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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- The predatory mites *Stratiolaelaps scimitus* (previously known as *Hypoaspis miles*) and *Macrocheles robustulus* reduced resultant numbers of WFT adults in the coir substrate in controlled temperature experiments. The nematode *Steinernema feltiae* was also effective on occasion.

Background and expected deliverables

Western flower thrips (WFT), *Frankliniella occidentalis*, is a devastating pest of protected strawberries and recent experiences have suggested that existing biocontrol agents sometimes provide inadequate control in hot conditions. WFT feeding on the flowers and developing berries lead to bronzing of the fruit, which can cause downgrading to Class 2 or, in severe cases, to crop losses.

This project aimed to identify alternative predators, not currently being exploited for WFT control, which could be incorporated into a biocontrol programme to replace or supplement *Neoseiulus cucumeris* for control of WFT on protected strawberry.

Summary of the project and main conclusions

In year 1 of the project, the efficacy of a range of commercially available biocontrol predators was assessed when applied both to strawberry plants to control WFT larvae and to the coir substrate to control pupal stages of WFT.

The predatory mites *Amblyseius montdorensis, Amblyseius swirskii*, *Amblydromalus limonicus* and the commercial standard *Neoseiulus cucumeris* were all effective at reducing numbers of WFT at 30/20°C day/night temperatures (Light/Dark ratio of 14:10 h).

Additional information was also gathered on alternative species. The predatory mites *Stratiolaelaps scimitus* (*Hypoaspis miles*) and *Macrocheles robustulus* were both found to reduce numbers of adult thrips through pupal predation in the substrate. *M. robustulus* was particularly effective at 30/20°C day/night temperatures.

The effect of predation by the rove beetle *Dalotia coriaria* (formerly known as *Atheta coriaria*) on pupae did not reduce thrips numbers significantly. The anthocorid bug *Anthocoris nemoralis* was also tested as a predator but was not as effective as *Orius spp*.

The results from Year 1 concluded that the predatory mites *A. montdorensis, A. swirskii*, *A. limonicus* and the commercial standard *N. cucumeris* are all effective predators of WFT. However, these alternative three species are not currently registered in the UK for use in field/polytunnel grown crops and are unlikely to be registered for this use in the near future. The commercial standard *N. cucumeris* therefore remains the most practicable predatory mite species for growers to use in field grown polytunnel crops.

Because the alternative species are unlikely to be registered for field use, work in Year 2 focussed on the two Neoseiulus species *N. cucumeris* and *Neoseiulus californicus* along with the predatory mites, used in the substrate, *S. scimitus* and *M. robustulus*.

It was decided to explore the relationship between *N. cucumeris* and *N. californicus* and their role in WFT control. *N. californicus* is not native to the UK and is not licenced for release in field grown crops. However, it has regularly been found in field crops for some years. Growers and agronomists find it difficult to distinguish between the two species using a hand lens and incorrect identification may lead to fewer *N. cucumeris* introductions which might lead to reduced control of WFT. Any competition between species may also adversely affect control.

Work was done using small Perspex boxes in controlled temperature cabinets. When used alone, both species reduced the number of thrips. When used in combination, there was a similar level of control to that achieved by either of the mites individually, showing that there was no interspecific competition between the adult mites. *N. californicus* is recommended in glasshouse structures for two-spotted spider mite control, so if alternative prey is available, the resulting WFT control may be different and agronomists may overestimate the populations of predators present which will effectively control WFT. Growers and agronomists are therefore advised to seek specialist identification of the Neoseiulus species which are naturally occurring in a crop, a task which can only be done by trained entomologists under the microscope.

The use of the substrate mites *S. scimitus* and *M. robustulus* was further explored in combination with either predatory nematodes (*Steinernema feltiae*) or *N. cucumeris*. As in year 1, the mites controlled WFT in a coir substrate in small pot units (8 cm x 8 cm) in controlled temperature cabinets. However, there was an indication of an interaction between the nematode *S. feltiae* and *M. robustulus*.

In the third year of the project, work continued to investigate the use of the substrate mites and predatory nematodes in small pot unit experiments. *M. robustulus* was used at two rates, both alone and in combination with *S. feltiae*. *S. feltiae* was also assessed alone. All treatments were compared to an untreated control. All treatments reduced WFT numbers to some extent. There was a statistical interaction, showing that the two species in combination were less effective than the sum of the two species alone. However, the two species in combination, still gave higher control than either species individually. When using predatory substrate mites in combination with other substrate biocontrol agents, timings may need to be considered to avoid an interaction. WFT larvae may not remain in grow bags to pupate and can fall to the ground. Therefore control systems need to consider application timings for best effect.

The successful use of substrate mites in this work supports the report by Clare Sampson in 2014, who found that many growers who had achieved good control of WFT had made one release of *S. scimitus* between March and May, in addition to other biocontrol agents such as *N. cucumeris*.

Financial benefits

The majority (>80%) of strawberries sold by multiple retailers are grown under protection and late season production using everbearer varieties has expanded. WFT is a major pest of strawberries, and when conditions are favourable pest numbers can increase rapidly. On some farms, WFT damage to everbearer fruit has been so severe following failure of Tracer (spinosad) to control the pest, that total crop loss has occurred for the latter third of the season, equating to a loss of £18,000 per ha. More typically, on some farms 20% of the fruit has been downgraded to Class 2 for half of the picking season.

The biocontrol options currently available do not always control thrips effectively. Although biocontrol agents such as *N. cucumeris* are regularly released, they have not worked effectively for every grower. Some growers use them early in the season as a preventive rather than a curative measure. As a result, they are not able to suppress thrips populations once they have increased later in the season. In seasons when conditions have been hot and humid and optimal for WFT development, *N. cucumeris* has not always provided adequate control on some sites, leading to enormous crop losses. Problems with this pest continue in glasshouse and polytunnel crops.

Conditions under tunnels can fluctuate widely throughout the season and different biological control agents may perform better at different temperature/humidity levels. This project compared the efficacy of different biological control agents both alone and in combination

with *N. cucumeris* to enable different solutions to be selected as the season progresses. The project determined the efficacy of commercially produced bio-control agents applied to the substrate, which should not compete with *N. cucumeris* in the plant, and have an additive effect.

If growers can effectively complement the use of *N. cucumeris* with substrate predators such as *S. scimitus*, *M. robustulus* and the predatory nematode *S. feltiae*, the financial losses listed above will be avoided.

Action points for growers

- Continue to use AHDB recommendations for western flower thrips control as described by Sampson (2014) such as preventive introduction of *Neoseiulus cucumeris* early in the season for polytunnel grown strawberries.
- Follow the guidelines laid out in the new AHDB Factsheet 14/15 'Western flower thrips control in strawberry'.
- Consider the use of the substrate predatory mites *S. scimitus* and *M. robustulus* and the predatory nematode *S. feltiae* to complement introduction of *N. cucumeris*, as part of integrated WFT control strategy.
- Where *N. cucumeris* is thought to already exist in a crop, arrange to have the species verified by a specialist entomologist as it can be confused with *N. californicus* which, if present rather than *N. cucumeris*, may offer less effective control of WFT as it also preys on other pests.
- Discuss the timings of applications with your crop advisor particularly when using biocontrol agents that may have an interaction (such as *N. cucumeris* and *N. californicus*).

SCIENCE SECTION

Introduction

Western flower thrips (WFT), *Frankliniella occidentalis,* is a major pest of strawberry, which feeds in strawberry flowers and on young developing fruitlets, causing the fruitlets to have a bronzed, unsightly appearance. Such damage can cause fruit to be downgraded or rejected. The majority (>80%) of strawberries sold by multiple retailers are grown under protection to secure continuity of supply and quality of production and late season production with everbearer varieties has expanded. However, serious outbreaks of WFT in warmer weather conditions that favour the pest in mid and late summer have caused serious crop losses.

WFT has developed resistance to many pesticides, including spinosad; resistance to this insecticide is becoming more widespread. This is leading to a situation where growers have failed to control the pest with multiple sprays of the full range of approved plant protection products. AHDB funded screening trials of existing and novel insecticides in 2008 and 2009 have not provided alternative insecticides that are likely to be registered on strawberry in the UK.

