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Project leader:	Michelle Fountain, NIAB EMR
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Key staff:	Bethan Shaw, Adam Walker, Francis Wamonje, Celine Silva, Jonah Bubb, Ben Brough, Francesca Elliott, Zoe Clarke, Greg Deakin, David Harbour, Rebecca Channon, Sam De St Croix, Aidan Wickens (NIAB EMR); David Hall, Dudley Farman (NRI); Jude Bennison, Andrew Gladman, Peter Seymour, Elysia Bartel (ADAS); Gaynor Malloch; Ailsa Smith; Carolyn Mitchell; Ali Karley (JHI) **Advisors:** William Kirk (Keele University), Tom Pope (HAU), Janet Allen (ADAS), Clare Sampson (Russell IPM), Caroline Reid (Bioline Agrosciences)
Location of project:	NIAB East Malling, growers' holdings
Industry Representative:	**Chairman:** Stephen McGuffie **Industry representatives:** Andrey Ivanov, Steve Greenaway, Cristian Marmandiu, Richard Harnden
Date project commenced:	01 April 2020

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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.

Michelle Fountain

Deputy Head of Pest and Pathogen Ecology

NIAB East Malling, New Road, East Malling, Kent ME19 6BJ

Signature: Michelle T Fountain............................... Date

Stephen McGuffie

[Position]

[Organisation]

Signature ....   Date ....

Report authorised by:

Debbie Wilson

Senior Research and Knowledge Exchange Manger

AHDB

Signature ....   Date ....26/04/23...................................

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GROWER SUMMARY

The UK soft fruit industry is experiencing a period of change which offers opportunities for new and novel pest control options. Uncertain pesticide approvals, losses of actives (and associated insecticide resistance), emerging and invasive pests, labour shortages, and climate change offer the industry an opportunity to explore and exploit high-tech, non-pesticide control methods. These will span cultural to bio-control products for integration into pest management strategies for long lasting control, building up resilience through conservation biology and augmented applications of natural enemies.

Our project covers a range of strategies targeted at key pests identified by AHDB soft fruit panel including capsids, thrips, early-season aphids, and midges. We offer testing and integrating of solutions that are often applicable across the range of soft fruit crops, including cane fruits, strawberries and blueberries and consider control measures being applied for spotted wing drosophila (SWD).

In this project we 1) researched and reported new and emerging pests which pose a future threat to UK soft fruit production informing the industry ahead of potential pest outbreaks, allowing better preparation for prevention and control options; 2) tested the efficacy of the repellent successfully used in strawberry to control capsid in cane fruit and optimise the dispensing method for the repellent compound; 3) investigated the ability of Orius to predate the capsid juvenile stages for use under warmer, summer, temperatures; 4) determined whether early season aphids can be kept in check with a novel biocontrol strategy utilising mass releases of hoverflies with semiochemical attractants for retention in the crop; 5) determined winter survival of parasitoids in aphids in strawberry crops and how insecticide use in the autumn and spring can be adjusted to protect these key natural enemies; 6) gained scientific data on efficacy of floral margins on soft fruit crop protection and potential to harbour pest species to inform growers on sowings; 7) pilot tested a ‘push-pull’ method to prevent non-western flower thrips entering strawberry crops and causing fruit damage; 8) developed a culturing method for thrips so that cost effective experiments can be done to understand the biology, damage and control strategies for future use and, finally; 9) field tested a semiochemical push pull strategy of control of midges in cane fruit.

This final report includes Grower Summaries on all the work done in the three years with a Science Section containing the detail of research in 2022. Previous Science Sections are in the first- and second-year reports.

WP1. Identify and report new and emerging pests which pose a future threat to UK soft fruit production (Year 1-2, Lead; NIAB EMR, Contributors; ADAS, JHI, NRI)

Headline

A range of future potential pest threats to the soft fruit industry have been identified.

Background

Whilst there continues to be successes in pest control strategies, changing climate (Sharma 2016; Taylor et al. 2018), the introduction of invasive pests into new territories (Early et al. 2016) and resistance to a declining selection of Plant Protection Products (PPPs) (Lamichhane et al. 2016) raises new challenges for food production. It is estimated that arthropod pests destroy up to >20% of annual crop production worldwide, at a value of more than US$470 billion (Fried et al. 2017; Sharma et al. 2017; Savary et al., 2019). In the last decade, in the UK, growers of soft fruit crops have been required to shift from the use of broad-spectrum PPPs to fewer selective PPPs combined with biopesticides, augmented and conservation biocontrol, cultural practices and novel semiochemical manipulation of insect pest populations to reduce the incidence and damage caused by pests. However, the removal of some broad-spectrum PPPs in combination with a warmer and more unpredictable climate can result in higher populations and unpredictable outbreaks of familiar and native, and non-native species (Hulme 2016). Increased movement of plant material around the globe in recent decades (Chapman et al. 2017) also leaves UK fruit production vulnerable to new pests, which often thrive in the extended season and warmer temperatures created by protected cropping. Hence, new monitoring tools for both arthropod pests and their natural enemies are needed in combination with new, less environmentally damaging approaches that can be integrated, but not at the detriment of other pest outbreaks. The reduced range of PPPs inevitably results in the same products being applied to crops sequentially, hence other control measures are needed which can be interspersed with remaining conventional PPPs, but which have different modes of action to reduce the occurrence of resistance to remaining products.

In 2020 the SF 174 team attended national and international meetings to report back potential new and invasive pests of soft fruit crops. This has been summarised in the tables, and selected references and web links). There has been liaison with AHDB, Fera, Animal and Plant Health Agency, RHS, and EPPO and CABI databases have been searched to identify and alert growers and agronomists to potential new pest problems.

Future potential pest threats to the UK soft fruit industry are summarised in tables in the report, including their, Species / Common name, Geographic distribution, Hosts / Crops, Symptoms, Description, Control used in other parts of world, Monitoring, and potential Risk for soft fruit.

Threats include three species of thrips; Japanese flower thrips, and flower thrips, chilli thrips, a true bug; Brown Marmorated Stink Bug, a whitefly; honeysuckle whitefly, a scale insect; white peach scale, two beetles; Japanese flower beetle, whitefringed weevil and several tortix moths; strawberry tortrix, *Blastobasis*, lesser apple leaf-folder, *Acleris nishidai*, *Acleris fimbriana*, yellow tortrix moth and snowy-shouldered acleris moth. In addition, a spider mite threatens to cause damage in glasshouse crops; *Tetranychus mexicanus*. Details of useful literature including links to keys are also included. Another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*). For species names, see full tables in main report.

In 2021 we also met with Wageningen scientists to discuss progress with Brown Marmorated Stink Bug research and attended various on-line conferences where we were made aware of additional potential future pest threats to the soft fruit industry. Summary tables in the main report were updated with the latest scientific information and another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*).

Concern was raised on pests of hedgerows/ windbreaks in the UK. Alder leaf beetle which causes defoliation of *Alnus incana* & *A. glutinosa* windbreaks and has also been seen on *Populus* TX 32 windbreaks surrounding soft fruit & vegetable crops at site near Worthing. Other hedgerow pests of note include woolly beech aphid (*Phyllaphis fagi*), scale insects such as Euonymus scale (*Unaspis euonymi*), beech scale or felted beech coccus (*Cryptococcus fagi*), vine weevil (*Otiorhynchus sulcatus*), winter moth caterpillars and beech red spider mite (*Eotetranychus fagi*).

Summary

Future potential pest threats to the UK soft fruit industry include;

1. three species of thrips; Japanese flower thrips, Taiwanese flower thrips and Chilli thrips
2. two true bugs; Brown Marmorated Stink Bug and Yellow Spotted Stink Bug
3. a whitefly; honeysuckle whitefly,
4. three scale insects; white peach scale, Indian wax scale, and tortoise wax scale,

5. six beetles; Japanese flower beetle, whitefringed weevil, citrus longhorn beetle, tortoise beetle, peach red necked longhorn, and *Anthonomus bisnignifer* - a species raised as a potential concern, but little information has been found on this to date
6. several tortix moths; strawberry tortrix, *Blastobasis*, lesser apple leaf-folder, *Acleris nishidai, Acleris fimbriana,* yellow tortrix moth and snowy-shouldered acleris moth, and
7. a spider mite, *Tetranychus mexicanus*.

Financial Benefits

Native and non-native pests are increasing due to increased transport of goods globally and fewer approved broad-spectrum products. These are likely to have financial impact on fruit growers.

Action Points

- Growers and their agronomists should be vigilant to new pests in the UK
- All imported plant material should be isolated and rigorously checked before planting
- Non-native species should be reported to plant health https://www.gov.uk/government/organisations/animal-and-plant-health-agency/about/access-and-opening
- Note that information in this report was correct at the time of writing.
- All control options should be checked with a BASIS qualified adviser.

Task 2.2. Dose and method of deployment of capsid repellent in strawberry and cane fruit (Year 1-2, Lead; NIAB EMR, Contributors; NRI, Russell IPM)

Headline

A product (Lybolty) developed in this project has been commercialised by Russell IPM to repel capsids from crops.

Background

In previous work under SF156, successful control of European tarnished plant bug, *Lygus rugulipennis,* was achieved in strawberry in two years of replicated field trials using a push-pull approach based on synthetic semiochemicals (Fountain et al. 2021).

The repellent "push" component, hexyl butyrate (HB), is a component of the sex pheromone of several *Lygus* species. To date, monitoring crops containing the HB repellent has not revealed any adverse effects on natural enemies.

Various blends of hexyl butyrate were formulated in blister packs by Russell IPM and their release rates and longevity evaluated in the laboratory at NRI. A blister-pack formulation of hexyl butyrate was selected having similar release rate to the NRI polyethylene sachets used in all previous trials. However, the lifetime of these formulations was less than two weeks at 27°C and 8 km/h windspeed. Russell IPM polyethylene sachet formulations based on their commercial "Dismate" formulations were evaluated, and a thick-wall formulation was developed with satisfactory release rate and lifetime of over five weeks under laboratory conditions. Formulations of HB were optimised through laboratory release rate measurements with the aim of developing a suitable formulation(s) for evaluation in field trials during 2021. Results produced two HB dispensers both providing a convenient formulation of HB; 1) a blister pack (Russell IPM) and 2) a "thick-wall" polyethylene sachet (Russell IPM). The current commercial product is a wax-like disk.

Summary

Between June and September 2020, a field trial was done in a raspberry plantation in Kent with a known history of capsid damage to fruits and foliage. The objective was to generate data to demonstrate that the semiochemical push could control capsids in cane fruits. The push was the standard formulation used in push-pull trials in commercial strawberry 2017 and 2019. The raspberry plantation was divided into 6 replicates, each divided into the following 3 equal sized plots to test two methods of deploying the semiochemical push; 1) capsid repellent sachets deployed every 2 m along the row at 1 m height, 2) capsid repellent sachets deployed every 2 m along the row, but at alternating staggered heights 0.5, 1.0 and 1.5 m, compared to 3) an untreated control. We also tested whether the semiochemical push had side effects on numbers of beneficials or caused phytotoxicity to raspberry plants.

Fortnightly assessments were made in all plots. Assessments per plot consisted of 1) tap samples of 100 young lateral stems, counting capsids and beneficials, 2) damage assessments of approximately 100 raspberries, 3) damage assessments of approximately 100 young leaves, and 4) a phytotoxicity assessment after 1 month attachment of the repellent to young lateral stems.

Both push treatments significantly reduced numbers of capsids in the crop, and damage to fruit and young leaves. Treatments had no clear adverse effect on numbers of beneficials counted in the crop, due to low numbers sampled, hence this may need further investigation. However, previously in strawberry, push-pull treatments had no adverse effect on numbers of beneficials counted in the crop. The repellent did not cause any detectable phytotoxic effects to the raspberry plants.

The aim of the field trial in 2021 was to test increasing the spacing of the HB dispensers in the crop from the standard 2 m spacing, to further reduce cost whilst maintaining control of capsids by deterring them from crops.

The trial was carried out by NIAB East Malling on commercial strawberry crops at five locations in Kent. Previous HB dispenser spacings (2 m) were compared to lower densities (5 m and 20 m). Russell IPM blister packs were used during the first two weeks and the polyethylene sachets during the next four weeks.

Numbers of both capsid nymphs and adults were lower in the treatment plots overall compared to numbers in untreated plots. However, capsids were less abundant than in previous years and there were no significant treatment effects. Damage was also low with no significant treatment effects. There were no detectable effects of the treatments on numbers of beneficials in the plots and the formulations showed no phytotoxic effects, so this approach is compatible with IPM strategies.

Financial Benefits

L. rugulipennis causes damage in raspberry and *L. pabulinus* terminates fruiting laterals in this crop (Cross 2004). Up to 100% of fruit can become downgraded because of capsid damage to raspberry. Capsid bugs can also taint the fruit with their odour. During the trial in 2020, we observed an 8% increase in undamaged fruit where the push was applied compared to untreated plots. *L. pabulinus* is also a damaging pest of blackcurrant, apple, pear and cherry. Recent changes to PPP approvals have seen registration withdrawal for key capsid controlling products in the EU, including the broad-spectrum organophosphate chlorpyrifos, and more recently, the neonicotinoid thiacloprid. This repellent strategy offers a comparable alternative to PPPs and is IPM compatible.

A commercial formulation of the capsid repellent has been developed that lasts for at least five weeks compared with the two weeks of previous formulations. Increasing the spacing of the dispensers from 2 m to 5 m or 20 m would decrease cost by 6-fold and 100-fold respectively.

Action Points

- Monitor for capsids around the crop from spring:
  - For *L. rugulipennis* 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
  - For *L. pabulinus* use a blue sticky trap baited with synthetic attractants
- *L. rugulipennis* overwinter as adults in weeds surrounding soft fruit crops, breeding in spring and then adult offspring migrate into crops late June/early July
- *L. pabulinus* overwinter as eggs in young shoots of various shrubs and trees. Nymphs of the first generation emerge in April or May
- Management of weeds that host capsids in and around the crop is recommended. Weed hosts include groundsel, mayweed, fat-hen, nettle, dock and common mugwort
- Weedy areas could be replaced with perennial wildflowers which host a range of natural enemies and pollinators important to fruit crops and can outcompete undesirable weeds (SF 174)
- Contact Russell IPM for more information on the repellent https://russellipm.com/contact/
- Growers are encouraged to trial the commercial product on crops where capsids are known to cause damage.

