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Key staff:	Dr Chantelle Jay Zeus Mateos Fierro Eduardo Jimenez Lopez
Location of project:	East Malling Research, New Road, East Malling, ME19 6BJ
Industry Representative:	Marion Regan, Hugh Lowe Farms, Farm Office, Barons Place, Mereworth, Maidstone, Kent, ME18 5NF
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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.

Dr Chantelle Jay

Research Entomologist

East Malling Research

Signature .... Date ....

Dr Michelle Fountain

Senior Research Entomologist

East Malling Research

Signature .... Date ....

Report authorised by:

Prof Jerry Cross

Head of PPESCM

East Malling Research

Signature .... Date ....

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GROWER SUMMARY

Headline

The predatory mites Hypoaspis miles (also known as Stratiolaelaps scimitus) and Machrocheles robustulus both reduced resultant numbers of WFT adults through pupal predation in soil-less substrate.

Background and expected deliverables

Western flower thrips (WFT), Frankliniella occidentalis, is a devastating pest of protected strawberries and experiences in 2013 have demonstrated that existing bio-controls are inadequate in hot conditions. Feeding by the pest on the flowers and developing fruits leads to bronzing of the fruit, which can cause downgrading to Class 2 or, in severe cases, to crop losses.

This project aims to identify potential predators not currently widely exploited for WFT control, which could be incorporated into a bio-control programme for the pest to replace or supplement Neoseiulus cucumeris. The efficacy of these predators will be determined in controlled environment conditions typical of those found under Spanish tunnels. Predators that are currently recommended for use on other crops but may be effective in protected strawberry will be evaluated. Other naturally occurring predators of WFT in crops and surrounding habitats will also be identified. In addition, the efficacy of commercial control agents that are applied to the substrate will be determined.

Summary of the project and main conclusions

In the first year of the project, the efficacy of commercially available predators applied both to the plant to control the larval stages of WFT and 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. The predatory mites Amblyseius 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 (Light/Dark ratio of 14:10 h). The predatory mites Hypoaspis miles and Machrocheles 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. The effect of Atheta coriaria on pupal predation was not significant. Although Anthocoris nemoralis was tested as a predator this was not more effective than Orius spp.. Other naturally occurring predators found in crops infested with WFT and surrounding habitats have been identified and will be assessed for their suitability for commercial use.

Financial benefits

The majority (>80%) of strawberries sold by multiple retailers are grown under protection and late season production with everbearer varieties has expanded. WFT is a major pest of strawberries, and when conditions are favourable, pest numbers can increase rapidly. On some farms, where spinosad (Tracer) has failed to control the pest, WFT damage to everbearer fruit has been so severe that total crop loss has occurred for the latter third of the season (i.e. 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.

There is great concern that the losses will become more widespread in future years with the spread of spinosad resistant strains of WFT.

The bio-control options currently available do not always control thrips effectively. Although bio-control agents such as N. cucumeris are being released, only partially control has been achieved with this predator on some farms. It is often used early in the season as a preventive rather than a curative measure. The predator is not always able to suppress thrips populations once they have increased later in the season. In seasons such as 2013, when conditions are hot and humid and optimal for WFT development, it has not been an adequate control measure on some sites leading to enormous crop losses. Problems with this pest continued to be seen throughout 2014 in glasshouse and polytunnel crops.

This project is assessing the efficacy of alternatives to N. cucumeris against WFT. Conditions under tunnels can fluctuate widely throughout the season and different biological control agents may perform better at different temperature/humidity levels. The project is comparing the efficacy of different insect and/or mite predators both alone and in combination with N. cucumeris to enable different solutions to be selected as the season progresses. Non-native predator species are not currently available for use in polytunnels, but they are being explored to determine effectiveness for glasshouse use. The project is determining the efficacy of commercially produced bio-control agents applied to the substrate, which therefore should not compete with N. cucumeris, and have an additive effect. If effective, and new biological control agents are identified in this project, this will enable growers to exploit a wider range of solutions for WFT control in strawberry and thus reduce the damage caused by this pest. The results obtained in the project will also provide additional information to inform the choice of biocontrol agents to be made throughout the growing season as conditions change.

Action points for growers

There are no new action points for growers at this stage in the season. .

