control	Amount	Rate	Source
Whiteflies	*Encarsia formosa*	2 sheets	Weekly	Biological Services
Aphids	*Aphidius colemani*	2 vials	Weekly	Biological Services
Thrips	*T. montdorensis*	20,000	Fortnightly	NSW DPI
Fungus gnats	*Stratiolaelaps*	40,000	Fortnightly	NSW DPI
Whiteflies	*Encarsia formosa*	6 sheets	Weekly	Biological Services
Spider mites	*Phytoseiulus persimilis*	4-5,000	Weekly	Bugs for bugs

Sampling

A regular sampling procedure for pests and beneficials was conducted in all houses, including non-modified greenhouses. Sticky traps were installed with four traps per house - two high and two low; High - at plant height and Low - media height. The traps were replaced weekly.

The crops were monitored regularly with four rows in each house with 500 bags per house (approximately 1000 plants) being divided into 10 blocks starting at front of house with Block 1 and ending at Block 10 using orange flagging tape to delineate the blocks. Each block with had approximately 10 bags. One plant in each block was assessed for thrips, whitefly, mites and aphids with other pests noted if they occurred. Thrips numbers were divided into classes (Table 2). When mites were identified the bag was flagged and surrounding plants checked for mites that allowed hot spots to be treated with predators. Each house had 20 leaves selected at random with five leaves from each row. Samples were bagged and washed at the laboratory for accurate counts of pests and beneficials.

Table 2: Numbers of thrips were divided into separate classes for characterisation.

Category	Definition	Data entry
Absence	no thrips	0
Trace	single thrips on one leaf	1
Low	2-5 thrips on two or more leaves	2
Medium	10-20 thrips on several leaves	3
High	>20 thrips on majority of leaves	4

Numbers of insects and mites were all recorded for analyses. Crop growth, health and yield were all monitored during the course of the crop. These details were recorded for analyses to compare between modified and unmodified greenhouses.

Results

Reduced Risk Pesticides – External Effects on *Beauveria bassiana*

Effect of Application Rates of *Beauveria bassiana* Against Western Flower Thrips

The high rates of DPI 9 provided approximately 50% reduction in WFT numbers across all treatments (Figure 1). There was no difference in the reduction of WFT numbers between the three rates applied to plants during this trial. It is expected that an entomopathogen such as DPI 9 will exhibit a flat dose response curve in that it will work at similar levels until the spores reach a critical minimum number for efficacy. At this point the pathogen will no longer provide a reduction in numbers.

This level of control is acceptable especially given the pathogen's ability to be used with a variety of other control methods including biological control. The fact that a rate was not identified where there was no impact on numbers suggests that the minimum recommended rate might be significantly lower than initially expected. This may lead to a more cost effective system where by more end-user product can be produced with few spores, thereby reducing costs for the commercial supplier.

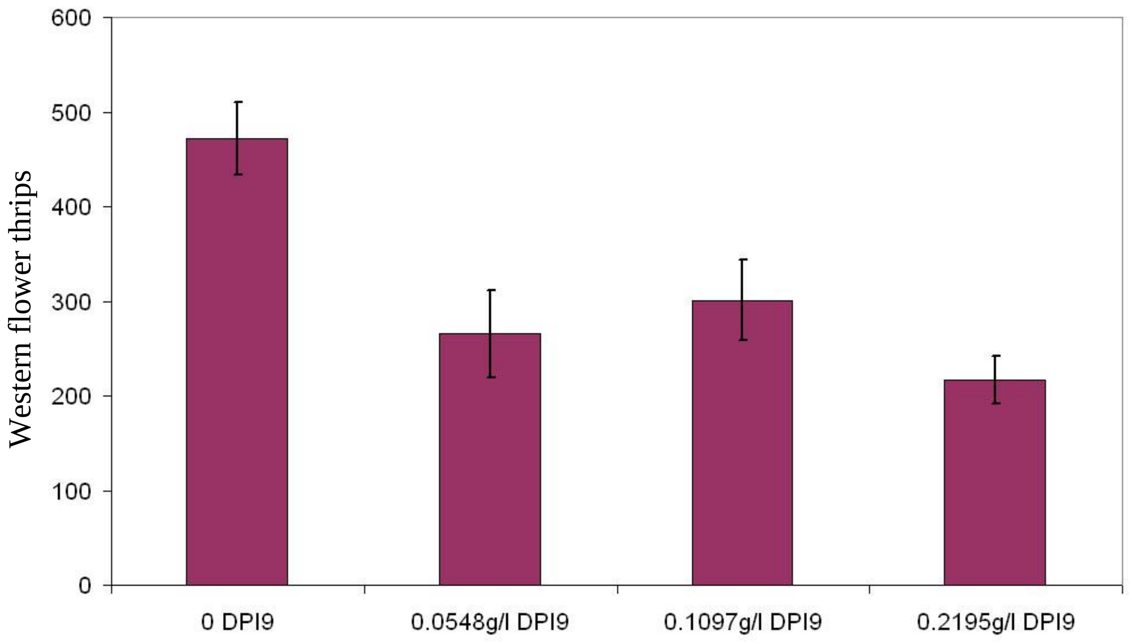

Figure 1: Effects of the entomopathogen, DPI9, on total numbers of western flower thrips.

There did appear to be a significant response from DPI9 that did not appear to be caused by the oils that are required to prepare the treatments (Figure 2). It appears that the oil used in the formulation of this product does not play a significant role in the reduction of WFT numbers.

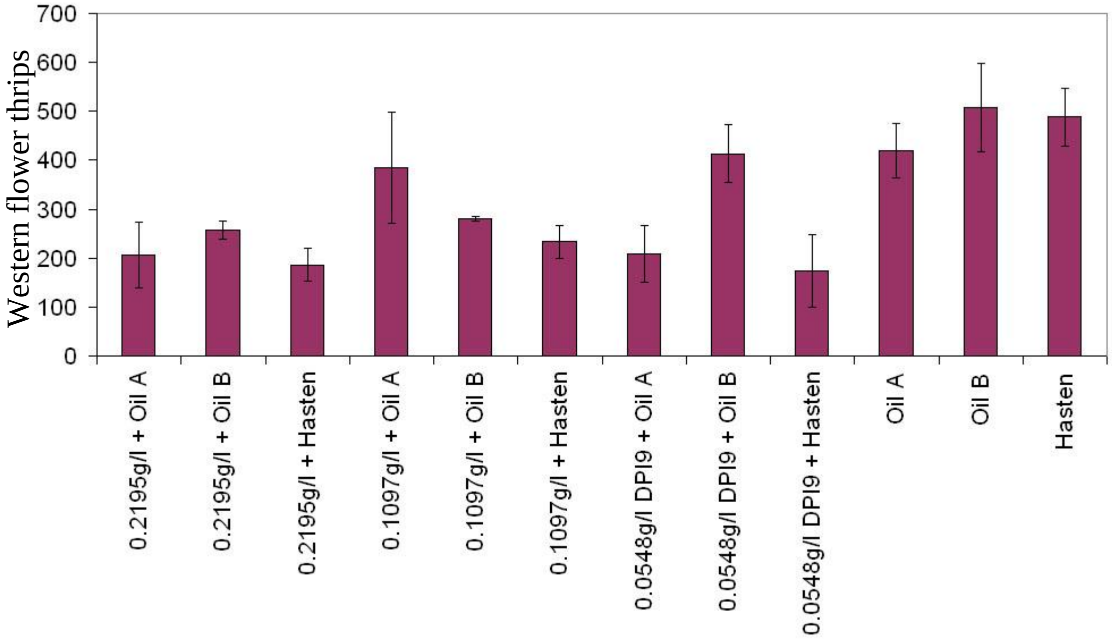

Figure 2: Effects of entomopathogenic pesticide, DPI9, on total numbers of western flower thrips.

The identification of the lowest rate for the application of the entomopathogen is important in the commercial success of the product. This trial identifies that the product does produce an effect that would be well placed in an IPM system and that the oil used in the formulation is not causing this effect.

Further work was identified as needed to continue the development of this product for use by growers in the industry. In order to make the product commercially available, it will be necessary to reduce the number of spores needed for the final product thereby making the production more cost effective. Increasing the target pests that the product is used for is another means to create a place in the market for this product.

Effect of High Application Rates of *Beauveria bassiana* Against Greenhouse Whitefly

A reduction in the numbers of GWF was observed at both rates of DPI9 as well as the oil (Figure 3). The reduction at the highest DPI9 rate, 2.195g/l, was greater than that of the oil alone indicating that DPI9 has a significant impact on populations of GWF.

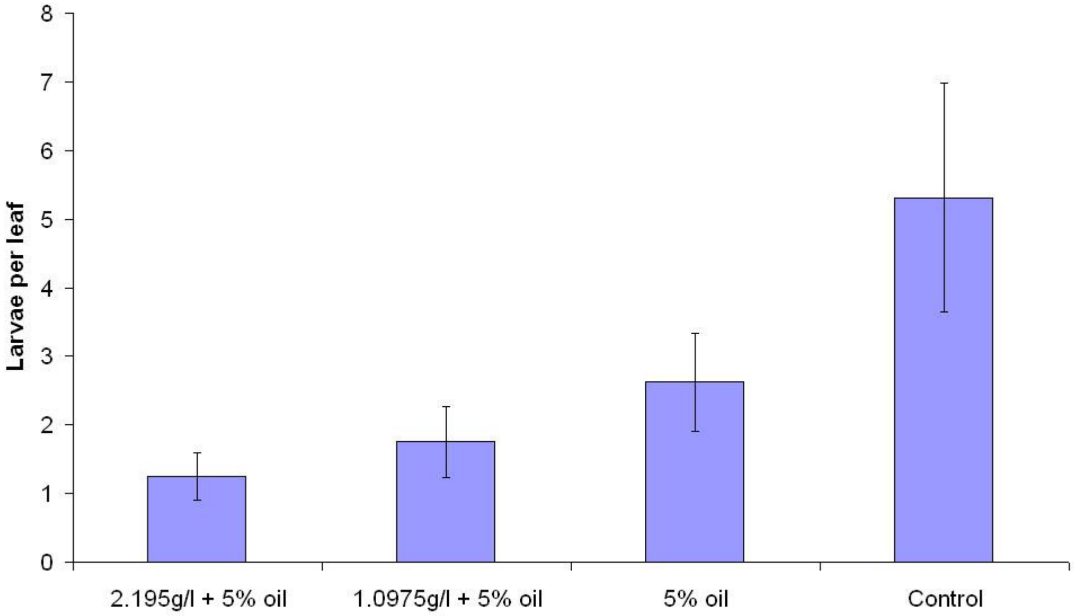

Figure 3: Effect of high rates of DPI9 and oil on efficacy against greenhouse whitefly on tomato plants.

The commercial uptake of a reduced risk pesticide is dependent on, amongst other things, host range and expected use of the product. This trial showed that this formulation of *B. bassiana* is not only effective against populations of WFT but also greenhouse whitefly. By targeting multiple pests, there is a greater chance of uptake by growers and a greater possibility of commercial development by producers as it expands the market.

While DPI9 has not been shown to be compatible with biological control agents such as *Encarsia formosa*, anecdotally there is evidence to suggest that a combination of these two management strategies is not only effective but highly recommended. Evidence of parasitisation by the self-introduction of local individuals of *E. formosa* during this trial indicates the likelihood that the two management strategies are compatible. By using two or more methods, growers will be able to achieve substantial reductions in whitefly numbers in their crop and avoid the use of synthetic pesticides.

Effect of Low Application Rates of *Beauveria bassiana* against Greenhouse Whitefly

In previous trials the lowest rate for DPI9 for effective reduction in GWF populations was not identified. The lowest rate previously tested was 1.0975g/l and this was no less effective than higher rates. This trial quantified the effect of a series of DPI9 rates against GWF in order to identify the lowest rate possible to increase the commercial viability of the product.

Of the rates tested, there was no difference between the negative control and the lowest four rates of DPI9 (Figure 4). This indicates that at the lower rates there is not the critical concentration of fungal spores required to increase mortality in populations of GWF. The highest rate tested, and the lowest rate in previous trials, reduced GWF numbers but approximately 70% (Figure 4). This rate represents the lowest possible rate for the efficacious application of the DPI9 fungal entomopathogen.

