AHDB

HORTICULTURE

Grower Summary

SF 156

Improving integrated pest management in strawberry

Final 2020

Disclaimer

The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use, except where the crop or situation is the subject of an off-label extension of use.

Before using all pesticides check the approval status and conditions of use.

Read the label before use: use pesticides safely.

Further information

If you would like a copy of the full report, please email the AHDB Horticulture office (hort.info.@ahdb.org.uk), quoting your AHDB Horticulture number, alternatively contact AHDB Horticulture at the address below.

AHDB Horticulture,
AHDB
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

Tel – 0247 669 2051

AHDB Horticulture is a Division of the Agriculture and Horticulture Development Board.

Project title:	Improving integrated pest management in strawberry
Project number:	SF 156
Project leader:	Dr Michelle Fountain
Report:	Year 5 Final Report, March 2020
Previous report:	Year 4 Annual Report, March 2019
Key staff:	Jerry Cross, Jean Fitzgerald, Chantelle Jay, Phil Brain, David Buss, Adrian Harris, Glen Powell, Bethan Shaw, Adam Walker, Francesco Maria Rogai, Celine Xavier e Silva, Umberto Rosalina, Luca Csokay, Francesco Maria Rogai, Zoe Clarke, Jacob Lowe, Molly Perry-Clark, Ben Brough, Piroska Mohay, Greg Deakin, Rosa Blanco Fernandez, Gabriele Antoniella, Alastair Gibbons, Chris Coyne, (NIAB EMR); Steve Edgington, Bryony Taylor, Belinda Luke, Rhian Whelan, David Moore, Emma Thompson (CABI); Jude Bennison, Sam Brown (ADAS); William Kirk, (Keele University); Clare Sampson (Russell IPM); David Hall, Dudley Farman (NRI); Tom Pope, Juliane Graham, Rosie Homer, Rob Graham (Harper Adams University) Robert Irving (ADAS), Neil Audsley (Fera)
Location of project:	NIAB EMR, New Road, East Malling, Kent ME19 6BJ
Industry Representative:	Louise Sutherland, Freiston Associates Ltd.
Date project commenced:	01 April 2015
Date project completed	31 March 2020
(or expected completion date)	

GROWER SUMMARY

This project addresses the main pest problems reported by the UK strawberry industry, except for spotted wing drosophila (SWD), which is covered in other projects. Within this project, it was planned to work on five objectives over the five-year duration. A sixth objective was added during the life of the project to investigate *Thrips fuscipennis* which developed as an industry problem after the start of the project:

1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD, improve the reliability of biocontrol of WFT with predatory mites, and develop effective approaches to the use of entomopathogenic fungi (EPF) for control of WFT.
2. Refine pest control programmes on strawberry, integrating pesticides with phytoseiid mites.
3. Develop IPM compatible controls for European tarnished plant bug (*Lygus rugulipennis*), common green capsid (*Lygocoris pabulinus*) and strawberry blossom weevil (*Anthonomus rubi*).
4. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae,* so as to be more compatible with IPM programmes.
5. Improve the control of aphids through the growing season.
6. Fill key gaps in knowledge on *Thrips fuscipennis* biology in strawberry crops so that IPM strategies can be developed.

All of these objectives were explored and the majority led to significant outcomes and actions that growers can implement to improve pest management in commercial strawberry crops. In some cases, additional studies were done as problems arose through the duration of the project.

For ease of reading, this Grower Summary report is split into sections for each of the objectives being worked upon. The Science Section of this report contains research carried out in year 5 (2019/20), the final year of the project. Details of previous year's studies can be found in Annual Reports 1-4 (2016, 2017, 2018 and 2019).

Objective 1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD, improve the reliability of biocontrol of WFT with predatory mites, and develop effective approaches to use of entomopathogenic fungi (EPF) for control of WFT.

Task 1.1. Determine the distribution of *Neoseiulus cucumeris* on commercial strawberry plants, after introduction, for WFT management.

Headline

- The presence of WFT as prey in strawberry plants increases the number *of N. cucumeris* on flowers and button fruits.

Background and expected deliverables

In the first year of the project, the major target was western flower thrips (WFT). At present, growers rely on introductions of the predatory mite *Neoseiulus cucumeris* (formerly called *Amblyseius cucumeris*) to control WFT. It is relatively inexpensive to mass produce and can be introduced in large numbers but only predates first-instar WFT larvae. However, biocontrol with *N. cucumeris* sometimes fails. This is usually due to insufficiently early or frequent introductions, poor predator viability and/or adverse effects of crop protection programmes. For effective biocontrol, a high proportion of flowers must contain *N. cucumeris*. Growers find it difficult to assess whether *N. cucumeris* populations have established adequately and whether they are in balance with their prey. It is crucial to develop grower-friendly methods for estimating WFT and *N. cucumeris* populations in relation to fruit damage and to develop attendant predator-prey ratio thresholds for interpreting relative populations.

In 2016, when multiple releases of high numbers of *N. cucumeris* were made in small field plots, very few predators were recovered from flowers or button fruit after release. A study was set up to determine; where mites disperse when released onto the plant; the influence of WFT on *N. cucumeris* distribution, and the diurnal movement of *N. cucumeris* on strawberry button fruits and flowers.

Summary of the project and main conclusions

To gain the background information needed to develop effective sampling strategies and treatment thresholds for WFT, samples of individual flowers and ‘button’ fruit were collected from two commercial crops, where *N. cucumeris* were being released, every two weeks from

April to September. In addition, replicate samples of different plant parts, from unopened flowers to ripe fruit, were collected twice from each of two plantings to determine the distribution of pest and predator over the plant. One-off collections of flowers and fruit were also made from 12 crops that had different levels of WFT on the plants. Numbers of WFT and *N. cucumeris* were extracted and recorded in the laboratory and the data used to determine the most effective sampling strategy for *N. cucumeris* and to model the interaction between pest and predator.

In a glasshouse experiment, to assess the distribution of *N. cucumeris* on strawberry plants after release, eighteen plants were placed in each of two glasshouse compartments at NIAB EMR. WFT from laboratory cultures were released onto plants in one compartment at approximately 20 mixed stages per plant; the second compartment had no WFT released. Five days after WFT release *N. cucumeris,* from a commercial supplier, was released onto each plant in both compartments at a rate of ~200 mites per plant. One, four and seven days after release, six plants were randomly selected from each treatment. Numbers of each plant part at the time of sampling were recorded and the plants were destructively sampled in the glasshouse; all plant parts were separated into closed containers. Plant parts assessed were: old leaves, recently expanded leaves, folded leaves, flowers, button fruit, remaining fruit, developing fruit clusters and the crown. In addition, a sample of the *N. cucumeris* carrier material from the leaf surfaces of each plant was taken. Numbers of *N. cucumeris* and WFT were counted from the different plant parts to assess distribution over the plant after release and the data analysed to determine if there were differences in *N. cucumeris* distribution when prey was present.

Most WFT were found on the strawberry flowers and fruits. Most *N. cucumeris* had dispersed from the carrier material within one day of release, but around 50% of the total numbers of mites released were not recorded on the plants. *N. cucumeris* were recorded on all assessed plant parts but there were low numbers on the leaf samples. In the overall analyses of the results the presence of prey affected the distribution of *N. cucumeris* on the plants; there were significantly higher numbers of *N. cucumeris* on both flowers and fruits in the treatment where WFT had been released. These results confirmed earlier work that button fruit were the most effective plant parts to assess populations of *N. cucumeris* in the crop and highlights that the presence of prey (WFT) has a significant effect on the distribution of the predator.

Button Fruit: Some senescing petals may be visible on some fruits

In a following field experiment on a commercial crop to determine if there is a diurnal pattern of movement of *N. cucumeris* over the plant, several introductions of *N. cucumeris* were made. Data loggers were used to record temperature and humidity throughout the experimental period, and the photosynthetically active light levels (400-700 nm) were also monitored. Button fruit and flower samples were taken five times during the day; 09.00; 12.00; 15.00; 18.00 and 21.00. Sampling was repeated on three days, with a one day gap between the first two samples and a four day gap between the second and third sample to allow the plants to recover and produce more open flowers and button fruits. Each assessment unit consisted of 10 flowers or 10 button fruit. These bulk samples were collected into ethanol and arthropods were extracted using our standard laboratory washing technique. Numbers of *N. cucumeris,* thrips adults and larvae and *Orius* adults and nymphs were counted. Arthropods recorded on the sample units in relation to sampling time and date, position within the tunnel, and environmental conditions (mean temperature and mean light intensity for the 60 mins before each sample) were analysed.

There was a diurnal pattern of movement of arthropods on strawberry. In the overall statistical analyses of the data, the mean temperature in the hour prior to sampling significantly affected the number of arthropods recorded in samples of flowers and button fruits. No other variable tested had any effect on arthropod distribution. Numbers of *N. cucumeris* declined by around 3% for every 1°C increase in mean temperature calculated per hour, over the range recorded in the experiment (18-33°C). Predatory *Orius* adults and WFT adults were recorded in higher numbers as the mean temperature increased whereas WFT larvae decreased in abundance. Numbers of *N. cucumeris* were also lower in flowers and button fruit at higher temperatures. Therefore if very low numbers are recorded in samples it would be worth revisiting the plantation when temperatures have decreased to confirm establishment of the predator.

In a subsequent, late season experiment, five daily time points were selected (09.00; 12.00; 15.00; 18.00; 20.00) to achieve varying temperatures, then samples of 20 button fruits were placed in the extraction device at each time point in the field. The percentage of arthropods extracted from the button fruits at each time point and corresponding temperature were analysed. Findings showed that *N. cucumeris* extraction was not linked to time of day, or average temperature, however mean percent extraction did appear to follow a pattern, whereby it was lowest at the beginning and end of the day when average temperatures were coolest, and highest mid-afternoon when average temperature was warmest (average temperatures ranged from 13.9°C at 20:00 to 20.7°C at 15:00). The highest mean percent of *N. cucumeris* extracted was 44.5% at 15:00. Hence, when using the device to estimate numbers of *N. cucumeris* in the crop, temperature should be taken into consideration.