Growers should continue to follow HDC recommendations for western flower thrips control made by Clare Sampson of Keele University in the 2014 HDC Report (Management of pesticide-resistant western flower thrips on tunnel-grown strawberry: a study of the reasons for successes and failures on commercial production sites) such as preventive introduction of Neoseiulus (Amblyseius) cucumeris early in the season for polytunnel grown strawberries.

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, and causes 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 polytunnel or glasshouse protection to secure continuity of supply and quality of production. Consequently late season production with everbearer varieties has expanded. However, serious outbreaks 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. HDC 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 (Gaum *et al*., 1994; Nothnagl *et al*., 2007; Nothnagl *et al*., 2008; Rhainds *et al*., 2007; Robb, 1989; Wang and Shipp, 2001). Development is fastest at 28-30°C. Above 35°C and below 10°C WFT development effectively stops. 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 HDC-funded project 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.

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 HDC project 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.

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 the 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*., 2006; 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, *Hypoaspis miles* (also known as *Stratiolaelaps scimitus*) and *H. 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 *Atheta coriaria* will feed on WFT life stages in the soil. *A. coriaria* reduced numbers of WFT on potted bedding plants in HDC-funded project PC 261, using a ‘DIY’ rearing system developed in HDC project PC 239 (Bennison, 2006, 2007, 2008, 2009). However, *H. miles* and *A. coriaria* did not give improved control of WFT when used to supplement control by *A. 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 *H. miles* 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 *H. miles* can be a useful back up to *N. cucumeris* and it was released in five of the six crops where thrips control was successful.

Entomopathogenic fungi (EPFs) that are known to attack thrips include isolates of *Beauveria bassiana* and *Metarhizium spp.* (Sánchez-Peña *et al*., 2011; Arthurs *et al.*, 2013). EPFs are being studied as a strand in the HortLINK project SF 120. Nematodes such as *Steinernema feltiae* and *Heterorhabditis* spp. are also effective against the pupae. 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.

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 first and second 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 nematode *Steinernema feltiae* is 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.

- Research strategies at this stage have addressed the effectiveness of selected biocontrol agents on a small scale in individual microcosms, moving to semi-field/field stage experiments in Year 2
- Work has addressed the temperature requirements of the biocontrol agents and the prey stage that is targeted
- The effectiveness of predators targeting the soil dwelling stages of WFT have been quantified in coir substrate that is typically used in commercial practice
- This project complements the HortLINK project SF 120 and the new SF 156.

Project aim(s):

The overall aim of the project is 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

Materials and methods

Objective 1 - Predator species were identified for assessment in consultation with biocontrol suppliers. They were assessed in cabinets for control of WFT in fluctuating temperature conditions typical of spring and summer temperatures. Predators were compared with the commercial standard, *N. cucumeris*. Efficacy of control of WFT was quantified.

Insect cultures and supply

WFT were cultured in a CT room at 20–25°C on potted chrysanthemum to ensure continuity of supply. Predators were obtained from biocontrol suppliers and held at 10°C until use.

Predatory mite experiments

The mites *Amblyseius montdorensis, A. barkeri, A. swirskii,* and *Amblydromalus limonicus* were compared against the commercial standard *Neoseiulus (Amblyseius) cucumeris.*

Small microcosms for the predatory mite experiments consisted of either:

A: A potted strawberry plant cv. Flamenco, with at least one flower, planted into compost and with the plant contained within a glass bell propagator (in a hurricane lamp style) with a double horticultural fleece top;

B: A potted strawberry plant cv. Flamenco, with at least one flower, planted into compost and with the plant contained within a laminated plastic surround with a double horticultural fleece top and double horticultural fleece air vents;

C: French bean pods (20 cm in total) that had been dipped in 0.1% bleach solution, rinsed in distilled water, dipped in 20% sucrose solution, left to air dry and then placed in a Perspex container 11.5 x 17 x 6 cm with damp filter paper 2.5 cm x 2.5 cm plus a small amount of pollen (Nutrimite, Biobest).

WFT females were introduced into the microcosms and were allowed to settle and lay eggs for two days at a fluctuating temperature of 30°C/20°C, 14:10 Light:Dark and 60–70% RH. Adults were not removed from the whole plant systems, but were removed from the bean pod systems. Predators were introduced using either a sable haired paintbrush or using an electronic air pump attached to a pipette tip to pooter the predators. Females of each species were selected. Populations of WFT at all stages i.e. first and second larval instars and adults were counted on multiple assessment dates.