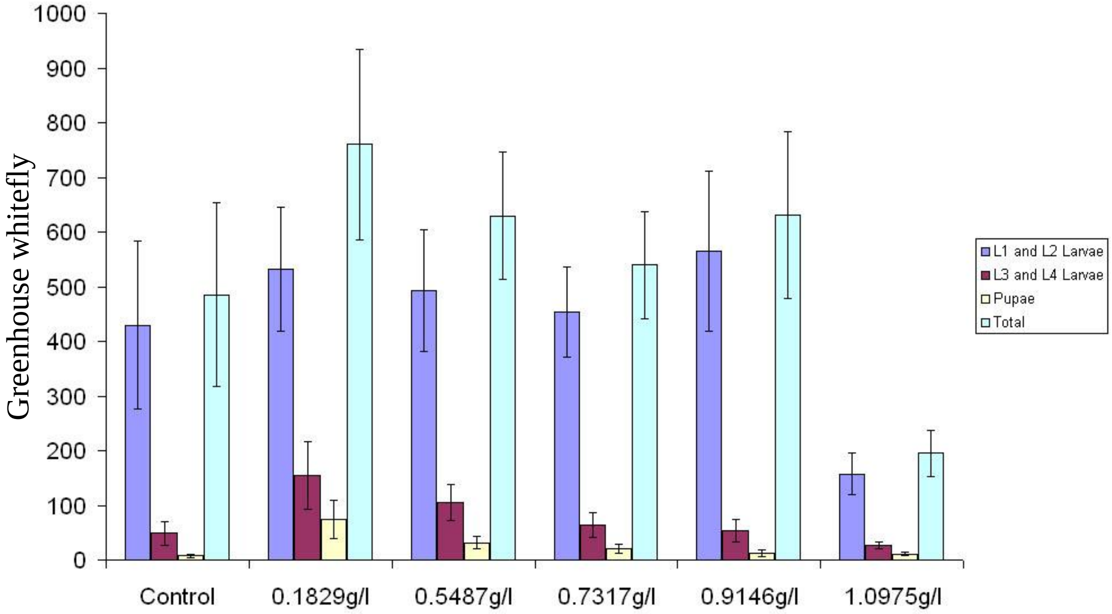

Figure 4: Effect of low application rates on the efficacy of DPI9 on greenhouse whitefly on tomato plants.

Effect of Humidity on *Beauveria bassiana*

An analysis of variance (ANOVA) of the proportions of dead WFT was conducted. The diagnostic plots from the ANOVA suggested that the errors could be assumed normally distributed.

For experiment 1, the effect of humidity treatment on proportion of WFT dead due to DPI9 was not significant. As we'd expect there was a significant effect of fungus, with 80% of WFT dead due to DPI9 in the fungus treatments compared to 11.3% in the negative control treatments. This suggests contamination of the negative controls.

For experiment 2 the main effects of humidity treatment and fungus were significant, as well as their interaction. This suggests that effect of the humidity treatment was not consistent between the DPI9 treatments and the negative controls.

For the negative controls there was no significant difference in the proportion of WFT dead due to DPI9 between the nine humidity treatments. For the DPI9 treated leaf discs, humidity treatments where WFT were introduced at 90% and then held at no less than 70% had high proportions dead compared to the other treatments.

These data suggest that humidity does have an impact on the utility of *B. bassiana* in the management of pest thrips and a minimum threshold is required for at least nine hours for the pathogen to have an effect. This provides growers with a framework with which to work under with respect to applications of the bio-pesticide. Unless humidity of at least 70 % can be guaranteed for an extended period of time after application, there will be little commercial utility for the bio-pesticide.

Humidity control in greenhouses is not a common management practice. As crops grow in size, however, humidity will naturally increase within the greenhouse environment. This effect is somewhat negated during periods of heating and this would need to be factored into the application protocol.

Effect of Ultraviolet Light on *Beauveria bassiana*

WFT in the DPI9 treatment had significantly higher mortality (0.77) than the Control treatment (0.31) although this effect was not consistent from time to time and between the three UV levels. For DPI9 mortality was similar regardless of exposure time, however for the Controls 180 mins exposure had significantly higher mortality than exposure for 90 minutes. For Control treatments, highest mortality was observed in WFT in the no UV compared to the 50 and 100% UV treatments. For WFT treated subjected to DPI9, significantly higher mortality was found in the 50% UV treatments than the other 2 UV treatments.

There was a significant main effect of Time with a significantly lower proportion of dead WFT due to fungi after 180 minutes exposure (0.14) compared to 0 and 90 minutes. This effect was consistent regardless of the UV level. No significant effect of UV treatment on proportion dead due to fungi was detected.

These data suggest that the length of time that the leaf disks were exposed to UV had no effect on the mortality of the pest insects. The length of time between the application of the entomopathogen and the introduction of the insect pests seemed to be the most significant factor in that as time increased between application of DPI 9 and the introduction of the insects, the mortality effect was reduced. This may indicate that humidity has a greater effect on the utility of the entomopathogen rather than exposure to UV light.

What this means, practically, to greenhouse growers is that a greater concern is the control and monitoring of humidity in areas where applications are being made. The level of UV light within the greenhouses, especially in the foliage where the major effect is expected to take place for the applications of DPI 9, is expected to be too low to negatively impact on the efficacy of the agent being applied.

This suggests that UV light will not be a limiting factor in the use of this entomopathogen. Care should still be taken with the timing of applications, however, as the oil surfactant could still possibly cause a burning on foliage if sprayed during or before the heat of the day or in direct sunlight.

Reduced Risk Pesticides – Efficacy Trials

Efficacy of Multiple Reduced-Risk Pesticides

Several reduced-risk pesticides were tested against WFT on cucumber plants with populations at the completion of the trial showing high variation. This variation confounds the results that should be viewed with caution. More trials should be conducted with these products to verify the results.

Of the pesticides tested, it appears that Cyazypyr (HGW86 in figures 5 and 6), Pyrus and Symphony show the greatest reduction in WFT numbers (Figures 5 and 6). Whilst there was some reduction evident when populations in single leaves were counted that had treatments of BioCover and PestOff applied (Figure 5), these findings were not shown when whole of plant samples were assessed (Figure 6).

Similar reduced-risk pesticides were tested against populations of GWF and a greater range of products appeared to be effective against this pest. All pesticides tested except Abrade, E2Y45 and Natrasoap appeared to reduce GWF numbers across all lifestages (Figure 7). These findings were consistent when data was examined against individual lifestages with the exception of first and second larval stages when treated with NatraSoap (Figure 8) that was the only lifestage that showed no reduction. All other lifestages of GWF when treated with NatraSoap showed a reduction in numbers. This result may be explained by the eggs of whitefly possibly being protected from applications of NatraSoap. With careful application and targeting of susceptible lifestages, NatraSoap could be an effective management tool against GWF. All other pesticides were consistent when broken into their individual lifestages (Figures 8, 9 and 10) suggesting that the egg stage of the pest is susceptible to applications of the pesticides or that there is some residual effect present when the larvae emerge.

Experiment 3 looked at the role of reduced risk pesticides in the reduction of green peach aphid populations and it was clear that all reduced-risk pesticides reduced populations of the pest within two weeks (Figure 11). Numbers were further reduced with another week of pesticide applications (Figure 12) and in the case of Cyazypyr numbers were reduced to zero. The entomopathogen, DPI9, also showed reductions to levels that were close to zero, and the higher rate of Agri50NF reduced numbers by approximately 80%. All treatments in experiment 3 indicate that the reduced-risk pesticides were as effective as the synthetic industry standard and could be considered as a viable alternative, or as part of a rotation, when managing numbers of green peach aphids in crops.

The identification of reduced-risk pesticides that are effective, and often as effective as existing synthetic chemistries available to growers, is an important aspect of the development of integrated pest management strategies. Without access to pesticides that are compatible with biological control options, or that have long pesticide residues that also impact of food safety, the role of IPM is difficult to implement by growers. Pesticide companies often are slow to pursue registration of these pesticides in the greenhouse industry due to the high cost of the process and because of the relatively low market share that greenhouse producers represent. As the greenhouse industry expands, and as pesticide producers can see that there is a significant profit margin to be realised, the availability and use of reduced-risk pesticides will increase quickly.

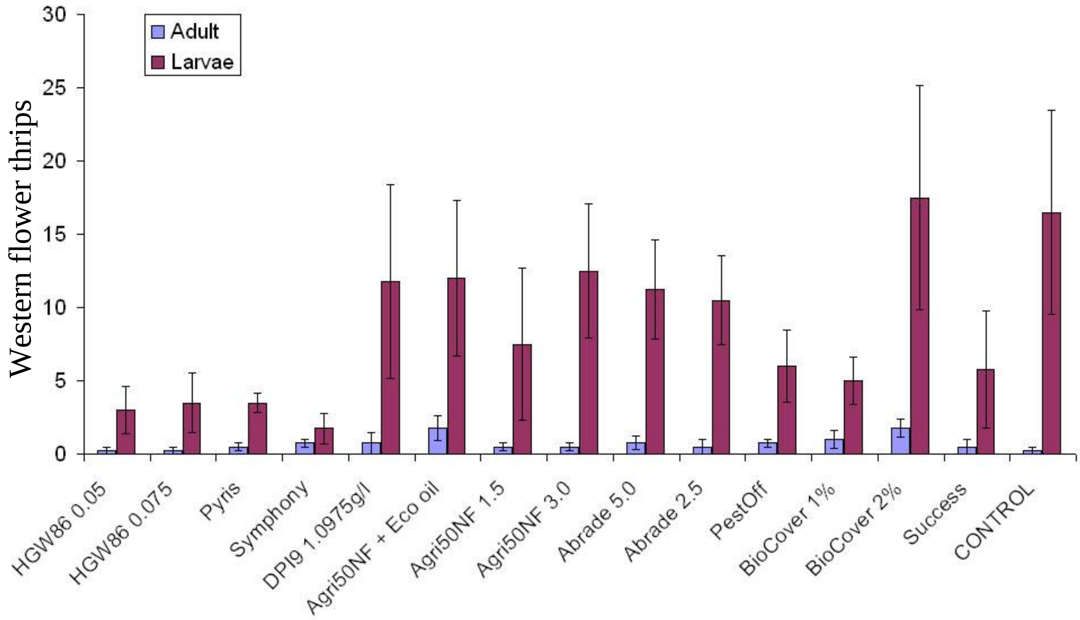

Figure 5: Experiment 1, effect of multiple pesticides on numbers of western flower thrips on single leaves of cucumber plants.

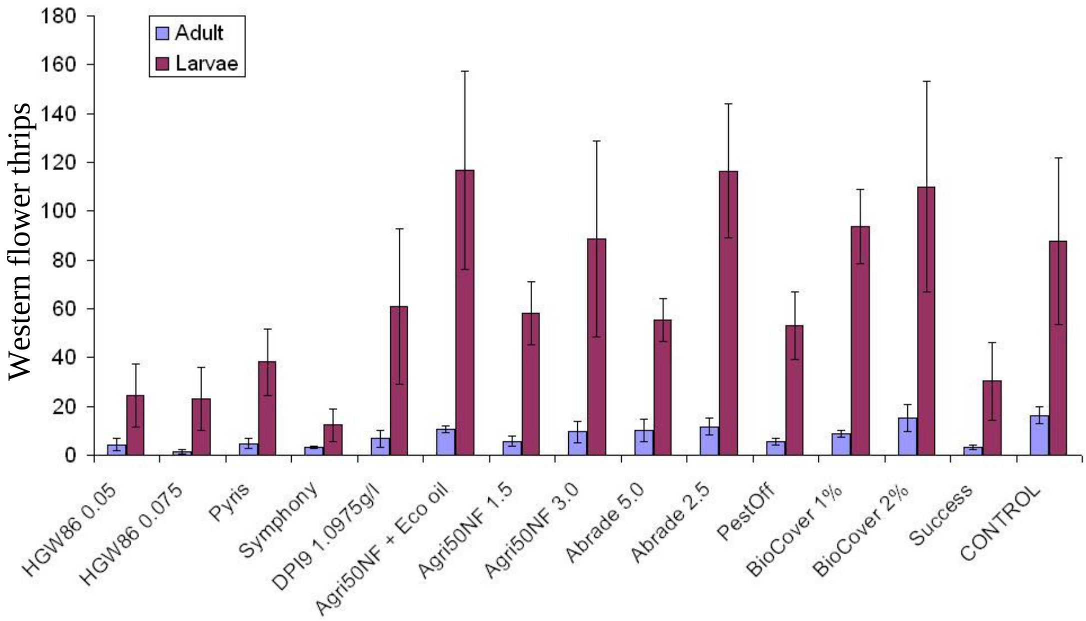

Figure 6: Experiment 1, effect of multiple pesticides on numbers of western flower thrips on entire cucumber plants.