The population growth of WFT depends mainly on temperature and host plant. Most WFT developmental data have been obtained on cucumber and chrysanthemum in glasshouse crops (Robb, 1989; Gaum *et al*., 1994; Wang and Shipp, 2001; Nothnagl *et al*., 2007; Rhainds *et al*., 2007; Nothnagl *et al*., 2008). Development is fastest at 28-30°C. Above 35°C and below 10°C WFT development ceases. At higher temperatures mortality rises rapidly and lifespan declines sharply; mortality does not increase appreciably at low temperatures (>10°C). At optimum temperatures, generation time can be as short as 11 days on chrysanthemum, compared to 39 days at 15°C (Robb, 1989). In the early season in the UK, crop canopy temperatures usually fluctuate greatly in the range of 5-30°C under Spanish tunnels (Bennison & Fitzgerald, 2009). In AHDB SF 80, WFT were found to be active in overwintered everbearer crops from March onwards (Bennison & Fitzgerald, 2007, 2008 & 2009). WFT development was modelled under the HortLINK project SF 120, with a focus on early season information; the model prediction of early activity fitted well with the observed behaviour.

Control of the larval stages of WFT

UK growers of glasshouse strawberries are using Integrated Pest Management (IPM) programmes. Thrips control is based mainly on use of the predatory mite *Neoseiulus (Amblyseius) cucumeris* (Sampson, 2008; Sampson *et al*., 2009). This predator eats the young thrips larvae on the plants and is widely used in many other protected crops, where it gives good control of WFT if used preventatively. Similarly many growers make routine introductions of *N. cucumeris* in Spanish tunnels in spring against this and other pests. This can give good control. However, the effectiveness can be unreliable, especially if used later in the season. This strategy is also inadequate when high populations of thrips develop early. *N. cucumeris* feeds only on young thrips larvae and cannot always control increasing populations due to large influxes of WFT adults e.g. from infested growing media held over from the previous season or from adjacent infested crops (Bennison & Fitzgerald, 2007, 2008, 2009). The predatory mite *Amblyseius barkeri* has shown promise for tarsonemid control in strawberry in AHDB SF 133. This was considered for testing in comparison to *N. cucumeris* for its ability to seek out and prey on different stages of thrips; however it is not currently marketed in the UK, although this may be included in an experiment in Europe this year against WFT.

Other available/recommended predators for WFT include *Orius* predatory bugs which are costly, but which can eat all life stages of WFT. This predator is released in protected crops such as peppers as soon as the plants are in flower, where it establishes before thrips are present. In SF 80, *Orius* spp. occurred naturally in strawberry plantations at EMR and contributed to reduction of WFT. Naturally occurring *Orius* spp. have also been observed in some commercial UK everbearer crops. In Israel and northern Italy, it is considered unnecessary to release any biological controls to field-grown strawberries for WFT control, as naturally occurring *Orius* spp. maintain control of the pest (Coll *et al*., 2007; Bosco *et al*., 2009). Research in the HortLINK project SF 120 investigated optimal release strategies for current commercially used predators such as *N. cucumeris* and *O. laevigatus*. However there are still gaps that need to be addressed within the bio-control armoury.

Control of pupal stages of WFT

The soil-dwelling predatory mites, *Stratiolaelaps scimitus* (also known as *Hypoaspis miles*) and *Hypoaspis aculeifer*, primarily used for control of sciarid flies, were shown in Defra-funded research on chrysanthemum to feed on late second stage WFT larvae which drop to the ground to pupate, and also on the pupal stages (Bennison *et al*., 2002). These mites are used in some protected crops including table top strawberries in glasshouses, for supplementing control of WFT by *N. cucumeris*. They were highlighted as a predator worthy

of further research in a review of biocontrol strategies for use in strawberry and raspberry (Fitzgerald *et al*., 2005). Another soil-dwelling predator, the staphylinid beetle *Dalotia coriaria* will feed on WFT life stages in the soil. *D. coriaria* reduced numbers of WFT on potted bedding plants in AHDB PC 261, using a 'DIY' rearing system developed in AHDB project PC 239 (Bennison, 2006, 2007, 2008, 2009). However, *S. scimitus* and *D. coriaria* did not give improved control of WFT when used to supplement control by *N. cucumeris* in SF 80, probably due to most of the field soil in everbearer beds being too dry for these predators to survive and breed. The predators are likely to have more potential where strawberries are grown in well-irrigated substrates. Rahman et al (2011) found that although *S. scimitus* is insufficient to control thrips on its own, the combined use of this mite and *N. cucumeris* resulted in better control than the use of *N. cucumeris* alone. In the recent management report for WFT, Sampson (2014) found that *S. scimitus* can be a useful back up to *N. cucumeris* and it was released in five of the six commercial crops where thrips control was successful.

Entomopathogenic fungi (EPFs) that are known to attack thrips include isolates of *Beauveria bassiana* or *Metarhizium spp.* (Sánchez-Peña *et al*., 2011; Arthurs *et al.*, 2013). EPFs are being studied as a strand in the AHDB project SF156. Nematodes such as *Steinernema feltiae* and *Heterorhabditis* spp. are also effective against the pupae, and can have good persistence (Bennison *et al*. 2006). Factors that affect these bio-control agents include the temperature and moisture levels in the substrate. Ebssa *et al*. (2006) showed that there was potential in combined applications of predatory mites and nematodes to control foliage-feeding and soil-dwelling life stages of thrips. A recent paper by Saito & Brownbridge (2016) explored the compatibility of soil-dwelling predators and microbial agents and their efficacy in controlling pupal stages of WFTs. In their work, the combined use of the predators and the nematodes did not work as well as predicted; there was no difference between the *S.scimitus* and *S. feltiae* plus *S. scimitus* treatments.

Control of WFT in protected crops

Several predatory mite species are now used for WFT control in some glasshouse crops e.g. cucumber. *Amblyseius swirskii* can establish and develop faster than *N. cucumeris* and lead to more effective control (Messelink *et al*., 2005). *A. swirskii* targets young WFT larvae and is the main predator of thrips in strawberries in South Africa. It is active from 12°C, and the predator population starts to develop when the day temperature regularly exceeds 20-22°C, with tolerance to the high temperatures that can be found in tunnels in summer. This species is effective at higher temperatures, when it can out-compete *N. cucumeris*. At the

other end of the temperature spectrum *Amblydromalus limonicus* feeds on both the 1st and 2nd larval stages and is an excellent predator at lower temperatures of 13°C, whereas *N. cucumeris* ideally needs a few hours at 20°C. *Amblyseius (Typhlodromips) montdorensis* is also being used to control pests in protected crops. The nematodes *Steinernema feltiae* are used to give control against pre-pupae and pupae. However, some of the above species are currently only licensed for release in fully protected glasshouses in the UK, thus cannot be released to outdoor crops or those in tunnels.

Project aim(s):

The overall aim of the project was to identify and evaluate new bio-control agents for Western Flower Thrips (WFT), to replace or supplement *Neoseiulus (Amblyseius) cucumeris* for control of WFT on strawberry in polytunnels.

Project objective(s):

1. To quantify the efficacy of the five most promising predatory insects and mites available from bio-control suppliers as predators of WFT in strawberry flowers.
2. To quantify the efficacy of five control agents applied to the substrate.
3. To investigate the species of insects and mites responsible for natural predation of WFT in flowers in crops and surrounding habitats, identifying those which may potentially be exploited for bio-control of WFT

This project complements SF156.

Summary of work in Year 1

In year 1 of the project, the efficacy of commercially available predators applied to the plant to control the larval stages of WFT and applied to the substrate for bio-control of the two pupal stages were determined in controlled environment conditions typical of those found under Spanish polythene tunnels. In addition potential predators of WFT were sampled.

Year 1, Objective 1 – Control of larval stages of WFT in flowers

Predatory mite experiments

The mites *Amblyseius montdorensis, A. barkeri, A. swirskii* and *Amblydromalus limonicus* were compared against the commercial standard *Neoseiulus cucumeris.* Small units consisting of French bean pods (20 cm in total) placed in a Perspex container with damp filter paper plus a small amount of pollen (Nutrimite, Biobest UK Ltd) were used. For the majority of the experiments 20 WFT females were added to lay eggs for 2 days, before removing, and 20 predatory mites were introduced prior to egg hatch.

The predatory mites *A. montdorensis, A. swirskii*, *A. limonicus* and the commercial standard *N. cucumeris* were all effective at reducing numbers of WFT at 30/20°C day/night temperatures in at least one of the experiments (Light/Dark ratio of 14:10 h). In one experiment there was a significant decrease in WFT larval numbers with *A. swirskii* compared to the untreated control at the first assessment date after 4 days, but not after 8 days. A significant decrease was not seen for the other treatments, *N. cucumeris* (although numbers were reduced) or *A. montdorensis*. In a separate experiment *A. limonicus* reduced numbers of thrips larvae to almost zero, whilst *N. cucumeris* halved the numbers compared to the untreated control at the 4 day assessment.

At 20/10°C day/night temperature, in one experiment *N. cucumeris, A. montdorensis* and *A. swirskii* significantly reduced numbers of WFT larvae and pre-pupae. In a separate experiment comparing *N. cucumeris* with *A. barkeri*, neither of the treatments were significantly effective at reducing the numbers of WFT larvae, however the mean numbers were lower in the *N. cucumeris* treatment compared to the *A. barkeri* treatment and the control.