As mites may be obtained from different suppliers at different supply times it was feasible to break experiments down into smaller sets as long as each set contains a commercial standard and an untreated control. Treatments for foliar/plant predator experiments were as in Table 1. Experimental set-up and design is given in Table 2.

Table 1. Treatments for the foliar/plant predatory mite experiments

Experiment	*Neoseiulus (Amblyseius) cucumeris*	*Amblyseius montdorensis*	*Amblyseius swirskii*	*Amblydromalus limonicus*	*Amblyseius californicus*	*A. cucumeris + A. californicus*	*Amblyseius barkeri*	Untreated
Preliminary mite	X	X	X					X
Potted plant, mite 1	X	X	X	X				X
Potted plant, mite 2	X	X	X					X
Bean pod, mite 1	X	X	X					X
Bean pod, mite 2	X	X	X					X
Bean pod, mite 3	X			X				X
Bean pod, mite 4	X	X	X					X
Bean pod, mite 5	X				X	X		X
Bean pod, mite 6	X						X	X

Table 2. Experimental set-up and design for the foliar/plant predatory mite experiments

Experiment	Experimental set-up	Number of replicates	Number of WFT females introduced	Number of WFT larvae introduced	Number of predators introduced	Date of WFT Introduction	Date of WFT removal	Date of predator introduction	Assessment dates (after introduction)	Temperature °C (day/night)
Preliminary mite	c	4	10	0	1	29/07	01/08	04/08	0, 3	35/20
Potted plant, mite 1	a	6	10	0	5		NA			30/20
Potted plant, mite 2	b	7	20	0	5		NA			30/20
Bean pod, mite 1	c	5	10	0	3	02/12	04/12	04/12	4, 8	30/20
Bean pod, mite 2	c	4	20	0	20	09/12	11/12	11/12	4, 8	30/20
Bean pod, mite 3	c	4	20	0	20	16/12	18/12	18/12	4, 8	30/20
Bean pod, mite 4	c	4	20	0	20	20/01	22/01	22/01	4, 8, 11	20/10
Bean pod, mite 5	c	3	20	0	20	27/01	29/01	29/01	4, 8, 11	30/20; 22
Bean pod, mite 6	c	4	20	0	20	04/02	06/02	06/02	3, 7	30/20; 20/10

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 (5 cm) 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 three first instar WFT larvae (L1) and two second instar WFT larvae (L2). Treatments were held at 26°C/20°C 14:10 h light:dark and were assessed after 24 hours.

Although a coccinelid predator experiment was also completed, the mortality of the coccinelids was high and so will not be included in this report.

Objective 2 – Control of WFT in substrate

Different soil predators were compared as treatments. The predatory mites *Hypoaspis miles (Stratiolaelaps scimitus) and Macrocheles robustulus* were compared with an untreated control at 30/20°C day/night temperature in 'substrate mite experiment 1' and at 20/10°C day/night temperature in 'substrate mite experiment 2. The predatory staphylinid *Atheta coriaria* was compared to an untreated control at 30/20°C day/night temperature in 'substrate *Atheta coriaria* experiment 1' and at 30/20°C & 20/10°C day/night temperatures in 'substrate *Atheta coriaria* experiment 2'. The experimental set-up and design is shown in Table 3.

To quantify the efficacy of control agents applied to the substrate, the bean pod system was used as in Objective 1, however, beans 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. Second instar WFT were introduced onto the plants and allowed to move into the substrate, and pupate. A yellow sticky trap was hung from the upper roof of the Perspex box for the mite experiment and the first *Atheta coriaria* experiment. Resultant WFT populations on the plant were counted as in Objective 1, by counting WFT both on the sticky trap and within the box, and on the bean pods and surface of the substrate, as a measure of predation in the soil; pupal stages can be damaged easily if substrate is disturbed.