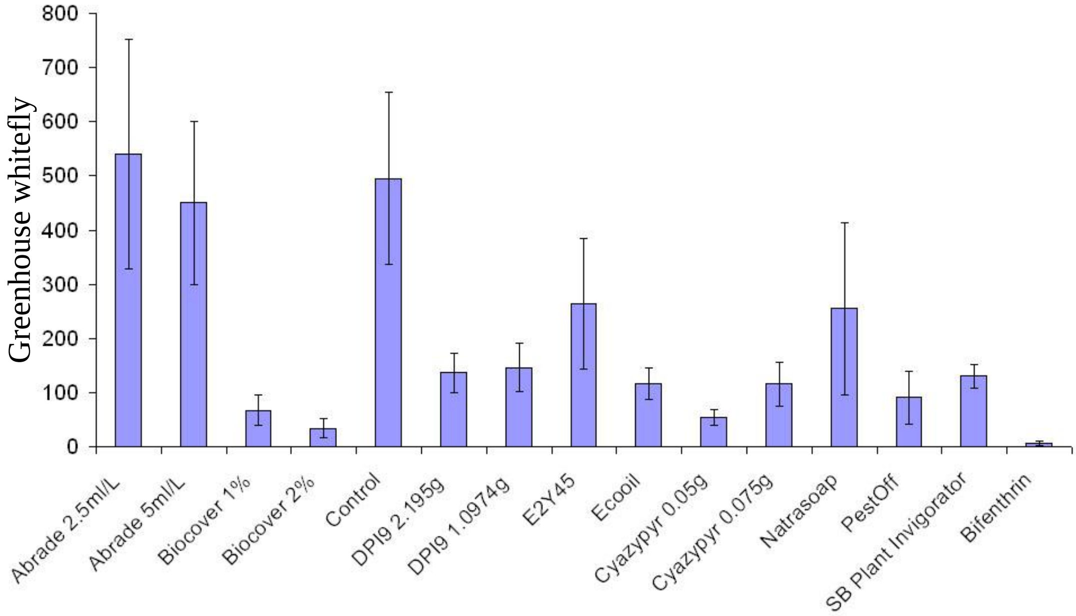

Figure 7: Experiment 2, effect of multiple pesticides on numbers of all lifestages of greenhouse whitefly on tomatoes.

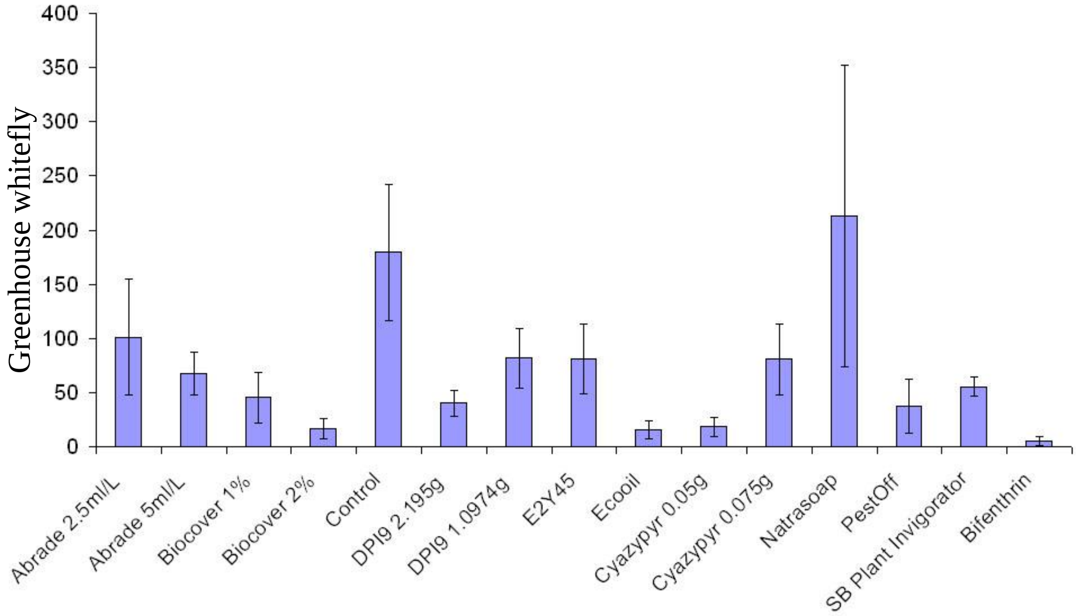

Figure 8: Experiment 2, effect of multiple pesticides on numbers of greenhouse whitefly, larval stages one and two, on tomatoes.

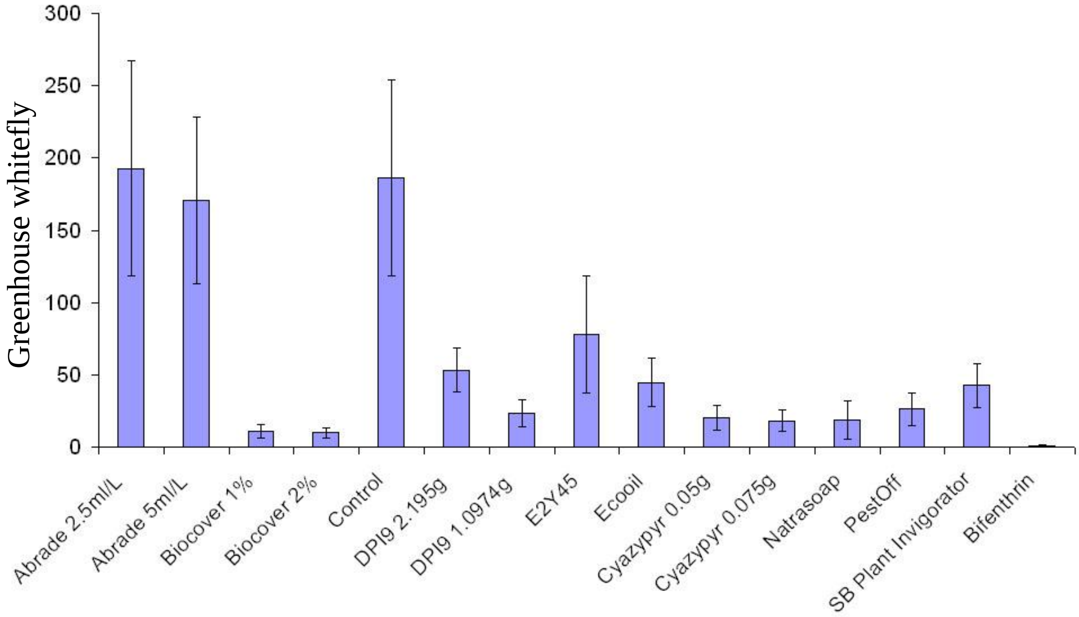

Figure 9: Experiment 2, effect of multiple pesticides on numbers of greenhouse whitefly, larval stages three and four, on tomatoes.

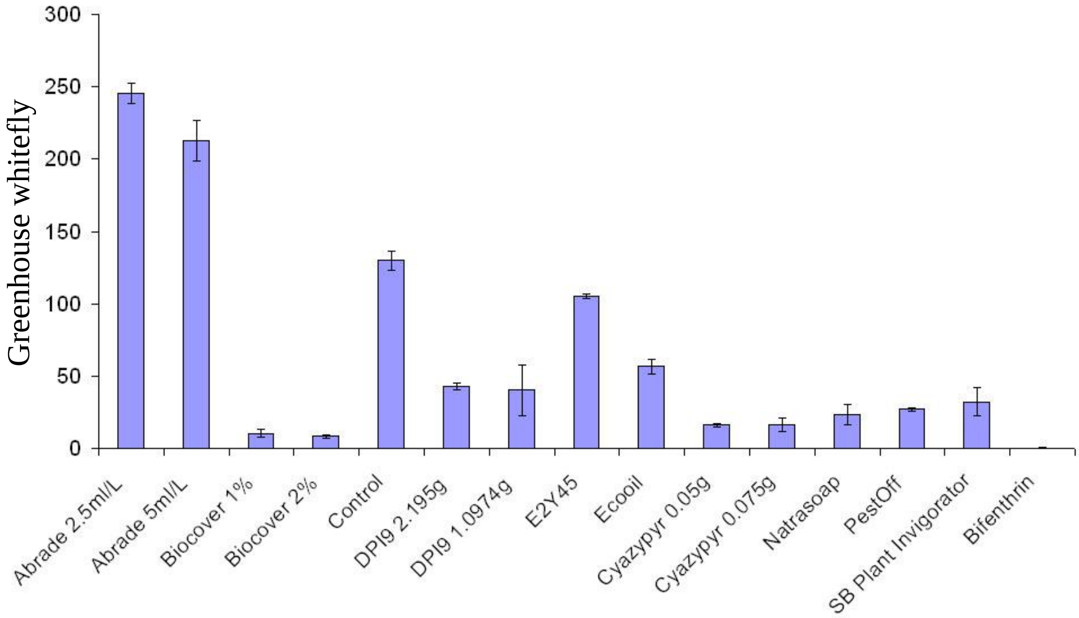

Figure 10: Experiment 2, effect of multiple pesticides on numbers of greenhouse whitefly pupae on tomatoes.

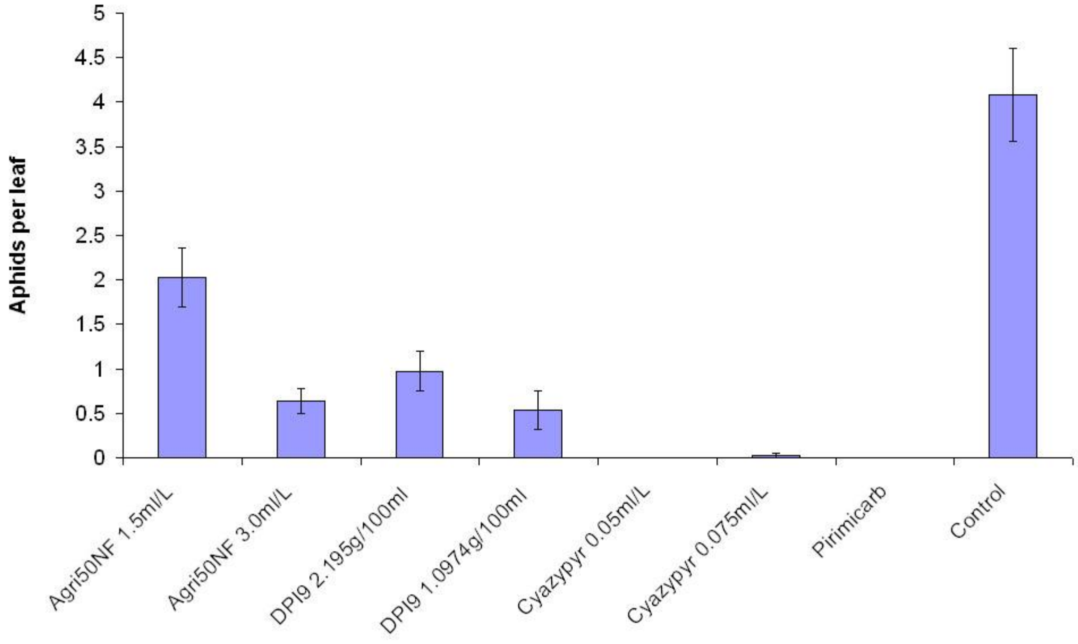

Figure 11: Experiment 3, effect of multiple pesticides on numbers of green peach aphids on individual cucumber leaves after two applications.

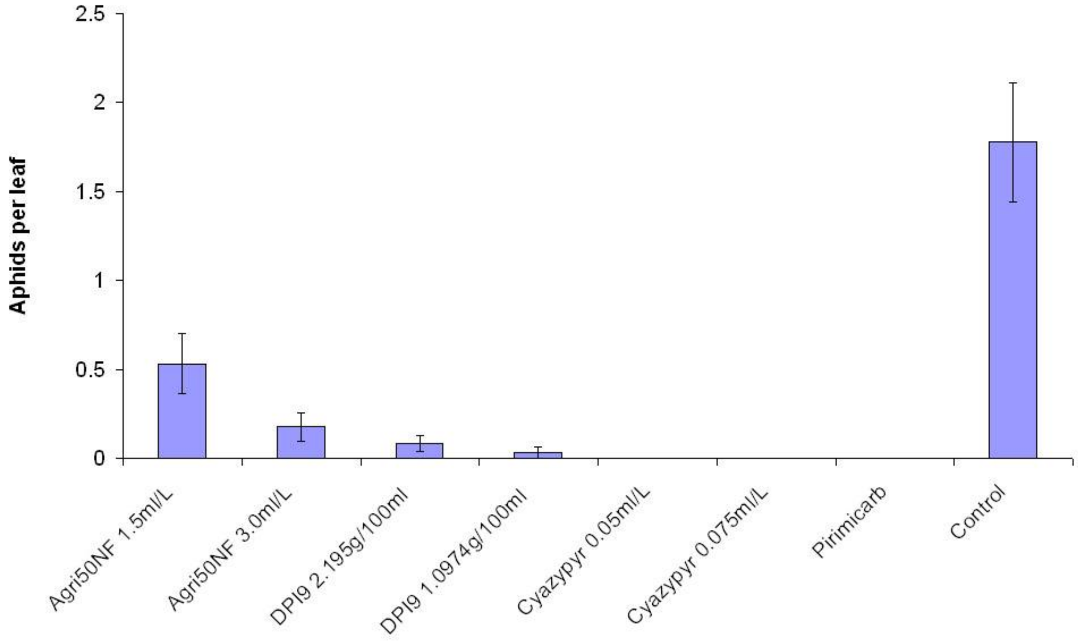

Figure 12: Experiment 3, effect of multiple pesticides on numbers of green peach aphids on individual cucumber leaves after three applications.