Main conclusions

- The presence of WFT as prey in strawberry plants increases the number *of N. cucumeris* on flowers and button fruits.
- Sampling button fruit rather than flowers gives a more reliable estimate of *N. cucumeris* establishment.
- Ambient temperature can affect the numbers of predatory mites observed in strawberry flowers and fruits.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- Sample button fruit to detect *N. cucumeris* in the crop.
- Thrips are also found in button fruit, but numbers are higher in flowers using the extraction device (Task 1.2).
- Take into consideration numbers of WFT as there are more likely to be more *N. cucumeris* in flowers and fruits where there are high numbers of WFT.
- If temperatures are high, it is likely that fewer *N. cucumeris* will be found in the fruitlets and flowers and re-sampling to ascertain establishment may be needed.
- Avoid sampling for *N. cucumeris* in the mid-day heat in mid-season.

Task 1.2. To 1) develop an easy-to-use extraction device for monitoring *N. cucumeris* and WFT in commercial strawberry crops, and determine methods of using Calco Red to stain *N. cucumeris* in culture so they can be more easily identified in the field.

Headline

- An extraction device has been developed to improve detection and monitoring of *Neoseiulus cucumeris,* thrips, *Orius,* and predatory thrips in strawberry crops, and can be produced for grower and agronomist use.

Background and expected deliverables

Some commercial growers report finding very few or no predators in flowers or on fruit after multiple releases. In order to make rational decisions on release and sampling strategies for *N. cucumeris*, it is important to determine whether the mites are present on the plant, or if they are not surviving in the crop. This objective examined the distribution of *N. cucumeris* and WTF on strawberry flowers and fruits, aimed to dye mites to make them easier to identify in the crop and develop an easy-to-use extraction device to assist with the detection of predatory mites in strawberry.

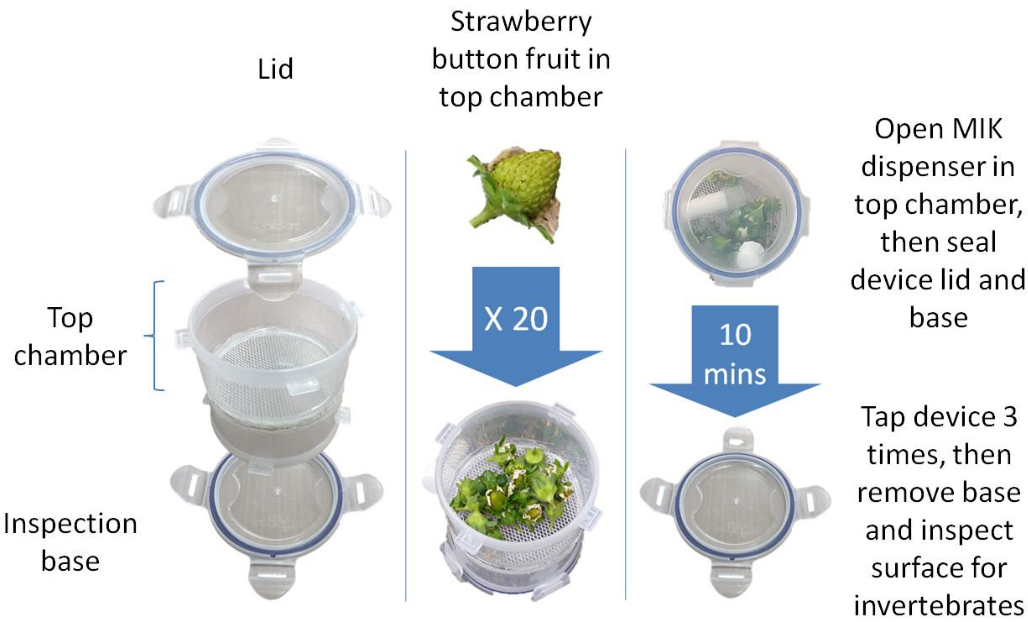
Summary of the project and main conclusions

In 2015, to develop a field-based extraction/monitoring system, three fumigants were tested in replicated experiments for their efficacy in extracting WFT and *N. cucumeris* from flowers and fruit. The most effective fumigant, methyl isobutyl ketone (MIK) was used successfully in a prototype extraction/monitoring device in the field. In subsequent years work was done to refine and optimise its use and calibrate the device.

Button fruit (young fruits where the petals had withered and/or fallen off), (see Task 1.1) yielded higher numbers of *N. cucumeris* in the extraction device compared to 'by eye' assessments of flowers or fruitlets.

Three prototype monitoring devices, making use of this fumigant extraction method, were constructed and tested. Following grower/advisor feedback on the different designs and prototypes, a 'food container' design with a metal grid was chosen for further development based on its robustness, ease of use and transparency.

Following initial laboratory studies to assess the efficacy of the device in extracting thrips and mites from button fruit, further laboratory and field experiments calibrated the device for detection of *N. cucumeris*. Fruits collected from commercial crops were initially inspected using a hand lens, then arthropods extracted using MIK in the extraction device before washing the fruit back in the laboratory with ethanol to remove remaining arthropods. In the laboratory, after inoculating button fruits with known numbers of predatory mites, ~57% of predatory mites were recovered using the device by counting under a microscope. In the field, using a hand lens the recovery of mites was closer to 27%. However, this was significantly higher than direct visual inspection of the button fruit where the majority of predatory mites were missed (in most cases no predatory mites were observed by inspecting button fruit in the field with a hand lens – although this will vary depending on the expertise of the assessor). *Orius* on both button fruit (direct observation 26%; extraction device 85%) and flowers (direct observation 55%; extraction device 94%) was also easier to detect with the extraction device.



Schematic diagram of extraction device and how to use it. The device should be operated in a well-ventilated area and a full Risk Assessment completed before use

Further improvements to the MIK release tube were made. These new dispensers gave a higher release rate and were subsequently field tested for different exposure times (1, 3, 5, 10 and 20 minutes) on samples of 20 strawberry button fruits per device. The percent of arthropods extracted was compared for each exposure. Overall, for *N. cucumeris*, pale thrips and dark thrips, numbers extracted increased up to a 10 minute exposure time. After this time, there was no significant increase in arthropod numbers. The mean percent *N. cucumeris* extracted in the laboratory was 57% - similar to the earlier studies. *Orius* and aphids were also observed in the extractions, but were too few in number for statistical analysis. Hence, a 10 minute exposure period was recommended for extraction of predatory mites from button fruits. In addition, the MIK dispensers were effective for at least 57 uses (providing lids were replaced after each use).

In another study, early on in the project, we tested whether a method could be developed to enable *N. cucumeris* to be more easily visualised on plants. Laboratory experiments were undertaken to assess the efficacy of staining the mites with CalcoRed, but this proved to be ineffective.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- The extraction devices developed for this research can be purchased directly from Adrian Harris at NIAB EMR should growers or agronomists wish to employ them as an aid to their crop monitoring for WFT, *N. cucumeris* and other predatory mites.
- Before using or transporting the extraction device, ensure that a full risk assessment is carried out, as MIK is a solvent. Ensure the MIK tube and extraction device are fully closed when not in use and only open/use in a well-ventilated area (i.e. cropping area).
- This device will not replace crop monitoring but will assist in determining numbers of predatory mites in the crop and inform the need to make further predatory mite applications.
- Compare the practicality of the extraction device to your existing methods for detecting *N. cucumeris* and thrips in the crop.
- To determine numbers of *N. cucumeris* in the crop it is better to sample the button fruit and leave the extraction device for 10 minutes for each 20 button fruit sample.
- MIK tubes can be used at least 57 times.

Task 1.3 Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD

Headline

- Met52 EC is unlikely to have adverse effects on the survival of the commercially available pest control products Thripor-L, Ervipar, Aphiscout, Aphidalia and Chrysopa.

Background and expected deliverables

This task explored sprays of entomopathogenic fungi (EPF) as a second-line-of-defence against WFT. For effective control of a target pest, spores of an EPF strain need to adhere to the pest's cuticle, then germinate and penetrate the cuticle to cause mycosis. Efficacy requires an adequate number of spores to adhere to vulnerable parts of the body, then adequate high humidity and temperature for a sufficient period for spore germination and infection to take place. Mortality occurs after a few days, but insects stop feeding, moving and reproducing well before death.

Four main studies took place as part of this task;

1) The EPF formulation of Met52 OD (Fargro), as a foliar spray, was tested in a laboratory bioassay against adult female WFT using a direct dosing method.
2) The addition of adjuvants was tested to determine if improved spore distribution, adhesion and biological efficacy of EPF (Naturalis L) against WFT could be achieved.
3) A literature review on the effects of *Metarhizium brunneum* strain F52 (the active ingredient of Met52) against WFT and natural enemies was compiled.
4) Bioassays were carried out, testing Met52 against three commercially produced natural enemy products (Chrysopa, Aphidalia and Ervipar), to fill a knowledge gap so that growers may best know how to utilize it within their growing systems.

Summary of the project and main conclusions

Efficacy of Met52 OD: In two laboratory experiments there was 44% higher WFT mortality after 6 days, and over 40% WFT mortality after 6 days and nearly 70% mortality after 8 days, at the highest label dose, compared to the untreated control, respectively. However, there was also around 40% WFT mortality in a blank oil control.

Adjuvant addition: No significant difference in deposition/retention of spores was identified between adjuvants following spraying. However significantly higher deposition/retention was observed on flowers compared to leaves in all treatments. The addition of adjuvants significantly improved spore distribution, adhesion and biological efficacy of EPF (Naturalis L) against WFT in laboratory bioassays and replicated field experiments.