Table 3. Experimental set-up and design for the substrate laboratory experiments

Experiment	Number of replicates	Number of WFT L2 introduced	Number of predators introduced	Date of WFT Introduction	Date of predator introduction	Assessment dates (after introduction)	Temperature °C (day/night temperature)
Substrate, mite 1	5	50	20	17/02	19/02	4, 7, 8, 11, 13	30/20
Substrate, mite 2	5	50	20	25/02	27/02	4, 6, 11, 14	20/10
Substrate, *Atheta* 1	6	50	3	03/03	03/03	5, 11	30/20
Substrate, *Atheta* 2	4	50	3				30/20 20/10

Objective 3 – Identifying new predators

Strawberry crops under tunnels and surrounding habitats at five sites were assessed to identify naturally occurring predators. Standard sampling methods such as tap and sweep samples were used. Sites were assessed throughout the spring and summer and all samples were classified to order, with key predators identified to species.

Results

Objective 1: Control of larval stages of WFT on plant material

Preliminary mite experiment

Although WFT larvae were found in the units, the treatments in the preliminary experiment were not significantly different from the control, partly due to the fact that a single mite was introduced per unit, which were not always recovered in the assessment. This lead to more mites being used in subsequent experiments.

Potted plant, mite 1 & Potted plant, mite 2 experiments

Although thrips were found the numbers were low and therefore the data are not presented.

Bean pod mite experiment 1

When predatory mites were introduced to bean pods (three per unit) ahead of WFT egg hatch/ at the early L1 stage, there was a significant decrease in WFT larval numbers for all treatments *Neoseiulus (Amblyseius) cucumeris, Amblyseius montdorensis* and *A. swirskii* compared to the untreated control (Table 4). The numbers of mites were similar between treatments four days after introduction (DAI), but there were more *A. swirskii* at eight DAI (Table 5). The numbers of mites recovered was inversely proportional to the numbers of WFT larvae.

Table 4. The effect of introductions of three predatory mites of either *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius montdorensis* (Mo) and *A. swirskii* (Sw) on developing populations of WFT at 30/20°C 14:10 Light:Dark conditions (following introduction of 10 WFT females which were removed prior to predator introduction) compared to the untreated control (Un).

	Assess 4 DAI				Assess 8 DAI			
	L1		L2		L1		L2	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.
Cu	9.6	2.7	2.2	1.47*	0.29	0.29	2.0	1.42*
Mo	9.0	2.5	3.4	1.83*	0.43	0.34	4.5	2.13*
Sw	4.4	1.5	0.9	0.94*	0.00	0	0.8	0.92*
Un	15.0	3.5	12.2	3.49	1	0.65	18.5	4.30
Fpr		0.221		0.009		0.22		0.003
d.f.		24		24		24		23
s.e.d.		0.914		0.704		0.301		0.844
l.s.d.		1.887		1.453		0.622		1.745

DAI – Days after predator introduction

Table 5. The mean numbers of predatory mites recovered (following introductions of 3 mites per treatment) of *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius montdorensis* (Mo) or *A. swirskii* (Sw) at 30/20°C day/night temperature.

	Assess 4 DAI		Assess 8 DAI	
	Mites		Mites	
	No.	Sqrt No.	No.	Sqrt No.
Cu	1.14	0.88*	0.92	0.96*
Mo	1.43	0.98*	0.55	0.74*
Sw	1.57	1.06*	2.02	1.42*
Un	0.00	0.00	0.00	0.00
Fpr		0.013		<0.001
d.f.		24		24
s.e.d.		0.330		0.301
l.s.d.		0.681		0.622

DAI – Days after predator introduction

Bean pod mite experiment 2

When 20 mites per treatment were introduced to bean pods ahead of WFT egg hatch/ at the early L1 stage, there was a significant decrease in WFT larval numbers with *A. swirskii* compared to the untreated control at the first assessment date after four days (Tables 6a & b). This was not significant at the eight day assessment. Similar numbers of pre-pupae and pupae were recovered from all treatments. Fewer *A. montdorensis* were found at the second assessment compared to *N. cucumeris,* and *A. swirskii* (Table 7).

Tables 6a & b. The effect of introductions of twenty predatory mites of either *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius montdorensis* (Mo) and *A. swirskii* (Sw) on developing populations of WFT at 30/20°C 14:10 Light:Dark conditions (following introduction of 20 WFT females which were removed prior to predator introduction) compared to the untreated control (Un) at four and eight days after predator introduction (DAI).