Task 2.3. Ability of *Orius* to predate the capsid, *Lygus rugulipennis* juvenile stages (Year 1, Lead; NIAB EMR)

Headlines

Laboratory experiments in year one showed increased mortality of *Lygus rugulipennis* in the presence of *Orius laevigatus*.

In the second year (2022), there was no reduction in damage to strawberry fruits by *L. rugulipennis* where Orius was introduced onto strawberry plants.

The presence of an alternative prey species, Western flower thrips *F.* occidentalis, also had no measurable impact on the predation Orius on *L. rugulipennis* or subsequent fruit damage.

Background and expected deliverables

Capsids, such as the European Tarnished Plant Bug (*Lygus rugulipennis* Poppius), cause direct crop damage by feeding on developing fruits (Easterbrook, 2000). This results in deformation known as 'cat-facing', making the fruit unmarketable. Chemical Plant Protection Products (cPPP) are typically relied on to supress capsid populations. However, conventional use of broad-spectrum insecticides for capsid control may disrupt biological-based Integrated Pest Management strategies used for other major soft fruit pests, such as Western Flower Thrips (WFT - *Frankliniella occidentalis*).

Anecdotal information from growers indicates that the presence of *Orius laevigatus* (Say), used to control WFT in the summer months, may also reduce capsid numbers. This was supported by data collected in project SF 174 in which fewer *L. rugulipennis* were found in tap samples where *Orius* were also collected.

The purpose of this trial was to investigate the possible role of *Orius* in *Lygus* predation in soft fruit crops, and specifically to determine the ability of *Orius* to predate on *L. rugulipennis* and ability to reduce fruit damage. In the first year of the study, laboratory-based bioassays assessed the impact *Orius* adults and nymphs had on juvenile *Lygus* stages. Wild caught *Lygus* adults were used to establish breeding cultures. Green beans containing *Lygus* eggs were offered to *Orius* for several days and the number of nymphs that emerged were counted. *Orius* behaviour was also observed using an insect-tracking software (EthoVision) in the presence of *Lygus* exposed green beans (containing *Lygus* eggs) compared to untreated green beans. The amount of time spent in the vicinity of the 2 bean treatments was recorded. Nymph predation assessments were conducted over 24- and 72-hours in which different *Lygus* nymph instars were exposed to *Orius* and mortality was compared to untreated controls.

There was a reduction in emergence of *Lygus* nymphs from eggs exposed to *Orius* although this was not significant. From the insect-tracking software, *Orius* spent more time in the vicinity of green beans that contained *Lygus* eggs than those that did not. There was a significantly higher probability of *Lygus* nymph death at both 24- and 72-hours of exposure to *Orius* regardless of *Lygus* instar in comparison to the control. For both 24- and 72-hour exposures there was a 17 and 18% probability of *Lygus* death in the *Orius* treatments (regardless of *Lygus* instar and *Orius* stage) compared to <0.01 and 0.02% in the controls respectively.

The second year of this project aimed to evaluate the impact of *O. laevigatus* on *L. rugulipennis* numbers and damage in a semi-field setting, more realistic, environment. In addition, the impact of *L. rugulipennis* predation in the presence of an alternative prey source, *F. occidentalis,* was also assessed.

Summary of the project and main conclusions

Cages housing four potted strawberry plants were inoculated with female *L. rugulipennis* and/or *F. occidentalis*. The number of pests and subsequent damage was assessed in the presence or absence of *O. laevigatus* over a period of 6 weeks. Applications of *O. laevigatus* did not reduce numbers of *L. rugulipennis* and did not reduce numbers of damaged fruit compared to untreated (no *Orius*) equivalents. The presence of an alternative prey, *F. occidentalis*, did not have a noticeable effect. It is possible that high temperatures in 2022 during the trial (up to 43°C) impacted the experiment or that *Orius* in caged strawberry plants compared to individual insects in Petri dish did not predate *Lygus*.

Action points for growers

- Although no influence of *O. laevigatus* on *L. rugulipennis* was found in the one year experiment on strawberry plants, it is recommended to release the predator for control of *F. occidentalis* in warmer summer temperatures.

Task 3.1. Promoting the control of early aphid in strawberry by augmenting and retaining aphidophagous hoverflies in the crop (Year 1/2, Lead; NIAB EMR, Contributors; NRI, Russell IPM, Koppert UK

Headline

- Synthetic hoverfly lures (including the commercial standard MagiPal™) deployed in strawberry crops attracted wild aphid feeding hoverflies and possibly helped to retain commercially released *S. rueppellii*.
- Where there were substantial aphid colonies, higher numbers of the commercially released hoverfly (*S. rueppellii*) were observed. This indicates hoverflies should probably be released once aphid numbers build up because hoverflies are unlikely to lay eggs in small aphid colonies.

Background

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years partly due to a reduction in chemical plant protection products and a need for suitable alternatives.

Hoverflies (Family: Syrphidae) are important predators of aphids. Adults have a high fecundity and larvae are voracious predators. However, naturally occurring hoverflies often only migrate into crops as pest populations increase, and thus too late in the season to prevent damaging populations of the pest from occurring.

Herbivore-induced plant volatiles (HIPVs), such as methyl salicylate, can be formulated into commercially available lures to attract beneficial insects, including hoverflies, into crops. Moreover, the addition of other HIPV's, has been shown to increase hoverfly numbers, demonstrating there is considerable potential to improve the attractiveness of commercially available lures using readily available chemicals, with the added benefit that such lures do not require regulatory approval. Added to this, at least three companies have been successful in mass producing hoverflies for release in commercial crops.

During 2021, a field trial was done in polytunnel grown June bearer strawberry, to test whether deployments of aphidophagous hoverflies could reduce populations of aphids (*M. euphorbiae*) early in the spring and whether this interaction could be enhanced using 2 types of hoverfly attractant to retain aphidophagous hoverflies in the crops. The trial was set up mid-April 2021 (after the aphid clean-up spray) in 4 replicate strawberry crops in Kent and ended early-June. Strawberries were June bearer varieties grown conventionally on tabletops in polytunnels. Each replicate crop was divided into 4 plots; 1) control (untreated), 2) hoverfly release only, 3) hoverfly release plus MagiPal™ lure, 4) hoverfly release plus NRI modified lure. Plots were mostly in the centre of separate strawberry fields to avoid hoverfly migration out of plots.

Seven days after, hoverflies (*Episyrphus balteatus*), in-kind contribution of Jasper Hubert at Koppert UK Ltd), were deployed in treated plots, sentinel strawberry plants infested with equal numbers of *M. euphorbiae* aphids, were deployed in all plots to attract hoverfly egg laying and compare subsequent aphidophagy between treatments. Plants were returned to NIAB East Malling and aphid and hoverfly life stages counted during 3 weeks incubation.

Trial findings were inconclusive and did not show enhanced aphidophagy in strawberry early in the season. Numbers of hoverfly and aphid counted on sentinel plants after field deployment were highly variable, possibly because plants were on the ground where other predators (e.g. Carabidae) may have reduced aphid numbers on sentinel plants. However, there was some evidence to suggest that hoverfly activity was positively correlated to aphid abundance. Most other arthropods recorded on sentinel plants were parasitoids (indicated by mummified aphid and adult parasitoids), but we found no clear treatment effect, due to numbers being low and variable between plots.

In 2022, we aimed to test whether 1) which volatile organic compounds (VOCs) are most attractive to natural aphidophagous hoverflies and other natural enemies in strawberry crops, and 2) investigate if a commercially available attractant (MagiPal™) could retain commercially produced hoverflies and attract natural aphidophagous hoverflies and other natural enemies into strawberry crops.

Summary

Between May and September 2022, two field trials were set up in polytunnel grown commercial everbearer strawberry crops with a history of high aphid numbers.

Trial 1 investigated which VOCs are most attractive to natural aphidophagous hoverflies and other natural enemies. Dispensers were formulated each containing a different VOC blend, then these were hung individually in white Delta Traps (Agralan ltd), suspended below tabletops 20 m apart. Seven days later, 5-minute crop walk surveys were done within a 10 m radius of each Delta trap and hoverflies and natural enemies observed on plants were counted. Following crop walk surveys, white sticky inserts (Agralan ltd) were placed inside Delta Traps. After 7 days sticky inserts were removed and adult hoverflies caught were identified to species (when possible) and counted. This trial was done at two different farms in May and again in July to increase the numbers of hoverfly species assessed.

Results showed almost twenty times more wild hoverfly adults were captured on sticky traps with VOCs compared to control traps without VOCs. However, VOC dispensers with blends did not improve the attraction of hoverflies in strawberry crops compared to the commercial standard dispenser. More than 50% of the hoverfly species on sticky traps were *M. mellinum* and *E. corollae*. Other species were included *E. balteatus*, *S. rueppellii*, *E. latifasciatus* and *C. festivum* in roughly equal numbers. Larvae of all species identified are aphidophagous and adults are nectar feeding. Almost 4-fold more hoverflies were present in strawberry crops in July compared to May.

Crop walk surveys did not detect an increase in numbers of adult hoverflies where VOCs were deployed. It is possible that our survey area was too small to detect differences between hoverfly numbers as these are highly mobile adult flying insects. Free-flying hoverflies in order of highest abundance were *E. corollae*, *E. balteatus*, *S. rueppellii* with very few *E. latifasciatus*. There was no evidence that our VOC treatments increased numbers of other aphid natural enemies.

The objectives of trial 2 were to investigate whether the commercially available VOC lure (MagiPal™) can retain commercially released adult *S. rueppellii* and attract natural aphidophagous hoverflies into 1 ha commercial strawberry crops and whether hoverfly releases and MagiPal™ dispensers could reduce numbers of aphids in commercial strawberry crops. The trial was limited due to its large scale across two farms and so results should be interpreted with caution.

The trial was set up in May at two farms. At each farm there were two 1 ha. strawberry crops; a 'treated' crop containing a grid of 100 MagiPal™ dispensers fastened to grow bags at 10 m intervals and releases of 1000 *S. rueppellii* hoverfly pupas every 4 weeks. The other crop was left as an untreated 'control'. Every week for 11 weeks, crop walk surveys and tap samples were done within each crop and hoverflies (including the released species), aphids and natural enemies observed on plants were counted.

Crop surveys found more *S. rueppellii* in crops where they had been released and where the MagiPal™ had been installed at both farms compared to the untreated (control) crops. Numbers of other native species of adult hoverflies were higher in the treated crop than the untreated control at one farm, but lower at the other. As with trial 1, most species of wild hoverfly identified in the field at both farms were *E. corollae* and *E. balteatus*.

Results of aphid counts were inconclusive; one farm had fewer aphids in the treated crop and the other had fewer aphids in the untreated control. The same trend was observed during aphid tap sample assessments at each farm. Overall, aphid numbers per plant were higher at farm 2 than farm 1 during plant inspections and this may go some way to explaining why higher numbers of *S. rueppellii* were observed at farm 2. Female hoverflies are more likely to remain and lay eggs where there are high numbers of aphids for their offspring to feed on.

Finally, there was no evidence that MagiPal^{TM} attracted other aphid natural enemies into the studied crops on the two farms.

Financial Benefits

None currently

- Product costs are dependent on volume; consult an advisor.
- During the trial in 2022, MagiPal^{TM} dispensers were deployed once (late June) during the 12-week trial period, at a rate of 100 per ha, costing approximately £130-140 per ha (Based on 100 lures to the ha.) plus labour.
- *S. rueppellii* hoverfly pupae (Predanostrum 100 pupae per tube, Koppert UK Ltd) were deployed 3 times (monthly intervals) at a rate of 1000 pupae per ha, each deployment. In 2022 the price of Predanostrum (*S. rueppellii*) tube of 100 pupae was £42.98. Ten of these were deployed per ha, per release, plus labour.
- The recommended release rate for *E. baltatus* hoverfly (Syrphidend 50 pupae per tube, Koppert UK Ltd), as used during the 2021 field trial, is ~500 hoverfly pupae per ha. In 2022 the price of Syrphidend, pack of 50 pupae was £48.65. Ten of these were deployed per ha
- Labour costs should be added to these figures.

Action Points

- To increase chances of lures and hoverfly releases controlling aphid, treat strawberry crops where aphid numbers are building up and native aphid predators are low in the crop.
- To treat aphid build-ups early in the growing season, deploy *S. rueppellii* hoverfly tubes and MagiPal^{TM} lures when mean daytime temperature exceeds 8°C and night-time is 0ºC or above, and the crop is in flower to provide pollen for hoverfly adults.
- Secure hoverfly tubes at crop height.
- Deploy 100 MagiPal^{TM} lures per hectare in a grid pattern throughout the crop (at 10 m intervals) (Russell IPM).
- Place the lures at or above crop height (Russell IPM) (e.g. lures can be wedged between growbag and tabletop).
- Replace lures every 2-3 months, or as recommended by your advisor (Russell IPM).

- During the main growing season *S. rueppellii or E. balteatus* hoverflies can be released to control aphid and help pollinate the crop.

Tasks 3.4. Parasitoids for aphid control in overwintered protected strawberry (Lead NIAB, Contributors JHI and Harper Adams University)

Headline

Parasitoids overwinter inside aphids in strawberry crops.

It is important to know if parasitoids (mummified aphids) are present in the crop going into the winter as this can inform the need to release parasitoids in the spring.

This study showed that the diversity of aphids and parasitoids was not what we predicted and hence more research is needed to understand the increasing complexity of these pest and natural enemies in modern strawberry crops.