Control of WFT by both *N. cucumeris* and *N. californicus* was investigated as 1) it is difficult to discriminate between the species in the field using a hand lens, 2) incorrect identification of *N. californicus* may lead to less *N. cucumeris* being applied which could negatively affect control of WFT and 3) if there is competition between the species this again could have a negative effect on control of WFT. *N. californicus* is a non-native species and therefore is not licensed for release, however it has been found in strawberry crops therefore it is important to understand the potential competition between this species and any released predators. This is essential not only from a control point of view post-release, but also to allow crop advisors to better monitor the species present in the crops. *N. californicus* is not permitted for use in polytunnels. The effect of introductions of twenty predatory mites of *N. cucumeris*, *N. californicus* or *N. cucumeris* plus *N. californicus* (ten of each species) on developing populations of WFT was compared to the untreated control. All treatments reduced the numbers of WFT.

Insect predator experiment

The insect predators *Orius majusculus* and *Anthocoris nemoralis* were compared against the commercial standard *O. laevigatus*. The experiment was set up with bean pods (5cm) in a 9 cm Petri dish. Treatments were *Orius laevigatus, Orius majusculus, Anthocoris nemoralis* and an untreated control. One predator was introduced per unit with 3 1st instar WFT larvae (L1) and 2 2nd instar WFT larvae (L2). All treatments *Orius laevigatus, Orius majusculus, Anthocoris nemoralis* were effective compared to the untreated control.

Although the treatments were not significantly different from each other, *Anthocoris nemoralis* consumed fewer WFT than the *Orius* spp. in this short experiment.

Year 1, Objective 2 – Control of pupal stages of WFT in the substrate

Different soil predators were compared as treatments: the predatory mites *Stratiolaelaps scimitus (Hypoaspis miles) and Macrocheles robustulus,* and the predatory staphylinid *Dalotia coriaria.* These were done at 30/20°C & 20/10°C day/night temperatures. French bean pods
were placed on coir substrate in 7 cm pots placed inside Perspex boxes (11.5 x 17 x 6 cm), which had air vents covered with thrips proof mesh. Fifty second instar WFT were introduced onto the plants and allowed to move into the substrate, and pupate. Either 50 mites or 3 *D. coraria* were introduced and WFT populations on the plant were counted.

The predatory mites *S. scimitus* and *M. robustulus* both reduced resultant numbers of adult thrips through pupal predation in the substrate. *M. robustulus* was particularly effective at 30/20°C day/night temperatures. Under these conditions *S. scimitus* and *M. robustlus* significantly reduced the numbers of resultant WFT adults by 13 days after predator introduction (p<0.001). *M.robustlus* was also more effective at control than *S. scimitus* at this temperature, when only 3 WFT adults emerged compared to 11 in the H. miles treatment, and with 23 in the untreated control. At a 20/10°C day/night temperature both *S. scimitus* and *M. robustlus* significantly reduced the numbers of resultant WFT adults by half by 14 days after predator introduction (p<0.05). The effect of *D. coriaria* on pupal predation was not significant.

Year 1, Objective 3: Identifying new predators of WFT

Strawberry crops at five sites, three with and two without WFT, were assessed to identify naturally occurring predators both within the crops and in the surrounding vegetation. All insects (1300 in total) were identified to order and in some cases to species level. Thrips predators were identified belonging to the Anthocoridae family (Hemiptera). *Orius* sp. and *Anthocoris* sp., such as *Anthocoris nemorum*, were found. Other mirid, lygaeid and nabid species were also found. Additional species identified as potential and beneficial include *Chrysoperla carnea* and coccinelids including *Micrapsis 16-punctata, Propylea 14-punctata, Adonia variegate, Coccinella 7-punctata* and *Subcoccinella 24-punctata*. No parasitoids were found and no new predators were identified that could be easily reared commercially. The possibility of using *Chrysoperla carnea* and coccinelids was not further explored as where aphid numbers are high in strawberry crops, thrips may not be the preferred food source.

Summary of work in Year 2

Objective 1 aimed to provide additional data on non-native species that are effective in reducing WFT populations in a glasshouse situation and may be registered for use in polytunnels in the future. However, by year 2, these species were less likely to be approved, therefore the focus was redirected towards products that could give more immediate results for growers. Control of WFT by both *N. cucumeris* and *N. californicus* was further explored. Objective 2 focussed on the use of the substrate mites in combination with either nematodes or *N. cucumeris*. Objective 3 was not continued given that the species that had been identified in strawberry crops were already commercially available.

Year 2, Objective 1 – Control of larval stages of WFT in flowers

The relationship between *N. cucumeris* and *N. californicus* was further explored. In 2014, there was a reduction in the number of thrips compared to the control for the treatments *N. cucumeris* and *N. californicus* both individually and when they were combined, however as only a few replicates were tested at the higher temperatures this work was continued in 2015. Two further experiments were set-up using the methodology as in year 1. The data for both 2014 and 2015 were combined to assess the effect of *N. cucumeris* and *N. californicus* both singly and in combination, i.e. 1 experiment from 2014 and 2 experiments from 2015. At 30:20 °C day and night temperatures, *N. cucumeris* and *N. californicus*, singly and in combination were able to significantly reduce the total numbers of WFT larvae by at least a third (p<0.001). Although there was no significant difference between treatments, the treatments with *N. californicus* had slightly higher mean numbers of WFT than the *N. cucumeris* alone.

Year 2, Objective 2 – Control of pupal stages of WFT in the substrate

To quantify the efficacy of control agents applied to the substrate, the methodology was used as in the substrate experiments in year 1. Two experiments were done. In experiment 1 treatments were:

- *M. robustulus* (20 adult mites per pot)
- *S. feltiae* (25 ml of water, with a total of 1200 nematodes)
- *M. robustulus* + *S. feltiae* (rates as above)
- Untreated control

In experiment 2, treatments were as for experiment 1, although with *S. scimitus* as the predatory mite species. Treatments that did not include nematodes received 25 ml of water (where mites were included in the treatment, the water was added first so as not to drown

the mites). Resultant WFT populations were counted.

In experiment 1, the treatments which included the substrate mite i.e. *M. robustulus* alone, or *M. robustulus* with *S. feltiae* both gave a significant reduction in the total numbers of adult WFT ($p<0.01$). The *S. feltiae* treatment alone did not significantly reduce the numbers of thrips. In experiment 2, although the experiment overall showed the treatments were not statistically significant at the 0.5 % level, there is still an indication that *H. miles* alone gave a reduction in the total numbers of adult WFT. As with the previous experiment the *S. feltiae* treatment alone did not significantly reduce the numbers of thrips.

A third experiment aimed to determine the effect of the predatory mites *M. robustulus* and *S. scimitus* in combination with *N.cucumeris* on control of WFT pupae in small field cages on strawberry. Thrips-poof Bugdorm cages, 1 m x 0.5 m (MegaView Science Co. Ltd. Taichung, TAIWAN) were set up in a polytunnel, with each containing a compost grow bag, 1.7 m x 0.5 m (B&Q Ltd, UK) with 8 strawberry plants var. Flamenco. These were drip irrigated. The plants were inoculated with 10 female thrips per plant..

The experiment was set up on 17 August 2015 with 4 treatments and 4 blocks in a randomised block design. Treatments were:

1. *N. cucumeris* 10 predators per plant
2. *N. cucumeris* 10 predators per plant + *M. robustulus* 20 predators per plant
3. *N.cucumeris* 10 predators per plant + *S. scimitus* 20 predators per plant
4. Control, no predators

Two flowers and two button fruit were collected per cage and placed in alcohol on 24 August and 04 September. As flower numbers increased, four flowers and four button fruit were collected per cage and placed in alcohol on 11 and 21 September. Arthropods were washed from the flowers/fruit and numbers of predatory mites and thrips were counted under a binocular microscope. All plants per cage were tap sampled on 11 and 25 September and numbers of predators and thrips were noted.

The results of this experiment were disappointing, with the presence of other predators such as *Orius* spp, spiders, *Chrysoperla* larvae, staphylinids and *Anthocoris* spp. being seen in the tap samples. The analysis of the WFT adults from the flower and button fruit samples showed no difference between the treatments, with no more than 5 WFT adults per sample at any one time. Other species of thrips were also present. Analysis of the larvae from the collected samples showed no difference between the treatments, with no more than a mean of 10 larvae per sample at any one time. The results of the tap samples followed the same

pattern, with no significant difference between treatments and a mean of 4 to 9 thrips adults per cage.