Efficacy of Cyazypyr on Western Flower Thrips on Cucumbers

Discussions with the pesticide producer indicated a willingness to pursue registration for a promising reduced-risk pesticide, Cyazypyr, for use against WFT. A final experiment was conducted comparing the pesticide against no pesticide application, control, and the industry standard, spinosad.

Numbers of WFT were significantly reduced by the application of Cyazypyr at both application rates (Figure 13). The reduction in WFT numbers was the same as that experienced with the application of the industry standard, spinosad.

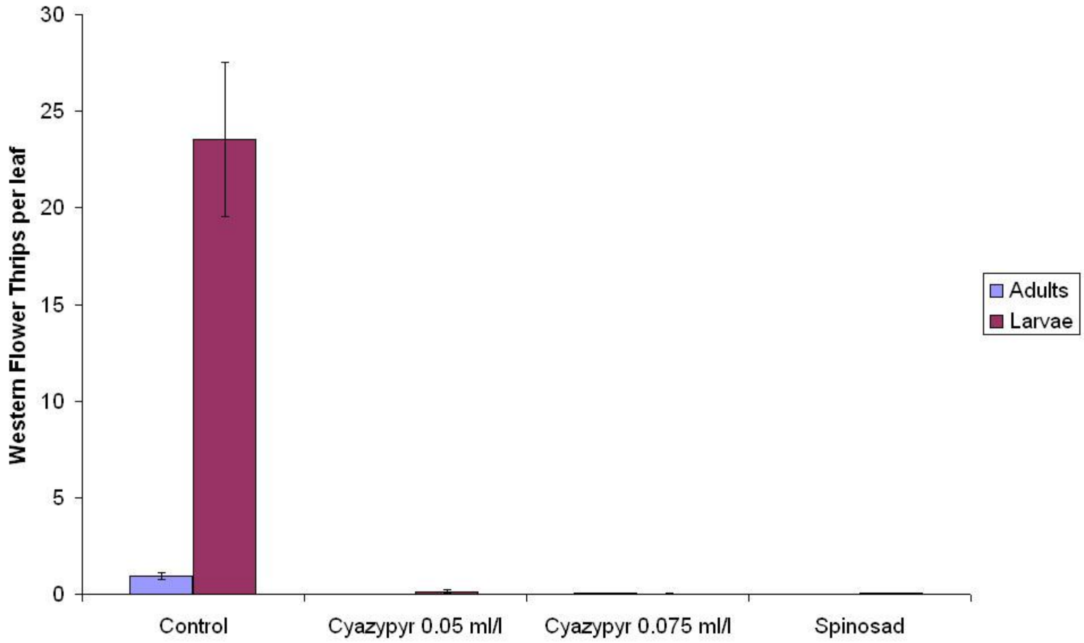

Figure 13: Final count showing the effects of Cyazypyr against western flower thrips on cucumbers.

When compared with no treatment, the reduction in WFT numbers was very close to 100% with numbers taken from 10 – 25 per leaf with no control to below 1 per leaf, on average. This reduction indicates that the product tested shows great promise as an effective and cost effective management tool against this important pest. Further trials involving lowering the application rate, frequency of application, and additives need to be considered if the company decides to pursue registration in greenhouse horticulture.

Efficacy of Agri50NF against Western Flower Thrips, Greenhouse Whitefly and Two-spotted Mites on Cucumbers

In addition to other reduced-risk pesticides that were recognised as having great potential in the management of greenhouse pests, Agri50NF was identified largely because of its efficacy but also because of its successful use overseas. Trials against WFT using Agri50NF showed that its efficacy against WFT was limited (Figure 14). There was a small numerical reduction in numbers of larvae on cucumber plants but this was not a significant reduction. It is unlikely that Agri50NF will be a useful tool in the management of this pest in greenhouse crops.

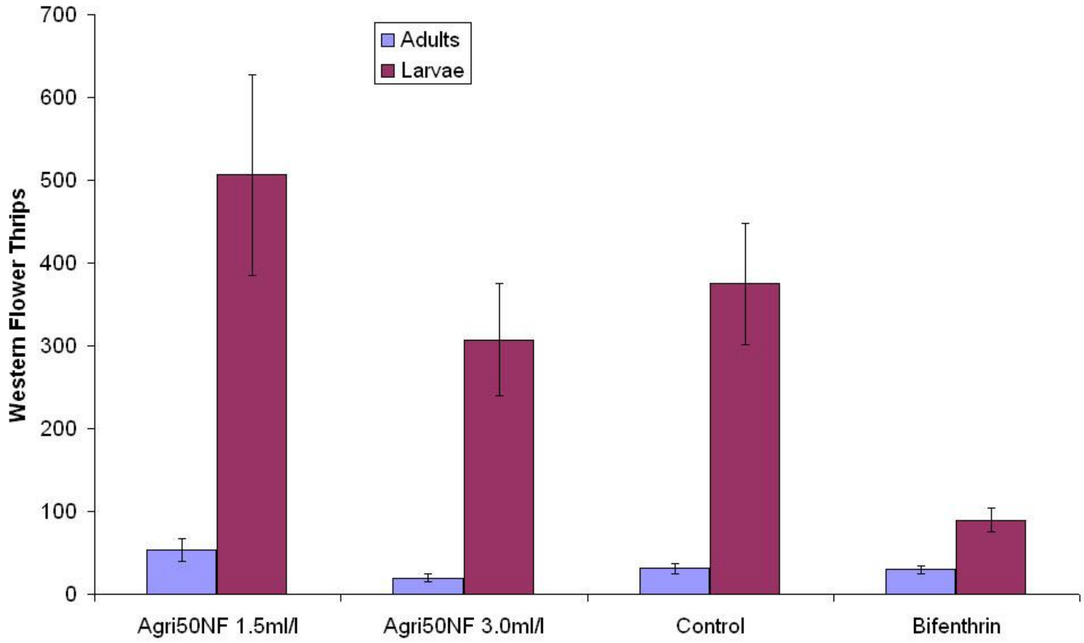

Figure 14: Effect of Agri50NF on numbers of western flower thrips on cucumber plants.

The utility of the pesticide was examined with respect to the management GWF on cucumbers. It was seen that there was a reduction in larval and pupal stages of greenhouse whiteflies (Figure 15). The reduction in all lifestages was the same as that shown by the application of the industry standard, bifenthrin. This is an indication that the product will provide the same level of protection for growers, but be more compatible with other management options such as the use of biological control agents.

The reduction in numbers of two-spotted mites were not as pronounced, but the application of Agri50NF did reduce numbers of the pest mite at the higher rate of Agri50NF (Figure 16). These reductions were, however, limited with numbers of two-spotted mite being reduced by approximately 25-30%. This is a poor reduction in numbers when compared to the industry standard, abamectin, which reduced numbers to almost zero. Despite the poor performance in comparison with the industry standard, it would still be possible to consider the product as an alternative at lower pest infestation rates and in conjunction with other management tools.

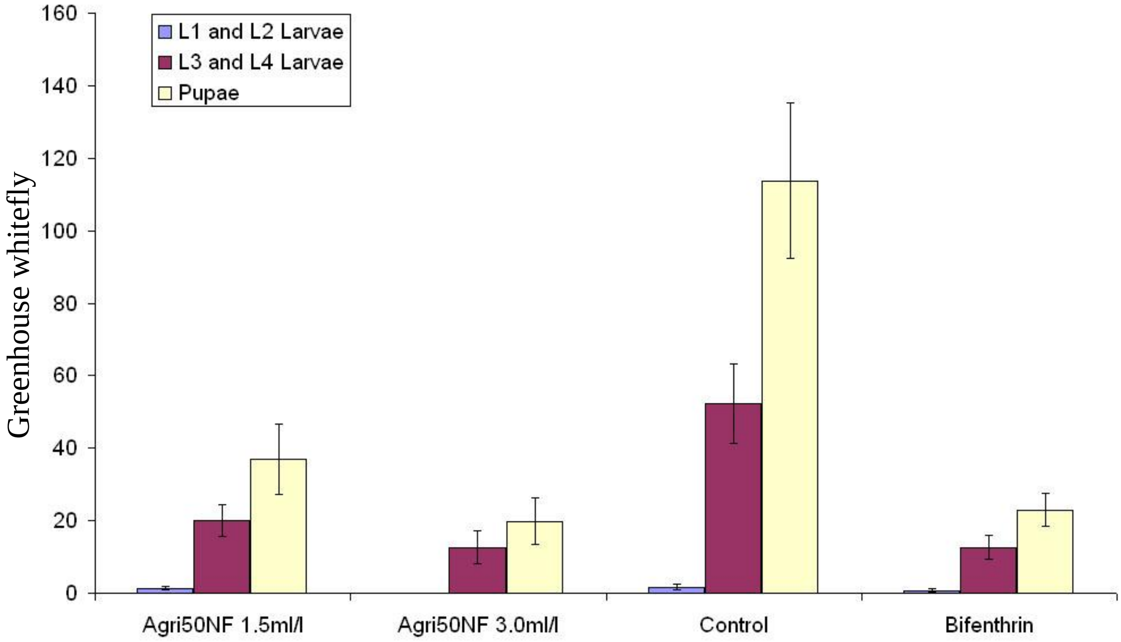

Figure 15: Effect of Agri50NF on numbers of greenhouse whitefly larvae (stages L1 and L2, and L3 and L4) and pupae on cucumbers.

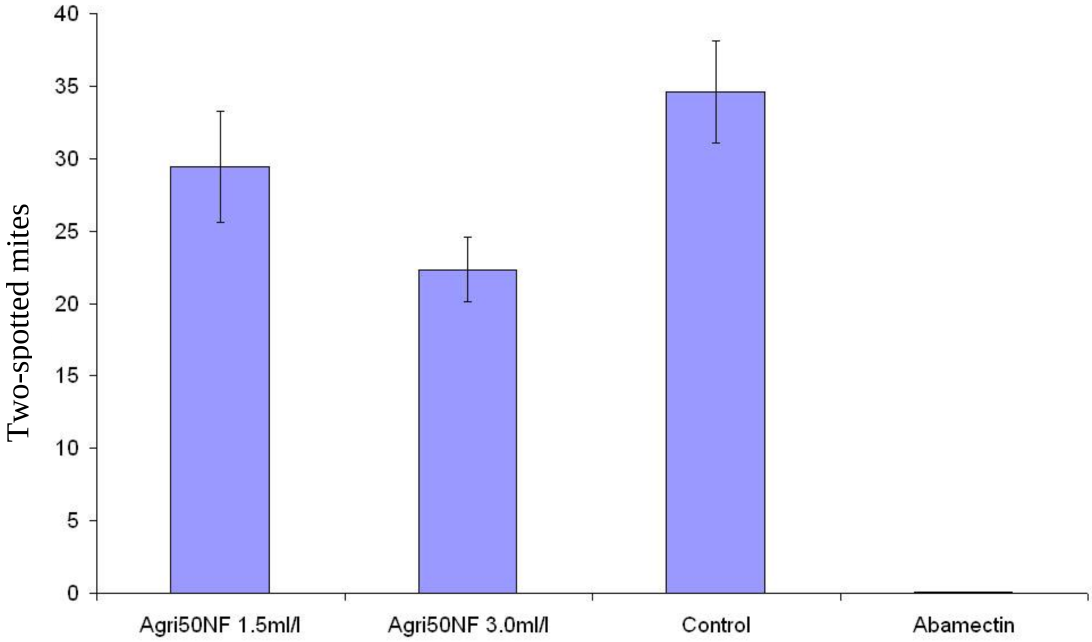

Figure 16: Effect of Agri50NF on numbers of two-spotted mites on cucumbers.

Agri50NF presents an opportunity in greenhouse horticulture to utilise a reduced-risk pesticide that is compatible with a number of different pest management options such as biological control. Registration of this product is encouraged and, whilst further trials and data collection may be needed, there should be further assistance offered in order to make this product available to greenhouse producers. The paucity of pesticide options, and in particular reduced-risk options, is the greatest shortfall of IPM in Australia and products such as Agri50NF provide opportunities to expand the products available to growers with very favourable characteristics on many levels.