The literature review highlighted that Saito and Brownbridge (2016) tested the compatibility of soil dwelling predators to Met52 EC and found that only *Dalotia coriaria* (Greenhouse rove beetle), was killed by the Met52 EC at a significantly different rate compared to the control. In addition, EFSA (2012) Annex IIM 8; HIM 10 showed evidence that direct application to *Orius majusculus* (*insidious* flower bug) (dripping onto the insect at a rate of 5.1 x 108 CFU /mL) causes 70% mortality after 7days. In addition, mortality was noted for *Chrysoperla carnea* (common green lacewing), through dietary exposure at 4.2 x 105 CFU/mL, as 37% after 12 days and *Hippodamia convergens* (convergent ladybird) (Coccinellidae) as 31% after 22 days. This review showed that some work on the effects of Met52 EC on beneficials had been done, so the experimental studies in this project focussed on the main beneficials used in the UK strawberry system.

Firstly, the active ingredient of Met52 EC was tested on five natural enemy products by a 'dipping assay' method, and, secondly, 'spray contact assays' were performed on the three products that showed kill in the dipping assay. All experiments were carried out at the field recommended rate for Met52 EC. The results for the dipping assay, where the insects were submerged in recommended dose of *M. brunneum* spore suspension showed that Aphiscout and Chrysopa had around 50% kill. For Thripor-L and Aphidalia there was around 65% mortality and 70% mortality in Ervipar three days after treatment. This was a worst-case scenario and is unlikely to happen in the field. The spray contact assays consisted of a recommended rate tank mix of Met52 EC sprayed onto strawberry leaves using a Burkard Computer sprayer, allowed to dry prior to insects being placed on the leaves for three days before removing the leaf. Three products; Chrysopa, Aphidalia and Ervipar, were tested. The results showed that there was around 20% death of the Chrysopa and Aphidalia treatments and less than 10% death of the Ervipar treatment after three days. The conditions used in the assays were the best for fungal growth and hence in the field it is likely that these effects will not be as high as in this experiment.

It was therefore concluded that Met52 EC will have insignificant effect on the survival of the commercially available pest control products Thripor-L, Ervipar, Aphiscout, Aphidalia and Chrysopa when used in UK strawberry production systems.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- The biocontrol product Met52 EC is recommended for use in UK strawberry production and has been shown to have minimal adverse effects on other beneficial organisms.

Objective 2. Refine pest control programmes on strawberry, integrating pesticides with phytoseiid mites.

Task 2.1. Investigation of how to minimize the adverse effects of pesticides on *Neoseiulus cucumeris*, used as a biocontrol of WFT.

Headline

- Repeated applications of some fungicides can cause significant reductions in predatory mite populations although this can be alleviated by further introductions of *N. cucumeris.*

Background and expected deliverables

Predatory mites such as *Neoseiulus cucumeris* can form a very successful part of Integrated Pest Management (IPM) strategies. However, they can be vulnerable to plant protection products, including, potentially, fungicides. In addition, increased use of plant protection products against other pests, such as SWD, can potentially interfere with IPM. Although some plant protection products have been shown to be safe or only slightly harmful to *N. cucumeris* in single applications, in the field, products are applied multiple times, and in tank mixes. The work in this objective explored whether 1) sprayer tank mixes are harmful to *N. cucumeris* on strawberry, and 2) if Calypso (thiacloprid) and potassium bicarbonate+Activator90, products commonly used by the industry, are harmful to *N. cucumeris* over multiple applications or in tank mixes, compared to Nimrod+Teldor applications. In addition, we tested whether a second release of *N. cucumeris* after spraying could mitigate the effects of harmful spray treatments.

Summary of the project and main conclusions

Experiment 1: To determine if the reduction in *N. cucumeris* numbers in commercial crops is due in part to applications of various crop protection products, the effect of repeated applications of three commonly used tank mixes of fungicides were compared to an application of spinosad and an untreated control in a replicated field experiment. *N. cucumeris* predatory mites were released onto the plants before the trial began and three applications of the fungicide mixes were applied, with assessment of *N. cucumeris* numbers made after each application. Significant reductions in *N. cucumeris* populations were recorded after the third spray application of tank mixes of Nimrod/Teldor and Signum/Systhane.

Experiment 2: *N. cucumeris* predatory mites were released onto strawberry plants before the field trial began and three applications of plant protection products were applied, with assessments made of adult and immature *N. cucumeris* numbers on button fruit after each application. No evidence was found that Calypso, potassium bicarbonate+Activator90, or Nimrod+Teldor had a detrimental effect on *N. cucumeris* populations. An additional release of

N. cucumeris after the second spray treatment led to an increase in adult *N. cucumeris* in the crop. Neither Calypso nor the secondary addition of *N. cucumeris* had a significant effect on thrips numbers. However, there were significantly lower numbers of thrips in the potassium bicarbonate+Activator90 treated plots compared to the water controls. The reason for this was not clear.

Financial benefits

WFT can cause fruit losses close to 20% if not adequately controlled. For a crop yielding 30 tonnes/ha, this equates to 6 tonnes/ha and at a value of £2,400 per tonne, losses of £14,400 per hectare. Frequent introductions of high numbers of *N. cucumeris* are costly both to purchase and to introduce to the crop. Potential damage or disruption to the mites caused by the use of harmful fungicide mixes or other crop protection products will lead to reduced efficacy of control and hasten the onset of WFT induced damage, resulting in further financial losses. It is therefore vital that growers are better informed of those fungicide mixes or other products that may have an adverse effect on the expensive predatory mites which have been introduced.

Action points for growers

- Carefully monitor strawberry crops for pest and predator numbers both before and after applications of fungicide tank mixes to determine if populations have been adversely affected.
- Careful thought needs to be given to the tank mixes used.
- Consider reducing the frequency of tank mixes of fungicides, or only spraying single products as the former may be harmful to introduced predatory mites.
- Be prepared to make additional releases of predatory mites as required to maintain control of pests such as WFT and tarsonemid mite.
- Ensure that populations of thrips and tarsonemid mite are adequately controlled before SWD enters the crop and requires treatment.

Task 2.2. In field, effect of insecticides commonly used to target spring aphids on the establishment of *N. cucumeris*

Headline

- A one-year study demonstrated that the persistence of Hallmark and Calypso in strawberry applied in early spring did not reduce numbers of the predatory mite *N. cucumeris.*

Background and expected deliverables

This field study explored the effect that insecticides, commonly used to target spring aphids, have on the establishment of *Neoseiulus cucumeris* and other predators. In order to make rational decisions on release of this predator, during the spring months it is important to determine whether *N. cucumeris* predatory mites are affected by plant protection products applied for aphid control. Data on the introduction of *N. cucumeris* following a pesticide application is generally based on laboratory side-effects tests and does not consider timing, temperature or leaf expansion.

Summary of the project and main conclusions

The experiment was set up on a commercial table-top of 2nd year Junebearer strawberry. On 7 March plots were sprayed with either field rates of lambda-cyhalothrin (Hallmark) or thiacloprid (Calypso), and compared to an untreated control. The experiment was set up with a randomised block design with six replicates of each treatment including an untreated control. *N. cucumeris*, releases were made at a rate of 200 mites per plant.

On 23 February, a pre-assessment was done; then three assessments post spray application. At each assessment the numbers of *N. cucumeris* adults, nymphs and eggs on either, leaves, flowers or button fruits (depending on availability) were recorded by collecting 30 samples from each plot. At the beginning of this trial the weather was unusually cold for the time of year. During the trial, no thrips were recorded, but tarsonemid mites were found in the young folded leaves, providing a source of food for *N. cucumeris*. The establishment of *N. cucumeris* adults, immature forms and eggs were not affected by one application of either Hallmark or Calypso applied to target spring aphids. Indeed following three releases of *N. cucumeris* the population indiscriminately increased over time in the control and treated plots.

The newly emerging folded leaves and flowers where *N. cucumeris* was detected had very little or no target pesticide residue potentially enabling the predatory mites to establish and reproduce (evidenced by the presence eggs and nymphs). Hallmark, which is suggested to have a persistence of activity against *N. cucumeris* of between 8 and 12 weeks in the laboratory, had no adverse impact on mite numbers in the field, in this trial.

Main conclusions from this work

The findings from the two years of work in this objective (Tasks 2.1 and 2.2) are in contrast in that repeated applications of fungicide mixes in Task 2.1 had adverse effects on the numbers of *N. cucumeris* while application of the insecticides Calypso and Hallmark in Task 2.2 appeared to have little impact. However, it should be remembered that only one application of Calypso and Hallmark were made in Task 2.2 and not repeated applications. In addition, spray coverage of young unfurling strawberry leaves is rarely complete and with later leaf expansion, there is usually sufficient plant leaf area free from deposit to allow the predators to survive single applications.

Financial benefits

Growers invest substantial sums in the purchase and release of biocontrol agents. Knowledge that an early spring spray targeted against aphids is unlikely to affect subsequent releases of *N. cucumeris* is helpful to encourage biocontrol as soon as possible and before numbers of thrips and tarsonemid mite proliferate.

Action points for growers

- Make early releases of *N. cucumeris* in crops, using slow release sachets when no or few strawberry flowers are available.
- Aim to get early control of aphids with insecticides, if needed, so that sprays are not necessary later in the season, when introduced and wild natural enemies are more active.
- *N. cucumeris* should be released into the crop frequently through the growing season.
- Releases of parasitoids for aphid control and *Orius* for thrips control can mitigate the need for later insecticide applications which disrupt WFT control.
- Growers need to couple this with control of SWD and control of non-WFT species (see Objective 6).

Objective 3. Develop IPM compatible controls for European tarnished plant bug, *Lygus rugulipennis*, common green capsid, *Lygocoris pabulinus*, and strawberry blossom weevil, *Anthonomus rubi*.

Task 3.1. To investigate the potential of a multi-pheromone blue sticky trapping system for *Lygus rugulipennis*, *Lygocoris pabulinus* and *Frankliniella occidentalis*

Headline

- Blue sticky traps combined with pheromones were compatible for capturing WFT and capsids, but also captured natural enemies including hoverflies.