A final experiment was set up to determine the effect of the predatory mites *M. robustulus* and *N. cucumeris* on control of WFT pupae on chrysanthemum. The plants were placed in thrips proof Bugdorm cages in a CT room at 25° C. With four blocks, treatments were: 20 *N. cucumeris*, 20 *M. robustulus*, 20 of each predator in combination or an untreated control. When treatments targeted the same part of the plant, i.e. foliage, then the total number of predators was the same in all treatments. Where both foliage and substrate were targeted then treatments were additive i.e. A + B. Each of 16 plants were inoculated with 80 female thrips on 10 November. Two days later the predatory mites were introduced into the cages. Assessments were done at 7, 14 and 20 days after predator introduction by tap sampling the plants and counting the numbers of WFT (all life stages) and predatory mites.

At the first assessment date, 7 days after predator introduction, the majority of WFT were at the 2nd instar stage with some 1st instar thrips present. There were no significant differences between treatments at this first assessment. At the 14 day assessment the majority of WFT were adults and there was a significant difference between the combined treatment and the control, with 31.5 and 67 adults per plant respectively (p<0.5, lsd = 24.83). Numbers in the other treatments were similar to the control at this date. These differences were not sustained as the experiment progressed.

In year 3 of the project, it was decided to focus on control of WFT in the substrate.

Materials and methods

Control of WFT in substrate

Experiment 1a. *Determining the efficacy of predators of WFT applied curatively to substrate in semi-field experiments*

Objective

The objective of this experiment was to determine the efficacy of predators of WFT applied curatively to substrate in semi-field experiments.

This experiment aimed to represent a situation later in the season where WFT may have built up on a crop follow a period of high temperatures.

Predatory mites

The predatory mites *Stratiolaelaps scimitus or Macrocheles robustulus* (Koppert UK Ltd) were applied curatively as treatments for control of WFT in substrate. Predators were held at 10 °C until use.

WFT cultures

WFT were cultured in a CT room at 25°C on potted broad beans (Sutton dwarf) to ensure continuity of supply. A week before the experiment, 'clean' bean plants were placed in the culture room and adults were allowed to lay eggs. Five days before the start of the experiment, the adults were tapped from the plants and the 'clean' plants were moved to a new CT room at 25 °C. This allowed same age larvae to be generated for the experiments.

Experimental set up and design

Strawberry plants var. Finesse were potted into forty coir grow bags (Botanicoir, London, UK) in May 2016, with 14 plants per bag. This was more than the 8-10 plants per bag typical of commercial practice, firstly due to the small size of the plants, and secondly to ensure that sufficient flowers were present on these first year plants. The grow bags were initially placed in sandbeds at NIAB EMR and received daily overhead hand-watering to ensure that all plants received individual watering. Plants were de-blossomed to encourage growth. In August, 24 grow bags (that were similar in terms of initial leaf and flower numbers) were moved to an experimental site (Rocks Road, East Malling, Kent). Each grow bag was placed into a thrips proof cage 50 cm x 90 cm (Bugdorm Ltd) (Figure 1). Plants

were watered using drip irrigation with two drip points and four lines from each of those inserted via the arm holes of the cage, secured with cable ties. The irrigation schedule was 4 x 15 minutes watering per day. Plants were fed to encourage flowering and fruiting, using a 12:6:36 NPK nutrient regime at a rate of 25 kilos/ha. WFT late second instar larvae (L2) were inoculated onto the plants in each compost bag (approx. 550+ per cage) by cutting broad beans onto the plants in 5 cm segments on day 0 (Figure 2). The numbers of L1, L2 and adult WFT were counted on 5 broad bean stalks before infesting the strawberry plants. Although the majority of the WFT were L2 larvae, there were also a small proportion of first instar larvae (L1) and adults (Table 1). Approximately 3.4 bean stalks were used per plot.

Figure 1. Semi-field experiment showing Bugdorm cages containing strawberry grow bags

Figure 2. Inoculation of the strawberry plants with WFT infested dwarf broad bean plants

Table 1. The number of first instar (L1), second instar (L2) and adult WFT on infested dwarf broad beans (var. Sutton dwarf) prior to inoculation onto strawberry plants in a grow-bag.

	WFT lifestage		
Per bean stalk	L2	L1	adults
stalk 1	191	51	43
stalk 2	200	26	5
stalk 3	92	26	10
stalk 4	232	29	5
stalk 5	112	17	3
Mean per stalk	165	29.8	13.2

Experimental design and statistical analyses

There were 6 replicates of each treatment in a randomised block design.

Treatments

Treatments were:

Trt 1. *S. scimitus (H. miles)* as Entomite-M (Koppert UK Ltd) 18 per plant

Trt 2. *S. scimitus* as Entomite-M ((Koppert UK Ltd) 36 per plant

Trt 3. *M. robustulus* as Macro-mite (Koppert UK Ltd) 18 per plant

Trt 4. Untreated control

To ensure that the product quality had been maintained during transport, a sub-sample of predatory mites from each container (5 x 1 ml samples) were assessed, by counting the number of adult and immature mites (prey mites were not counted). This allowed the number of mites/ml to be obtained. The predatory mites were introduced to the systems on day 2 by using a known volume of product and distributing at the base of the plant around the planting hole.

Assessments and statistics

Tap samples were done at weekly intervals to assess adult and larval (L1 and L2) WFT numbers. Any beneficial arthropods were recorded. Analysis was by ANOVA as a snapshot on each assessment date. Larval categories were combined for analysis. The numbers of flowers in each cage were counted at each assessment date.

Temperature and humidity data

Dataloggers were placed inside the cages to record the temperature and humidity once the predators were introduced, and further dataloggers were placed into the soil on the second assessment to compare the soil temperature with the canopy temperature.

Experiment 1b. *Determining the efficacy of predators of WFT applied curatively to substrate in semi-field cage experiments*

Objective

The objective of this experiment was to determine the efficacy of predators of WFT applied curatively (to the substrate and the ground) at high rates in semi-field experiments.

At the end of Experiment 1a on 8 September there were no significant differences between treatments, however given that the plots were still infested with WFT, an extremely high rate of predators (higher than a commercial rate, and designed for experimental use only) was applied to both the planting hole, and also applied around the edge of the grow bag to aim to reduce populations to zero.

Predatory mites

The predatory mites *S.scimitus or M. robustulus* (Koppert UK Ltd, Bioline AgroSciences Ltd) were applied curatively as treatments for control of WFT in substrate.

Treatments

The same species of mites were used with the same randomisation as previously. Therefore treatments were:

Trt 1. *S. scimitus* (*H. miles*) as Hypoline (Bioline AgroSciences Ltd) 31 mites per plant and 31 mites applied adjacent to the plant at the edge of the grow bag

Trt 2. *S. scimitus* as Hypoline (Bioline AgroSciences Ltd) 62 mites per plant and 62 mites applied adjacent to the plant at the edge of the grow bag

Trt 3. *M. robustulus* as Macro-mite (Koppert UK) 31 mites per plant and 31 mites applied adjacent to the plant at the edge of the grow bag

Trt 4. Untreated control

For treatments 1 & 2, applications for blocks 1, 2 and 4 were on 9 September and blocks 3, 5 and 6 on 14 September. Treatment 3 was applied on 9 September.

Assessments and statistics

Tap samples and flower counts were done on 15, 22, 29 September and 06 and 13 October as for experiment 1a. Analysis was as for experiment 1a.

Temperature and humidity data

This was as for experiment 1a.

Experiment 2. *To investigate the effect of the biocontrol agents* Macrocheles robustulus *and* Steinernema feltiae*.*

Objective

The objective of this experiment was to investigate the effect of the biocontrol agents *M. robustulus* and *S. feltiae* on WFT, applied both individually and in combination to coir substrate in small pot systems, with different rates of the *M. robustulus*. This experiment was included as there was evidence of an interaction between the bio-control agents in 2015.

WFT cultures

WFT were cultured in a CT room at 25°C on chrysanthemums to ensure continuity of supply.

Experimental design, methods and statistical analyses

As in 2015, the same coir substrate in small pot systems was used. To quantify the efficacy of control agents applied to the substrate, bean pods (4 x 5 cm lengths) were placed on coir substrate in 7 cm pots placed on a Petri dish 'saucer' inside Perspex boxes (26 x 14 x 9 cm), which had either one or two air vents covered with thrips proof mesh (2.5 cm diameter). Fifty second instar WFT were introduced onto the pods and allowed to move into the substrate and pupate (blocks 1-3 were added on day -2 and blocks 4-5 were added on day -1). Pots were held in a CT room set at 25 °C, on a 14:10 Light:Dark daylength regime. There were 5 replicates of each treatment in a randomised block design. Two additional control pots were also included to be used for moisture readings.