Biological Control Agents – Feeding Trials

Transieus montdorensis – Greenhouse Whitefly and Western Flower Thrips Feeding Rate

The role of *T. montdorensis* could potentially expanded as a management tool against a number of different pests. The predatory mite is currently being produced and sold as a biological control agent against WFT, against which it is shown to be an effective predatory (Figure 17). A single predatory mite was shown to consume between four to seven WFT larvae every 24 hours. A consumption rate such as this provides excellent management of WFT. An important factor for a biological control agent is not only the feeding rate, but also the fecundity of the beneficial organism, how many off spring are produced on a given prey source. This trial showed that whilst the consumption rate for the predatory mite was high, this was also matched with a high rate of egg lay each 24 hours with each mite paying between one and three eggs each day. This will lead to populations of predatory mites potentially establishing effectively in a crop when there is a population of WFT to feed on.

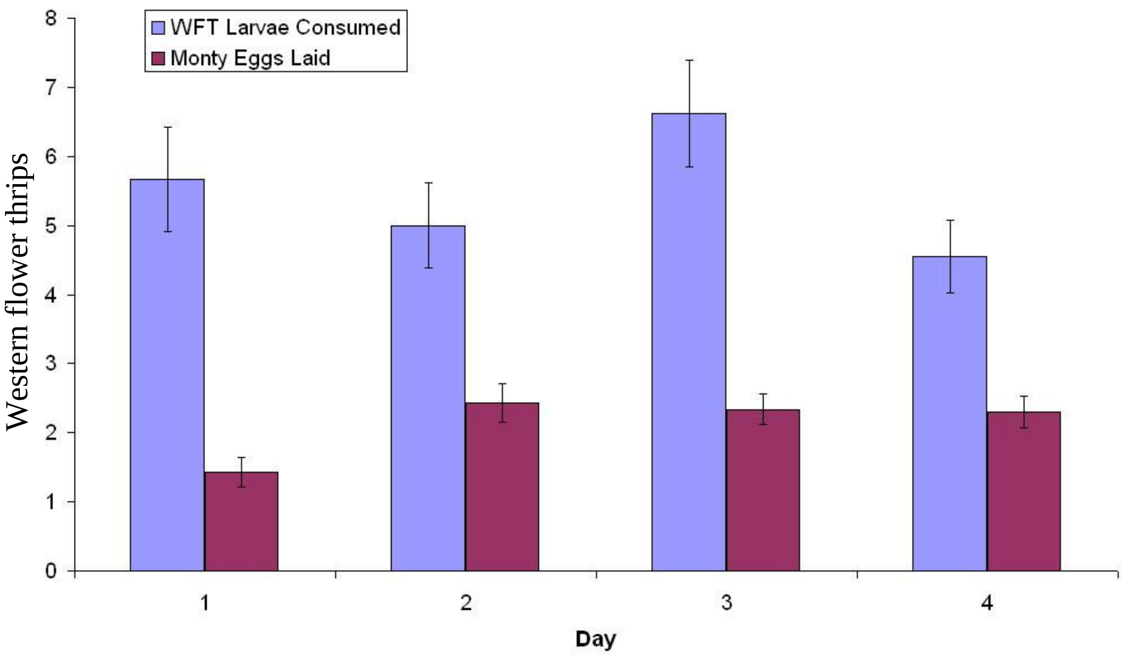

Figure 17: Number of western flower thrips larvae consumed by individual *T. montdorensis* (Monty) predatory mites and the number of eggs laid by *T. montdorensis*.

Greenhouse whiteflies have two lifestages that were potentially susceptible to predation by *T. montdorensis*, as eggs and as early larval stages. When individual *T. montdorensis* were presented with GWF eggs as a food source it was shown that they were able to consume between three to seven GWF eggs every 24 hours (Figure 18). This provides an effective reduction in pest numbers and is an indication that the consumption rate would allow the predatory mite to be used as an effective management tool.

The number of eggs laid by predatory mites whilst feeding on GWF was between one and two eggs per 24-hour period (Figure 18). This slightly lower number of eggs might indicate that the food source is not as ideal for the mites as other pests, but without comparing numbers within the same experiment, it is not possible to make a link.

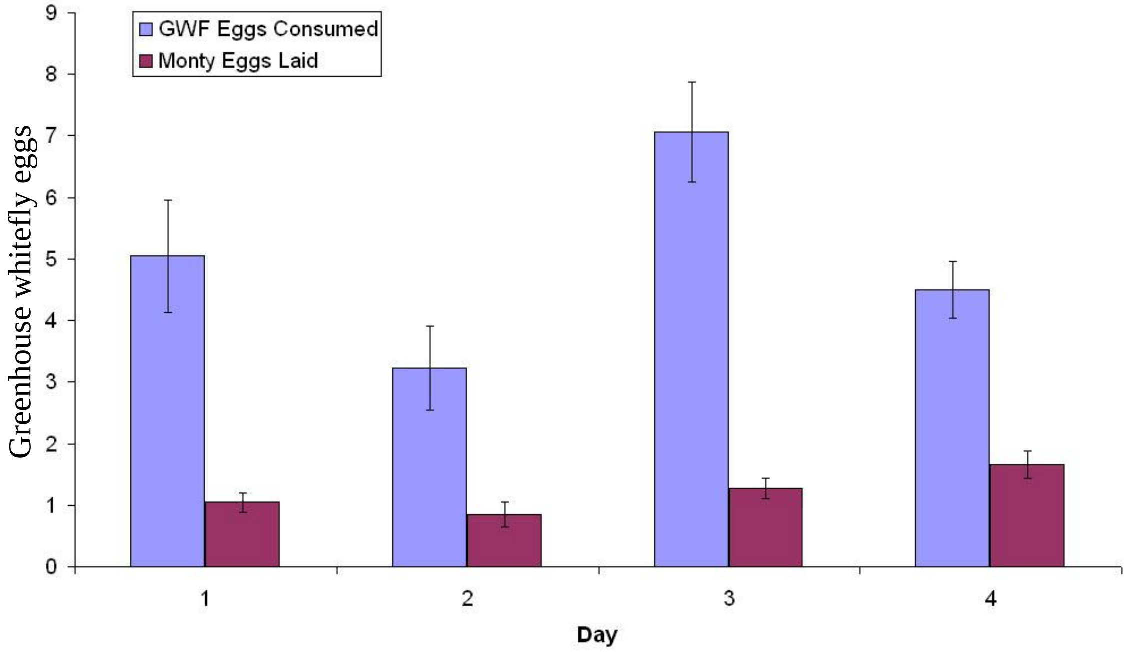

Figure 18: Number of greenhouse whitefly eggs consumed by individual *T. montdorensis* (Monty) predatory mites and the number of eggs laid.

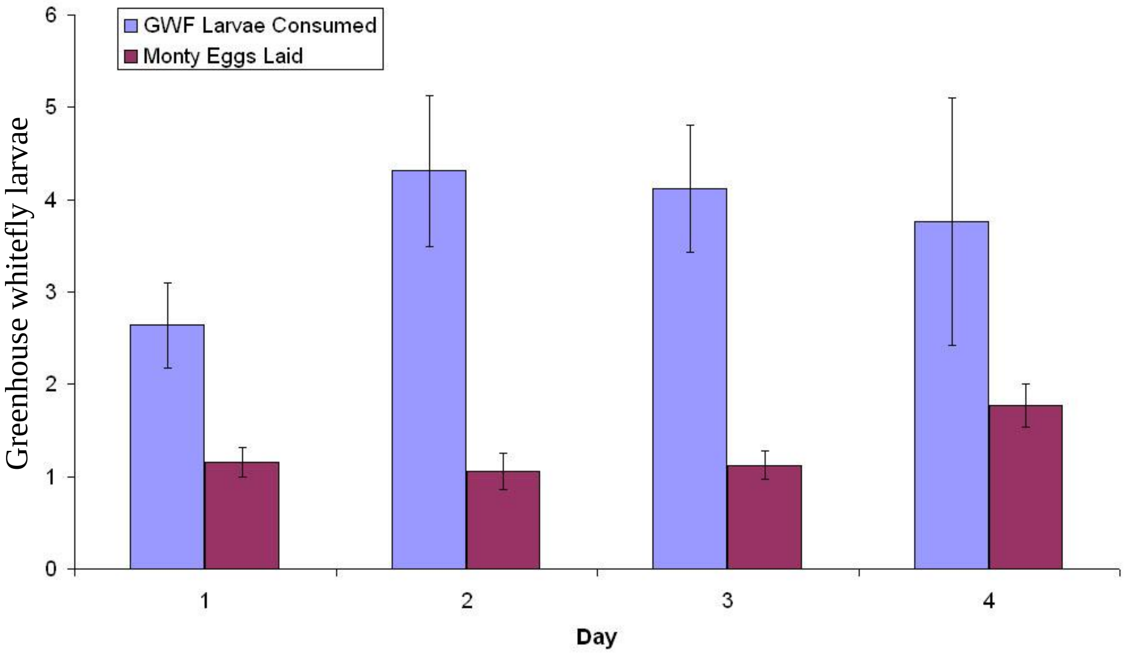

Figure 19: Number of greenhouse whitefly larvae consumed by individual *T. montdorensis* (Monty) predatory mites and the number of eggs laid by *T. montdorensis*.

When provided GWF larvae, *T. montdorensis* consumed between two and five individuals every 24 hours (Figure 19). Egg lay whilst feeding on GWF was between one and two eggs per 24 hours (Figure 19) and is in line with the fecundity shown when feeding on GWF eggs. These results indicate that the predatory mite would be a viable option as a biological control agent against whitefly and target a number of lifestages, increasing their efficacy.

In order to determine if *T. montdorensis* consume more WFT larvae than GWF larvae each day, an experiment where prey was provided to different *T. montdorensis* individuals at the same time was conducted. The results indicate that although there are occasionally numerical differences in the numbers consumed, there was no pattern to the consumption rates (Figure 20). This suggests that the predatory mite is as effective against GWF as it is against WFT. This could potentially expand the utility of the predatory mite against another prey species.

These trials represent a no-choice scenario for the predatory mite and whilst this provides evidence that the biological control agent could be used for either pest, further trials were required to determine if the agent could be used for both pests simultaneously. In order to achieve this feeding trials were conducted giving predators access to both pests at the same time as well as individuals prey species.

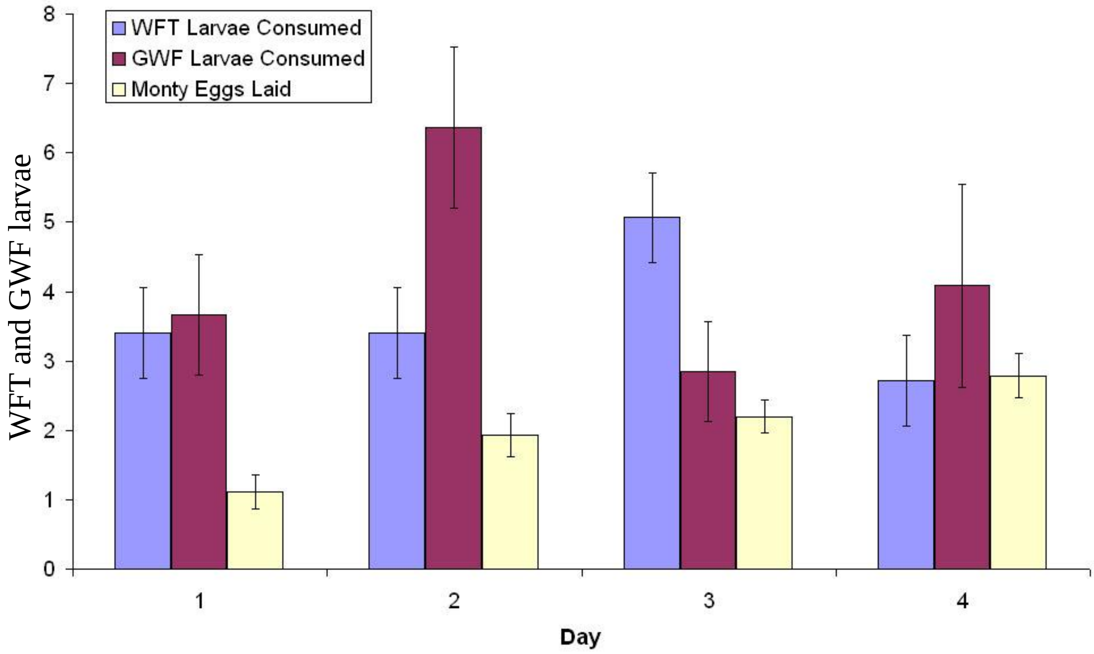

Figure 20: Number of western flower thrips larvae and greenhouse whitefly larvae consumed by individual *T. montdorensis* (Monty) predatory mites and the number of eggs laid by *T. montdorensis*.