Background and expected deliverables

In strawberry, western flower thrips, *Frankliniella occidentalis* (WFT), causes bronzing of the fruit. It has become difficult to control because of resistance to crop protection products and lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. From June onwards European tarnished plant bug, *Lygus rugulipennis*, becomes a damaging pest of strawberry requiring routine control. Feeding in flowers and on green fruits can cause up to 80% crop loss, rendering production uneconomical. Traditional crop protection products used for control can disrupt biological control agents and increase residues in fruits. *Lygocoris pabulinus* (common green capsid) is also a damaging pest, which tends to be sporadic in appearance and locally distributed within the crop.

Blue sticky traps are currently employed for WFT control. These can be enhanced with a WFT aggregation pheromone, which can typically double the catch. If these could also be used in conjunction with capsid pheromones, this would potentially provide in-crop control of three pest species. *L. rugulipennis* is currently trapped using a *Lygus* sex pheromone lure within a green bucket trap and cover; catches, including of females, can be increased with the addition of the plant volatile phenylacetaldehyde (PAA). The trapping system for *L. pabulinus* uses the same pheromone lure, but attached to a blue sticky trap placed vertically in the crop. We investigated whether *L. rugulipennis* and *L. pabulinus* can be attracted to blue sticky traps with the addition of a *Lygus* sex pheromone lure + PAA only or whether the *Lygus* pheromone + PAA can be used in conjunction with the WFT pheromone, and, finally, if beneficial arthropods are also attracted to the trapping system.

Summary of the project and main conclusions

Experiments were set up in multiple strawberry crops in mid- to late- June for two months in 2017. Treatments included: 1) Blue dry sticky trap board - 25 cm x 10 cm, 2) blue dry sticky trap board + WFT pheromone lure, 3) blue dry sticky trap board + *Lygus* sex pheromone lure + PAA, or 4) blue dry sticky trap board + WFT pheromone lure + *Lygus* sex pheromone lure + PAA. Traps were placed 10 m apart in a randomised block design.

L. rugulipennis and *L. pabulinus* were attracted to a blue sticky trap with *Lygus* sex pheromone + PAA. However, 20% of capsids could detach themselves from the blue sticky traps. The *Lygus* sex pheromone lure + PAA was compatible with the WFT pheromone and thrips catches were always higher when a WFT lure was present. The PAA lure also appeared to attract lacewings and syrphids. PAA is essential to increase catches of the female *L. rugulipennis.* However, the floral component may be detrimental to some beneficial species, including hoverflies.

Main conclusions

Although the combined use of blue sticky traps, pheromones and PAA have potential for the control of both WFT and capsid pests in strawberry, the capsids ability to detach themselves from the traps is a flaw in the system, so the scientists turned their attention to a different control strategy using a ‘push-pull’ system described in Task 3.2 below.

Financial benefits

Lygus rugulipennis (European tarnished plant bug) and *Lygocoris pabulinus* (common green capsid) are serious pests on everbearer strawberries causing crop losses by feeding on developing fruits which become deformed and unmarketable. Over 50% of fruit may be downgraded as a result of capsid feeding in unsprayed crops. This results in loss of profitability of the crop. The crop protection products currently used to control capsids can have an adverse effect on IPM control strategies used for other pests such as WFT, tarsonemid mite and aphids, so a novel IPM compatible control system is desperately needed by growers.

Action points for growers

- No immediate action points for growers arose from this work.

Task 3.2. To investigate the potential of a push-pull system for control of capsids in strawberry

Headline

- A synthetic semiochemical capsid push-pull strategy has been developed for commercial strawberry which significantly reduced capsid numbers in the crop and reduced damage to the fruits.

Background and expected deliverables

In late-season UK strawberry crops, the European tarnished plant bug (*Lygus rugulipennis*) is considered to be the major cause of fruit malformation 'cat-facing' (Easterbrook 1997). One *L. rugulipennis* per 40 plants is considered enough to cause economic loss (Jay et al. 2004) and if left uncontrolled, over 50% fruit can potentially be downgraded (Fitzgerald et al. 2011). The common green capsid (*Lygocoris pabulinus*) may also be a damaging pest. Control usually requires several crop protection sprays from June onwards in everbearer crops. However, products currently used for control can disrupt biological control agents and increase occurrence of residues in fruits.

Push-pull is an IPM strategy with potential to control capsids that damage UK strawberries. The technique uses a stimulus to repel the capsids from the crop (push), in combination with another stimulus (pull) which attracts them to traps surrounding the crop where they are concentrated and eliminated. In a previous project we showed that synthetically produced hexyl butyrate can be repellent to *L. rugulipennis* and therefore used as a potential push. We also showed that synthetically produced *L. rugulipennis* female sex pheromone can be used to attract *L. rugulipennis* males to baited traps, along with males of the common green capsid *L. pabulinus* (Fountain et al. 2014); also associated with strawberry plant damage (Alford 1984). Another attractant has also been shown to encourage the capture of female *L. rugulipennis* (Fountain et al. 2010; Koczor et al. 2012), and a standard green bucket trap (Unitrap) with green cross-vanes and no bee excluder grid was found to be the most effective trap for *L. rugulipennis* (Fountain M. 2015); all three components combining to offer a potential pull.

Summary of the project and main conclusions

Replicated field studies on large plots in commercial strawberry were done in 2017, 2018 and 2019. In the first year, the study in Kent showed significantly reduced numbers of capsids and damage to fruits in crops where the push was applied (either alone or in combination with a pull). In 2018, capsid numbers in the target crops were too low for statistical analysis, believed to be because of the very hot and dry conditions.

In 2019, the objective was to generate data to support the 2017 push-pull result and test two methods to improve the push. Field trials were done in seven strawberry plantations in Kent and Herefordshire (including crops known to have high capsid numbers). The experiment was conducted between June and September in seven tunnel grown commercial strawberry plantations. To compare the different push-pull variations, each plantation (except the WET centre at NIAB EMR), was divided into the following four equal sized plots; 1) push-pull (same as 2017 – repellent units inside the plots with pheromone bucket traps around the perimeter of the plots), 2) a push-pull, with double the number of repellent units in the push, 3) a push-pull with the same number of repellent units as 2017, but each with double the concentration and 4) a control plot with no push or pull. The pull was the same as 2017 and 2018, consisting of traps holding a lure and a killing agent, positioned at 8 m intervals around the perimeter of the push-pull plots. The WET centre at NIAB EMR tested plot 2 against a control. We also tested whether the push-pull strategy had side effects on numbers of beneficials, or if the repellent caused phytotoxicity to strawberry plants.

Fortnightly assessments were made in all plots at each of the seven plantations. Assessments per plot consisted of 1) tap samples of 100 or 50 strawberry plants (depending on capsid numbers), counting capsids and natural enemies within the plots, 2) counts of capsids in traps around the perimeter of push-pull plots, 3) damage assessments of approximately 100 strawberries within the plots and 4) a phytotoxicity assessment after one month attachment of the repellent to strawberry plants.

In plantations where there were more capsids, all push-pull treatments significantly reduced numbers of capsids in the crop and damage to fruit by more than 80%. Treatments had no noticeable adverse effect on numbers of beneficials counted in the crop therefore this push-pull strategy shows IPM compatibility. The repellent did not cause any detectable phytotoxic effects when applied close to the strawberry crown. Increasing the level of repellent did not improve the push so future work could investigate reducing the level of repellent for cost effectiveness. Numbers of capsids in Kent 2019 were again too low to analyse.

Financial benefits

Lygus rugulipennis (European tarnished plant bug) and *Lygocoris pabulinus* (common green capsid) are serious pests on everbearer strawberries causing crop losses by feeding on developing fruits which become deformed and unmarketable. Over 50% of fruit may be downgraded where capsids are not adequately controlled. The ‘push-pull system’ will help to reduce reliance on traditional plant protection products, further reducing disruption to other IPM strategies for other pests.

Action points for growers

To protect everbearer strawberry from *L. rugulipennis* using this method of push-pull:

- Use a standard green bucket trap (Unitrap) with green cross-vanes (no bee excluder grid) baited with synthetic attractants and water with a drop of detergent as a drowning solution.
- Position traps around the edge of the crop (not within) to intercept the primary invasion of adults from late spring and draw capsids out of the crop.
- Repellents could be deployed in the crop throughout the growing season to deter adult capsid immigration.
- Potentially earlier applications of repellents from early spring could further reduce capsid numbers in heavily affected crops.
- Good management of weeds in and around the crop is recommended as *L. rugulipennis* can breed in these.
- Most *L. rugulipennis* likely overwinter outside strawberry fields, and even those that stay in the crop appear to leave in the spring to feed on weeds or other crops.
- Weed hosts include; Groundsel, Mayweed, Fat-hen, Nettles, Dock and Common mugwort. Adults migrate into strawberry fields in June/early July, although many remain on suitable weed hosts. In Southern England there are two generations of *L. rugulipennis* a year.

Objective 4. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae,* so as to be more compatible with IPM programmes.

Task 4.1. Investigate the potential of garlic grown in strawberry bags to reduce pests in the crop.

Headline

- Planting garlic in a strawberry crop may reduce the numbers of aphid, namely strawberry aphid in the crop.

Background and expected deliverables

In 2017, a grower of a Hampshire-based strawberry business reported that intercropping garlic and breaking garlic leaves onto the strawberry crop, could reduce the prevalence of thrips. This effect had not been quantified alongside an untreated crop. There is experimental evidence in other crops showing that garlic intercropping can reduce the prevalence of pests. To investigate the pest control potential of garlic intercropping, during summer 2018, NIAB EMR conducted a garlic trial on a commercial everbearer strawberry plantation in Kent. During the trial, a group of strawberry plots were intercropped with garlic and garlic leaves were broken fortnightly and laid on to the crop. Alongside these were another group of strawberry plots without garlic. Assessments were made fortnightly in both groups of plots to determine if the garlic treatment could deter the main strawberry pests, without adversely affecting beneficials. Here we aimed to determine if this method of intercropping garlic is a feasible pest control option for commercial everbearer strawberry.