6a)	Assess 4 DAI			
	L1		L2	
	No.	Sqrt No.	No.	Sqrt No.
Cu	3.61	1.90	41.99	6.48
Mo	5.52	2.35	76.39	8.74
Sw	0.72	0.85*	15.68	3.96*
Un	5.71	2.39	75.86	8.71
Fpr		0.041		0.008
d.f.		12		12
s.e.d.		0.522		1.266
l.s.d.		1.138		2.758

6b)	Assess 8 DAI				Assess 8 DAI			
	L1		L2		Prepupa		Pupa	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.
Cu	0.00	0	5.43	2.33	4.12	2.03	8.94	2.99
Mo	0.06	0.25	7.34	2.71	6.81	2.61	8.82	2.97
Sw	0.00	0	2.28	1.51	4.54	2.13	7.02	2.65
Un	0.06	0.25	6.81	2.61	6.92	2.63	11.02	3.32
Fpr		0.588		0.146		0.715		0.944
d.f.		12		12		12		12
s.e.d.		0.250		0.521		0.657		1.097
l.s.d.		0.545		1.136		1.432		2.391

DAI – Days after predator introduction

Table 7. The numbers of predatory mites recovered following introductions of 20 mites per treatment *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius montdorensis* (Mo) *or A. swirskii* (Sw) at 30/20°C 14:10 Light:Dark conditions.

	Assess 4 DAI		Assess 8 DAI	
	Mites		Mites	
	No.	Sqrt No.	No.	Sqrt No.
Cu	2.43	1.56	9.49	3.08
Mo	2.89	1.70	2.10	1.45
Sw	5.62	2.37	9.06	3.01
Un	0	0	0	0
Fpr		0.015		<.001
d.f.		12		12
s.e.d.		0.620		0.473
l.s.d.		1.350		1.031

DAI – Days after predator introduction

Bean pod mite experiment 3

Both predators significantly reduced numbers of thrips larvae at the Day 4 assessment (Table 8). *A. limonicus* reduced numbers of thrips larvae to almost zero, whilst *N. cucumeris* halved the numbers compared to the untreated control. Although a similar pattern was seen at the day 8 assessment this was not significant. The mean numbers of predatory mites recovered were not significantly different between the treatments with 10.5 and 11.9 *N. cucumeris* and *A. limonicus* four days after predator introduction and 17.7 and 6.0 *N. cucumeris* and *A. limonicus* eight days after predator introduction, respectively (there were 0.6 predatory mites in the untreated control).

Tables 8a & b. The effect of introductions of twenty predatory mites of either *Neoseiulus (Amblyseius) cucumeris* (Cu) and *Amblydromalus limonicus* (Li) on developing populations of WFT at 30/20°C 14:10 Light:Dark conditions (following introduction of 20 WFT females which were removed prior to predator introduction) compared to the untreated control (Un) at four and eight days after predator introduction (DAI).

8a)	Assess 4 DAI					
	L1		L2		Prepupa	
	No.	SQRT No.	No.	SQRT No.	No.	SQRT No.
Cu	6.30	2.51	20.52	4.53*	0.00	0
Li	0.25	0.50*	1.30	1.14*	0.36	0.6
Un	11.56	3.40	51.98	7.21	0.06	0.25
Fpr		<.001		<.001		0.286
d.f.		9		9		9
s.e.d.		0.508		1.053		0.357
l.s.d.		1.150		2.383		0.807

8b)	Assess 8 DAI							
	L1		L2		Prepupa		Pupa	
	No.	SQRT No.	No.	SQRT No.	No.	SQRT No.	No.	SQRT No.
Cu	0.72	0.85	6.76	2.60	2.62	1.62	0.62	0.79
Li	0.06	0.25	2.40	1.55	0.06	0.25	0.36	0.60
Un	0.06	0.25	12.67	3.56	0.12	0.35	0.36	0.60
Fpr		0.238	6.76	0.482		0.012		0.931
d.f.		9		9		9		9
s.e.d.		0.379		1.592		0.395		0.558
l.s.d.		0.857		3.602		0.893		1.263

Bean pod mite experiment 4

At 20/10°C day/night temperature, introductions of 20 predatory mites of *N. cucumeris, A. montdorensis* or *A. swirskii* significantly reduced numbers of WFT larvae and pre-pupae (Table 9). Although numbers of *A. montdorensis* were significantly lower than the other mites at the first assessment, this was not observed for subsequent assessments (Table 10). The total mite numbers may have been greater than the initial introduction numbers as nymphs were also counted.