Treatments

Treatments were applied up to two days after larvae were introduced. Treatments were different rates of the mite *M. robustulus*, with and without nematodes, *S. feltiae*, plus a nematode alone treatment and an untreated control (Table 2). Treatments that did not include nematodes received 20 ml of water. The nematode treatment or water was applied first so as not to drown the mites.

Table 2. The numbers of female mites (*Macrocheles robustulus*) and nematodes (*Steinernema feltiae*) applied to coir pots to which 50 second instar larvae had been introduced on french bean pods.

Treatment colour	No. female mites - *Macrocheles robustulus*	No. nematodes – *Steinernema feltiae* (in 20 ml water)	Distilled Water (ml)
Red	20	0	20
Orange	5	0	20
Blue	20	1000	0
Grey	5	1000	0
Yellow	0	1000	0
Green	0	0	20

Assessments

As a measure of predation in the soil, emerging adult WFT populations were counted on the bean pods, surface of the substrate and inside of the box on days 3, 5, 7, 10, 12 and 14. The total number of adults over all assessment dates was analysed using ANOVA.

Moisture readings were taken on the two additional control pots at each assessment using an AT W.E.T. Sensor (Delta T Devices Ltd., Cambridge, UK). At the assessments 10 ml of additional distilled water was added per pot when required to ensure that the substrate did not dry out. In all cases the addition of the water was sufficient to run out of the pot and to form a 2-3 mm layer in the base of the Petri dish.

Experiment 3. *Developing methods to determine whether WFT second instar larvae will drop to the ground*

Objective

The objective of this experiment was to develop a practical method to determine whether late second instar WFT larvae will fall to the ground from table-top strawberries. Knowing where to apply control agents is essential in an IPM system.

WFT cultures

Cultures were used as in experiment 2.

Experimental design, methods and statistical analyses

Strawberry plants var. Finesse were potted into coir bags (Botanicoir), with 14 plants per bag as per the semi-field experiment. Seven grow bags were placed onto table height wire benches (Figure 3), there was a mean of 14.4 cm between bags, the majority of fruit that

developed hung over the bag between 2 – 7 cm over the edge. Between any bag pairing there was never any fruit that intermingled and clear visual separation between bags. The grow bags were fully watered ahead of the start of the experiment on 30 September and soil in the bags was damp to touch throughout the experiment.

Figure 3. Grow bags used for the larval drop experiment, at the end of the experiment in November

WFT populations were inoculated onto the strawberry plants in the grow bags on 16 September 2016. For each grow bag a chrysanthemum plant from cultures was tapped over a Perspex box and the thrips were released onto the bag. At least 100 adults were released per bag and these were mainly adults. The grow bags were not caged and the thrips were free to move between bags.

Monitoring WFT populations

The development of the populations were monitored by tapping a flower cluster (with one to two flowers and button fruit) per bag twice (on 27 Sep and 30 Sep) ahead of trapping larvae.

Direct observations of the numbers of thrips of each lifestage, first (L1) or second (L2) instar larvae or adults, and a note of the area in which they were situated were done one week later on 7 October. Neither the fruit nor the flowers were touched at this point so as not to disturb them. Given that the 'peel back' method to assess thrips in fruits and flowers could not be used, and that direct observation may not be representative of the total number of thrips, further populations were not done until the end of the experiment. At the end point

(25 November) a further tap sample of all plants per bag over a white tray was done.

Trapping of WFT populations

To determine whether it was possible to detect whether thrips larvae were dropping from the plants, a clear plastic sheeting covered with Oecotak (Oecos Ltd) was placed under the benching (30 September 2016). The plastic sheeting was changed after one month (24 October). This was left for a further month (25 November).

All thrips on the two sets of sticky sheeting were counted under a binocular microscope (for 24 Oct and 25 Nov). Thrips were classed as adult, and L1 and L2 larvae (Figure 4). The sheeting was labelled as the area under each bag (20 cm), and the areas between the bags, these were divided by drawing a line down the centre, to provide areas to the left and to the right of each bag. As there was no cross-over of fruit between the bags this would provide a clear representation of larval drop from the bags if they dropped directly down.

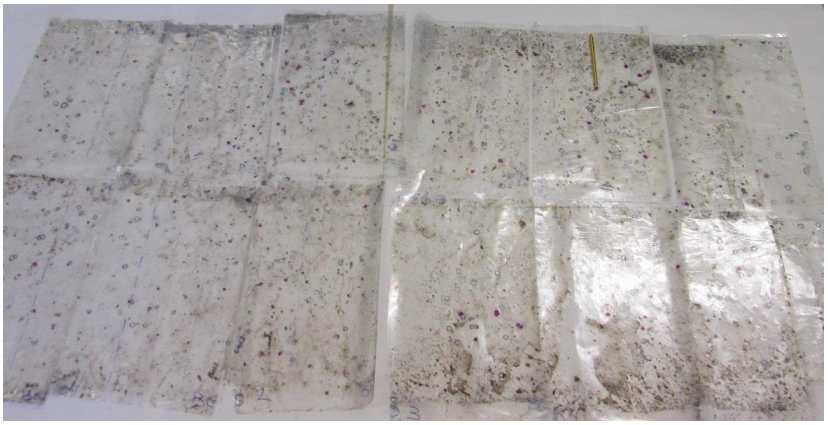

Figure 4. The sticky sheeting used in the larval drop experiment showing marked circles in different colours denoting different WFT stages

Flower and fruit assessments

A detailed assessment of the numbers of flowers, button fruit and fruit per plant was recorded ahead of the experiment on 30 September 2016. The numbers of red and green fruits and flowers in the centre, left and right of each bag were also recorded at the end of the experiment on 25 November 2016.

Results

Experiment 1a. *Determining the efficacy of predators of WFT applied curatively to substrate in semi-field cages*

The L2 larvae were added to the plants on 16 August and these were expected to move into the soil within one to two days. The temperatures in the cages were between 15 and 30°C in both the soil and in the canopy (Appendices 1a & b). At an average of 20°C (and based on development on chrysanthemum) it would be expected that WFT would take 2.2 days for the pre-pupal stage to develop and 5.1 days for the pupal stage. These values halve at 25 °C (Robb, 1989). Values on cucumber are 1.6 and 3.7 days at 20°C (Gaum et al, 1994). Therefore any differences in treatments may be seen from the 25 August following ANOVA

of data on each individual date. Results on 25 August showed a significant difference in the *M. robustulus* treatment compared to the *S. scimitis (H. miles)* treatments (Table 3), but not to the untreated control where WFT populations were lower, it is not clear why this should be the case. This difference between the treatments was not sustained at the later sample dates. The cages were free from other beneficials and only one parasitoid was observed.

Table 3. Square root number of adults and larvae of WFT following introduction of WFT 2nd instar larvae to plants on 16 Aug 2016, and predatory substrate mites, *Stratiolaelaps scimitus* (S. s.) or *Macrocheles robustulus* (M. r.), into planting holes around strawberry plants on 18 Aug 2016.

		S. s. 36/plant	**S. s. 18/plant**	**M. r. 18/plant**	**Control**	**F pr**	**s.e.d.**	**l.s.d.**
22 Aug	**Adults**	1.16	0.79	0.9	0.17	0.216	0.462	0.984
	Larvae	0.5	0.58	0.62	0.33	0.846	0.346	0.736
25 Aug	**Adults**	2.64	2.45	1.31	2.13	0.028*	0.413	0.879
	Larvae	0.74	0.79	0.50	0.24	0.336	0.323	0.688
30 Aug	**Adults**	5.24	5.05	5.10	5.38	0.924	0.536	1.142
	Larvae	1.99	2.13	1.64	2.15	0.533	0.382	0.814
02 Sep	**Adults**	6.38	6.14	5.46	6.87	0.138	0.567	1.208
	Larvae	4.16	4.58	3.41	4.10	0.229	0.542	1.155
08 Sep	**Adults**	6.70	6.69	6.28	6.80	0.924	0.825	1.759
	Larvae	14.84	15.68	13.19	14.93	0.450	1.536	3.273

15 d.f. *shows significance at the 0.05% level

Numerous flowers and/or button/green fruit were counted on each date.

Experiment 1b. *Determining the efficacy of predators of WFT in substrate in semi-field cages*

Following a high rate introduction of predatory mites in addition to the introduction in Experiment 1a, it can be seen in Table 4, that the *M. robustulus* gave a sustained reduction in numbers of adults and larvae, which were approximately 20 - 43% reduction of the control. On 22 Sep 2016, *S. scimitus* showed a significant reduction in adult numbers from

the control when applied at 31 mites per plant and per bag edge. Although this was not seen at double that rate, the numbers of adult WFT were not statistically different between the two treatments.