A trial with *T. montdorensis* being provided individual prey species as well as a two-choice treatment with both WFT and GWF larvae was conducted. The results indicated that although there were daily differences in the consumption rate, there appeared to be no trend in relation to the number of prey consumed under any of the treatments (Figure 21).

These results indicate that *T. montdorensis* can be used as effectively for the management of GWF as it is already being against populations of WFT. Due to the observation that there is no change in consumption rate when there is a choice of more than one prey species, they will be able to used in cropping situations where there is more than one kind of pest.

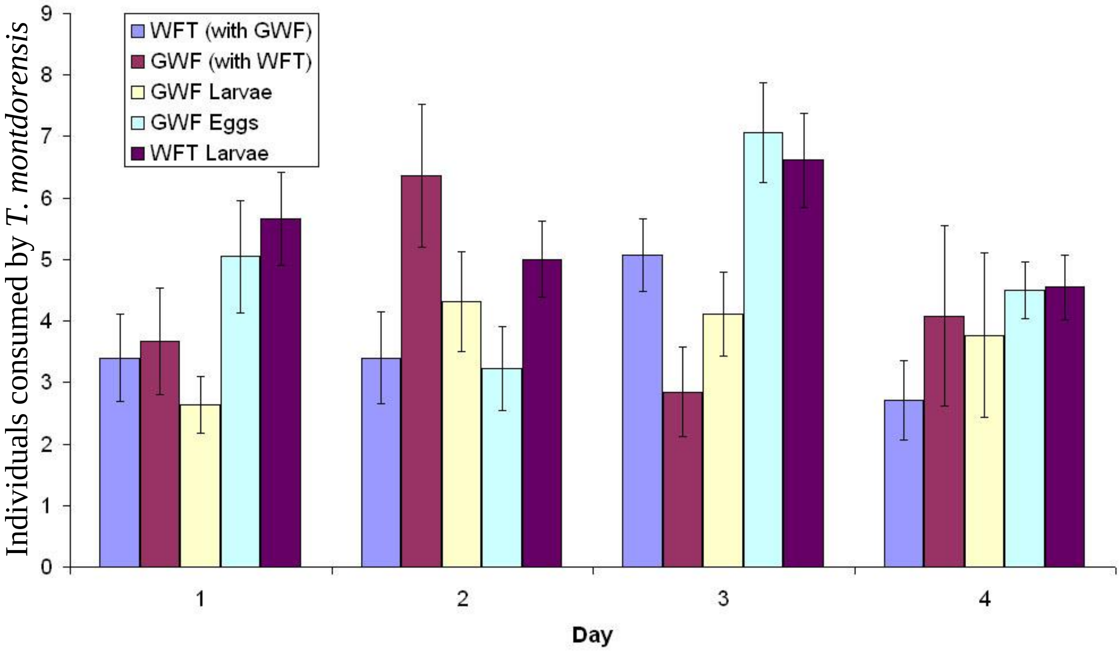

Figure 21: Number of western flower thrips larvae, greenhouse whitefly eggs, and greenhouse whitefly larvae consumed by individual *T. montdorensis* (Monty) predatory mites. Numbers are a comparison across all treatments.

The lack of differences when there is a variety of prey also indicates that *T. montdorensis* will possibly be more effective with multiple prey species present. Individual *T. montdorensis* consume just as many WFT or greenhouse whiteflies regardless of whether there is another prey species present. This suggests that individual predatory mites will actually consume more prey when there are two species present.

These results show that growers may utilise *T. montdorensis* for either pest when present, and use similar application rates when both pests are present in the greenhouse. Consideration will need to be given if the decision is made to use pesticides against either pest species, and further studies are recommended to determine the compatibility of *T. montdorensis* with other biological control agents such as *E. formosa*.

Hypoaspis aculeifer, *Hypoaspis* sp., and *Stratiolaelaps scimitus* Feeding Rates

The predatory mite *T. montdorensis* hunts for prey on the leaves of greenhouse crops. When targeting WFT the predatory mite consumes early instars of the thrips pest but is not able to have an impact on adult populations. There is work currently underway by private biological control producers to make larger predators such as *Orius armatus* available to target adult lifecycle stages in different parts of the crop.

There is substantial scope to utilise existing generalist predators to target the pupal lifecycle stage of WFT and trials have indicated that *H. aculeifer* consumers between three and four WFT pupae every 24 hours (Figure 22). The other two species of predatory mite did not perform as favourably with between one and two thrips individuals being consumed each 24 hours.

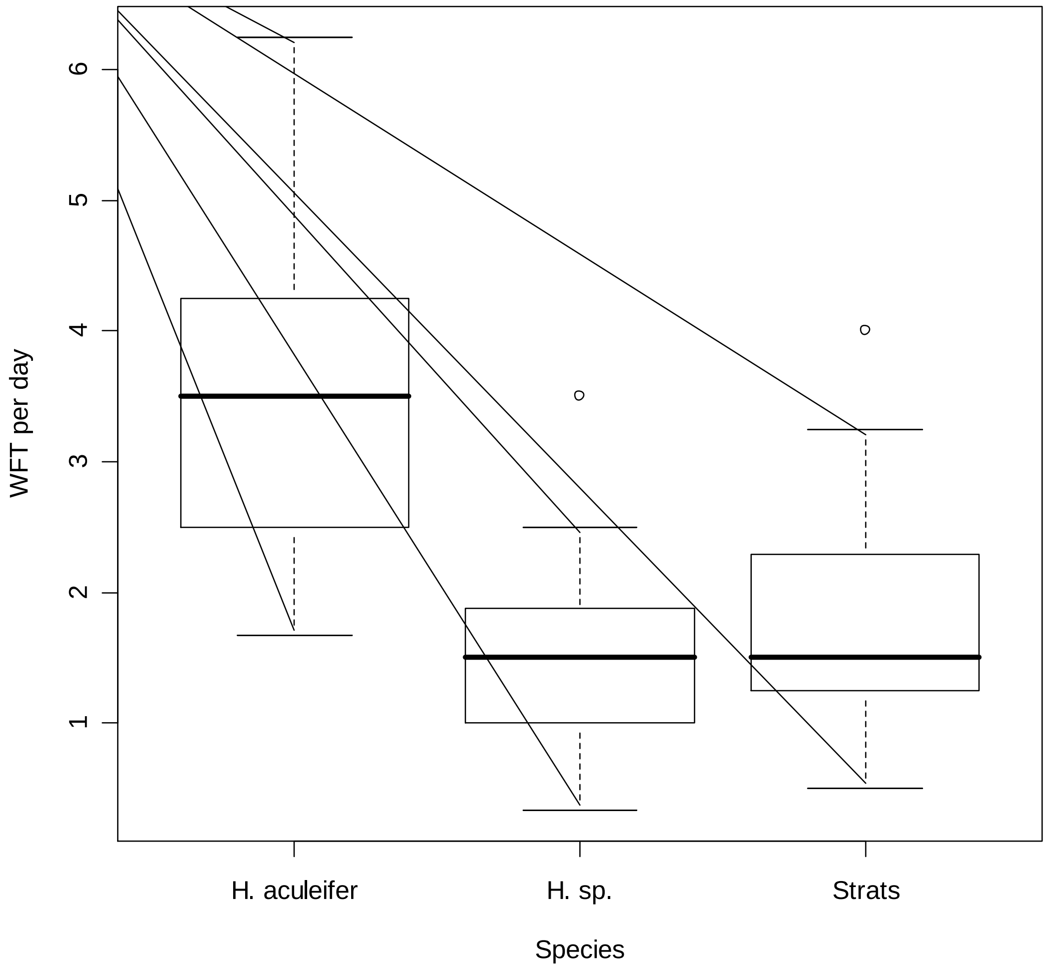

Figure 22: Western flower thrips pupae consumed every 24 hours by species of predatory mites, *Hypoaspis aculeifer, Hypoaspis* sp., and *Stratiolaelaps scimitus* (Strats).

Whilst the predation rate is not as high as those seen with the biological control agent *T. montdorensis, H. aculeifer* presents a great opportunity for complementary control.

Neither predator will provide 100% control of WFT numbers, but using two species to attack different lifecycle stages of the one pest is a very effective way to effectively manage populations of the pest.

While *T. montdorensis* may not consume 100% of the pest thrips on the leaf, any that make their way through the larval stages to pupate are likely to drop to the floor of the greenhouse or to the growing media to complete the lifecycle. If there is a population of one or more of the soil dwelling predatory mites present in the media, then there is likelihood that those predators will consume a high proportion of the pupae.

Hypoaspis aculeifer is currently commercially available in Australia although growers are not widely aware of this mite's use as a biological control agent against WFT. It is recommended that additional work examine its full utility is undertaken and more work on the way in which the species can be used as a complement to existing biological controls such as *T. montdorensis*.

Biological Control Agents – Side Effects

Transieus montdorensis – Pesticide Side-Effects

The methods for determining the toxic standard was developed based on International Organisation for Biological Control protocols and tested on *T. montdorensis*. The methods developed as part of this project have made it possible for the determination of pesticide side effects for numerous biological control agents, primarily *T. montdorensis*. Without the protocols developed here, this work would not have been possible.

Other Horticulture Australia Ltd projects (for example VG07003) have reported on the side effect information gathered as a result of these protocols. Extensive research and work was undertaken during the course of this project to make this information available.

Greenhouse Modification Trials

Sticky traps were monitored in all greenhouses or a number of different pests. One unmodified greenhouse had significantly higher numbers of WFT with up to four times the amount observed in other greenhouses (Figure 23). The other unmodified greenhouse showed a slight numerical increase in thrips numbers captured but was not as high.

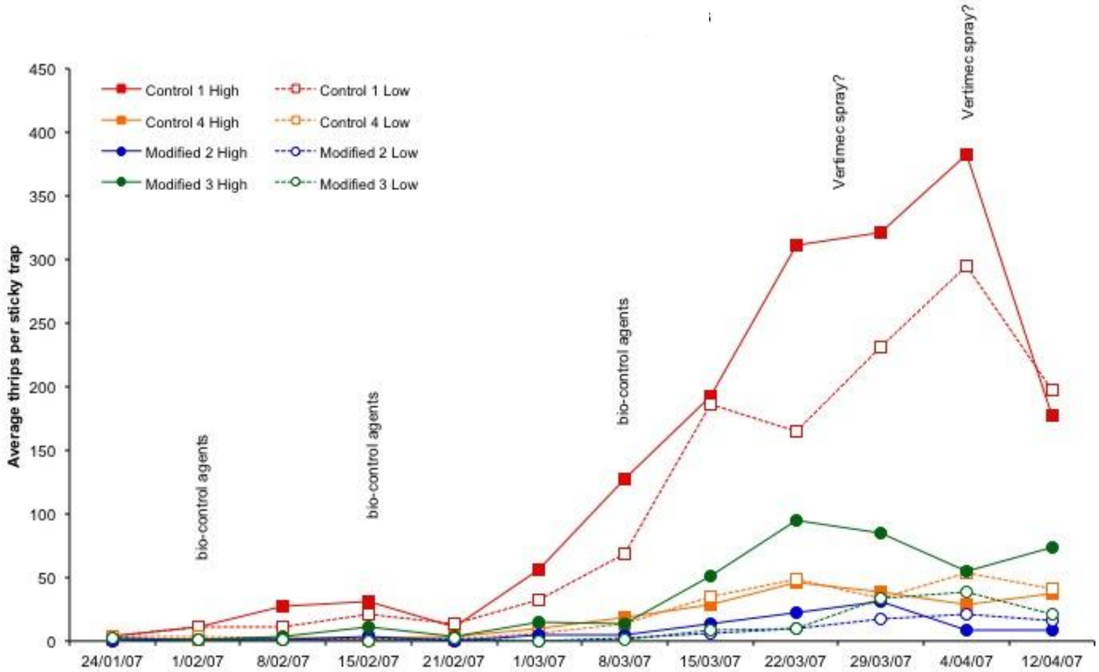

Figure 23: Western flower thrips adults captured on sticky traps. Lines with squares represent the sticky traps in modified greenhouses and lines with circles represent the sticky traps in unmodified greenhouses. Solid lines are traps located high in the crop, dotted lines are located low in the crop.

The screens installed in the vents were whitefly-grade mesh, the size of which would allow thrips-sized insects through the barrier. In order to minimise the number of thrips moving through the mesh it had a reflective thread woven into the mesh as a visual deterrent to thrips.