Summary of the project and main conclusions

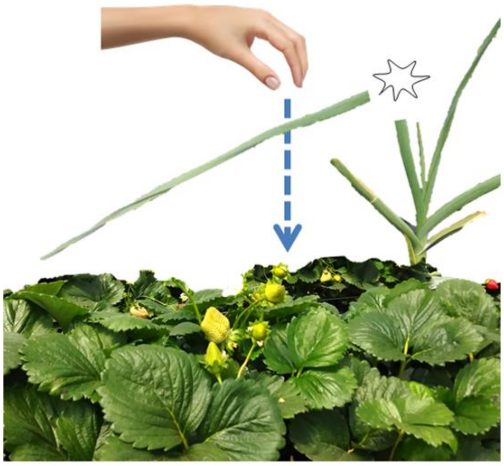
The trial was set up in a commercial strawberry plantation in Kent in everbearer varieties. The plantation was divided into two sections according to strawberry plant age: 1st or 2nd year. Within each plant age, four plots were intercropped with garlic and four comparable plots were not intercropped. In garlic plots, garlic cloves were planted in mid-May, then approximately a month later a garlic leaf from every plant was snapped off and laid on to the strawberry plants. This continued fortnightly until the end of the trial on 23 August.

Assessments were divided into two phases: pre-assessments and full assessments. Pre-assessments occurred between the planting of garlic cloves and the snapping of garlic leaves. Full assessments occurred during the period that garlic leaves were being snapped. Assessments were made in all plots, with and without garlic, and involved; examining 20 strawberry plants for the presence of aphids, examining 20 strawberry button fruits for the presence of *N. cucumeris* and thrips, and tap sampling 20 strawberry plants for capsids and natural enemies. Throughout the assessment period, the main aphid species found was the strawberry aphid (*Chaetosiphon fragaefolii*).

Of the key findings, fewer *C. fragaefolii* occurred in 1st year strawberry plantings than second year plantings. More mummified aphids, parasitoids and predatory spiders were also present in the older crop. The garlic treatment significantly reduced *C. fragaefolii* in strawberry compared to untreated strawberry. Breaking garlic leaves possibly releases compounds which repel aphids and control is sustained by the continuous presence of garlic plants in the crop. However, this is yet to be confirmed. It is also unclear whether this reduction is sufficient to reduce *C. fragaefolii* damage to the crop.

More predatory spiders were counted in garlic treated strawberry than the untreated strawberry. Garlic possibly provides a structure on which to spin webbing, but this remains to be confirmed.

Encouragingly garlic did not significantly affect numbers of the predatory phytoseiid mite, *N. cucumeris*, indicating that garlic does not have a negative impact on this natural enemy. However, thrips numbers (adults and larvae) were also unaffected, challenging observations made by the grower who employs this approach. Differences between our approach and the grower's approach were the climatic conditions, the variety of garlic planted and possibly the higher frequency at which the grower's staff break garlic leaves.



Garlic plant growing in strawberry bag and breaking the garlic leaf fortnightly and dropping onto strawberry plants in the same grow bag.

Financial benefits

The estimated cost of applying this garlic treatment is £263-395/ha per year. This includes purchase, splitting, planting, breaking-leaves, harvesting and labour. However this can be more expensive. Another grower with experience of intercropping garlic has informed us that it can cost up to £1,000/ha (personal contact). In our trial there was no loss to the grower in terms of spaces taken up in grow bags for garlic, because two spaces were free in each, but this should also be considered.

Action points for growers

NOTE: during this trial although there is evidence of a reduction in aphid numbers, it is unclear whether this resulted in less aphid damage, so if adopting the following actions points, do so with caution. Be guided by these action points if you would like to try this on an area of strawberry on your farm:

- If planning to test garlic intercropping to control thrips, plant a hard neck variety such as ‘Violet’ in autumn for control the next year, although control of thrips using this method is still anecdotal.
- For maximum effect, consider planting at a spacing of every 1 m.
- When garlic is established, snap leaves at least fortnightly and lay on the strawberry crop.
- Continue to apply *N. cucumeris* and other pest control products at the usual rate in garlic treated strawberry.
- Renew strawberry plantings each year to reduce the chance of aphid numbers building up.

Task 4.2. Determine the effect of low and fluctuating temperatures on the ability of aphid parasitoids to parasitize the potato aphid, *Macrosiphum euphorbiae*.

Headlines

- The parasitoids *Aphidius ervi* and *Praon volucre* require minimum temperatures of 8°C and 12°C respectively to effectively parasitize the potato aphid.

Background and expected deliverables

Several species of aphid are regularly found affecting strawberry crops. Five of the most frequently found and most damaging are the strawberry aphid (*Chaetosiphon fragaefolii*), the melon and cotton aphid (*Aphis gossypii*), the shallot aphid (*Myzus ascalonicus*), the glasshouse-potato aphid (*Aulacorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*).

In recent years the control of early season aphids such as the potato aphid has become more problematic due to the withdrawal of commonly used insecticides. The remaining chemical options often have limited efficacy (AHDB Projects SF 140 and 156) and there is little evidence that biological controls are effective at the low temperatures experienced in early spring. The potato aphid causes damage to the crop through the production of honeydew and cast skins which result in sooty moulds and make the fruit unmarketable. Feeding action of these aphids can also result in distortion of the leaves and fruit. The species may breed all year round on strawberry crops if conditions allow and populations can build up rapidly in the spring.

Two aphid parasitoid species (*Aphidius ervi* and *Praon volucre*) commonly found in strawberry crops are known to readily parasitize potato aphid and may contribute to control. Both species occur naturally in the environment but can be introduced as biological control products as either a single species in the case of *A. ervi* or as part of a mix of six parasitoid species (*Aphidius colemani, A. ervi, A. matricariae, Praon volucre, Ephedrus cerasicola* and *Aphelinus abdominalis*).

Temperature is a key factor in determining the developmental time of insect species. Current knowledge suggests that the lower developmental threshold of *P. volucre* from the egg to mummy stage is 3.8°C and for mummy to adult development is 5.5°C. In comparison, the lower developmental thresholds for egg to mummy development and mummy to adult development of *A. ervi* in *Sitobion avenae* are 2.2°C and 6.6°C respectively. Although parasitoid development at low temperatures is extremely slow, *A. ervi* has been found to have a negative effect on pea aphid reproductive capacity following oviposition. This suggests that even if the parasitoid larvae do not kill the adult aphids as quickly early in the season, they may still be effective at reducing aphid populations.

Temperature can also affect the ability of the parasitoid to successfully locate and parasitize the aphid. Previous work has shown that oviposition by *A. ervi* and *P. volucre* on the grain aphid remained low below 10°C in both species. Flight and walking activity both increased with temperature, with *A. ervi* being consistently more active than *P. volcure*. The lower flight threshold was 10°C for both species and walking activity continued down to 8°C. This suggests that these parasitoid species would still be capable of locating aphids at low temperatures early in the season.

The aim of this work was to determine the effect of low and fluctuating temperatures on the ability of *A. ervi* and *P. volucre* to parasitize the potato aphid.

Potato aphid, *Macrosiphum euphorbiae*, on strawberry leaf petiole

Summary of the project and main conclusions

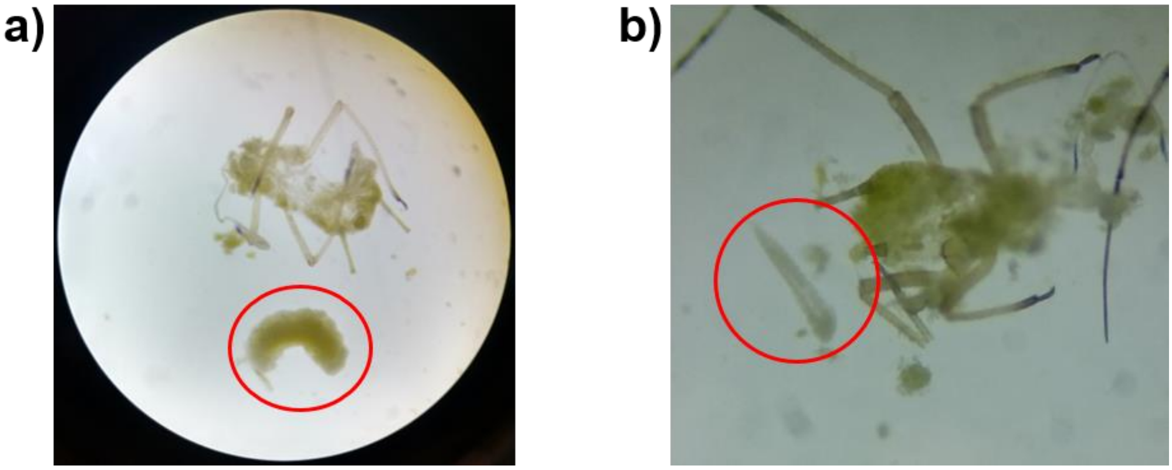
Air temperatures recorded in a polytunnel and an unheated glasshouse located in West Sussex confirmed that from early in the year, temperatures were above minimum thresholds for parasitoid activity. In the studied polytunnel, air temperatures rose above 12°C for at least 18% of the time in the month of February 2014, increasing to 33% in March and 52% in April. In the studied unheated glasshouse, air temperatures rose above 12°C for at least 11% of the time in the month of February 2015, increasing to 33% in March and 82% in April.

A series of experiments were completed under controlled temperature conditions. Each experiment used an unfurled strawberry leaf placed in a glass Petri dish with the stem immersed in 2.5 ml of water. The leaf was infested with 10 potato aphid nymphs and conditioned at the treatment temperature for 24 hours prior to the start of the experiment. Mated female parasitoids were separated out into a different glass Petri dish with access to a 20% sugar solution and conditioned similarly. Two female parasitoids were introduced to each dish of aphids and left for 24 hours at the treatment temperature. The parasitoids were then removed and the aphids were maintained on the strawberry leaf at 20°C for a further seven days before they were dissected to determine if parasitism had occurred. To confirm parasitoid larval development at low temperatures, additional replicates of parasitized aphid treatments and 20 mummies of each species were maintained at the lowest constant temperature at which parasitism was previously observed.