In this experiment, from the 22 September onwards some beneficials were seen sporadically, such as anthocorids, lacewing and a ladybird larva. Velvet mites were also found in the tap samples. Flower numbers fell sharply from 15 September.

Table 4. Square root number of adults and larvae of WFT following a high rate introduction of predatory substrate mites, *Stratiolaelaps scimitus* (S. s.) or *Macrocheles robustulus* (M. r.), into planting holes adjacent to strawberries and adjacent to the plant at the edge of the grow bag following snapshot ANOVA on each date

		S. s. **62/plant and /edge**	***S. s.*** **31/plant and /edge**	***M.r.*** **31/plant and /edge**	**Control**	**F pr**	**s.e.d.**	**l.s.d.**
22 Sep	**Adults**	8.68	**8.31**	**7.60**	9.55	0.025	0.563	1.200
	Larvae	7.32	7.30	**5.70**	7.81	0.018	0.609	1.297
29 Sep	**Adults**	9.02	8.13	**6.61**	8.61	0.002	0.538	1.146
	Larvae	6.28	6.46	**4.59**	6.23	0.007	0.507	1.079
06 Oct	**Adults**	6.68	6.14	**4.59**	7.18	0.002	0.560	1.194
	Larvae	5.04	5.29	**3.48**	5.25	0.012	0.541	1.152
13 Oct	**Adults**	6.50	7.29	**4.43**	7.73	<0.001	0.482	1.027
	Larvae	4.75	5.19	**3.26**	5.26	0.021	0.628	1.338

15 d.f.

Sig Level
0.050
0.010
0.001

Experiment 2. *To investigate the effect of the biocontrol agents* Macrocheles robustulus *and* Steinernema feltiae*.*

In this experiment, with an ANOVA following an angular transformation of the total adult %, there was a significant effect of treatments with nematodes grouped on WFT numbers ($p<0.001$) and of treatments with mites grouped on WFT numbers ($p<0.001$). However there was also a significant interaction between the nematodes and the mites ($p=0.001$).

Given that there was an interaction a further ANOVA following an angular transformation was carried out presenting all six treatments, again with a highly significant effect of the treatments ($p<0.001$, d.f. 20, s.e.d. 2.508, l.s.d. at the 5% level 5.232), with all treatments being significantly different from the untreated control. Transformed values are presented in Table 5 and back-transformed values presented in Figure 5.

Table 5. The effect of the predatory mite *Macrocheles robustulus* (Mac) and the nematode *Steinernema feltiae* (Stei), applied to coir substrate both individually and in combination, on % emergence of WFT adults (n 2nd instar WFT larvae inoculated = 50).

Treatment		**Mean following angular transformation***	**Backtransformed mean**	**Fishers test**
Mac (No.)	Stei (No.)			
20	1000	13.61	5.54	a
5	1000	21.76	13.75	b
20	-	22.33	14.44	bc
-	1000	27.35	21.11	cd
5	-	30.35	25.53	d
-	-	49.40	57.65	e

* $p<0.001$, d.f. 20, s.e.d. 2.508, l.s.d. at the 5% level 5.232

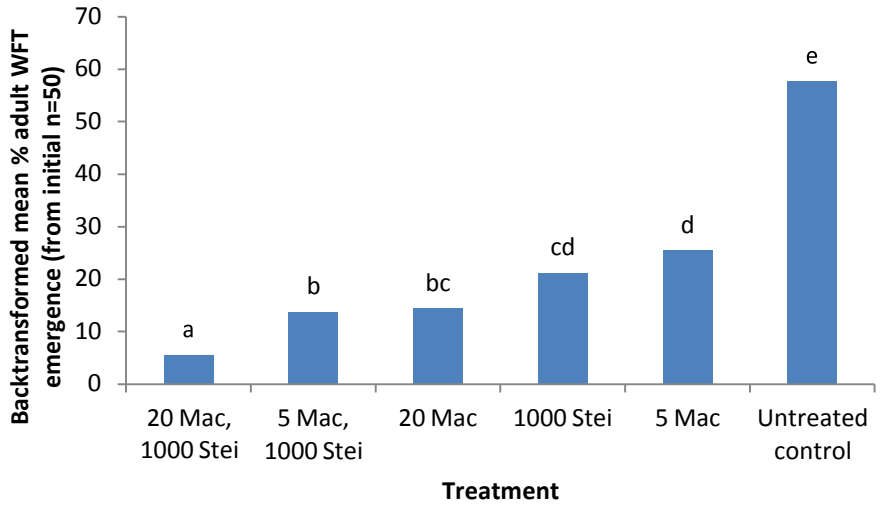

Figure 5. The backtransformed mean % adult WFT emergence (n=50) following introduction of the predatory mite *Macrocheles robustulus* (Mac) and the nematode *Steinernema feltiae* (Stei), applied to coir substrate both individually and in combination

Once the set temperature (25 °C) had been reached within the CT room, readings within the boxes showed a mean temperature of 25 °C, with a humidity of 88%. Moisture readings were between 0.23 and 0.35 m^3. m^{-1}.

Experiment 3. *Developing methods to determine whether WFT second instar larvae will drop to the ground*

WFT assessments

Ahead of the experiment on 27 September there were a mean of 0.4 L1, 3.7 L2 and 2.4 adult WFT per strawberry cluster (with 1-2 flowers and button fruit), with 7 clusters tapped, 1 per bag. On 30 Sep there were a mean of 4 L1,0.9 L2 and 2.7 adults.

For this experiment the numbers of L1, L2 and adult thrips were analysed in three positions, under the bag (approx. 20 cm width), and to the left and right (mean width for each 7.7 cm). Whilst the areas are different sizes there should be a clearly demarked dropping area if larvae are falling straight down therefore size of area was not included as a factor in the analysis. Using a Generalised Linear Model, with the Poisson distribution and a log link the date and position (Left, Bag, Right) were analysed. There was evidence of overdispersion for all variates, so all significances were adjusted for over dispersion.

For the L1, first instar larvae there were:

- Significant differences between Dates ($p<0.001$)
- Significant differences between Position ($p=0.046$)
- No evidence of a Date x Position interaction ($p=0.555$) For the L2,

second instar larvae there were:

- Significant differences between Dates ($p<0.001$)
- Significant differences between Position ($p=0.011$)
- No evidence of a Date x Position interaction ($p=0.932$)

For the adult WFT there were:

- No significant differences between Dates ($p=0.366$)
- Significant differences between Position ($p=0.002$)
- No evidence of a Date x Position interaction ($p=0.858$)

In all cases there were significantly less WFT of all life-stages caught at the later sampling date, as would be expected given that it was in Oct-Nov. There was no difference between the numbers of WFT caught to the left and the right side of the bag area (Table 6, Figure 6). There were significantly more adults caught in the area under the bag, however given that this area is larger, were the area to be taken into account this effect may disappear. The numbers of L2 larvae dropping to the ground were clearly higher at the edges of the bag than under the bag. There were also much higher numbers of L2 larvae than L1 or adult WFT.

Table 6. The mean numbers of first and second instar larvae (L1, L2) and adult WFT caught on sticky traps underneath a strawberry grow bag, in an area (20 x 100 cm) either directly underneath the grow bag (bag), or to the left (10 x 100 cm) or right (10 x 100 cm) of the grow bag, showing a comparison table.

Position	**L1**	**L2**	**Adults**
Left	2.07	16.50	2.93
Bag	2.86	10.86	8.36
Right	0.93	21.21	3.64
Significances	**Comparison**		
	Left vs Bag	**Left vs Right**	**Bag vs Right**
L1	0.374	0.099	0.014
L2	0.068	0.190	0.003
Adults	0.001	0.553	0.005

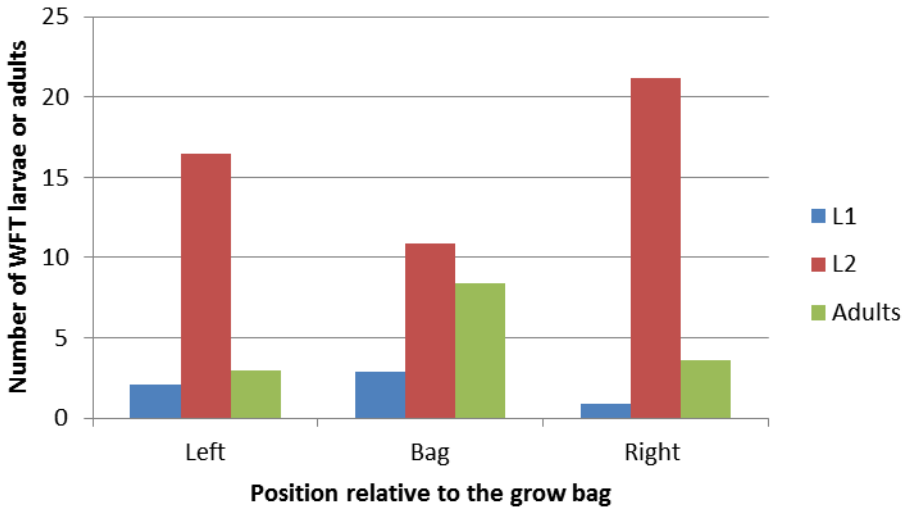

Figure 6. The numbers of WFT L1, L2 and adults caught on clear sticky traps either directly underneath a strawberry grow bag or to the left and right of the bag

Fruit and flower assessments

On 30 September the average number of clusters per bag was 14.6, these had 0.5 flowers, 0.7 button fruit and 1.7 fruit. On 7 October, so as not to affect the experiment, the fruit and flowers were not touched but were observed, therefore a peel back method could not be used. Only one adult was seen on the flowers and the larvae were concentrated on the ripe fruit. The mean number of thrips on a red fruit was 0.7 L1, 3.4 L2 and 0.1 adults. On the 25 November there were more fruit than flowers (Table 7). There were more ripe fruit at the edges of the bag.