Background

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years. Unfortunately, potato aphid populations can persist in over-wintered crops, surviving at temperatures below freezing and continuing to grow and develop very slowly when the temperature exceeds just 1°C. With the first warmer days of spring, the aphids start to grow and reproduce much more rapidly, leading to early outbreaks and damage. The withdrawal of chlorpyrifos and thiacloprid leaves soft fruit growers with few conventional options for early season aphid control, especially when temperatures are too low for biopesticide efficacy. In addition, aphid colonies can be difficult to target with contact-acting PPPs in strawberry, early in the season, because they are often out of spray range in the crown of strawberry plants.

With limited insecticide options now available, growers are increasingly relying on releases of parasitoid wasps in early spring for aphid biocontrol. Two parasitoid species (*Aphidius ervi* and *Praon volucre*) can be particularly effective at parasitizing potato aphid. Both species are present in the mixed parasitoid products available to growers for aphid control on soft fruit (e.g., FresaProtect from Viridaxis, Aphiline Berry from Bioline, AphiScout from Koppert, etc.), and *A. ervi* is also available separately from some biocontrol companies. However, there are three main possible areas of risk and uncertainty associated with release of parasitoids for early-season aphid control:

- Failure of parasitism due to low temperature
- Impact of insecticide residues on parasitism
- Failure of parasitism due to resistance

We aim to address some of these potential risks, so that growers can be better informed in releasing parasitoids appropriately (in terms of species and timing) for effective early season biocontrol of aphids. In addition, it was observed from work in SF 156 that some parasitoids may be surviving in aphids over the winter and ready to emerge the following spring giving a head-start to biological aphid control. However, it is difficult for growers to observe this hidden biocontrol and PPP harmful to emerging parasitoids maybe applied risking early season aphid control.

Summary

Three grower's sites in Kent and Scotland were used. Strawberry tunnels were surveyed for aphid and parasitoid species on 8 occasions at regular intervals between August 2021 and June 2022. Up to 80 aphid infested leaf samples were collected per site per sampling occasion and incubated in the laboratory at 20-23°C for 3 weeks. On each assessment, and for each sample, the following was recorded: i) vegetative material sampled; ii) aphid colony size; iii) number of parasitoids emerged at 7, 14 and 21 days of incubation after collection; iv) number of mummies present; v) number of other aphid predators; and vi) taxa of aphid parasitoid.

In addition, aphids from sites 1, 2 and 3 were sampled and DNA extracted for molecular taxonomic identification. Sequences from individuals collected at sites 1 and 2 matched sequences from *Aphis fabae* (black bean aphid). The sequence generated from site 3 aphid material matched *Chaetosiphon fragaefolli* (strawberry-aphid); this was the dominant aphid species at Site 3 although *Macrosiphum euphorbiae* was also detected at low frequency.

In late March and early April 2022, the releases of a parasitoid mix were made at a rate of 0.25 parasitoids per plant, and aphids were sampled before, during and after the release period to assess the prevalence of parasitoids.

In 2021, levels of parasitism were higher in August than September and were highest at Sites 1 and 3. Numbers of parasitoids emerging between sites were variable, probably due to management practices and number of aphids present. For example, discussion with the manager of site one at the beginning of sampling revealed no insecticides had been used up to the point of first sampling.

In 2022, the levels of parasitism were low in February and increased to a maximum in early March (before parasitoid release) then slowly declined to intermediate levels in April to June. There were no significant differences in aphid abundance or parasitism level between the control plots and the treated plots. Up to 12 morphotypes of parasitoids were collected. Parasitoids were assigned to genus following visual and molecular identification, although many samples could not be confirmed definitively, and were tentatively assigned to the

genera *Dendrocerus, Kleidotoma, Praon, Lysiphlebus, Binodoxys, Aphidius* and *Aphelinu*s genera. The genera of parasitoids detected varied with the aphid species sampled on each sampling occasion.

Financial Benefits

Assessing the level of natural aphid parasitism and parasitoid activity in strawberry tunnels in early spring could help growers decide the costs/benefits of parasitoid release and the impacts of early season sprays.

Action Points

None currently.

Task 3.5. Ability of floral margins to support natural enemies and pests in proximity to soft fruit crops (Year 1-2, Lead; NIAB EMR)

Headline

Wildflower margins could be source of natural enemies and pollinators, however, impacts into tunnelled crops are minimal and sowing wildflowers inside polytunnel crops should be the focus of future research.

Numbers of thrips in wildflowers in the margins were not significant and did not appear to migrate in significant numbers into the crop.

Background and expected deliverables

Two literature reviews have been published, partly funded by the AHDB, on the impact of organic treatments and floral margins for pest and disease control in orchards (Shaw et al. 2021; Fountain 2022).

With a growing need for alternatives to plant protection products, the implementation of wildflower margins that support natural enemies is a potential contributing solution. Floral resources implemented near crops are effective in increasing the abundance of pollinators and natural enemies (Fountain 2022). The crops themselves do not provide the diversity that most natural enemies need to establish a stable and growing population throughout the year (Ramsden et al. 2017). A properly managed floral resource provides a food source for natural enemies in the form of alternative prey, pollen, and nectar, and as a shelter and overwintering habitat.

In 2019, a replicated experiment of floral margins was sown around the WET Centre at NIAB East Malling to reduce runoff from polytunnel structures but provide secondary benefits of boosting natural enemies and pollinators in the vicinity of the tunnel (Holistic Water for Horticulture, HWH). The data from the first year will be collated and funding from and Interreg-NSR, BEESPOKE project facilitated surveys of pollinating insects.

Several other research studies have implemented floral margins which are thought to benefit strawberry crops, but with very little evidence of the species or phenology of natural enemies in the crop or which flora might be attractive to crop pests. The wildflower margins, established for other projects offered an opportunity to monitor margins for beneficial and pest species of soft fruit crops including ladybirds, lacewings, and hoverflies, but also capsids, and thrips.

In this study, we aimed to;

1. Compare 3 floral treatments to an unsown control
2. Monitor the establishment and floral resource in the margins
3. Identify key natural enemies utilising floral margins
4. Identify pest species inhabiting specific flora
5. Monitor floral margins in commercial farms in the vicinity of soft fruit crops

Summary

NIAB EMR WET Centre

In 20019, the replicated plots (unsown, sainfoin, chicory, perennial meadow mix (EM1)) established around the WET Centre (strawberry crop) were surveyed for soft fruit natural enemies and pest species in May, June, July, and August. Records of vegetation cover were made in July. Floral units were identified, and invertebrates extracted using the extraction device, developed in SF 156, and ethanol extraction to monitor for thrips species that may be attracted to floral margins. Thrips adults, relevant to strawberry production, were identified to species.

Floral margins

All sown plots established successfully. Single species plots had more than 90% coverage of the sown species, sainfoin and chicory. The EM1 meadow seed mix covered 72% of the plots with wild carrot and common knapweed being the better-established flowering species. Single species plots like sainfoin and chicory had shorter flowering periods than unsown and EM1 plots. Longer flowering periods provided a better food and habitat resource for natural enemies and pollinators. In 2021, single species plots had > 70% coverage of the sown species, sainfoin and chicory. EM1 seed mix species covered 99% of the plots with oxeye daisy and common knapweed dominating.

Arthropods in floral margins

There was a higher abundance of beneficial arthropods in the margins of the strawberry crop in May and June. Floral resources were adequate in July, but some arthropod groups like beetles, ladybirds, and moths declined. This may be related to life cycle and/or dispersal away from the plots. The meadow mixture (EM1) had a higher floral resource in June. Arthropod group diversity was highest with approximately 1 specimen of each group recorded per 1.5 m^2. Chicory plots had fewer arthropods when compared with all other treatments. In August, unsown and EM1 plots were dominated by predatory spiders, and groundbugs from genus *Nysius* (not a soft fruit pest).

Herbivores in floral margins

Most arthropod herbivores or potential soft fruit pests were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in May and June and were abundant in sainfoin plots. Capsids may have been breeding in sainfoin as higher numbers of nymphs were recorded in sainfoin in June. Most of the nymphs were Common green capsid. Numbers of herbivores declined in July. No aphids or capsid nymphs were found in July and August. Three capsid species were identified using the floral margins: Common green capsid, European tarnished plant bug, and Potato capsid. Common green capsid was in high numbers in all treatments except in chicory. The meadow mix (EM1) was less attractive to capsids than the unsown treatment.

<u>Thrips on flower heads</u>

Unsown species like dandelion, bindweed, hawkbit, white clover, and yarrow had, on-average, greater numbers of thrips (2 per flower head) than sown species (Park et al. 2007). In June, yarrow contained on average 5.2 ±1.0 *Thrips tabaci* per flower, known to affect soft fruit crops. White clover had 5.1 ±4.1 *Frankliniella intonsa* per flower also found on strawberry crops. Other unsown plant species had fewer than 2 thrips per flower or had thrips species not damaging to soft fruit.

In sown plots chicory, sainfoin, oxeye daisy, common knapweed and wild carrot had more than 2 thrips per flower on at least at one sampling occasion. Wild carrot had higher numbers of *Thrips tabaci* per flower head in June and July (respectively, 6.7 ±2.3 and 4.4 ±1.4). Common knapweed attracted (2.0 ±0.3) *Frankliniella occidentalis* (WFT) a known pest of strawberry crops and 2.2 ±0.6 'other' thrips not found in soft fruit crops. Overall thrips numbers declined in August.

The extraction device from project SF 156 gave very good recovery of adult thrips (at least 90%) but was less efficient at extracting larval thrips (around 50%) from flower heads.

<u>Beneficials on flower heads</u>

Low numbers of predatory thrips (*Aeolothrips*), parasitoids, ground beetles and *Orius* nymphs and adults were present in flowers. There was a more diverse and abundant community of pollinators in May than September, probably a reflection of floral resource. Wild bumblebees were frequent visitors to sainfoin flowers. Some bumblebee species with long-tongues prefer flowers with longer corolla flowers (Plowright et al. 1997) than those typical of strawberry flowers.

Commercial Farms

In 2021, floral margins adjacent to 2 strawberry and 2 raspberry crops were monitored. Most herbivores or potential soft fruit pests were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in the crop from July to September and in low numbers (mean of <0.2 aphids per plant). Capsids were recorded in low numbers in the floral margins and were not analysed. No capsids of soft pests were identified in this year.

Although the number of flowering species varied between sampling dates, thrips numbers and species in each flower type (species) were consistent. Overall numbers of adult thrips in the crop were low (<1 thrips per 4 flowers). The flower margin species, with the highest numbers of WFT, was common knapweed, in August (4 thrips per flower). Numbers of onion thrips were higher in dandelion (4 thrips per flower), in June and in yarrow (3 thrips per flower), in August. Rose thrips were more abundant in strawberry in June (6 per flower), and in sainfoin (4.3 per flower) in July. Thrips in floral margins did not appear to enter crops in significant numbers at up to 50 m into the crop.

Parasitoids, spiders and anthocorids were the most abundant beneficials in the floral margins and crops.

Bumblebees and honeybees were the most common pollinators recorded with bumblebees more abundant in the floral margin, and honeybees are more abundant in the crop.

Financial Benefits

None currently

Action points

- Growers might consider implementing wildflower strips in and around soft fruit crops as part of their on-farm biodiversity deliverables.
- Supporting natural enemies and pollinators on farms will provide pollination and pest control resilience to crops.
- Once established wildflower margins may help outcompete less desirable weeds and require minimum maintenance after the second year.

WP 4 Control thrips species other than western flower thrips damaging to strawberry crops (Lead ADAS)

Headlines

- In 2020 and 2021, a push-pull method for thrips control tested at two sites did not reduce numbers of thrips per flower compared with the untreated control. Except for one individual WFT adult, thrips in flowers were species other than western flower thrips (WFT) and numbers were low despite choosing sites with a history of problems with these species.
- In 2021 and 2022, trials were done to compare the individual effects of the semiochemicals Magipal (a natural enemy attractant also reported to be a pest repellent), Lurem-TR and Thripnok (both thrips lures). In 2021, the semiochemicals were added to blue sticky traps placed above the crop and tabletops. Traps baited with Lurem-TR and Thripnok caught significantly more thrips than unbaited traps (2.8x and 1.3x respectively). Traps baited with Magipal did not catch fewer thrips than unbaited traps. In 2022, the traps were placed below the table tops and both thrips lures caught more *Frankliniella* species (1.5x) but not more *Thrips* species than unbaited traps.
- In 2022, significantly more thrips (8.1x) were caught on unbaited traps placed above the table-tops than below. Thrips species on traps above the tabletops reflected the thrips species in the flowers more closely than those below the tabletops. The predominant thrips species on traps below the tabletops were incidental cereal thrips which are not a strawberry pest.
- Low numbers of beneficial insects were caught on the 'wet' roller traps in the push-pull trials. In the trials testing individual semiochemicals on 'dry' sticky traps, those baited with Thripnok caught more bumble bees than those baited with Lurem-TR. In 2021, Thripnok and Lurem-TR traps placed above the tabletops caught 4x and 2x as many as unbaited traps respectively and in 2022, Thripnok and Lurem-TR traps placed below the table-tops caught 9x and 2x as many respectively as unbaited traps.

Background and expected deliverables

Successful IPM programmes for management of western flower thrips (WFT), *Frankliniella occidentalis* on strawberry have been developed using knowledge of its biology and behaviour. These programmes are based on the use of the predatory mites, *Neoseiulus cucumeris*, predatory bugs, *Orius laevigatus* and on some farms, 'mass/precision monitoring' with blue roller traps, with or without the WFT aggregation pheromone lure which can increase numbers of WFT caught. Strategies for controlling WFT on strawberry are not effective against several other species of thrips which fly in as adults and can damage fruit. The biology and behaviour of these species is not well understood. Monitoring blue sticky traps can potentially allow earlier detection of adult thrips than monitoring flowers, particularly at low densities, thus they might aid timing of control measures such as release of *Orius* or lowering thrips netting at the ends of tunnels.