The minimum temperature at which parasitism of potato aphid by *A. ervi* occurred under constant conditions was 8°C. The minimum temperature at which parasitism of the same aphid species by *P. volucre* occurred under constant conditions was 12°C. There were a greater number of dishes with parasitism occurring in *A. ervi* compared to *P. volucre* as a result of the lower temperature threshold. Development of parasitoid larvae inside the aphid host was confirmed for both species of parasitoid in aphids maintained at constant low temperatures for two weeks. Similarly, adult emergence from aphid mummies was also confirmed at these constant low temperatures for both species.

Where temperatures fluctuated between 2°C and then eight hours at 8, 13 or 18°C, the minimum temperature at which parasitism by *A. ervi* occurred was 8°C. The minimum temperature at which parasitism by *P. volucre* occurred under fluctuating conditions was 13°C.

Both parasitoid species responded to higher temperature fluctuations (8°C for *A. ervi* and 13°C for *P. volucre*) and parasitized aphids in less than two hours when switched from 2°C.



Microscope images of *Aphidius ervi* larva dissected from *Macrosiphum euphorbiae* after a) 7 days at 20°C and b) 14 days at 8°C

Main conclusions

- The parasitoids *Aphidius ervi* and *Praon volucre* require minimum temperatures of 8°C and 12°C respectively to effectively parasitize the potato aphid.
- Fluctuating temperatures had no effect on the ability of the parasitoids to parasitize *M. euphorbiae* and both species were able to respond to short periods, as little as two hours, of higher temperatures.

- Both species have the potential to be used as early season biological control in polytunnels or glasshouses.
- The slow development of parasitoid larvae at low temperatures means that evidence of parasitism in the form of mummified aphids may not be apparent.
- Early season applications of control products may reduce the efficacy of natural and introduced biological control agents.

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of strawberries; worth £2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Consider autumn applications (post-harvest) of insecticides for aphid control as these have been shown to reduce populations of aphids found in crops the following year.
- Carefully monitor both aphid numbers and their associated natural enemies within crops in order to determine the need for control sprays. Do not treat all fields the same. Consider the species of aphid prevalent and the damage it may cause, including plant virus spread.
- Where spring applications of spray products are considered necessary, growers should ensure that there is good spray coverage, in particular the undersides of leaves and the crown of the plant. Consider the use of water sensitive papers to visualise how effectively spray applications achieve this.
- Some populations of aphid pests e.g. the melon and cotton aphid (*Aphis gossypii*) have developed insecticide resistance. Growers should ensure that they follow insecticide resistance management guidelines on the product label and rotate between products with different modes of action.
- Carefully consider the compatibility of the available product options with aphid natural enemies as well as the biological control programmes used to control other pests of strawberry crops.
- Consider early season releases of *Aphidius ervi* to control potato aphid when daytime temperatures exceed 8°C regularly for at least part of the day. *Praon volucre* is currently only available as part of a mix of parasitoid species (including also *A. ervi*) and may also be considered for releases when daytime temperatures exceed 12°C regularly for at least part of the day.

- Although aphid parasitism may occur at low temperatures, the development of the aphid parasitoid will be very slow at these temperatures and may take several weeks to complete. The absence of mummified aphids does not, therefore, reliably indicate lack of parasitoid activity. Carefully monitor aphid populations within crops for presence of adult parasitoids. If possible, move some aphid infested plants to a warmer environment for 7-10 days, checking regularly for presence of mummified aphids.

Task 4.3. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae* and melon-cotton aphid, *Aphis gossypii*, to be more compatible with IPM programmes.

Headline

- A single application of the approved product Batavia or the coded insecticide AHDB 9966 (= HDCI 108) gave durable (up to 3-week) and effective control of both melon-cotton aphid and potato aphid.

Background and expected deliverables

Several species of aphid are regularly found infesting strawberry crops. Five of the most frequently found and most damaging are the strawberry aphid (*Chaetosiphon fragaefolii*), the melon-cotton aphid (*Aphis gossypii*), the shallot aphid (*Myzus ascalonicus*), the glasshouse-potato aphid (*Aulacorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*).

In recent years the control of early season aphids such as the potato aphid has become more problematic due to the withdrawal of commonly used control products. The remaining chemical options often have limited efficacy (AHDB Projects SF 140 and 156) and there is little evidence that biological controls are effective at the low temperatures experienced in early spring. The potato aphid causes damage to the crop through the production of honeydew and cast skins which result in sooty moulds and make the fruit unmarketable. Feeding action of these aphids can also result in distortion of the leaves and fruit. The species may breed all year round on strawberry crops if conditions allow and populations can build up rapidly in the spring.

Outbreaks of melon-cotton aphid are also a concern for strawberry growers, as this species causes similar problems (feeding damage and contamination with honeydew and cast skins) as potato aphid. In addition, melon-cotton aphids are known to be resistant to multiple classes of insecticides, so this species can be very difficult to control.

The aim of this work was to assess the potential of plant protection products (without current approvals for strawberries) to control potato aphid and melon-cotton aphid. Comparisons were made with untreated control plants and with plants treated with approved products:

In 2016: Hallmark (lambda-cyhalothrin), Chess (pymetrozine) or Calypso (thiacloprid) with and without Silwet L-77 were compared to Silwet only or an untreated control.

In 2018/19: AHDB coded products, Batavia (spirotetramat) and Flipper (fatty acids) (both trials), Met52 OD (Metarhizium anisopliae) and Majestik (maltodextrin) (melon-cotton aphid trial), Benevia 10 OD (cyantraniliprole) and Spruzit (pyrethrins) (potato aphid trial) were compared to water only or unsprayed plots.

Summary of the project and main conclusions

2016 Semi-field trial on potato aphid:

Hallmark or Hallmark + Silwet gave 100% control, whilst Calypso or Calypso + Silwet gave moderate control initially (approx. 75% reduction in aphids numbers three days after spray application), but aphid numbers started to increase again eight days later. Chess, Chess + Silwet, Silwet, and the water control did not reduce potato aphid numbers on strawberry plants.

2016 Controlled environment room (20^{o}C and 60% RH) trial on potato aphid:

Each replicate consisted of a single aphid infested strawberry leaf. In the first bioassay, uninfested fully expanded strawberry leaves were sprayed on both surfaces to run-off and allowed to dry by placing the leaves on several layers of tissue paper before infesting each leaf with 20 potato aphid nymphs (1-3 instar). The second bioassay was prepared in the same way; however, leaves were infested with 20 potato aphid nymphs before spraying to run-off and allowing to dry. Calypso, Calypso + Silwet, Hallmark, and Hallmark + Silwet killed all aphids in both bioassays. Hallmark, and Hallmark + Silwet gave 100% kill within 24 hours in both cases whereas Calypso and Calypso + Silwet gave 100% kill within 24 hours only when aphids were directly sprayed. Chess + Silwet and Silwet applied on its own killed all aphids but only when aphids were directly sprayed. Chess applied without Silwet did not kill all aphids.

2018/19: Semi-field trials on melon-cotton aphid and potato aphid:

Single applications of the coded products AHDB 9966 and the approved insecticide product Batavia gave effective control of melon-cotton aphid and potato aphid on strawberries.

Effective control of melon-cotton aphid was also achieved using two applications a second coded product: AHDB 9951. The same product was also effective when tested against potato aphid (with just one application).

The other products tested were not associated with statistically significant reductions in aphid numbers. These included “softer” products such as Flipper, Majestik and Met52 OD. However, growers are likely to apply these products at shorter spray intervals than were used in some of the experimental treatments.

Main conclusions

- Hallmark gave 100% control of potato aphids with prolonged control while Calypso gave moderate control with reduced longevity. Control with Calypso is improved when the product contacts the aphids. Chess controlled potato aphids but only when mixed with Sliwet and when the spray contacted the aphids.

- A single application of the approved product Batavia or the coded product AHDB 9966 (= HDCI 108) gave durable (up to 3-week) and effective control of both melon-cotton aphid and potato aphid.
- A second coded product (AHDB 9951 = HDCI 109) also gave effective control of both melon-cotton aphid and potato aphid, following a single application (potato aphid trial) and two applications (melon-cotton aphid trial).
- The product coded AHDB 9966 was particularly effective against melon-cotton aphid, resulting in complete clean-up of aphids from plants. The same product was effective at controlling potato aphid, and even reduced numbers in the colonies that were hidden away on young, expanding leaves in the crowns of plants.

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of UK grown strawberries; worth £2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Consider autumn applications (post-harvest) of insecticides for aphid control as these have been shown to reduce populations of aphids found in crops the following year.
- Carefully monitor both aphid numbers and their associated natural enemies within crops in order to determine the need for control sprays.
- Where spring control applications are considered necessary, growers should ensure that there is good spray coverage, in particular on the undersides of leaves and the crown of the plant. Use water sensitive papers to visualise how effectively spray applications achieve this.
- Some populations of aphid pests e.g. the melon and cotton aphid (*Aphis gossypii*) have developed insecticide resistance. Growers should ensure that they follow insecticide resistance management guidelines on the product label and rotate between products with different modes of action.
- It is important to carefully consider the compatibility of the available product options with aphid natural enemies as well as the biological control programmes used to control other pests of strawberry crops.
- Useful information on the compatibility of available products is provided on biocontrol manufacturer websites including: https://www.koppert.com/side-effects/ or http://www.biobestgroup.com/en/side-effect-manual to help inform product selection.

- Since the trials were carried out in 2016, pymetrozine (Plenum or Chess) has lost its approval on strawberry and thiacloprid will not be approved for use from 2021. Hallmark is still effective and can be considered for early season control applications.
- Batavia provides effective control of melon-cotton aphid, potato aphid and other aphid species damaging strawberries. However, application of this product to strawberry crops (both protected and unprotected) is restricted to use up until 14 days before flowering or again after harvest and a maximum of two applications is permitted per season.