Table 7. The mean numbers of ripe fruit, green fruit and flowers in either the middle of the grow bag, or to the east (left) and west (right) of the grow bag on 25 November. Analysis was using a GLM with the Poisson distribution and a log link.

Position	**Ripe fruit**	**Green fruit**	**Flowers**
East (left)	11.14	5.14	10.29
Middle (centre of bag)	6.86	3.29	9.57
West (right)	11.00	5.29	7.86
Significance	0.116	0.466	0.665
(evidence of overdispersion so significances adjusted)			
Pairwise comparisons			
East vs Middle	0.069	0.307	0.806
East vs West	0.952	0.941	0.391
Middle vs West	0.076	0.277	0.533

Developing a methodology for assessing both drop and pupation

This experiment has shown that the different life stages of the thrips will drop and be stuck on the colourless sticky. However it has its limitations in its current set-up. Firstly as the glue will not be as effective when wet, watering opportunities were limited to watering when the plastic sheeting is changed, or watering with care in between. Therefore in future experiments a drip irrigated system should be set-up which is turned on manually in response to lowering water sensor measurements and which is measured so as not to allow drip through. In this experiment, although the soil was damp to touch, the plants may have been under water stress and it is difficult to say whether the L2 were dropping in order to pupate or if they were walking from the plants due to water stress. Secondly there is no way to compare the emergence of the ground dropping larvae vs the emergence of the larvae in the coir bag. This would need to be done by placing trays of coir in the 'drop zone' and then at a set-time point moving the bags and the trays into separate Budgorm cages with thrips proof mesh. The emergence of adults would then be monitored on a sticky trap. The emergence of the L2 in coir should also be compared with similar trays with sown grass/turf in coir using the same methodology.

Discussion

This project initially aimed to find new predators that could supplement *N. cucumeris* as the season progressed, temperatures increased and if WFT populations began to build. For foliar control, some ideal candidates were the non-native mites that are currently available for glasshouse use. The experiments from year 1 concluded that *Amblyseius montdorensis, A. swirskii, Amblydromalus limonicus* as well as *Neoseiulus cucumeris* would all be effective predators of WFT. However, these are currently not registered for use in field/polytunnel, and this looks unlikely in the near future, despite the fact that some of these species would not be able to overwinter in the UK based on the current temperature data.

The results from year 1 concluded that of those species tested *N. cucumeris* was still the most effective predatory mite registered for use in polytunnels to control foliar stages of WFT. Therefore the relationship between *N. cucumeris* and the non-native species *N. californicus* which has been found in strawberry crops since the 1980s was explored. Discriminating between *N. cucumeris* and *N. californicus* using a hand lens in the field is not possible, and required specialist identification under a microscope following slide preparation to allow the mite hairs to be visible. As *N. californicus* is a non-native species it is not licensed for release in polytunnels.

Combined results from years 1 and 2 showed that *N. cucumeris* and *N. californicus* , both singly and in combination, reduced the number of thrips to a similar significance level. When

both mite species were in combination there was a similar level of control of WFT as for either of the mites individually. This shows that there was no interspecific competition between the adult mites. However, these experiments did not present either species with immature mites of the other species which may have shown intraguild predation. *N. californicus*, where registered, is recommended for two-spotted spider mite (*Tetranychus urticae*) control, therefore results may be different if a choice of prey were presented i.e. WFT and spider mites. If a percentage of sampled predatory mites are not predating WFT then agronomists may overestimate the numbers of effective predatory mites in the crop. *N. californicus* can feed on larval stages of the predatory mite *Typhlodromips montdorensis*; however total fecundity and longevity are reduced when compared with *N. californicus* fed solely on spider mite (Hatherly *et al*. 2005). As *N. californicus* shows a preference for spider mite it is likely to feed primarily on this species. Of the predatory bugs tested, *Orius laevigatus* remained the most effective predator.

For control of WFT in the substrate, this project has shown that the predatory mites *S. scimitus* and *M. robustulus* were effective in controlled environment cabinets. The nematode *S. feltiae* also reduced the numbers of WFT in some experiments. Analysis showed an interaction between the nematodes and the substrate mite *M. robustulus*, although this still gave a better reduction that applying either alone. The use of substrate mites supports the report by Sampson (2014), who found that many growers who had achieved good control of WFT had made one release of *S. scimitus*, between March and May, in addition to other bio-control agents. Unfortunately the up-scaled experiments in cages did not give long-lasting significant control. The results of a preliminary experiment, to develop a protocol to determine whether a proportion of the late second instar larvae fall to the ground, indicated that this may indeed be the case. This work would need to be repeated using a non-drip irrigation system, and by also comparing the emergence of dropped larvae in the ground substrate to those within the coir growbag. However this may be considered when applying treatments.

Other solutions are available for foliar and substrate application, for example the use of EPFs for the control of WFT is one strand of the current project AHDB SF 156.

Conclusions

The work in 2016 has supported the previous results and the conclusions remain the same.

N. cucumeris remains the most practicable predatory mite species for use in polytunnels, whether due to licensing restrictions or due to the cost and ease of obtaining the predator from commercial suppliers in the UK. Given the number of product release options, such as slow release sachets, sprinkler tubes and the associated technologies for dispensing, this is

an easy to use, cost effective predator. It should be borne in mind that the experiments in Years 1 and 2 of this project offered an ideal scenario for the predators, being introduced ahead of egg hatch or at the early 1st instar WFT larval stage; *N. cucumeris* must be introduced ahead of populations increasing. In combination with *Orius* spp. this still remains a good option for control of WFT in flowers.

The reduction of WFT numbers in small controlled environment experiments following the introduction of the predatory mites *Stratiolaelaps scimitus* (also known as *Hypoaspis miles*) or *Macrocheles robustulus* adds additional evidence to support the use of these soil mites in a control programme. The nematode *Steinernema feltiae* also gave a reduction in the numbers of emerging WFT adults in some experiments. Applying the nematodes and the substrate mite *M. robustulus*, gave a better reduction that applying either alone, although there is evidence of an interaction between the species. Therefore the exact timings of use should be discussed with the grower advisor or supplier. Although the up-scaled semi-field experiments using predatory substrate mites in cages did not give long-lasting significant control, it should be noted that the mites were applied curatively mainly as the aim of the work was to find solutions for late season control when temperatures have increased and there are higher WFT populations.