Table 9. The effect of introductions of 20 predatory mites of *Neoseiulus (Amblyseius) cucumeris* (Cu)*, Amblyseius montdorensis* (Mo) or *A. swirskii* (Sw) on developing populations of WFT at 20/10°C 14:10 Light:Dark conditions (following introduction of 20 WFT females which were removed prior to predator introduction) compared to the untreated control (Un).

	Assess 4 DAI				Assess 8 DAI				Assess 11 DAI			
	L1		L2		L1		L2		L2		Pre-pupae	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.
Cu	10.8	3.29*	7.3	2.71*	0.0	0.00	1.1	1.05*	1.0	0.68*	0.0	0.00*
Mo	6.9	2.63*	2.3	1.51*	0.0	0.00	4.0	2.00*	1.8	1.29*	0.3	0.25*
Sw	1.0	1.00*	0.1	0.25*	0.0	0.00	0.1	0.25*	0.5	0.35*	0.0	0.00*
Un	21.3	4.61	42.6	6.53	0.1	0.25	37.5	6.12	26.0	4.77	4.8	1.74
Fpr		<.001		<.001		0.426		<.001		<.001		0.026
d.f.		12		12		12		12		12		12
s.e.d.		0.500		0.663		0.177		0.754		0.845		0.564
l.s.d.		1.090		1.445		0.385		1.644		1.840		1.229

DAI – Days after predator introduction

Table 10. The total numbers of predatory mites recovered following introductions of 20 mites per treatment of *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius montdorensis* (Mo) or *A. swirskii* (Sw) at 20/10°C, 14:10 Light:Dark conditions.

	Assess 4 DAI		Assess 8 DAI		Assess 11 DAI	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.
Cu	15.3	3.91 [a]	7.1	2.67 [a]	26.2	4.80 [a]
Mo	8.9	2.98 [ab]	8.9	2.99 [a]	12.8	3.53 [a]
Sw	15.6	3.95 [a]	15.1	3.88 [a]	12.2	3.34 [a]
Un	0.0	0.00	0.0	0.00	0.0	0.00
Fpr		<.001		<.001		<.001
d.f.		12		12		12
s.e.d.		0.351		0.798		0.881
l.s.d.		0.765		1.740		1.919

DAI – Days after predator introduction

Bean pod mite experiment 5

The addition of any species of predatory mites had an effect on the numbers of WFT. There may be an interaction between the mite species which should be further explored. The numbers of mites recovered in each treatment was similar.

Table 11. The effect of introductions of twenty predatory mites of *Neoseiulus (Amblyseius) cucumeris* (Cu), *Amblyseius californicus* (Cal) or *Neoseiulus* (*Amblyseius*) cucumeris plus *Amblyseius californicus* (Cu + Cal, ten of each species) on developing populations of WFT (following introduction of 20 WFT females which were removed prior to predator introduction) compared to the untreated control (Un).

	Assess 4 DAI				Assess 8 DAI		Assess 11 DAI					
	L1		L2		L2		L2		Pre-pupae		Pupae	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.
Cu		1.68*ab		2.96*		1.23*		1.24*		0.40*		0.00*
Cal		3.23*a		4.46*		3.14*		2.12*		0.71*		0.74*
Cu + Cal		3.22*a		4.78*		2.07*		0.80*		0.17*		0.17*
Un		5.67		7.99		5.73		3.28		2.09		1.57
Fpr		<.001		0.001		<.001		0.013		0.001		0.003
d.f.		16		16		16		16		16		16
s.e.d.		0.608		1.012		0.761		0.692		0.410		0.373
l.s.d.		1.290		2.146		1.614		1.467		0.870		0.790

DAI – Days after predator introduction

Units at either 30/20°C or 20/10°C 14:10 Light:Dark conditions, was data combined across temperature.

Bean pod mite experiment 6

At 20/10°C 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 (44 L2 per unit at 11 DAI) compared to the *A. barkeri* treated and the control (99 and 90 L2 respectively).