Objective 5. Improve control of aphids through the growing season.

Task 5.1. Thresholds for aphids and natural enemies; assessments to demonstrate confidence in control strategies.

Headline

- Before June, there are very few natural enemies in strawberry crops and therefore other control measures should be employed to supress aphid populations until natural numbers build.

Background and expected deliverables

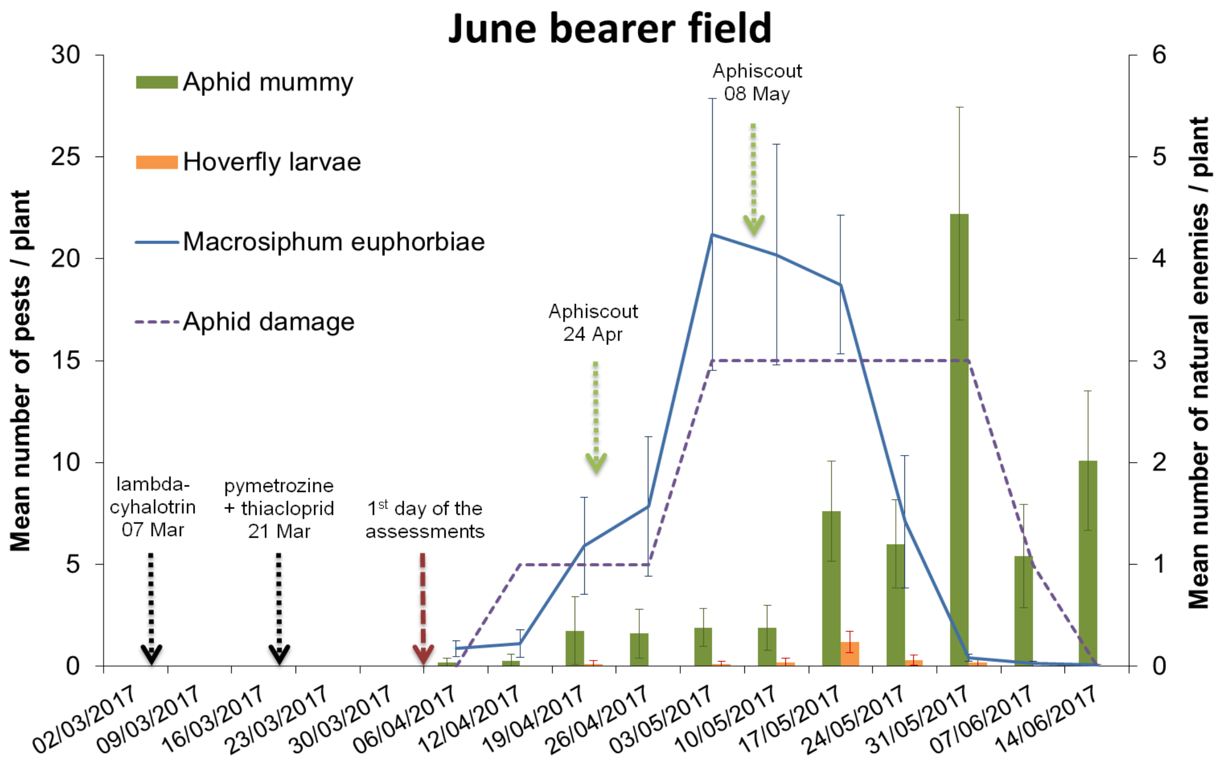
Strawberry crops are affected by a range of aphid pests. The most difficult to control is the potato aphid, *Macrosiphum euphorbiae*, as populations often resurge after spray application, probably due to incomplete control as shown in AHDB Project SF 140. In this project, it was also found that aphid numbers in the untreated plots had a tendency to decline rapidly by the end of the experiments because of the increases in natural enemies.

Crop protection sprays can be harmful to natural enemies which might otherwise be controlling pests in the crop. Often there is a lag between the build-up of the pest and the immigration and build-up of the predators and parasitoids. This lag period is often a critical time for the build-up of the natural enemies, but a time when sprays for aphids are more likely to be applied.

The aim of this study was to monitor and demonstrate the importance of naturally occurring aphid enemies in everbearer and Junebearer strawberry crops. We compared three crops in both Junebearer and everbearer fields for aphid build-up in the crop, in relation to natural enemy appearance. We also aimed to demonstrate the effects of pest spray programmes on potato aphid and natural enemies and show the relationship between population 'peaks and toughs' of pest and natural enemies. Studies were made on two farms with historically different degrees of aphid and natural enemy numbers. On each farm, three Junebearer and three everbearer fields were selected. To obtain an overall picture of the changes in natural enemy populations throughout the year, fields were chosen within the same or as similar a landscape as possible on the farms. Hence they had the same potential pool of pests and natural enemies.

Summary of the project and main conclusions

Both farms were visited each week from 5 April until 30 August. At each visit, 25 plants were thoroughly searched in a different central row of the cropping area and the numbers and species of aphids and natural enemies were counted and plotted.

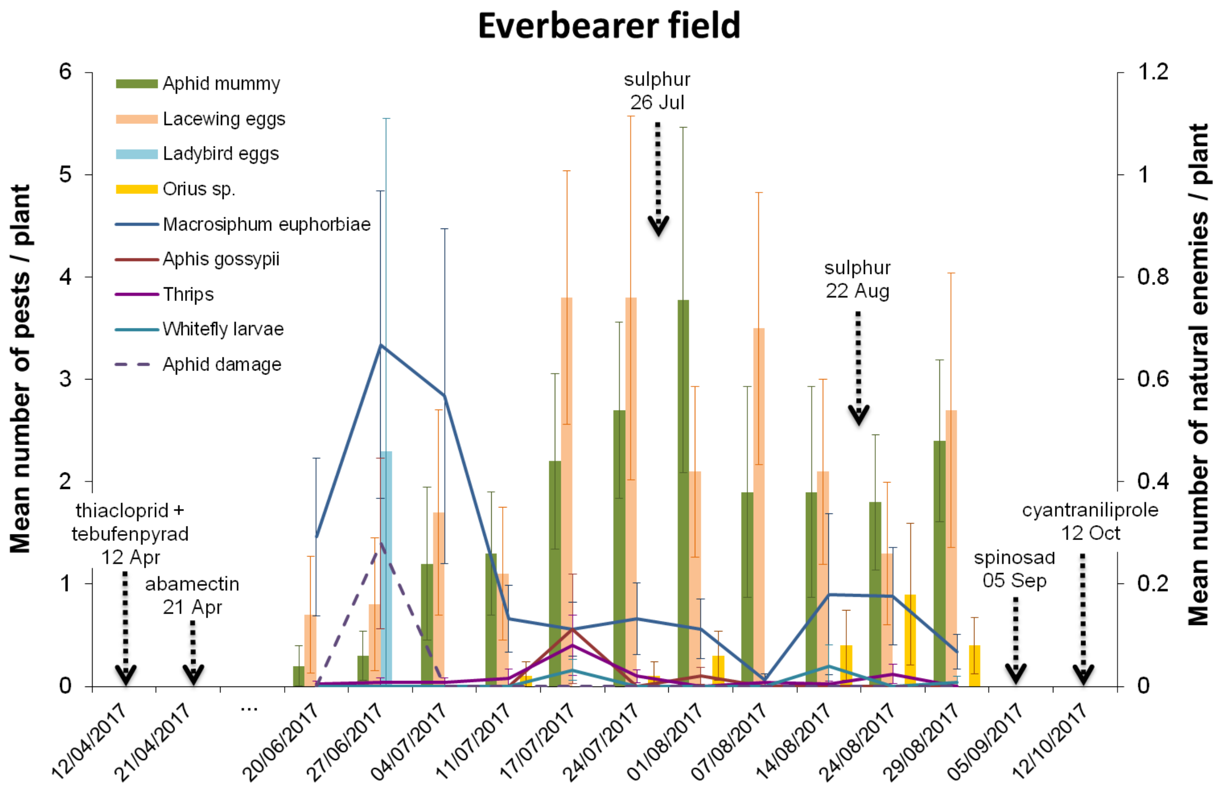


Aphids, parasitized aphids (mummies), lacewing eggs and hoverfly larvae per strawberry plant in a June bearer field. Maximum aphid damage is also shown; 0 – *none*, 1 – *slight* – some aphid skins, 2 - *moderate* – some aphid skins and honeydew but confined to leaves and 3 – *severe* – fruit/flowers affected, possible sooty moulds

There was a high variability in aphid species and numbers between farms and between crops in the same landscape. The main pest was potato aphid although other pests (*Aphis gossypii*, thrips, two-spotted spider mites and glasshouse whitefly) were present. Winged aphids peaked on 9 June. The main aphid predators recorded were the green lacewing and hoverfly larvae. Hoverfly larvae were present in low numbers across the two farms through the season and green lacewing larvae became more prevalent from 4 July. It is known that a single larva of the marmalade hoverfly (*Episyrphus balteatus*) can consume 660-1,140 aphids during development and a single green lacewing larva, 566-789 aphids before pupating. Other predators, such as spiders, ladybirds and *Orius* were also observed in low numbers.

The parasitoids *Praon* sp. and *Aphidius* sp. were the main species parasitizing aphids. *Aphelinus* sp. parasitism was also present but at a lower incidence.

The pest and natural enemy fauna was more diverse in the ever-bearers than in the June bearers. In both crop types, there were delays in the natural enemy population growth compared to the pest population growth. However, with the increase of natural enemies, the number of aphids declined. It is evident from this study, that before June there are very few natural enemies in strawberry crops and therefore other control measures should be employed to supress aphid populations until natural numbers build. Controls introduced by growers should be sensitive to the natural enemies likely to enter the crop later in the season.