Whitefly numbers were higher in the unmodified greenhouses than the modified greenhouses (Figure 24). Through most of the sampling dates both unmodified houses had higher numbers of whiteflies with the greatest difference being in the weeks before the end of the trial.

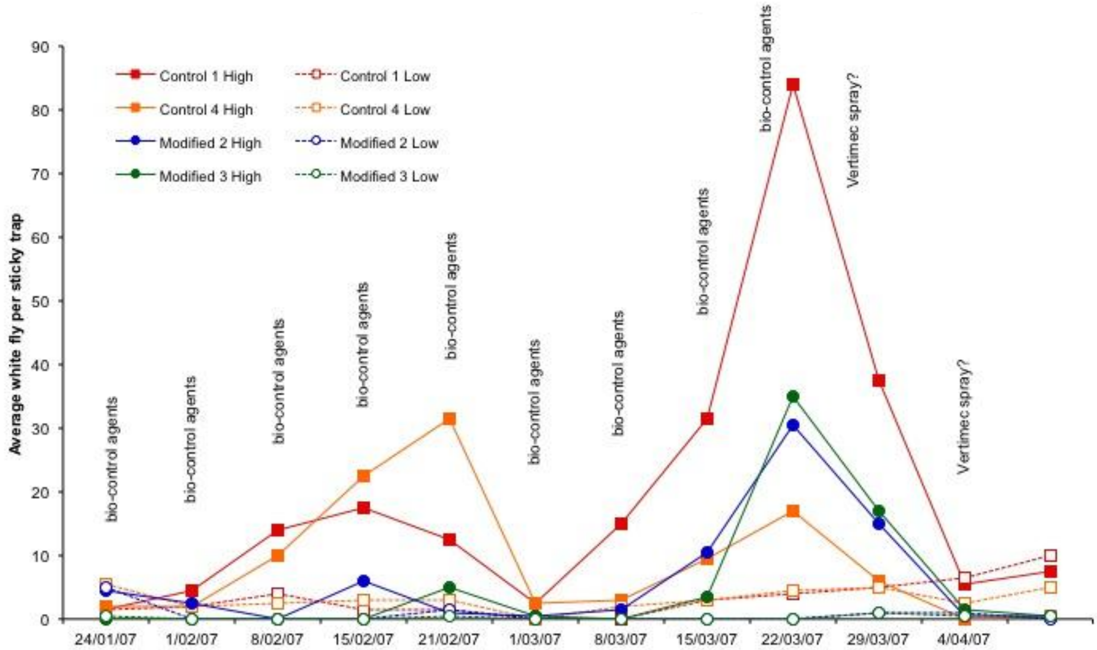

Figure 24: Whitefly adults captured on sticky traps. Lines with squares represent the sticky traps in modified greenhouses and lines with circles represent the sticky traps in unmodified greenhouses. Solid lines are traps located high in the crop, dotted lines are located low in the crop.

The numbers of thrips are important, but just information regarding the presence or absence of thrips can be vitally important due to their ability to effectively vector several virus diseases. Each house was broken into several blocks and when simple presence or absence of thrips is examined, it is possible to suggest that a unmodified house will have a greater incidence on thrips in individual blocks than a house that has been modified (figure 25). This higher rate of presence in a greater area of the greenhouse, up to 50% in one case, will possibly lead to a higher level of feeding damage and virus transmission.

Numbers of fungus gnats were monitored on both high and low traps but were captured predominantly on lower traps. There was no clear pattern to the distribution of fungus gnats between the greenhouses (Figure 26) although the highest numbers of fungus gnats were observed in at least one unmodified greenhouse on nine of the 12 sampling dates and both unmodified houses had the highest numbers on four of the 12 sampling dates. These results appear to suggest that the modified houses did have a positive exclusion effect on the movement of greenhouse whiteflies into the greenhouses.

The modifications completed on the greenhouses had no effect on the distribution of two-spotted mites (Figure 27). This is a reflection on the fact that mites do not disperse on the wing as thrips and whiteflies do. These pests are dependent on farm staff and visitors moving them around the greenhouses and screening the vents will not prevent this. The distribution of winged pests was random through each greenhouse they were observed in whereas the distribution of mites was heavily bias towards the entries into these greenhouses.

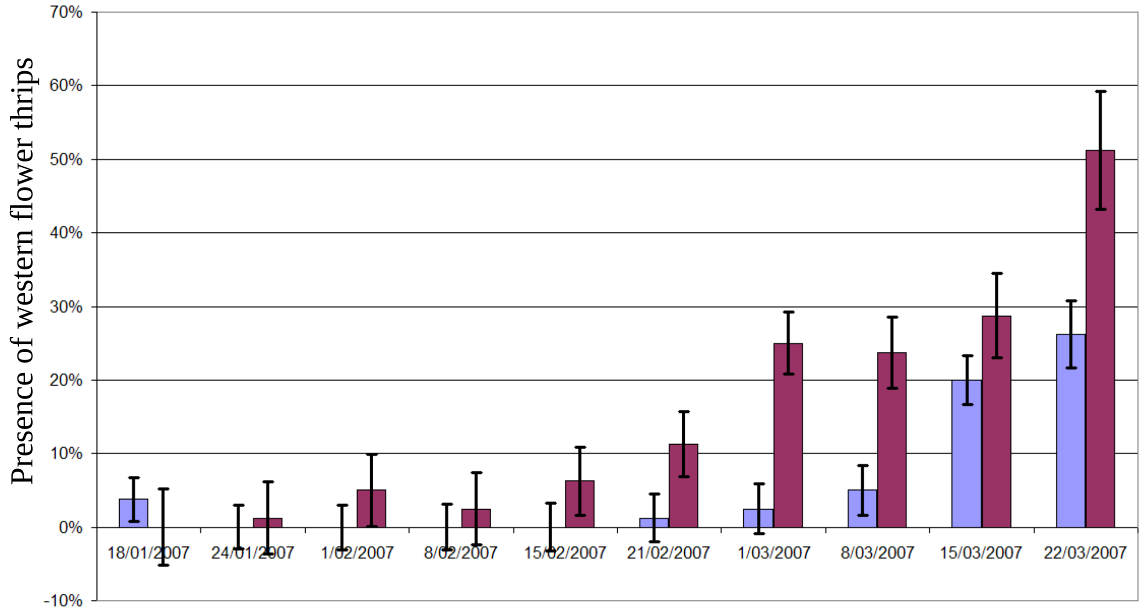

Figure 25: Percentage of blocks within unmodified (maroon bars on right) and modified (blue bars on left) that had a confirmed presence of western flower thrips. Unmodified houses showed a significant increase in the levels of western flower thrips in a greater proportion of the greenhouses.

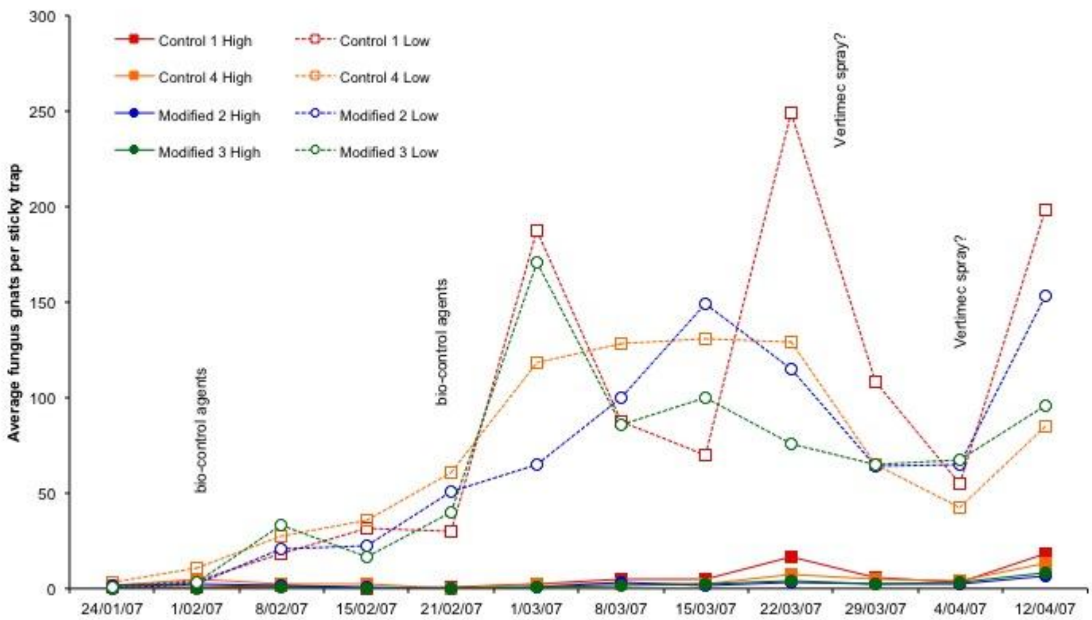

Figure 26: Fungus gnat adults captured on sticky traps. Lines with squares represent the sticky traps in modified greenhouses and lines with circles represent the sticky traps in unmodified greenhouses. Solid lines are traps located high in the crop, dotted lines are located low in the crop.

This distribution of mites indicates that growers need to be aware of their movement around the farm. Hygiene and cultural practices have long been touted as extremely important in pest management. Random movements through the farm by staff might be the cause of this even distribution of mites through the modified and unmodified greenhouses.

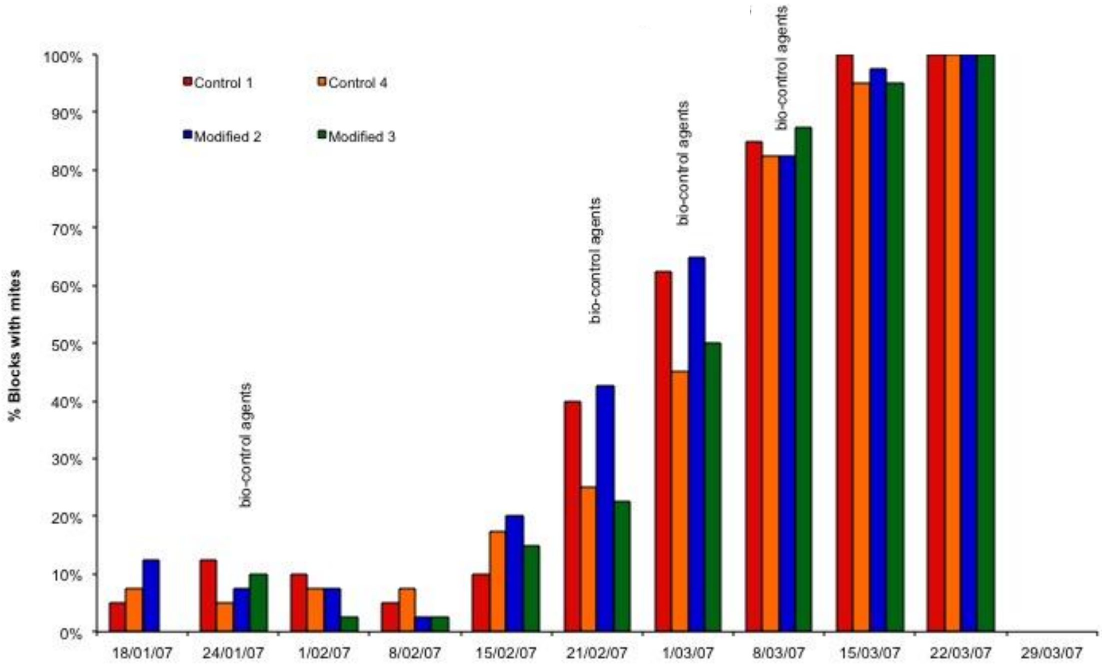

Figure 27: Two-spotted mites observed while monitoring in all greenhouses.

Temperatures in unmodified greenhouses was approximately 12°C higher than in modified greenhouses where maximum ventilation and air movement was achieved (Figure 28). The roof vents allowed hot air to move out of the roof ridge line and side vents maximised the cross flow of air. The internal fans moved the air around the greenhouses interior and cooled the air further. This reduction, from nearly 50°C in the middle of the day to less than 40°C, is extremely important for the use of biological control agents, the health of the plants, and the comfort of the farm staff.

The yield of cucumbers from the houses showed no trends between modified and unmodified greenhouses (Figure 29). The quality of the fruit was not monitored during the trial that is a measurement that should be done in the future. There was anecdotal evidence that suggested the plants and fruit were far healthier and vibrant in modified greenhouses. This could have been as a result of the lower temperature and reduced pressure from pests.

There are many barriers to a successful greenhouse production facility but this trial shows the importance of adapting low technology greenhouses to maximise airflow, reduce maximum temperatures and exclude winged pests. Through minimal capital expenditure winged pest infestations can be reduced and the efficacy of biological control agents increased.