Similar mean numbers of *N. cucumeris* and *A. barkeri* mites were recovered. As expected the populations of WFT developed more quickly at the higher temperature.

Table 12. The effect of introductions of twenty predatory mites of *Neoseiulus (Amblyseius) cucumeris* (Cu) or *Amblyseius barkeri* (Bar) on developing populations of WFT (following introduction of 20 WFT females which were removed prior to predator introduction) compared to the untreated control (Un) 30/20°C, 14:10 Light:Dark conditions.

	Assess 4 DAI				Assess 8 DAI				Assess 11 DAI					
	L1		L2		L2		Pre-pupae		L2		Pre-pupae		Pupae	
	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No.	No.	Sqrt No	No.	Sqrt No	No.	Sqrt No.
Cu	5.8	1.5*	19	3.4*	4.5	1.28*	0.3	0.25*	1.2	0.56*	1.3	0.67*	1.0	0.50
Bar	7.0	2.2*	48	6.0	3.0	1.49*	0.0	0.00*	0.2	0.25*	0.0	0.00*	0.0	0.00*
Un	25.8	5.0	110	10.4	29.0	5.30	3.8	1.90	10.5	3.08	4.8	2.05	3.5	1.71
Fpr		0.031		0.034		0.005		<.001		0.005		0.016		0.032
d.f.		9		9		9		9		9		8		9
s.e.d.		1.154		2.205		1.010		0.262		0.690		0.552		0.545
l.s.d.		2.611		4.988		2.286		0.594		1.561		1.273		1.232

DAI – Days after predator introduction

Anthocoridae predator experiment

All treatments of *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.

Table 13. The total numbers of first and second instar WFT larvae (L1, L2) found following introductions of a female *Orius laevigatus* (Ol), *Orius majusculus* (Om) or *Anthocoris nemoralis* (An) after 24 hrs at 26/20°C day/night temperature, with three first instar WFT larvae (L1) and two second instar WFT larvae (L2).

	L1		L2	
	No.	Sqrt No.	No.	Sqrt No.
Ol	0.0	0.00	0.2	0.20
Om	0.2	0.20	0.2	0.20
An	0.2	0.20	1.0	0.77
Un	1.8	1.18	2.2	1.45
Fpr		0.006		0.004
d.f.		16		16
s.e.d.		0.304		0.323
l.s.d.		0.644		0.685

Objective 2: Control of pupal stages of WFT in the substrate

Substrate mite experiment 1

At 30/20°C day/night temperature both *Hypoaspis miles* and *Macrocheles robustulus* significantly reduced the numbers of resultant WFT adults by 13 days after predator introduction (Table 14). *Macrocheles robustulus* was also more effective at control than *Hypoaspis miles* at this temperature, even though similar numbers of mites were recovered.

Table 14. The effect of introductions of 20 predatory mites of either *Hypoaspis miles* or *Machrocheles robustulus* on populations of WFT at 30/20°C 14:8 Light:Dark conditions (following introduction of 50 WFT larvae which moved into the substrate to pupate) compared to the untreated control.

Assess 13 DAI	Total Adults		Mites 4 Mar	
	No.	SQRT No.	No.	SQRT No.
Hypoaspis miles	11.0	3.23*[a]	7.6	2.67*
Macrocheles robustulus	2.8	1.64*[ab]	5.0	2.16*
Untreated	23.4	4.83	0	0
Fpr		<.001		<.001
d.f.		12		12
s.e.d.		0.346		0.367
l.s.d.		0.753		0.799

DAI – Days after predator introduction

Substrate mite experiment 2

At 20/10°C day/night temperature both *Hypoaspis miles* and *Macrocheles robustulus* significantly reduced the numbers of resultant WFT adults by half by the fourth assessment, 14 days after predator introduction (Table 15). At this date there were a mean of two *Hypoaspis miles* and 2.75 *Macrocheles robustulus* per unit, a decrease from the second assessment on 5 March when there were 10.75 *Hypoaspis miles* and 6.8 *Macrocheles robustulus* per unit.