This study included four trials in 2020 and 2021 testing a push-pull strategy for control of immigrant thrips adults, using Magipal™ as the 'push' and blue sticky traps with LUREM-TR as the 'pull'. Magipal™ is currently marketed as an attractant for natural enemies but has also been found to be a general pest repellent. LUREM-TR is a non-pheromone lure containing methyl isonicotinate (MI), which has been found to increase catches of 12 different species of thrips, including some that occur on strawberry i.e. WFT, the rubus thrips (*Thrips major*) and the onion thrips (*Thrips tabaci).* However, there is no published evidence that LUREM-TR attracts two other species that infest strawberry: the rose thrips, *Thrips fuscipennis* and the flower thrips, *Frankliniella intonsa*. However, it has been tested predominately in countries that lack these species.

Another thrips lure, Thripnok has recently become available and is reported to attract both WFT and onion thrips. There is no information yet on whether it attracts other strawberry pest thrips species. This study included an additional trial in 2021 comparing the individual effects of Magipal, Lurem-TR and Thripnok on thrips and beneficial insect catches on blue sticky traps. This trial was repeated in 2022, comparing Lurem-TR and Thripnok at lower thrips densities, earlier in the season than in 2021. A pilot trial was also done in 2022 comparing thrips catches on traps above or below the tabletops, as no data is currently available on optimal trap location.

Objectives

1. Test the 'push' (repellent activity) of Magipal™ on thrips adults from strawberry flowers and its attraction of thrips predators.
2. Test the 'pull' (attraction) of LUREM-TR to thrips adults on blue sticky traps and check numbers of beneficial insects caught on the traps.
3. Test the combined 'push' and 'pull' components when used together.
4. Test whether the thrips lures Lurem TR and Thripnok added to blue sticky traps increase catches of the thrips species mix that damage strawberry (*Thrips fuscipennis, Thrips major, Thrips tabaci, Frankliniella intonsa*, and WFT).

5. Test the effect of Lurem TR and Thripnok on trap catches of flying predators and pollinators when used with sticky traps mounted below strawberry tabletops – as is currently standard grower practice.
6. Test whether there is a difference in thrips sticky trap catches above or below tabletops in a commercial strawberry crop.
7. Establish a pure species laboratory culture of a *Thrips* species from strawberry flowers, to allow further work on filling key gaps in biology.

The results could potentially be used immediately by growers to aid early detection of low densities of thrips to time control methods such as release of *Orius* predators or lowering thrips netting at the ends of tunnels to reduce immigrant thrips.

The results could also be used by growers to aid mass/'precision monitoring' of thrips.

The researchers could use the results to explore further future research funding for developing improved IPM strategies for thrips management such as lure and infect, luring to trap plants etc.

Summary

Push-pull trials

In both 2020 and 2021, a push-pull method was tested at two sites. The method used the natural enemy attractant Magipal (also reported to be a pest repellent) as the 'push' and blue roller traps baited with the thrips lure Lurem-TR placed below the table-tops as the 'pull'. Despite choosing sites with a history of fruit damage by thrips species other than WFT, thrips numbers per flower were low overall in the untreated and treated plots at both sites in each of 2020 and 2021. There were no significant differences in thrips numbers or the low incidence fruit damage between untreated and push-pull treatments.

In 2020, thrips adults in flowers were predominantly *T. fuscipennis* at both sites followed by *T. major.* No WFT were seen at either site and only small numbers of *F. intonsa*. In 2021, thrips adults were predominantly *T. fuscipennis*, *T. major* and *T. tabaci* although numbers of *F. intonsa* increased at one site at the final assessment.

Low numbers of larvae were recorded in flowers in both 2020 and 2021, confirmed as *Thrips major*, *T. tabaci* and *F. intonsa.* No *T. fuscipennis* larvae were found in flowers despite this being the predominant species of thrips adults in flowers. There was no evidence that *T. fuscipennis* breeds in strawberry flowers which is a likely reason for the lack of control by *N. cucumeris*.

In 2021, the proportion of *Frankliniella* to *Thrips* species caught on the roller traps baited with Lurem-TR at both sites was higher than that recorded in the flowers. This indicated that blue roller traps baited with Lurem-TR may catch relatively more *Frankliniella* species than *Thrips* species.

Low numbers of beneficial insects were caught on the roller traps in both 2020 and 2021.

Trials testing individual semiochemicals

2021 trial

In 2021, blue traps baited with either Lurem-TR or Thripnok placed above the tabletops caught significantly more (2.8x and 1.3x respectively) adult pest thrips (*Thrips* spp. females, *Frankliniella* spp. females and males) than untreated traps. Traps with a Lurem-TR lure caught significantly more (2.1x) adult pest thrips than traps with a Thripnok lure. When comparing the catches of *Thrips* and *Frankliniella* species, Lurem-TR significantly increased trap catch of both genera relative to untreated traps and traps combined with a Thripnok or Magipal lure. Thripnok increased mean numbers of *Frankliniella* spp. adults per trap compared to untreated traps, but was significantly outperformed by Lurem-TR. Thripnok did not increase mean numbers of *Thrips* spp. per trap. Magipal did not affect mean numbers of thrips adults per trap compared with those on the untreated control traps. Of the thrips females identified to species, all the *Frankliniella* spp. on the traps were *F. intonsa* and the *Thrips* spp. were a mix of *T. fuscipennis*, *T. major* and *T. tabaci.*

Thripnok resulted in a significantly increased catch of bumble bees (4x as many as on untreated traps), however ‘dry glue’ traps were used in the trial which are known to catch more bees than the ‘wet glue’ used on roller traps. Lurem-TR and Magipal also increased mean numbers of bumble bees caught on traps (2x as many as on untreated traps) however significantly less so than Thripnok. None of the semiochemicals affected the number of predatory thrips, *Aeolothrips* spp. on the traps.

2022 trial

In 2022, flower-tapped samples revealed that *T. fuscipennis* was likely to be the most abundant thrips species at trial setup on 14 June, while at trial takedown, on 5 July, WFT was the most abundant. Numbers of *Thrips* species in flowers at take-down are likely to have been reduced by an application of lambda-cyhalothrin two days earlier. Thrips pressure in the flowers remained low throughout the monitoring period, with a mean of fewer than one adult per flower at trap take-down.

On blue traps (hung below the tabletops at the request of the steering group as this is usual commercial practice), sticky traps with either a Lurem-TR or Thripnok lure did not catch significantly more total adult pest thrips (*Frankliniella* spp. females, *Thrips* spp. females, male thrips) relative to blue sticky traps alone. When *Frankliniella* spp. females, *Thrips* spp.

females, and male thrips were considered separately, significantly more *Frankliniella* spp. females were caught on traps with a Lurem-TR lure (1.49x increase) or Thripnok lure (1.46x increase) than on untreated traps. There was no significant difference seen in total 'dark' thrips species on traps between treatments, with uniformly low numbers. The most prevalent (>50%) dark thrips species seen on the traps were incidental cereal thrips (*Limothrips* spp.) No cereal thrips were found in strawberry flowers, and they are not considered to be a pest of strawberry. As in 2021, thrips species composition and abundance on traps did not match those seen in flower-tapped sample, highlighting the value of supplementing sticky trap monitoring with regular flower-tapping thrips assessments.

Relative to the 2021 semiochemical trial, total thrips catch in 2022 was markedly lower. This may have resulted from (1) The 2021 trial being undertaken later in the season (2021: 15 July – 3 August, 2022: 14 June – 5 July), (2) sticky traps in 2021 being mounted just above the strawberry crop rather than in 2022 where traps were mounted below tabletops, and (3) In 2022, flower tapping samples indicated a significantly higher number of WFT than other thrips species which may have outcompeted other pest thrips species, reducing their numbers, (4) Natural variation in thrips species incidence and numbers and (5) application of lambda-cyhalothrin two days before the traps were collected in 2022 which is likely to have killed some thrips species other than WFT.

Frankliniella species were the dominant species on traps and WFT, *Frankliniella occidentalis*, were the dominant species in flowers on the date traps were collected. Catches of predators on traps were uniformly low, with *Aeolothrips* spp., *Orius* spp., other Anthocorid spp., hoverflies, lacewings, and ladybirds averaging fewer than 0.5 per trap.

Bee catches (predominantly bumble bees) on traps was notably higher on traps relative to all other assessed beneficials, with a mean of 1.4 bees per trap on untreated traps. Significant increases in bee catch relative to the control were seen with both a Lurem-TR lure (2.2x control) and a Thripnok lure (9.4x control). Sticky traps with a Thripnok lure caught significantly more bees than sticky traps with a Lurem-TR lure – increasing catch by 4.3x. 'Dry' sticky traps were used in this trial which are reported to catch more bees than 'wet' traps which are claimed to allow some bees to escape.

Sticky traps catch of all observed beneficial groups in 2022, most notably predatory thrips (*Aeolothrips* spp.), were substantially lower than in 2021; with trap location and trial date again the factors most likely to be underlying these differences.

Trial testing traps above/below tabletops

Sticky traps mounted above the strawberry crop and the tabletops caught significantly more total strawberry pest thrips than sticky traps hung below tabletops (8.1x increase in total thrips catch). Sticky traps mounted above the crop caught a wider range of strawberry pest thrips species than sticky traps hung below strawberry tabletops (five species above, three species below). *Frankliniella intonsa* and *Thrips fuscipennis* were only detected on traps above the crop.

Below-tabletop sticky traps caught significantly more cereal thrips than above-tabletop traps (>50% of total thrips compared with approximately 7% of total thrips catch on traps above tabletops). Visual similarity of 'incidental' cereal thrips and dark pigmented pest thrips (e.g. *T. fuscipennis*, *T. major* and *F. intonsa*) may lead to inaccurate estimates of the presence and abundance of strawberry species. A notable difference was seen in *Thrips* species composition between the semiochemical trial and the above and below tabletop trial in 2022 – highlighting the potential variation in thrips species even within a block of tunnels.

Significantly more predatory thrips (*Aeolothrips* spp.) were caught on traps above the crop tabletops compared to below the tabletops. No significant differences in catches of other observed beneficial species (*Orius* spp., other Anthocorid spp., bees, hoverflies, lacewings, and ladybirds) were given on traps above and below the tabletops.

Thrips culture

In 2020, a standard laboratory method was initially tested using WFT which were successfully reared from adults to the next generation of adults on French bean pods and providing commercial bee pollen as a food source. When the same rearing system was used for *Thrips* species adults collected from strawberry flowers at Site 1 used for the push-pull trial, larvae were successfully reared on bean pods. Larvae were produced 15 days after adding the adults, whereas with WFT, larvae were produced after one week at fluctuating temperatures of 20-25°C. This indicated that the development rate of the *Thrips* species was slower than that of WFT.

However, the *Thrips* species larvae did not survive the pupal stage to produce the next generation of adults. Although the adults used to rear the larvae were not identified to species on the date of collection as we needed to keep them alive, the proportions of thrips species adults in the strawberry flowers in trial plots were 72% *T. fuscipennis*, 25% *T. major* and 3% *T. tabaci* so the adults are likely to have been one of these species.

Further work would be needed to establish a successful laboratory rearing system for a thrips species such as *T. fuscipennis*.

Action points

- Be aware that several species of thrips adults can invade everbearer strawberry crops. Species composition is likely to vary with site, season, weather and surrounding crops, hedgerow plants and weeds. Although WFT females can usually be recognized by colour, those of other, 'dark' species cannot be distinguished from each other in the field. Pest thrips species can be distinguished in the field from the larger predatory *Aeolothrips* spp. with striped wings. If identification of pest thrips species is needed e.g. to assist in the choice of plant protection product, contact an entomologist who will use a microscope and diagnostic keys.

- In the IPM programme, make regular preventive releases of *Neoseiulus cucumeris* and supplement these with releases of *Orius laevigatus* when temperatures are high enough. *Neoseiulus cucumeris* can give good control of young WFT larvae and is also known to feed on *T. tabaci* larvae. *Amblyseius swirskii* can now be used in tunnels in England and this feeds on larger WFT larvae as well as young ones but needs higher temperatures than *N. cucumeris. Orius laevigatus* is likely to feed on both adults and larvae of all pest thrips species.
- Where spray boom setup permits, prioritise the placement of monitoring sticky traps above rather than below the tabletops as these are likely to catch more thrips and a wider range of strawberry pest species more representative of those in the flowers.
- If using the thrips lures Lurem-TR or Thripnok to improve thrips detection, these may also be more effective when used with blue sticky traps located above the crop rather than below the tabletops and they may increase catches of *Frankliniella* species more than those of *Thrips* species. Be aware that both Lurem-TR but particularly Thripnok are likely to increase catches of bumble bees if using 'dry' sticky traps (those with paper that is peeled off on either side). 'Wet' traps including roller traps are claimed to trap fewer bumble bees which are reported to be able to escape from the traps, but a comparison of 'wet' and 'dry' traps was not done in this study.
- Continue to monitor thrips numbers in flowers as well as on traps. This should be done regularly, using a minimum sample of 20 flowers per crop or tunnel to estimate mean numbers of thrips per flower. Choosing upward facing, medium-aged flowers (all petals present, pollen shed, and dark anthers) will give a more reliable estimation of thrips adults than choosing young or senescent flowers.

Objective 6. To investigate the efficacy of a pheromone-based push-pull strategy for control of first-generation raspberry cane midge and blackberry leaf midge in raspberry. (ADAS and NIAB EMR)

Headline

Trials in Kent and Norfolk did not demonstrate a significant impact of pheromone push-pull strategies on raspberry cane midge.

However, there was a significant reduction in blackberry leaf midge damage to raspberry leaves and shoots in in the Kent trial and this warrants further investigation.

Background and expected deliverables

The raspberry cane midge *Resseliella theobaldi* (RCM) and blackberry leaf midge D*asineura plicatrix* (BLM) are major pests in UK raspberry production. With the loss of thiacloprid and the importance of biological control for mites in raspberry production, novel IPM strategies are required for control of these pests. Semiochemicals have been successfully used in IPM programmes to improve control of other pest species in other crops. MagiPal^{TM} sachets containing methyl salicylate, a signal molecule for systemic acquired resistance (SAR) in plants, have been used in combination with pheromone lures imbedded in roller traps. In an initial push-pull trial against the blueberry gall midge *Dasineura oxycoccana* in blueberry promising results have been obtained. This objective aims to test the efficacy of this push-pull strategy against RCM and BLM in commercial raspberry which would be compatible with IPM for other pests.