Aphids, parasitized aphids (mummies), lacewing eggs and hoverfly larvae per plants in an ever-bearer field. The maximum aphid damage value is also given; 0 – *none*, 1 – *slight* – some aphid skins, 2 - *moderate* – some aphid skins and honeydew but confined to leaves and 3 – *severe* – fruit/flowers affected, possible sooty moulds

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of strawberries, worth £2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Each season, carefully consider choice of early-season aphid control products and wherever possible, select those that are likely to be less harmful to aphid parasitoids and *N. cucumeris* that may or may not be obvious within the crop. Use helpful information on commercial biocontrol suppliers' websites: https://www.koppert.com/side-effects/ or http://www.biobestgroup.com/en/side-effect-manual to help inform product selection.

Objective 6. Fill key gaps in knowledge on *Thrips fuscipennis* biology in strawberry crops so that IPM strategies can be developed

Headline

- During 2018 and 2019, adults of five thrips species that can damage strawberry fruit were confirmed at five sites.

Background and expected deliverables

Western flower thrips (WFT, *Frankliniella occidentalis*) is a serious pest of strawberry, feeding on flowers and developing fruits leading to damaged bronzed fruits which are unmarketable. In recent years, before work in this project began, ADAS identified the presence of rose thrips (*Thrips fuscipennis*) in strawberry flowers where fruit bronzing is occurring. Often rose thrips has been the predominant species in mixtures including the rubus thrips (*Thrips major*). At sites where fruit damage attributed to rose thrips has occurred, some growers have been using IPM programmes based on *Neoseiulus cucumeris* and good control of WFT has been achieved. However, at the same sites, rose thrips has not been controlled and growers have needed to apply plant protection products including spinosad (Tracer) to prevent further fruit damage. There is concern that, like WFT, rose thrips could develop resistance to Tracer and other chemical plant protection products. In addition, the number of Tracer applications permitted on each crop is limited and growers may prefer to reserve these for control of spotted wing drosophila (SWD).

The adult females of rose thrips and other *Thrips* species are darker than WFT but the species can only be identified using a microscope and specialist expertise. Fruit damage often seems to occur soon after 'dark' thrips adults are noticed in the flowers, so it is possible that rose thrips and possibly other thrips species adults are migrating into the crop and damaging the fruit before they start reproducing. Adult thrips would not be controlled by *N. cucumeris* which only feeds on first instar WFT larvae. The predatory bug *Orius laevigatus* will feed on thrips adults as well as larvae. However, *O. laevigatus* needs high temperatures to establish and they are sensitive to chemical plant protection products. In 2018 and 2019, the objectives were:

1. Determine when adult thrips activity starts and identify peaks in numbers between April and August inclusive.
2. Determine what species of thrips larvae develop in strawberry flowers.
3. Record fruit damage associated with rose thrips (*Thrips fuscipennis*) and other thrips species in flowers.

4. (2019 only) Determine colour attraction (using coloured water traps) of thrips species for potential development of a mass monitoring system.

Summary of project and main conclusions

Adults of five thrips species that can damage strawberry fruit were recorded at five sites in 2018 and 2019 where fruit damage attributed to rose thrips had occurred during the previous one or two seasons. These were the rose thrips (*T. fuscipennis*), rubus thrips (*Thrips major*), onion thrips (*Thrips tabaci*), flower thrips (*Frankliniella intonsa*) and western flower thrips (WFT, *F. occidentalis).*

In 2018, the earliest thrips species recorded during May in the June-bearer crops were the onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major*. Mean numbers were less than one per flower and only slight fruit damage occurred. In the June-bearer crops in 2019, *T. tabaci, T. major* and the rose thrips, *T. fuscipennis* were recorded from May and the flower thrips, *Frankliniella intonsa* was recorded from early June. Rose thrips were the most numerous reaching a mean of 1.2 adults per flower and only slight fruit damage occurred.

In 2019, numbers of the combined species peaked on 26 June in the two outdoor everbearer crops in Essex and Bucks at 2.2 and 3.5 adults per flower respectively and these were mainly rose thrips, *Thrips fuscipennis*. This differed from in 2018 when although rose thrips was the main species occurring during June, peak numbers of thrips adults peaked on 11 July at both sites and the predominant species was the flower thrips, *Frankliniella intonsa*.

In 2019, in the two tunnelled everbearer crops in Kent, numbers of thrips adults peaked on 11 June, in similar numbers to those in the two outdoor crops at around two and four adults per flower respectively and these were mainly WFT at Site 5 and rose thrips at Site 3. This differed from in 2018 in two tunnelled crops in Kent when peak adult numbers occurred in August and September and were mainly WFT. However, as in 2018, WFT was the predominant species at both sites in July and August.

In 2019, adults of the onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major* had similar patterns of activity to those in 2018 with a long period of activity between April/May and July/August. These species usually occurred in lower numbers than *T. fuscipennis* and, in the two tunnelled crops in Kent, than WFT, although at one of the Kent sites numbers of *T. major* were higher than those of *T. fuscipennis* and WFT in late May and late June.

Adults of the flower thrips, *Frankliniella intonsa* were found in higher numbers than usual in 2018. Very low numbers were found at the four monitoring sites in 2019. However, high numbers were recorded during 2019 in a different crop not monitored in this project, in the West Midlands and it has been recorded as damaging strawberry fruit in Denmark. This species is native to the UK but is thought to be more adapted to the more extreme climate in central Europe, so with climate change it could become a more common pest of UK strawberry crops.

In 2019, as in 2018, thrips larvae were recorded in lower numbers per flower than thrips adults in the two outdoor crops and were found mainly during July. Thrips species larvae confirmed in the two outdoor crops were the predatory banded wing thrips (*Aeolothrips* sp.), *T. tabaci, T. major* and *F. intonsa.* In the two tunnelled crops in Kent, greater numbers of larvae than adults per flower were recorded during August, when the species confirmed were mainly *F. intonsa* and WFT.

No larvae of *T. fuscipennis* were identified in strawberry flowers from any of the sites in either 2018 or 2019 and it is possible that this species does not breed in strawberry flowers. This could explain why *N. cucumeris* does not seem to control rose thrips, as this predatory mite feeds only on young thrips larvae and not on adults.

In both 2018 and 2019, fruit damage was only slight in the two outdoor everbearer crops. Damage was more severe at the two tunnelled sites in Kent but was well below a mean of 10% fruit area damaged which is usually considered as the 'threshold' above which fruit is downgraded. In 2019, fruit damage may have been caused by a mixture of *T. fuscipennis*, *T. tabaci, T. major* and *F. intonsa* adults in the two outdoor everbearer crops although *T. fuscipennis* was the predominant species. Fruit damage is likely to have been caused mainly by WFT in one of the tunnelled crops in Kent where it was the predominant species and by a mixture of WFT, *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* in the other tunnelled crop. Peak numbers of thrips adults (all species combined) per flower did not exceed four per flower at any site in both years so it can be concluded that on the everbearer varieties monitored (Favori, Finesse, Katrina and Murano), mean numbers of thrips adults per flower would need to be higher than this to cause severe fruit damage.

In both 2018 and 2019, numbers of thrips are likely to have been kept below damaging levels by a combination of released and naturally-occurring predators and by plant protection products applied for the control of strawberry blossom weevil and SWD.

An effective IPM programme needs to be developed for control of a range of thrips species other than WFT that are known to cause fruit damage. *Orius* is likely to feed on both adults and larvae of all thrips species but it needs warm temperatures to establish and these do not occur every year. In addition, *Orius* is very susceptible to some of the products applied for control of other pests such as SWD. *Aeolothrips* sp. is known to feed on thrips larvae but it is not known whether they also predate thrips adults. Although most thrips species other than WFT still seem to be susceptible to insecticides, there is a risk of pesticide resistance developing so reliance on control with chemical plant protection products is not sustainable.

In 2019, significantly more *T. fuscipennis* adults were caught in blue water traps than in yellow or green in one of the tunnelled crops in Kent. This result might lead to the opportunity to develop an IPM strategy for this species incorporating blue sticky traps for mass monitoring. No significant differences between the different coloured water traps were given in numbers of any of the other thrips species known to damage strawberry.

Financial benefits

Financial annual losses to the UK strawberry industry due to WFT damage exceeded £15m before an effective IPM programme was developed. Financial loss values due to other thrips species are not yet available but these species have the potential to cause severe losses if effective IPM strategies are not developed.

Action points for growers

- Thrips control should be planned as part of an Integrated Pest Management (IPM) programme. Until effective strategies are developed for thrips species other than WFT, the IPM programme should be the same as that commonly used against WFT. Further details are set out in AHDB Factsheet 14/15, but are summarised below.
- Release the predatory mites *Neoseiulus cucumeris* throughout the season from first flowers. The minimum release rate should be 25 per plant every week or fortnight, increasing to 50 per plant if numbers of thrips start to increase. This predator feeds only on young thrips larvae so it may not control rose thrips which might not breed in strawberry flowers.
- Apply the ground-dwelling predatory mites *Statiolaelaps scimitus* (formerly known as *Hypoaspis miles*) once at about 10 per plant. It is not yet known how effective these are against larvae of thrips species other than WFT that might drop to the ground to pupate, but as they are effective against WFT it is a sensible option.
- Release *Orius laevigatus* in addition to *N. cucumeris* once temperatures are suitable. This predator needs a minimum of 15°C for egg laying and over 20°C for good establishment. Commonly used release rates are a minimum of 0.25 to one *Orius* per plant, repeated after two weeks. *Orius laevigatus* is very sensitive to plant protection products so avoid using any that are harmful (consult your supplier or adviser).
- Some growers use blue roller traps in the leg rows to help control WFT adults in strawberry but there is no evidence yet that these also help to control other thrips species adults. Limited initial results of using coloured water traps in 2019 indicated that at one site, more rose thrips adults were caught in blue traps than in yellow or green.

- If fruit bronzing is seen, consider using an IPM-compatible plant protection product for control. Options include spinosad (Tracer) but growers may wish to reserve this for control of SWD. Do not use Tracer if only WFT are present as they are likely to be resistant to this product. Thrips species can only be confirmed using a high power microscope and specialist expertise. Consult your adviser on getting the thrips species identified and choice of plant protection product if required.