Table 15. The effect of introductions of twenty predatory mites of either *Hypoaspis miles* or *Machrocheles robustulus* on populations of WFT at 20/10°C 14:8 Light:Dark conditions (following introduction of 50 WFT larvae which moved into the substrate to pupate) compared to the untreated control.

Assess 14 DAI	Total Adults	
	No.	SQRT No.
Hypoaspis miles	13.8*	3.66
Macrocheles robustulus	10.0*	3.14
Untreated	23.2	4.78
Fpr	0.029	0.031
d.f.	6	6
s.e.d.	3.73	0.463
l.s.d.	9.12	1.133

DAI – Days after predator introduction

Substrate, Atheta coriaria *experiment 1*

There was no significant effect of addition of *A. coriaria* on total number of WFT adults by the final assessment on 16 Mar with a mean of 14.2 *A. coriaria* per unit compared to 17.5 in the control. Unfortunately there was a mean of 1.2 *A. coriaria* caught on the yellow sticky traps per unit which may have affected the experiment, therefore for the second *A. coriaria* experiment the sticky traps were removed.

Substrate, Atheta coriaria *experiment 2*

There was no significant effect of *A. coriaria* on the total numbers of WFT over both temperatures with a mean of 9.6 WFT per unit with the *A. coriaria* and 14.5 WFT per unit in the untreated control. There was a significant effect of temperature, with more WFT in the lower temperature units, 15.9 adults in the 20/10°C day/night temperature units compared to 8.2 adults in the 30/20°C day/night temperature units.

Interestingly a new generation of WFT was seen, with L1 and L2 larvae, in all of the 30/20˚C day/night temperature control units, however in only one of the 30/20˚C day/night temperature *A. coriaria* units.

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 (1,300 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. (*Anthocoris nemorum* was identified) were found. Both genres are confirmed predators of thrips. 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. Therefore for the purposes of this objective the possibility of using *Chrysoperla carnea* and coccinelids could be explored in Year 2, although where aphid numbers are high, thrips may not be the preferred food source.

Discussion

It was clear that some of the predatory mites, such as *A. swirskii*, *A. montdorensis* and *A. limonicus,* which are available for use in a glasshouse situation are effective bio-control agents at the warmer temperatures. However, as these are non-native species they are not licensed for use in polytunnels or un-covered crops. *N. cucumeris* was still an effective predator, as effective as / more effective than *A. barkeri* (which is not currently marketed in the UK, but is licensed for use in polytunnels). The relationship between *N. cucumeris* and *A. californicus* and the question of intraspecific competition could be further explored. However, even when both mites were in combination, there was still a reduction in the number of thrips compared to the control. *A. californicus* is a non-native species and therefore is not licensed for release.

Within the Anthocoridae, *Orius* spp. seemed to be more effective than *Anthocoris nemoralis* (although not significantly), and *Orius* predators are known to establish well in warmer conditions.

The predatory mites *H. miles* and *M. robustulus* were also effective in the substrate. This supports the recent report by Sampson (2014), who found that many growers who had achieved good control of WFT made one release of *H*. *miles* (*S. scimitus*), between March and May, in addition to other bio-control agents.

The possibility of using other predators such as coccinelids and lacewings that may also predate other pests will be explored, as will other control agents in the substrate.

Conclusions

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 and sprinkler tubes, this is an easy to use, cost effective predator. It should be borne in mind that these experiments offered an ideal scenario for the predators, being introduced ahead of egg hatch or at the early first 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 following the introduction of the predatory mites *Hypoaspis miles* (also known as *Stratiolaelaps scimitus*) or *Machrocheles robustulus* adds additional evidence to support the use of soil mites in a control programme, and this will be further explored.

In 2015 the use of soil treatments including the predatory mites, entomopathogenic fungi and nematodes will be compared for the control of WFT on plants in small growbags in cages in a polytunnel. Controlled environment experiments in small units will compare the treatments in combination with *N. cucumeris*.

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Knowledge and Technology Transfer

26/11/2014 – HDC/EMRA Soft fruit day - presentation

09/09/2014 – Overview of WFT research to German growers visiting EMR

23/07/2014 - Fruit Focus – manning of HDC stand on WFT

Glossary

WFT – Western flower thrips

L1 – First larval instar of western flower thrips

L2 – Second larval instar of western flower thrips

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

DAI – days after predator introduction

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