Summary

Two trial sites were established one in Kent and one in Norfolk in early spring 2021. The push (MagiPal sachets) and pull (white roller sticky traps) were deployed prior to midge detection in commercial raspberry crops. Monitoring traps were deployed to evaluate the variation in trap catches between untreated control and push-pull treated plots. Midge damage was assessed on leaves and shoots from BLM and the number of eggs and larvae of RCM present in artificially made cane splits. In Kent, significantly higher numbers of midges were caught in the control plots compared with the push-pull treated plots for both BLM and RCM. There was a significant reduction in BLM damage to leaves and shoots in two of the three assessments in the push-pull treated plots. There were significantly more RCM eggs found in green spawn growth than in woody growth in push-pull treated plots for the first assessment. There was no overall difference in the numbers of RCM eggs and larvae between push-pull treated and control plots within artificial cane splits.

In Norfolk there was no significant difference in the monitoring trap catches of BLM, however significantly more RCM midges caught in the monitoring traps in the control plots compared with the push-pull treated plots on 24 May 2021. There was no significant difference in BLM damage to shoots or leaves between the control and treated plots. This could be because the BLM population was too low to be significantly affected. There were significantly more RCM larvae found in push-pull treated plots compared with control plots on the second assessment (24 May 2021), however larval numbers were very low. No RCM larvae were found on the first and third assessments and there was no significant difference between treatments on the fourth assessment.

Action points for growers

- Growers should continue to remove green spawn from the crop to reduce availability of preferred egg laying sites for RCM.
- Growers should continue to monitor midge emergence with pheromone lures and monitoring traps. Traps should be checked at least twice a week so that control measures can be applied at the correct time.
- Growers may want to trial the push-pull technique against BLM on their local populations.

SCIENCE SECTION

WP1. Identify and report new and emerging pests which pose a future threat to UK soft fruit production (Year 1-2, Lead; NIAB EMR, Contributors; ADAS, JHI, NRI)

Introduction

Arthropod pests are estimated to destroy up to 20% of annual crop production worldwide, resulting in a loss of more than $470 billion (Fried et al. 2017; Sharma et al. 2017). The control of these pests has become increasingly challenging due to a number of factors, including changing climate (Sharma 2016; Taylor et al. 2018), the introduction of invasive pests into new territories (Early et al. 2016), and resistance to a declining selection of plant protection products (Lamichhane et al. 2016). In the UK, soft fruit crop growers have had to shift their strategies, utilizing a combination of fewer selective plant protection products, biopesticides, cultural practices, and the manipulation of insect pest populations to reduce the impact of pests. However, the removal of some broad-spectrum plant protection products (PPPs), combined with a warmer and more unpredictable climate, has resulted in higher populations and unpredictable outbreaks of both native and non-native species (Hulme 2016). Additionally, the global movement of plant material (Chapman et al. 2017) exposes UK fruit production to the risk of new pests, which often thrive in the extended season and warmer temperatures created by protected cropping. As the world faces the challenges of climate change and the proliferation of invasive pests, the need for effective and sustainable pest control strategies has never been greater. Unfortunately, the effectiveness of traditional PPPs is being undermined by the emergence of resistance, as well as the limited range of options available. Therefore, it is crucial that we develop new monitoring tools and alternative approaches that can be integrated into existing control measures, without compromising our ability to address other pest outbreaks. To achieve this, it is vital to find PPPs that have different modes of action, and that can be used in combination with the remaining conventional PPPs, in order to reduce the risk of resistance and ensure the long-term health of our crops.

Materials and methods

The SF 174 team attended national and international meetings to report back potential new and invasive pests of soft fruit crops. Additionally, extensive searches for up-to-date research into potential peat threats were conducted. The findings have been summarised in the tables below with selected references and web links.

Results

Future potential pest threats to the UK soft fruit industry are summarised in the tables below, including their, Species / Common name, Geographic distribution, Hosts / Crops, Symptoms, Description, Control used in other parts of world, Monitoring, and potential Risk for soft fruit.

Species included in this report are;

1. three species of thrips; Japanese flower thrips, Taiwanese flower thrips and Chilli thrips (*Scirtothrips dorsalis*),
2. two true bugs; Brown Marmorated Stink Bug and Yellow Spotted Stink Bug
3. a whitefly; honeysuckle whitefly,
4. three scale insects; white peach scale, Indian wax scale, and tortoise wax scale,
5. six beetles; Japanese flower beetle, whitefringed weevil, citrus longhorn beetle, tortoise beetle, peach red necked longhorn, and Anthonomus bisnignifer- a species raised as a potential concern, but little information has been found on this to date
6. several tortix moths; strawberry tortrix, *Blastobasis*, lesser apple leaf-folder, *Acleris nishidai, Acleris fimbriana,* yellow tortrix moth and snowy-shouldered acleris moth, and
7. a spider mite, *Tetranychus mexicanus*.

Details of useful literature including links to keys are also included. Note that information in this report was correct at the time of writing. All control options should be checked with a BASIS qualified adviser.

Thysanoptera – thrips

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Thrips setosus / Japanese flower thrips	Native to eastern Asia, has recently been introduced into UK (2016, West Sussex), France (2014), Germany, and the Netherlands. In 2016, it was found at a single nursery in Michigan. Presence in UK: present (limited) – PHRR, few occurrences (EPPO GD)	14 plant families. Inc. vegetable and ornamental crops: tomato (transmits TSWV), pepper, eggplant, chrysanthemum, cucumber, hellebore, hosta, hydrangea, impatiens, petunia, poinsettia, soybean. Currently causing issues in ornamentals on	Polyphagous thrips which can cause direct feeding damage to protected, ornamental and field crops, as well as vectoring Tomato spotted wilt virus. Will feed on all above ground parts of plants. Typical thrips damage: silvery streaks and spots.	Adults: 1.3mm long Females: basal quarter of wing pale otherwise dark brown body, obvious with a hand lens. Males: yellow and must be identified by an expert.	Broad spectrum insecticides including chlorpyrifos. May not respond well to biocontrol practices and be more abundant where biocontrol agents are the primary control method. *N. cucumeris* does not seem to be effective in control (Bennison Pers. Comm)	Monitor for presence, particularly following findings in the Netherlands and elsewhere, including the UK's first finding in 2016. Larvae and frass on underside of leaves.	MEDIUM (14/08/2020) Added to the EPPO Alert List in 2014 – Deleted in 2018 In UK, not yet reported on fruit crops. Legislative status: not in GB legislation PHRR information: Action: No

	Spread through cut flower imports. Updates on distribution at the EPPO database indicate few occurrences in the UK.	south coast of England (Bennison Pers. Comm)	Does not feed on pollen. RR review concluded that damage is "not thought to be any more significant than those of other thrip species"		Current thrips control measures should also be effective against this species.	Use of HortiPro - PheroThrip 2.0 pheromone attractant.	statutory action against findings.

IDENTIFICATION: https://keys.lucidcentral.org/keys/v3/british_thrips/the_key/key/britishthysanoptera_2017/Media/Html/thrips_setosus.htm

https://gd.eppo.int/taxon/THRISE

https://www.cabi.org/ISC/abstract/20183082689

https://www.oregon.gov/ODA/shared/Documents/Publications/IPPM/JapaneseFlowerThripsPestAlert.pdf

https://www.aphis.usda.gov/publications/plant_health/card-japanese-flower.pdf

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Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**
Frankliniella intonsa / Flower thrips or Taiwan flower thrips	Mostly a pest in China and Japan, much more than in the UK. Worldwide including UK. Europe, Palearctic Asia (spreading to Taiwan, Northern Thailand,	Wide range of unrelated plant species, with little evidence of any specificity, including fruit trees and vegetable crops	Leaves and flowers Fruit/Inflorescence skin discoloration/ distortion. External feeding. Vector of TSWV, TCSV, GRSV	Body and legs variable, mainly brown with head and pronotum often paler than abdomen, tibiae, and tarsi largely yellow; antennal segments III–IV yellow with	Natural enemies: *Ceranisus menes* (parasite), *Misumenops tricuspidatus*, *Orius sauteri* (predators) *Rosmarinus officinialis* L.	Cinnamyl alcohol found in blueberry flowers, *Vaccinium corymbosum* is an attractant of the flower	MEDIUM In UK, not yet reported causing significant damage. Risk with warmer summers.

	Bangladesh, Northern India and Pakistan) Presence in UK: present (CABI)	Denmark: The most abundant thrips species found on commercial strawberry farms.		apices shaded; fore wing pale with setae dark. Very similar to WFT, but *F. intonsa* has considerably shorter postocular setae than WFT and lacks campaniform sensilla on the metanotum	(Lamiaceae) is a promising repellent. Elevated CO2 amplifies the efficacy of spinetoram. Spinetoram resistance drives interspecific competition between *Megalurothrips usitatus* and *F. intonsa.* Interspecific competition between *F. intonsa* and *F. occidentalis* Insecticide Broflanilide, used for controlling thrips	thrips *F. intonsa*	Not on PHRR. Legislative status: not in GB legislation

IDENTIFICATION: https://keys.lucidcentral.org/keys/v3/nz_thrips/the_key/key/New_Zealand_Thysanoptera/Media/Html/frankliniella_intonsa.htm

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Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Scirtothrips dorsalis/ Chilli thrips	Southern and eastern Asia, Africa, and Oceania, USA (Florida), Venezuela,	Broad host range more than 100 plant taxa among 40 families Ornamental plants (such as Knock Out roses, cleyera, Indian hawthorn, duranta, ligustrum, viburnum, camellia and bottle brush), grapevines, pepper, amaranth, bean, eggplant, okra, pumpkin, tomato and watermelon,	Chilli thrips create damaging feeding scars, distortions of leaves, and discolorations of buds, flowers and young fruits In mature plants- rolling of the leaf upward- what is called "chilli leaf curl." and leaf size reduction and disfigured plant parts. Severe infestation makes the tender leaves and buds brittle, resulting in complete	Pale colored and the lengths of their first and second instar larvae and the pupae are 0.37-0.39, 0.68-0.71 and 0.78-0.80 mm, respectively. Adults are about 1.2 mm long with dark wings and dark spots forming incomplete stripes which appear dorsally on the abdomen	Chemical control Spinetoram used as a foliar application and imidacloprid as soil drench Biological control. Minute pirate bugs, Orius spp., entomopathogenic nematodes, *Thripinema* spp. lacewings, Chrysoperla spp. ladybird beetles predatory thrips, *Franklinothrips vespiformis* (vespiform thrips), *Scolothrips*	yellow sticky traps Beating sampling	Potential risk to Strawberry (already occurring in Florida) Relatedly, horticultural crops such as sweet peppers and tomatoes. On the EPPO A2 list of regulated plant pests

		cucumber, Momordica bitter melon, Citrus spp. Roses, cotton, beans, carrots, mango, wild yams, strawberry.	defoliation and total crop loss. Infested fruits develop corky tissues. Strong viruliferous behavior for seven recorded viruses; chilli leaf curl (CLC) virus, peanut necrosis virus (PBNV), tobacco streak virus (TSV) in groundnut crops, three tospoviruses (i.e., melon yellow spot virus (MYSV), watermelon silver mottle virus (WsMoV), and capsicum chlorosis virus (CaCV)		*sexmaculatus* (sixspotted thrips), *Selenothrips rubrocinctus* (redbanded thrips), *Leptothrips mali* (black hunter thrips) predatory phytoseiid mites, such as *Amblyseius* spp., *Euseius hibisci* and *Euseius tularensis*		
https://entnemdept.ufl.edu/creatures/orn/thrips/chilli_thrips.htm							

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https://specialtycropindustry.com/integrated-pest-management-of-chilli-thrips-in-strawberries/

Hemiptera

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Halyomorpha halys / Brown marmorated stink bug	Native to eastern Asia, including China, Taiwan, Korea, and Japan. Expanding range in North America (first detected in 1996), in Europe (first detected 2004), UK in pheromone traps in 2020. Brown marmorated stinkbug is a pest which is spreading in many parts of the world. Rhodes, Greece (also includes parasitoids),	More than 100 plant species, primarily fruit trees, nuts, and woody ornamentals, but also field crops. Citrus, apple, mulberries, blueberry, apricot, sweet cherry, plum, pear, raspberry, grapevine. Also, field crops and woodland trees. Peach, Almond, Cranberry, Satsuma, okra,	Adults feed on fruit, nymphs feed on leaves, stems, and fruit. Leaf feeding characterized by small lesions (3 mm diameter) which become necrotic and coalesce. Fruit: small necrotic spots (corky spots) or blotches, grooves, and brownish discolorations to severely disfigured	Eggs: elliptical (1.6 x 1.3 mm) light green-blue, in groups of 20-30. Five nymphal in stars, 2.4-12 mm length, deep-red eyes, abdomen is red/orange with black markings in first instar with later stages mottled with dark brown and pale areas, pronotum and head armoured with spines.	**Chemical control:** Triflumuron caused significantly higher mortality on BMSB nymphs. Essential oils or their individual terpenic compounds. Essential oils of Turmeric and clove. Pyrethroid insecticides (e.g. deltamethrin and lambda-cyhalothrin). Insect exclusion mesh.	Hitchhiker on packing material or via plant imports or passenger luggage. Eggs: underside of leaves. Aggregation pheromone traps and tap sampling. Pyramid traps attracted significantly more BMSB	MEDIUM Detected active in UK in 2020 and 2021, not yet at high numbers. Females detected in 2021 in UK. PHRR information: No statutory action against findings. Management by industry.