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Knowledge and Technology Transfer

Soft Fruit Review magazine 2016 – AHDB

AAB IPM Conference, November 2016

Soft Fruit Agronomists Day, February 2015

Glossary

WFT – Western flower thrips

L1 – 1st larval instar of western flower thrips

L2 – 2nd larval instar of western flower thrips

Pre-pupa – western flower thrips has two pupal stages the pre-pupa and pupa

DAI – days after predator introduction

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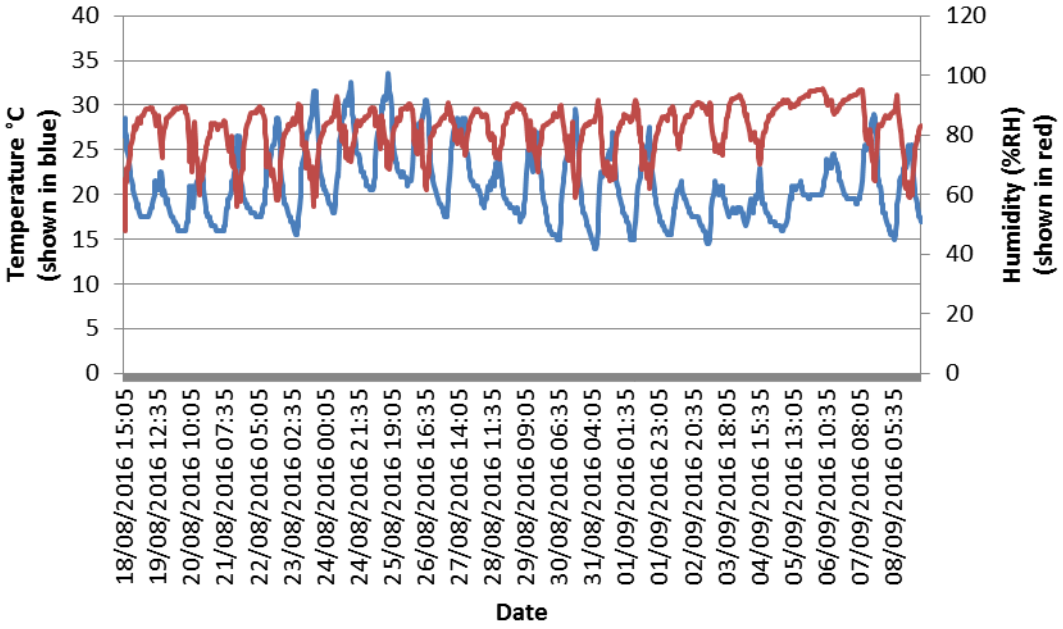
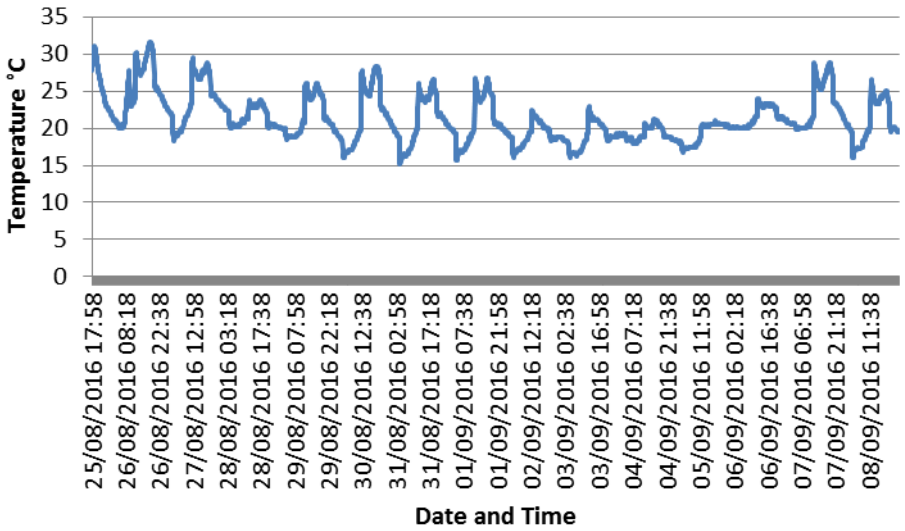
APPENDICES

APPENDIX 1. Meteorological data

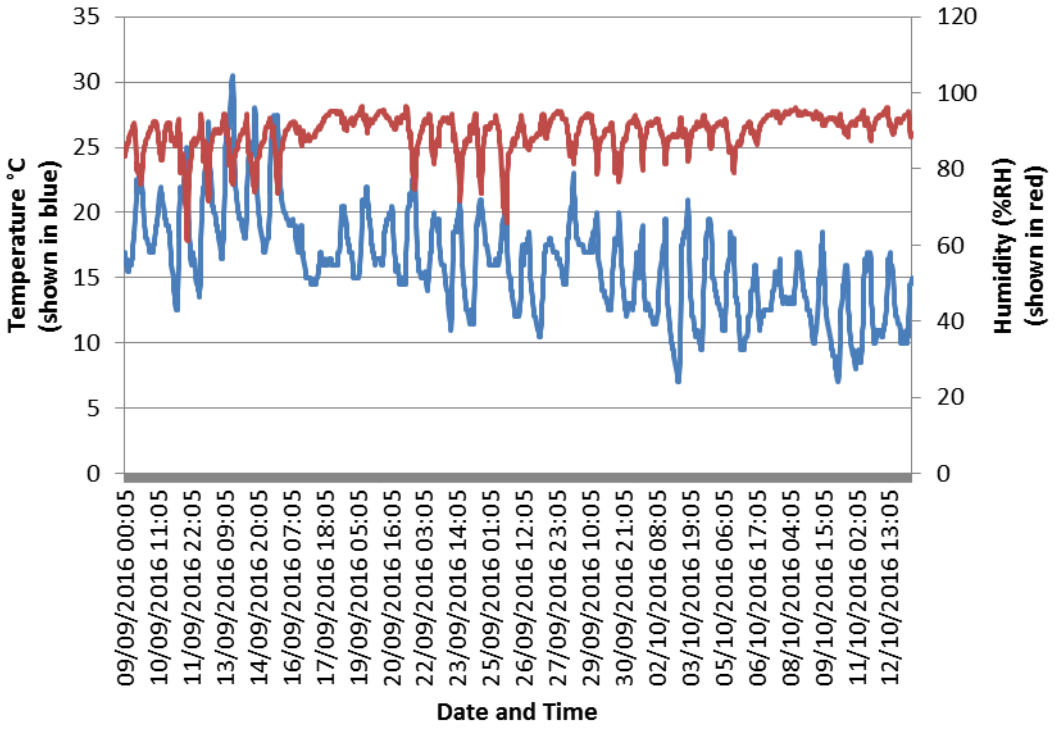
Appendix 1a. Temperature and humidity records from EL-USB-2+ dataloggers placed within the strawberry plant canopy of the grow bag inside the Bugdorm cage, during the semi-field cage experiment 1a, from 18 August to 08 September 2016.



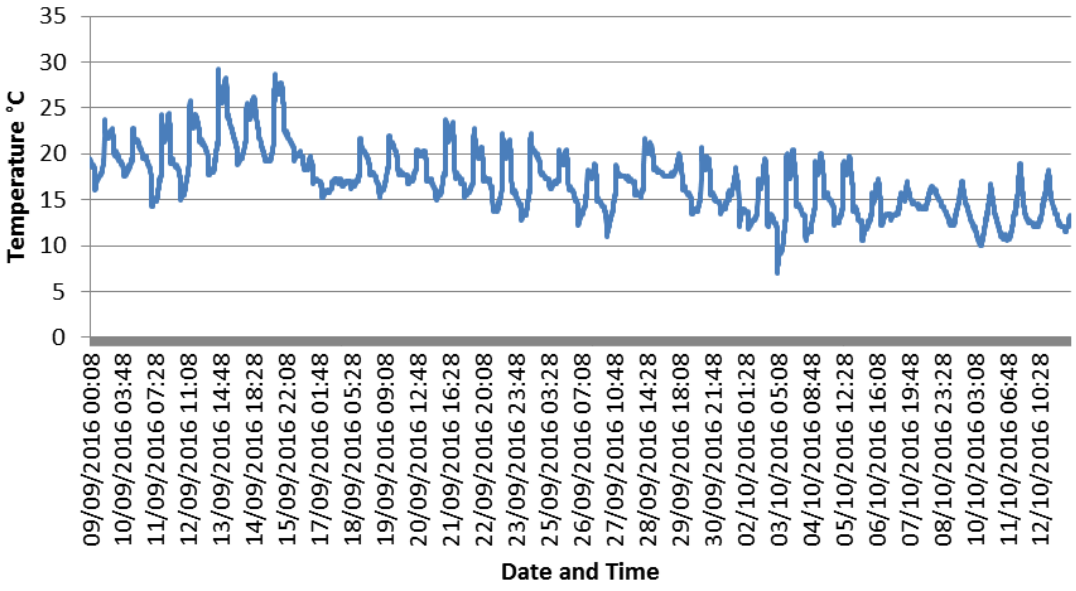
Appendix 1b. Temperature data from EL-USB-TC-LCD dataloggers placed 1-5 cm under the surface of the grow bag, during the semi-field cage experiment 1a, from 25 August to 08 September 2016.



Appendix 1c. Temperature and humidity records from EL-USB-2+ dataloggers placed within the strawberry plant canopy of the grow bag inside the Bugdorm cage from 9 Sep to 13 Oct 2016.



Appendix 1d. Temperature data from EL-USB-TC-LCD dataloggers placed 1-5 cm under the surface of the grow bag, from to 9 Sep to 13 Oct 2016.



Appendix 1e. External air temperatures and humidity, adjacent to the gauzehouse, for the period of the larval drop experiment 3.