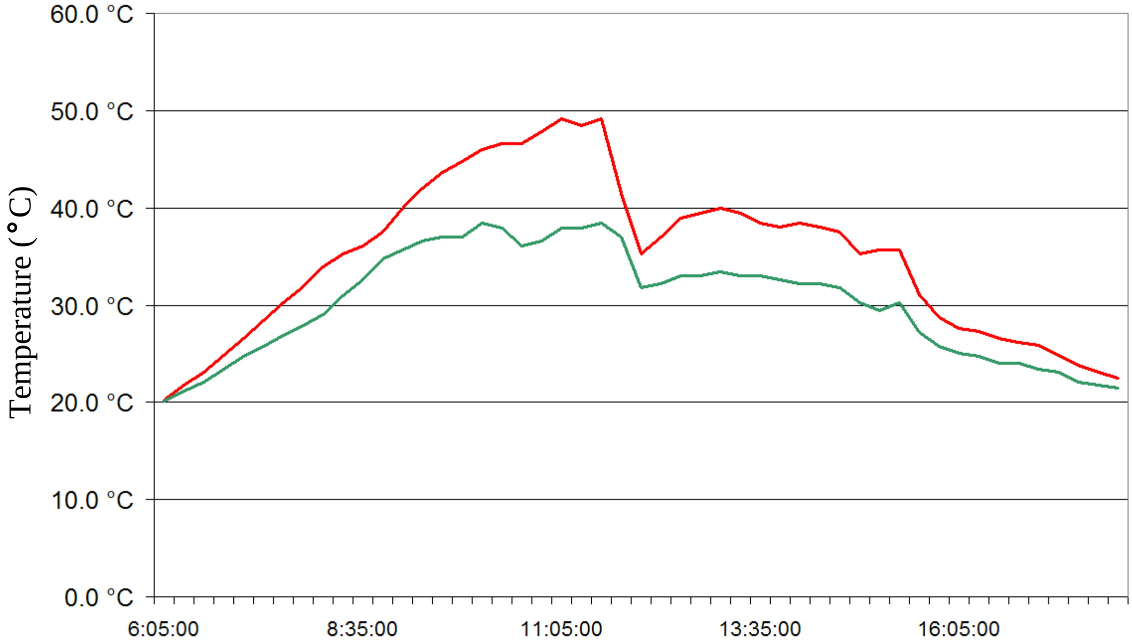

Figure 28: The average temperature in modified (green line) and unmodified (red line) greenhouses.

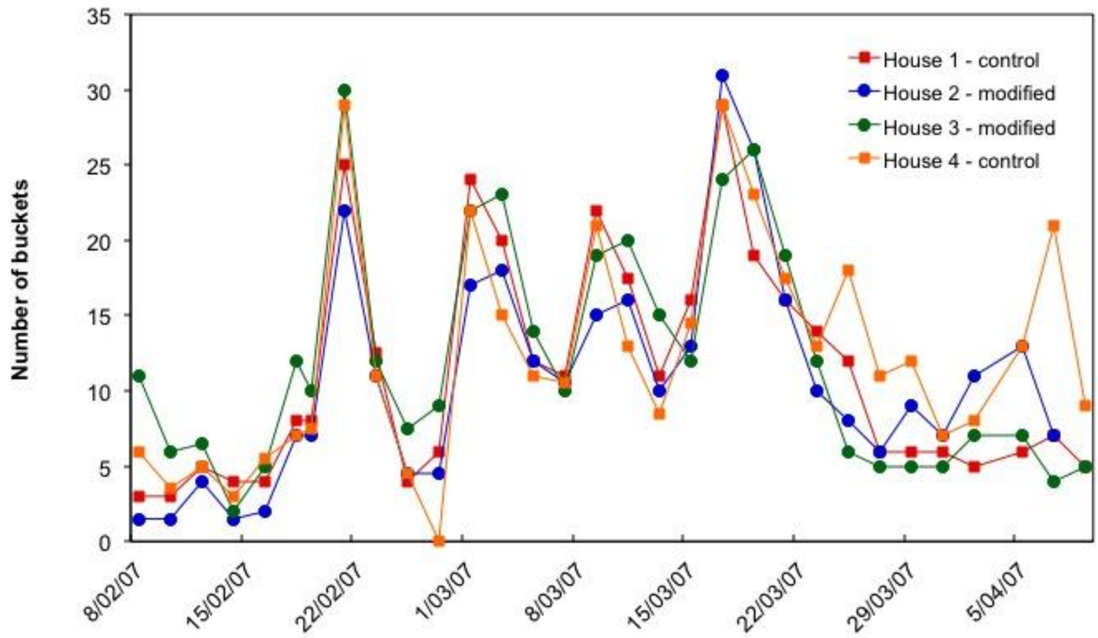

Figure 29: Cucumber yields, represented as the number of buckets harvested from the crop, across all greenhouses.

Discussion

Managing pests in a greenhouse environment can be very difficult for growers for a number of reasons. The paucity of available synthetic pesticides, high temperatures in low technology greenhouses reducing the efficacy of biological control agents and the natural high pressure of pest populations in many parts of Australia all contribute to these difficulties.

This project has developed a number of tools that can be used by growers to manage a variety of insect and mite pests as part of an integrated pest management system. The intention of developing integrated pest management tools is never to replace pesticide options, but rather to augment their use or retain the efficacy for when they are needed in the future. IPM techniques aim to enhance pest management options by providing several strategies for managing pest populations.

Growers that undertake biological control as a management strategy will have already reduced their conventional pesticide use to nearly nothing. The use of reduced-risk pesticides is a stepping-stone towards biological management. The measurement of reduction of conventional pesticide use and the increase in the use of biological control agents was effectively done during benchmarking studies as part of HAL project number VG03098. This related project showed an increase in integrated pest management adoption across the growers surveyed and the use of soft pesticides and biological control agents. Some of those effects can be directly attributed to this project and new knowledge gained.

Key results from the project include;

Reduced-risk pesticides

- The knowledge regarding the entomopathogen, DPI9, was increased to a level where commercial uptake is highly likely. The effects of application rates, UV light and humidity were all examined to provide a greater framework for the successful commercialization of the reduced-risk pesticide.
- Several reduced-risk pesticides were shown to be highly effective against pests such as western flower thrips, greenhouse whitefly and green peach aphid. By quantifying the efficacy of these pesticides it is hoped that the producers of each product will actively seek registration for use in the vegetable greenhouse industry. It is hoped that commercial producers of these products will seek registration and make these products available to growers. Each producer has expressed keen interest in the prospect.

Biological control agents

- The feeding rates and competitive characteristics of three biological control agents were investigated. The knowledge obtained on these organisms will allow the expansion of their use or lead to new uses of the organisms.
- The expansion of the use of these biological control agents will allow growers to move away from conventional pesticide use. An understanding of their limitations and where they perform well will assist in the development of any management strategies.

Greenhouse modifications

- The cost effective and simple modifications to low-technology greenhouses will enhance pest management and vegetable production. This can now be achieved through the use of information in this project that looks at improving temperature and humidity controls and enhancing pest exclusion. Through the implementation of the modifications and integrated pest management strategies, growers can reduce their reliance on conventional pesticides.

Technology Transfer

A fundamental component of moving information into the public realm is through scientific journals and conference proceedings. This project delivered several articles at different conferences both within Australia and overseas, for industry and for the scientific community.

Relevant literature produced includes:

Goodwin, S. and Pilkington, L. J. (2006). The Use of a Novel Reduced-Risk Chemical in the Control of Western Flower Thrips in Greenhouse Crops. Australian and New Zealand Entomological Societies' Conference. Adelaide, South Australia, September 24-27, 2006. 39.

Pilkington, L. J. (2007). Overuse of Synthetic Pesticides – How can Integrated Pest Management Help? International Plant Propagators' Society 35th Annual Conference. Dubbo, New South Wales, April 26-27, 2007.

Pilkington, L. J., Kent, D. and Goodwin, S. (2007). Hacking the Heat? Greenhouse Screening to Manage Temperatures and Reduce the Movement of Pests. Australian Entomological Society's 38th Annual General Meeting and Scientific Conference. Beechworth, Victoria, September 23-26, 2007. 26.

Kent, D. S. and Pilkington, L. J. (2008). *Orius gracilis* (Hemiptera: Anthocoridae), a Potential Biocontrol Agent for Greenhouses in Australia. Australia and New Zealand Biocontrol Conference. Sydney, New South Wales, February 10-14, 2008. 19.

Pilkington, L. J. (2008). Current Research in Protected Cropping Biocontrol in Australia. Australia and New Zealand Biocontrol Conference. Sydney, New South Wales, February 10-14, 2008. 53.

Pilkington, L. J. (2008). The State of Play in Biological Control in Australia - Where to now? IOBC Greenhouse 2008. IOBC/WPRS Working Group "Integrated Control in Protected Crops, Temperate Climate" meeting 2008. Sint Michielsgestel, The Netherlands, April 21-25, 2008.

Pilkington, L. J., Crampton, K. and Spohr, L. J. (2008). Eat your heart out - the Predatory Performance of Three Species of Predatory Mite (Acari: Laelapidae) – *Hypoaspis aculeifer*, *Stratiolaelaps scimitus* and *Stratiolaelaps* sp. Australian Entomological Society's 39th Annual General Meeting and Scientific Conference, Orange, New South Wales, September 28 – October 1, 2008. 26.

Fact sheets and newsletters were also produced under the auspices of VG03098. This project (VG03098) aimed to deliver the findings of several projects including this one and these publications are reported fully within that final report. In addition to the publications, the outcomes of this project were also communicated at several grower workshops across the Sydney Basin as part of that project.

Staff from NSW Department of Primary Industries will continue to work with the producers of both reduced-risk pesticides and biocontrol agents in an attempt to have them either registered, or increase their use within industry. Great demand is still placed upon the training resources developed by staff at the Department, and the findings from this project will be continued to be communicated through workshops and training presented by staff.

The staff at the Central Coast Primary Industries Centre are often contacted by industry members to provide advice and guidance on growing techniques and business activities. The findings in this project now feature as part of the often provided advice to industry and one on one facilitation of training and coaching is an extremely effective transfer of knowledge to individual, or groups of, growers.

Recommendations

This project has several new options to greenhouse vegetable growers with respect to pest management. Modification of structures, cultural management strategies (such as hygiene, use of sticky traps or monitoring, and improved spraying techniques), reduced risk pesticides and biological control agents have been described in order to assist growers in the very difficult situation of pest management.

The following recommendations are made to ensure that growers continue to capitalize on IPM strategies developed as part of this project.

- That the entomopathogen, DPI9, be supported for any work required to establish registration for use in greenhouse crops. Whilst a commercial partner is currently progressing swiftly towards registration with a view to commercially produce the product, support is needed through this process. Small projects will need to be supported to provide NSW DPI the ability to develop further strategies to commercialise this entomopathogen such as new formulations, storage protocols and compatible organisms that the product can be used with.

- That the producers of reduced-risk pesticides Agri50NF, Cyazypyr, Pyrus and Symphony be encouraged to register their products for use in greenhouse crops against western flower thrips. That the pesticides biocover, DPI9, Ecooil, Cyazypyr, PestOff and SB Plant Invigorator be supported in their registration for use against greenhouse whitefly in greenhouse crops.That the pesticides Agri50NF, DPI9 and Cyazypyr be registered for use against green peach aphid in greenhouse crops. This support may be required from existing HAL projects that are involved with minor use permits or other pesticide development strategies. It is also recommended that the APVMA continue to establish an easier registration process for reduced-risk pesticides in accordance with procedures in other countries such as USA and Canada.

- That the biological control agent, *Transeius montdorensis*, is marketed as effective in the management of populations of greenhouse whitefly and particularly effective against a mixed population of this pest and western flower thrips. This expansion of the utility of the predatory mite will increase market share and potentially reduce the use of pesticides further in the industry. This progress should be undertaken by Bugs for Bugs, a biological control producer in Queensland and a collaborator on a related HAL project (HG08043) developing the use of this organism.

- That the biological control agent, *Hypoaspis aculeifer*, be marketed as an effective ground treatment against populations of western flower thrips. This marketing should include information about how to use this species as a complementary biological control with *T. montdorensis*. The current producer is Biological Services in South Australia who already produce this organism for the management of other pests.

- That the pesticide side effect protocols developed in this project be used for all future side effect data gathering for pesticides against biological control agents.

- That those growers with low technology greenhouses be encouraged and supported in the adaptation of their houses to include ridge venting and side-wall venting with insect mesh applied to all openings. In conjunction with common IPM practices these modifications will increase the efficacy of biological control agents and will reduce the level of insect migration into the crop. This could be supported through the presentation of small workshops or inclusion in workshops being presented under other projects.

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