	Croatia Algeria, North Africa Aegean Region of Turkey Azov Sea coast of Russia Germany (Hamburg and northern areas)	tangerine, Kiwifruit, Sweet corn, Field maple (*Acer campestre*), Green ash (*Fraxinus pennsylvanica)*, London plane (Platanus × hispanica), Persian walnut (*Juglans regia*), Oregon grape (*Berberis aquifolium*), **Insect culture:** A rearing system for BMSB on live cowpea plants, Vigna unguiculata	('cat-facing') and unmarketable. Nuisance to humans because of aggregation in buildings. Induces a strong phenolic response in the injured area of the apple. Increases capsaicinoid content in the infested peppers which implies that capsaicincoid could have defence properties. *Wine*: Molecules responsible for the off-flavours in contaminated musts volatilise	Adults: 12-17 mm long, brown with lighter bands on antennae and darker bands on membranous, overlapping part at the rear of wings, patches of coppery or bluish metallic-coloured punctures on the head and pronotum, head more rectangular than likely confusion species. In the forward flip BMSB creates a tripod of support using the hindlegs and	Ghost nets – attract and kill. Irradiation supports the potential for the use of SIT. Plant Growth-Promoting Rhizobacteria induce systemic resistance in plants. Native egg parasitoids and predators not very effective. Samurai wasp, *Trissolcus japonicus,* and *T. mitsukurii* have potential as classical biological control agents; adventive populations of both	than sticky panel traps. Modelling by a zero-inflated negative binomial regression (ZINB) model **France:** Citizen science to track BMSB expansion in France. **New Zealand:** A ddRAD sequencing approach to track origins. New Zealand: Genetic	Legislative status: not in GB legislation

			during the fermentation process. Though contamination has potential to alter the quality of grape juices and musts, there is little risk for influencing the taste of processed wines.	the tip of the abdomen to elevate the anterior portion of the body **Insect physiology:** low humidity decreasing first-instar survival high temperatures decreased BMSB reproduction. Increasing photoperiods increased probability of higher rates of fecundity. Mutualism: BMSB facilitates	species recently reported in Europe. Slovienia: parasitoids-native species *Anastatus bifasciatus* and non-native *Trissolcus mitsukurii*. **New Zealand:** Modelling the climatic niche of parasitoid T. mitsukurii to estimate its global potential distribution. **Japan:** Japanese acrobat ants *Crematogaster matsumurai* and *C. osakensis* reduced the survival of early instar BMSB.	diversity using two mitochondrial genes, COI and COII High-throughput sequencing of gut contents has potential for exploring the dietary histories. Parasitoid monitoring and detection using COI. Bimodal traps: Traps with a combination of UV-A and blue or green	

				feeding of European wasps and ants Hymenoptera: Vespidae, Formicidae) on plant exudates Phenology of BMSB	**France, Italy**: parasitoid *Trissolcus mitsukurii, Trissolcus japonicus.* **Bulgaria:** Trapping in heated shelters. **Georgia:** Parasitoids-five species of *Trissolcus* Ashmead Virome reveals viruses that may be useful in future biocontrol work Potential of the parasitic tachinid fly, *Pentatomophaga latifascia* (Diptera: Tachinidae), as a biological control agent	visible wavelengths provided higher H. halys attraction (up to ~8-fold) compared to traditional sticky or small pyramidal traps.	

					Amylo-X® for symbiotic control through field applications targeting egg masses *B. velezensis* deserves further studies to explore its additional functions against insects. Semi-natural habitats promote biological control of H. halys (Stål) by the egg parasitoid *Trissolcus mitsukurii* Study on fumigation with ethyl formate, applied as 16.7% by mass dilution in		

					carbon dioxide, for control of adults Augmentative releases of *A. bifasciatus* contributed to increasing parasitization without causing negative effects on parasitization by naturally occurring species.		

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Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control**	**Monitoring**	**Risk for soft fruit**
Erthesina fullo Thunberg *yellow spotted stink bug (YSSB),*	China Bangladesh Japan, India, Indonesia, Myanmar, Taiwan, Sri Lanka, Vietnam, Brazil, Intercepted in the U.K. Present in Albania First report in Brazil	Highly polyphagous over 57 host plants in 29 families, including some economically important fruit crops such as kiwifruit, pear, peach, apple, and pomegranate.	Nymphs and adults feed on leaves, flowers, shoots, and fruit of various host plants. YSSB inserts its stylet into the plant tissue for feeding and secretes a thick saliva to break down tissue cells and enable the consumption of the liquified contents Feeding results in discoloration, appearance of yellowish-brown spots, withering	Adult slightly brownish black, and the body sizes (male: length 18–22 mm, width 8–10.5 mm; female: length 19–23 mm, width 9–11 mm) The adult head is relatively big and tapering towards the front. There are some yellowish white dots between the red simple and black compound eyes. Antennae	Cultural control Physical control (bagging fruit to prevent bug damage) organophosphates and pyrethroids Genetic- host plant resistance. parasitoids, predators and entomopathogens *Trissolcus flavipes* parasitoid maximum parasitism rate between May and August was 30.6% and 43.5%, respectively	Blue-green sticky traps Alarm pheromone	LOW Intercepted in the UK in 2021 from imported wood.

			and even defoliation of leaves or shoots. Feeding can cause dry, corky tissues just below the surface of feeding sites on fruit, which can harden, depressing and distorting the surface of the fruit, In the worst cases, feeding can also cause fruit to abort prematurely.	are black and filamentous with five segments, while the basal portion of the fifth segment is pale yellowish. A whitish yellow line runs back from the apex of the head, across the middle of the praescutum, and ends at the base of the scutellum. YSSB spends winter in the adult stage, sometimes under bark or in natural crevices and leave overwintering	*Anastatus fulloi* Eupelmidae) and Telenomus sp. (Hymenoptera: Scelionidae) were the two dominant parasitoids attacking 1st generation YSSB eggs. For 2nd generation YSSB eggs, Ootetrastichus sp. (Hymenoptera: Eulophidae) was the dominant parasitoid Virome: novel arlivirus from a yellow spotted stink bug.		

				sites in spring when temperatures exceed 13C			

Interception in the UK: https://hortnews.com/yellow-spotted-stink-bug-intercepted-in-england/?mc_cid=8c08e36929&mc_eid=8f25bd0507

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Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control**	**Monitoring**	**Risk for soft fruit**
Aleyrodes lonicera/ honeysuckle whitefly	Native and widespread species in the U.K.	*Lonicera periclymenum* and *Rubus fruticosus.*	Overwintered as adults on *R. fruticosus* on the woodland floor, spreading onto	PUPA: 1 mm long, light yellow in color, oval and dorsally ADULTT: 1 mm	parasitoids *Euderomphale chelidonii* and *Encarsia tricolor* and the specialist		LOW

	Found throughout Europe and east into Russia; Israel, Turkey, Iran, and Korea.	Cultivated strawberry *Fragaria x ananassa* Violets From Evans (2008): Balsainaceae—*Impatiens noli-tangere* Campanulaceae—*Platycodon grandiflorum* Caprifoliaceae—*Lonicera* spp. Ericaceae—*Vaccinium myrtillus* Fabaceae—*Robinia viscosa* Oxalidaceae—*Oxalis* spp.	spring growth of *L. periclymenum, Geum urbanum* and other minor hosts to reproduce, before retreating to *R. fruticosus* in the autumn.	long light yellow body and white wings with a faint grey curved line in the lower portion of the forewing. LARVA: larvae do produce a fringe of wax around the circumference but are devoid of wax dorsally. All post-egg stages are an opaque light yellowish-green dorsally. The lingula, which is barely visible under a hand lens, is bluntly triangular and brown. An oval	whitefly predators *Clitostethus arcuatus* and *Acletoxenus formosus* are natural enemies. 11 parasitoid wasp species associated with *A. lonicerae*–eight in the family Aphelinidae (*Cales noaki, Encarsia spp., Eretmocerus mundus*), and three in Eulophidae (*Ceranisus pacuvius, Euderomphale sp1, Euderomphale sp2*). *Encarsia inaron, E. lutea, E. meritoria, E. pergandiella* and *Eretmocerus mundus* are		

		Papaveraceae—*Chelidonium majus, Dicentra spectabilis* Rosaceae—*Crategus microphylla, Filipendula ulmaria, Fragaria* spp.; *Geum rivale, Prunus dulcis, Rubus chamaemorus* Urticaceae—*Urtica* spp. Violaceae—*Viola* spp. Wood avens-*Geum urbanum*		ring of wax residue can be seen on the leaf surface after the pupal exuviae are removed	recorded from Florida.		
https://www.nhm.ac.uk/our-science/data/uk-species/species/aleyrodes_lonicerae.html https://www.researchgate.net/publication/321137872_Woodland_Ecology_of_Aleyrodes_lonicerae_in_the_Southern_United_Kingdom https://gd.eppo.int/taxon/ALEUFA https://www.cabi.org/isc/datasheet/119630							

https://www.gbif.org/species/4484307 - geographic distribution

https://www.cabi.org/isc/abstract/20203248230 - on strawberry

https://www.researchgate.net/publication/311534613_Pest_Alert_The_Honeysuckle_Whitefly_Aleyrodes_lonicerae_Walker_New_to_Florida_and_the_United_States - alert

Description: Stocks, I. C., 2012. Pest Alert: The Honeysuckle Whitefly, Aleyrodes lonicerae Walker, New to Florida and the United States. USA: Florida Department of Agriculture and Consumer Services, Division of Plant Industry .3. https://www.fdacs.gov/ezs3download/download/25060/515976/aleyrodes-lonicerae.pdf

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Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control**	**Monitoring**	**Risk for soft fruit**
Pseudaulacaspis pentagona/ White peach scale	Since 2006 several outbreaks (Cornwall, Devon, Gloucestershire, Kent and Oxfordshire)	100 plant genera Inc. peach (*Prunus persica*) trees grown under protection,	Foliage of infested trees may become sparse and yellow. Fruit size may be reduced, and premature fruit drop is likely to	Adult female scale covers are convex, circular to oval, dull white with a subcentral yellow spot	Infested hosts can be trimmed/pruned to remove infested parts, which can then be burned. Chemical options are available, but	Visual inspection. Sticky tape erected with its stickiness facing	MEDIUM Easily spread from imported material. Lack

	Kenya- first report 2021.	*Malus, Prunus, Pyrus, Ribes, Rubus, Sorbus,* and *Vitis* *Catalpa bignonioides* Kiwi fruit lilac (*Syringa*) dogwood (*Cornus*)	occur, especially if scale feeding is accompanied by other stresses. Heavy infestations can result in the drying out and death of twigs, branches, and even large mature trees if left unattended. Young plants can die very quickly after infestation.	(shed skins), 2.0 – 2.5 mm in length. The body of the adult female is yellow. The male cover (test) is smaller, felted, white, elongate, often ridged with a terminal yellow spot (shed skin), 1.5 mm in length. The male tests often occur in conspicuous masses occasionally smothering the bark and turning it white. The adult males are winged and	the waxy covering of the organism affords it some protection. Repeated application of chemical insecticides over more than one season may be required to control the pest. acetamiprid, deltamethrin or petroleum oil South Korea: Parasitoids, Biological Control, Four aphelinid and one encyrtid parasitoid species (Hymenoptera: Chalcidoidea) were collected from Pseudaulacaspis	outwards on the trunk and branches can help to optimise spray of young larvae (‘crawlers’) timings. In the spring.	of good controls. Wide host range.

				mobile in order to locate a mate. Temperature affects spawning and egg stages to the emerging adult stage on the induction of reproductive diapause in females.	pentagona were identified as Aphytis proclia (Walker), Encarsia berlesei (Howard), Marietta carnesi (Howard), Pteroptrix orientalis (Silvestri) (Aphelinidae) and Arrhenophagus chionaspidis Aurivillius (Encyrtidae). Iran Pesticides: Highest percentage of efficacy on the first generation of observed when using Spirotetramate 1 ml/l. after the second generation, highest efficiency from		

					Spirotetramate 1ml/L and Chlorpyrifos 4 ml/L. Among the bio-insecticides, 1/5 ml/L of Palizin and 8 ml/L of Tondexir were highly effective.		

https://planthealthportal.defra.gov.uk/assets/factsheets/Defra-Factsheet-Pseudaulacaspis-pentagonaV3.pdf

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Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**
Ceroplastes ceriferus/ Indian wax scale	Near global distribution. Native to Southern Asia, Switzerland,	Wide host range including trees but notably Prunus, Salix	Infestations on the foliage, stems and branches.	The body hidden under a roughly convex, circular or	**Chemical control:** Acetamiprid, Buprofezin,	DNA barcoding	Not yet identified in UK.

	Italy, Turkey, Bulgaria, Hungary, parts of East and South Africa, Australia, US, Brazil, Chile.	(willows), Citrus, Tea, Coffee etc. (see Plantwise website).	Reduced vigour and general debility. Heavy infestations may cause chlorotic spotting on the leaves, dieback of stems and wilting. Honeydew leads to growth of black sooty moulds.	oval covering of wax. Wax is white in nymphs and young adults and becomes pinkish in older individuals. Adults have a forward-pointing waxy horn and there are waxy filaments projecting from the margin of the scale, giving the insect a daisy-flower-like appearance. Most populations are and reproduce parthenogenically.	Malathion **Cultural controls:** Maintain overall plant health and reduce plant stress. Avoid overfertilization. Adult wax scales are protected against insecticide treatments by their thick waxy coating. When adults are present, best to physically remove them by handpicking or pruning.		

Good Resource: https://www.plantwise.org/knowledgebank/datasheet/12342

Description: http://scalenet.info/catalogue/Ceroplastes%20ceriferus/

Chemical control: https://vtechworks.lib.vt.edu/bitstream/handle/10919/84256/ENTO-238.pdf?sequence=1&isAllowed=y and https://mgnv.org/wp-content/uploads/2021/03/2021PestManagementGuideHomeGroundsandAnimals.pdf First records of Ceroplastes ceriferus (Fabricius) (Hemiptera: Coccidae) and Ceroplastes japonicus (Gray) in Switzerland identified by DNA barcoding https://onlinelibrary.wiley.com/doi/full/10.1111/epp.12805?campaign=wolearlyview

Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**
Ceroplastes japonicus *Tortoise wax scale*	France, Germany, Switzerland, Italy. Slovakia, Turkey, Greece, Croatia, Russia, China.	Wide host range and an important pest of many ornamentals, forest trees and shrubs but also Citrus, Prunus (stone fruit).	Infestations on the foliage, stems and branches. Reduced vigour and general debility. Heavy infestations may cause chlorotic spotting on the leaves, dieback of stems and wilting.	Body oval or rectangular; convex in lateral view in old females, nearly flat in young females. Body reddish brown; with a thick wax covering. Eggs laid in chamber under body of adult. Eggs less than 0,5 mm long.	Chemical control not effective due to protective wax covering. The coccinelid, *Chilocorus kuwanae*, & parasitoid, *Microterys clauseni*. Longer list of natural enemies provided in the CABI website and EU factsheet.	DNA barcoding	Not yet identified in the UK

			Honeydew leads to growth of black sooty moulds.	One female may lay till 2500 eggs. Small females lay 400 – 500 eggs. No pupa stage.			

Resource: https://www.cabi.org/isc/datasheet/12349

Description: http://idtools.org/id/scales/factsheet.php?name=6877

Description: http://scalenet.info/catalogue/Ceroplastes%20japonicus/

Natural enemies/ control: https://www.cabi.org/isc/datasheet/12349#tonaturalEnemies and https://gd.eppo.int/download/doc/1318_ds_CERPJA_en.pdf

First records of Ceroplastes ceriferus (Fabricius) (Hemiptera: Coccidae) and Ceroplastes japonicus (Gray) in Switzerland identified by DNA barcoding

https://onlinelibrary.wiley.com/doi/full/10.1111/epp.12805?campaign=wolearlyview

Coleoptera - beetles

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Popillia japonica / Japanese beetle	Native to Northern Japan and far east Russia. North America (1911), Canada, Azores (1970s), mainland Europe (2014). No UK records to date. Extensive damage in US, with a significant outbreak confirmed in northern Italy in 2014.	Wide host range, over 300 hosts in 79 plant families, including crops and woody plants. Fruit trees, turf, ornamentals. Blueberry, apple, grapevine, cherry, plum, peach, raspberries, strawberry. Adult beetles eat inside blueberries. Seasonal abundance,	Adults: skeletisation of foliage, which may turn brown and fall. Can cause significant defoliation and may damage flowers. Larvae: feed on roots, symptom not specific, e.g. strawberry.	Chafer beetle Adults: 8 to 13 mm long, metallic green thorax and head and coppery bronze wing cases with distinct white setal tufts/spots on margins. Eggs: round, elliptical or nearly cylindrical, 1.5 mm long.	Plant Protection Products, broad spectrum including pyrethroids. Chemical control outperforms organic methods. Insect excluding mesh. Mulching of container-grown nursery stock. Native generalist predators and birds. Entomopathogenic nematodes;	Regulated in EU (Annex IAII of the EC Plant Health directive). Adults hitchhike on non-host commodities or vehicles. Larvae highly cryptic and easily moved with rooted plants. Traps: part food-type lure (phenethyl propionate +	LOW (long lifecycle in UK – 2 years) PHRR information: Action: Statutory action against findings. Awareness raising. Already listed in legislation, but stakeholders may wish to monitor for

	Presence in UK: no (EPPO GD) There is a recent incursion in Northern Italy (Lombardy) Modelling paper shows potential of this beetle to achieve global distribution due to Land Use and Climate Change Scenarios	defoliation, and parasitism dependent on the apple cultivar. 3 Carpinus taxa, *Carpinus caucasica* , *Carpinus tschonoskii* and the hybrid *Carpinus caroliniana* x *C. coreana.*	Dug up by badgers and foxes in turf.	Larvae: typical chafer, C-shape form, well developed legs and head capsule.	*Steinernema* and *Heterorhabditis*. *Metarrhizium anisopliae.* Gradual Decline of Japanese Beetle Populations in Michigan Follows Establishment and infection by the microsporidian pathogen, *Ovavesicula popilliae*	eugenol + geraniol) and sex attractant (Japonilure) Modelling: Model outputs can support the best timing for implementation of monitoring and control activities. Immunomarking method to investigate the flight distance. Stable isotopes provide a method to determine where and what insects are feeding on.	possible presence. EPPO protocol has been developed which sets out measures needed in the event of an outbreak. Legislative status: GB QP

						Italy: Modelling diapause termination and phenology Molecular screening: SYBR Green-based real-time PCR test for the identification of adults and larvae Optimizing the Use of Semiochemical-Based Traps for Efficient Monitoring	

IDENTIFICATION: https://idtools.org/id/beetles/scarab/factsheet.php?name=15216 & https://planthealthportal.defra.gov.uk/assets/factsheets/popillia-japonica-factsheet.pdf

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Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Naupactus leucoloma / white fringed weevil	South Africa, Europe (not UK), North America, Oceania, South America	*Brassica* *Daucus carota subsp. sativus* Fabaceae *Fragaria x ananassa* *Pisum sativum* *Rubus* *Solanum tuberosum* *Trifolium* vegetable plants *Vigna unguiculata* *Zea mays*	Eggs, larvae, pupae (on roots, stems and lower leaves and in growing media) Adults (on foliage). **Physiology:** Modulating gene expression may be an important mechanism of successful colonization.	Eggs: Oval approximately 0.9 mm long and 0.6 mm wide, laid in clusters of approximately 10–60. Milky-white when first laid, changing to dull light-yellow. Larvae: Legless, slightly curved, yellowish-white grub with a light brown head up to 13 mm long, 6 mm wide. Pupa: Creamy white, 10–12 mm long occurring in	Natural enemies: *Conoderus exsul* *Heterorhabditis* *Hexamermis* *Paecilomyces farinosus* *Passer domesticus* *Rhabditis hambletoni* *Steinernema feltiae* Phytosanitary measures Soil fumigation Crop rotation Nematodes and EPFs	Phytosanitary inspections Pest survey cards	LOW Not yet identified in UK.

				chambers in soil. Two or three days before adult emergence, the pupa turns brown. Adult: Approximately 10–13 mm long, 4 mm wide across the abdomen with a short snout, greyish, with a broad longitudinal white stripe along each side of the elytra. The body is densely covered with short pale hairs which are longer on the elytra.			

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Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Anoplophora chinensis- Citrus longhorn beetle	Asia (China, Korea, and Japan, with occasional records from Indonesia, Malaysia, Philippines, Taiwan, and Vietnam) Europe, Turkey	Highly polyphagous. Deciduous trees and shrubs, for example: Acer spp., Betula spp. and Prunus spp. Hazelnut	Adult beetles make a distinctive circular hole in the bark when they emerge from their larval and pupation stages. Typically, 6-11mm wide (0.25 – 0.4in). Holes mostly found towards the base of trunks and exposed roots. On smooth-barked trees they resemble drilled holes. Scars or slits on the bark at sites	Adults species are glossy black with 10–20 distinct irregular shaped patches on the elytra, although in rare instances the number of patches ranges from 0 to over 60. Patch colour is usually white and at times pale yellow. Body length between 17 and 40 mm.	Fell and chip, burn or deeply bury infested trees. Foliar insecticide sprays can be effective against adults. *Aprostocetus fukutai*, an Egg Parasitoid	Test trapping protocols. Molecular diagnostics from whole body insects (adults and larvae) and frass samples. Climate change effects on the global distribution and range shifts	Not yet in the UK Notifiable

			where eggs have been laid, frass at the base of an attacked tree.	Presence of 20–40 small projections (tubercles) on the basal quarter of each elytron.		Effects of temperature	

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Lingafelter, S. W. & Hoebeke, R. E. 2002. Revision of the genus Anoplophora (Coleoptera: Cerambycidae). The Entomologcal Society of Washington, Washington D. C. 238 pp.

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Rizzo D, Daniele Da Lio, Linda Bartolini et al. 2021 The Rapid Identification of Anoplophora chinensis (Coleoptera: Cerambycidae) From Adult, Larval, and Frass Samples Using TaqMan Probe Assay, Journal of Economic Entomology, 114, 2229–2235, https://doi.org/10.1093/jee/toab138

Wang X et al. 2021 Optimal Conditions for Diapause Survival of Aprostocetus fukutai, an Egg Parasitoid for Biological Control of Anoplophora chinensis, Insects, 535; https://doi.org/10.3390/insects12060535

Yuting Zhou, Xuezhen Ge, Jenny Liu, Ya Zou, Siwei Guo, Tao Wang, Shixiang Zong Climate change effects on the global distribution and range shifts of citrus longhorned beetle Anoplophora chinensis https://doi.org/10.1111/jen.12996

Ali Turan, Veli Erdoğan Spread and Damage of Citrus Longhorned Beetle [Anoplophora chinensis (Forster, 1771) (Coleoptera: Cerambycidae)] to Hazelnut Orchards in Turkey DOI: https://doi.org/10.24925/turjaf.v10i4.531-535.4480

Melody A Keena, Jessica Y Richards, Effects of Temperature on Anoplophora chinensis (Coleoptera: Cerambycidae) Larvae and Pupae, Environmental Entomology, Volume 51, Issue 1, February 2022, Pages 153–166, https://doi.org/10.1093/ee/nvab132

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Anthonomus rubi/ Strawberry blossom weevil	Europe, North America (Canada) Established in Washington State USA	Strawberry Raspberry (increasing importance)	Severed buds Non-severed buds containing an egg develop through to open flowers with a dark spot near the base of the receptacle, resulting in malformed berries.	Adults: black in colour and 2– 4 mm in length, with scattered greyish pubescence and a long snout about 40% of the length of the body. Eggs: 0.5 x 0.4 mm in size, oval, white and translucent. They are found	Insecticides Mass trapping Attractive tapes Pheromone lures (Russell IPM)	Baited yellow sticky traps	LOW Effective control options are available

				inside flower buds. Larvae: 3.5 mm long, dirty creamish-white, legless, with a brown head. The body has a noticeable C shape and is wrinkled. It is found inside severed, withered flower buds.			

Zanettin TL et al. 2021 Anthonomus rubi on Strawberry Fruit: Its Biology, Ecology, Damage, and Control from an IPM Perspective. Insects, 12, 701. https://doi.org/10.3390/insects12080701

Nathan D. Roueché, T. M. Wilson, Chris Looney, M. Lourdes Chamorro "Anthonomus rubi (Herbst) (Coleoptera: Curculionidae) is Established in Washington State and the United States of America," Proceedings of the Entomological Society of Washington, 124(2), 367-371,

Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**

Charidotella sexpunctata - Tortoise beetle	North America, Central America, Caribbean, South America	Cabbage Strawberries Raspberries Corn Milkweed Eggplant Sweet potato (most damage)	Both larvae and adults feed on foliage. The typical form of injury is the creation of numerous small to medium-sized irregular holes. Both stages usually inhabit the lower surface but eat entirely through the foliage.	Adult; Length: 5 to 8 mm. Variable in colour from reddish-brown with black spots to brilliant, mirror-like gold, earning it the nickname "goldbug". Elytral margins are expanded and nearly transparent.	Parasitoids of this species include the eulophid wasp *Tetrastichus cassidus* and the tachinid fly *Eucelatoriopsis dimmocki*.		LOW Not yet in the UK
Identification: https://www.insectidentification.org/insect-description.php?identification=Golden-Tortoise-Beetle https://entnemdept.ufl.edu/creatures/veg/potato/golden_tortoise_beetle.htm Taxonomy: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=720028#null							

Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**

Aromia bungii – Peach red-necked longhorn/ plum and peach longhorn/ red-necked longhorn	China, North Korea, South Korea, Mongolia, Japan and Vietnam. Germany, Italy, (possibly) Spain. Intercepted in the UK and US	Prunus species, in particular stone fruit trees, such as peach, Apricot, plum, cherry and almond. Other species such as pomegranate, kaki and olive trees are potential hosts.	Detection of reddish coloured frass at the base of the trunk, bark or near the crown in upper branches. Removal of the bark reveals larval galleries and holes. Adults observed in field conditions because of their diurnal activity.	Adult brightly black elytra and the red dorsal region of the prothorax, hence, red neck longhorn beetle (23– 37 mm). A. bungii ssp. cyanicornis is black Eggs: elongated, subcylindrical approx. 2 mm long. Larvae: hatched larvae are 2-2.5 mm long; mature larvae are 42- 52 mm. Pupae: pupae light yellow and are 22-38 mm	Pheromone traps Male sex aggregation pheromone Parasitoid: *Sclerodermus guani* female-repellence ingredients from Mentha spicata: myrcene, (S)-(+)-carvone, (E)-β-caryophyllene, and borneol Effects of dinotefuran trunk injection	Genetic information- mito- genome Pest survey card Genetic diversity study in Japan	LOW Not yet established in the UK

				long showing clearly defined legs, and long coiled antennae. Larvae may overwinter two or three times and usually mature after 21–36 months. Characteristics of infested and uninfested ornamental cherry trees- host trees with rough surface bark, large in size, and weakened conditions are prone to *A. bungii.*			
Good resource:							

Pest survey card on Aromia bungii. European Food Safety Authority (EFSA), https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/sp.efsa.2019.EN-1731

Aromia bungii Pest Report to support ranking of EU candidate priority pests. EFSA (European Food Safety Authority), https://.doi.org/10.5281/zenodo.2786515

Germinara GS et al. 2019 Electroantennographic Responses of Aromia bungii (Faldermann, 1835) (Coleoptera, Cerambycidae) to a Range of Volatile Compounds. Insects, 10(9), 274; https://doi.org/10.3390/insects10090274

Men J et al. 2019 Evaluating host location in three native Sclerodermus species and their ability to cause mortality in the wood borer Aromia bungii (Coleoptera: Cerambycidae) in laboratory https://doi.org/10.1016/j.biocontrol.2019.04.007

Russo E, Francesco Nugnes, Francesco Vicinanza, Antonio P. Garonna & Umberto Bernardo 2020 Biological and molecular characterization of Aromia bungii (Faldermann, 1835) (Coleoptera: Cerambycidae), an emerging pest of stone fruits in Europe. Scientific Reports, 10, 7112 https://www.nature.com/articles/s41598-020-63959-9

Song RLZ & Yimin Du 2021 Mitochondrial genome of Aromia bungii (Coleoptera: Chrysomeloidea: Cerambycidae) and phylogenetic analysis. https://doi.org/10.1080/23802359.2020.1846475

Yasui H, et al 2019 Electroantennographic responses and field attraction of an emerging invader, the red-necked longicorn beetle Aromia bungii (Coleoptera: Cerambycidae), to the chiral and racemic forms of its male-produced aggregation-sex pheromone. Applied Entomology and Zoology, 54, 109–114 https://link.springer.com/article/10.1007/s13355-018-0600-x

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Cao, D.; et al. Chemical Compounds Emitted from Mentha spicata Repel Aromia bungii Females. Insects 2022, 13, 244. https://doi.org/10.3390/insects13030244

Tamura, S.; Shoda-Kagaya, E. Genetic Differences among Established Populations of Aromia bungii (Faldermann, 1835) (Coleoptera: Cerambycidae) in Japan: Suggestion of Multiple Introductions. Insects 2022, 13, 217. https://doi.org/10.3390/insects13020217

Yuichi Yamamoto, Shuji Kaneko & Tsuyoshi Yoshimura (2022) Effects of dinotefuran trunk injection against the red-necked longhorn beetle Aromia bungii (Coleoptera: Cerambycidae) in Japanese flowering cherry trees, Journal of Forest Research, 27:6, 460-468, DOI: 10.1080/13416979.2022.2075524

Yamamoto Y, Ishikawa Y, Uehara K. Characteristics of Trees Infested by the Invasive Primary Wood-Borer Aromia bungii (Coleoptera: Cerambycidae). Insects. 2022; 13(1):54. https://doi.org/10.3390/insects13010054

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Anthonomus bisignifer Schenkling, *(Coleoptera: Curculionidae)*	Japan South Korea, North Korea, Russia (Siberia)	Strawberry Rubus and Rosa spp.	Adults clip developing buds, preventing fruit development and reducing yield.	Eggs are 0.6 mm long and 0.4 mm wide. Larvae are 3–4 mm long (by analogy with related species), off-white becoming greyish with age No description of the pupae could be found. Nevertheless, it is assumed to be similar to the pupae of *Anthonomus rubi* (3.0–3.5 mm long,	Natural enemies; *Phytoseiulus macropilis*	Rubus and Rosa plants for planting could provide a potential pathway	Not in the UK or EU however Considering climatic similarities of the region where occurs and where hosts occur in the EU, there is the potential to establish within the EU and UK

				curved, white, head brown) Adults are from 2.5 to 4.0 mm long. The head and pronotum is dark brown to black with an elongated curved rostrum Elytrae are pale brown to dark reddish brown. Legs are brown One generation per year			
Pest categorisation of Anthonomus bisignifer: doi: 10.2903/j.efsa.2017.5073							

Lepidoptera – moths

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Acleris comariana / strawberry tortrix moth	Widely distributed in Europe, inc. Denmark, North America, China, and Japan Presence in UK: present (CABI)	strawberry, *Fragaria x ananassa*	Spun or rolled leaf, causing sufficient damage to be a serious pest in some areas	Wingspan 13-18 mm with costal blotches. Closely resemble forms of *A. laterana*, from which reliably separated by dissection of the genitalia. This is a highly variable species, having several known forms in Britain	Other tortricid moth controls are likely to be affective. common egg-larval parasitoid *Copidosoma aretas* found in the UK	Pheromone identified E11,13-14Ald Eggs on lower surface of leaves on the proximal half of the leaflets. Eggs most frequently occurred on older plants and on medium-sized leaves.	MEDIUM In UK, reducing options for control of caterpillars. Not on PHRR. Legislative status: not in GB legislation

IDENTIFICATION: https://britishlepidoptera.weebly.com/065-acleris-comariana-strawberry-tortrix.html

http://idtools.org/id/leps/tortai/Acleris_comariana.htm

https://www.cabi.org/isc/datasheet/2713

Fryer, J. C. F. 1928. Polymorphism in the moth Acalla comariana Zeller. J. Genet. 20: 157-178.

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Svensson, G.P., Tönnberg, T., and Sigsgaard, L. 2019. Identification and field evaluation of (E)-11,13-tetradecadienal as sex pheromone of the strawberry tortrix (Acleris comariana). J. Appl. Entomol. 143:535-541.

Turner, J. R. G. 1968. The ecological genetics of Acleris comariana (Zeller) (Lepidoptera: Tortricidae), a pest of strawberry. Journal of Animal Ecology. 37: 489-520.

Vernon, J. D. R. 1971. Observations on the biology and control of tortricid larvae on strawberries. Plant Path. 20: 73-80.

Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used on apple**	**Monitoring**	**Risk for soft fruit**
Blastobasis lacticolella/ decolorella	Introduced into western Europe. Now reported in Netherlands, Sweden, Denmark, and UK (1946) from	Wide host range including leaf-litter, vegetation, and stored products.	Scalloping of epidermis of fruit, weep and are sometimes covered by a sticky	Wingspan 18-21 mm. Adults: quite variable some being very plain,	1-2 sprays of methoxyfenozide - protective deposit. Chlorantraniliprole applied during egg-	Tap sampling Online reporting	LOW In UK, sporadic occurrence in crops. Causes significant

	Madeira. Belgium (2017). Established and expanding its range. Presence in UK: present (CABI)	Strawberry, apple, pear.	mass of black frass. Webbing and tenting of foliage, with foliar damage and frass. In strawberry under calyx and feed superficially on berries.	others quite well-marked. Broad forward pointing 'V' mark at one third, dots or patch at two thirds and a sub-terminal fasci. Closely related species only discriminated by genitalia. Larvae: purplish-brown.	laying, before egg-hatch. Pyriproxyfen (Harpun) inhibits egg hatch, metamorphosis of nymphs to adults and reduces the fecundity of adult females. Indoxacarb may be effective. *Bacillus thuringiensis* has little activity against Blastobasis. Synthetic pyrethroids highly effective.		damage when it occurs, reducing control options available. Not on PHRR. Legislative status: not in GB legislation

IDENTIFICATION: https://britishlepidoptera.weebly.com/blacticolella-vs-badustella.html

https://ukmoths.org.uk/species/blastobasis-lacticolella

https://apples.ahdb.org.uk/blastobasis.asp

Online reporting: https://www.norfolkmoths.co.uk/micros.php?bf=8740

Species / Common name	**Geographic distribution**	**Hosts / Crops**	**Symptoms**	**Description**	**Control used in other parts of world**	**Monitoring**	**Risk for soft fruit**
Acleris minuta / lesser apple leaf-folder *yellow-headed fireworm*	North America: USA, Canada, Europe (possibly). Presence in UK: absent (PHRR)	apples, plums and cranberries, blueberry, peach, also pear.	Larval feeding on underside of leaves and superficially on berries.	Tortricid moth: Adult: 6.5-9.5 mm, forewing uniform, colour; summer form yellow or orange, winter form grey. Larvae: last instar greenish yellow ~ 12 mm.	Other torticid moth controls are likely to be affective and should be timed with sex pheromone traps. Cranberry management guide	Regulated quarantine pest. Sex pheromone identified.	LOW Not yet identified in UK. PHRR information: Action: Statutory action against findings. Planting material of several hosts are mitigated by current regulations

							prohibiting imports. Legislative status: GB QP

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=1406

http://idtools.org/id/leps/tortai/Acleris_minuta.htm

https://pherobase.org/database/species/species-Acleris-minuta.php

https://gd.eppo.int/download/doc/1145_minids_ACLRMI.pdf

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de Jong Y et al. 2014. Fauna Europaea - all European animal species on the web. Biodiversity Data Journal 2: e4034. doi: 10.3897/BDJ.2.e4034.

Gilligan TM, Epstein M. 2014. Tortricids of Agricultural Importance. Interactive Keys developed in Lucid 3.5. Last updated August 2014. http://idtools.org/id/leps/tortai/index.html

OSU. No date. Codling Moth Information Support System (CMISS). Natural Enemies of Codling Moth and Leafrollers of Pome and Stone Fruits. Integrated Plant Protection Center, Oregon State University. http://www.ipmnet.org/codlingmoth/biocontrol/natural/ (accessed August 2015).

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Weatherby, Julie C., "The life system of the yellow-headed fireworm, Acleris minuta (Robinson) (Lepidoptera: Tortricidae) " (1982). Retrospective Theses and Dissertations. 8396.

Weatherby J C., E. R. Hart, Seasonal Development and Color Morph Determination of the Yellowheaded Fireworm (Lepidoptera: Tortricidae), Environmental Entomology, Volume 13, Issue 3, 1 June 1984, Pages 818–821, https://doi.org/10.1093/ee/13.3.818

2021-2023 Cranberry Chart Book Book revised September 2021 https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1274&context=cranchart

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Acleris nishidai	Known only from mountains of central Costa Rica Presence in UK: absent (PHRR).	Rubus, cultivated blackberry	Larvae fold, roll, and tie young leaves of the host, feeding on them and surrounding leaves; the larvae reside within or adjacent to the folded or rolled leaves.	Typical Tortricidae Taxonomic identification in Brown and Nishida (2008) Larva: last instar 7–8 mm, head pale caramel, thorax, and abdomen green.	Other torticid moth controls are likely to be affective.	Pheromone not listed on Pherobase.	LOW Not yet identified in UK. PHRR information: Action: Statutory action against findings. Legislative status: GB QP
https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=29502 Brown JW and Nishida K, 2008. A new species of Acleris Hübner, [1825] from high elevations of Costa Rica (Lepidoptera: Tortricidae, Tortricini). SHILAP Revista de Lepidopterología, 36, 341–348.							

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Acleris nivisellana / snowy-shouldered acleris moth	North America, and southern Canada Presence in UK: absent (PHRR)	hawthorn apple paradise apple mallow ninebark pin cherry mountain ash feeds on the leaves of various plants in the family Rosaceae	Larval feeding occurs in a silken chamber on the lower surface of leaves along the midrib. Larvae skeletonize the leaves and may partly sever the midrib, causing injured leaves to have a characteristic twisted appearance. Larvae have not been recorded feeding on fruit or other parts of the plant.	Adults: 15–17 mm. Forewings white with large blackish semicircular patch along the costa and irregular patches of light grey mixed with brown in the median area and along the inner margin. Dark spot near the inner margin in antemedial area and subterminal	Other torticid moth controls are likely to be affective.	Pheromone not listed on Pherobase.	LOW Not yet identified in UK. PHRR information: Action: Statutory action against findings. Likelihood of entry on the main pathways is mitigated by current regulations prohibiting imports of the host.

				area is dark grey. Hindwings are brownish grey. Larvae: Mid- to late instar ~ 9-16 mm long. Abdominal color varies. Head is brown to dark brown posteriorly and dark brown to black anteriorly.			Legislative status: GB QP
IDENTIFICATION: https://bugguide.net/node/view/58615/bgimage Chapman, P. J. and S. E. Lienk. 1971. Tortricid fauna of apple in New York (Lepidoptera: Tortricidae); including an account of apple's occurrence in the state, especially as a naturalized plant. Spec. Publ. Geneva, NY: New York State Agricultural Experiment Station. 122 pp. Powell, J. A. 1964. Biological and taxonomic studies on tortricine moths, with reference to the species in California. University of California Publications in Entomology. Vol. 32. 317 pp.							

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit

Acleris fimbriana/ Yellow tortrix moth	pest of fruit trees in Northern China, found in mainland Europe but not the UK France, Germany, Denmark, Italy, Slovakia, Hungary, Romania, Poland, Norway, Sweden, Finland, the Baltic region, Ukraine and Russia. South Korea	Malus and Prunus In Germany mainly on sloes *Prunus spinosa, Vaccinium uliginosum, Betula nana, Malus domestica* and *Spiraea* species		wingspan is 18–20 mm		Pheromone discovered	LOW Not yet identified in UK.

IDENTIFICATION:

https://lepidoptera.eu/species/2770

https://www.cabi.org/isc/datasheet/2714

Yuxiu Liu and Xianzuo Meng Trapping Effect of Synthetic Sex Pheromone of Acleris fimbriana (Lepidoptera: Tortricidae) in Chinese Northern Orchard. Verlag der Zeitschrift für Naturforschung | 2015 DOI: https://doi.org/10.1515/znc-2003-5-622

https://www.pherobase.net/database/species/species-Acleris-fimbriana.php

Gustafsson, B. (Lep) (2003) Catalogus Lepidopterorum Sueciae. Naturhistoriska riksmuseet, Stockholm, Excelfil hämtad från http://www.nrm.se/en/catalogus.html.se. - via Dyntaxa. Svensk taxonomisk databas

Gärdenfors (ed.) (2010) Rödlistade arter i Sverige 2010 - via Dyntaxa. Svensk taxonomisk databas

Jin-Liang Zhao,Yu-Peng Wu,Tian-Juan Su,Guo-Fang Jiang,Chun-Sheng Wu &Chao-Dong Zhu 2014 The complete mitochondrial genome of Acleris fimbriana (Lepidoptera: Tortricidae). 2200-2202

Phytophagous mites

Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control used in other parts of world	Monitoring	Risk for soft fruit
Tetranychus mexicanus / Polyphagous spider mite	China, Netherlands, North America, South America Presence in UK: no records (EPPO GD)	Glasshouse crops. 100 hosts (in 44 plant families), including Citrus spp., Malus domestica, Vitis vinifera, papaya, and many ornamentals Guarana plants	Like other spider mites. Feeding punctures lead to whitening or yellowing of leaves, followed by desiccation, and eventually defoliation. Biological parameters in papaya and passion fruit	Identify using Gutierrez (1968) and Jepson et al. (1975)	Natural enemies; *Phytoseiulus macropilis*	Pathways for entry are Plants for planting, cut foliage fruits with green parts.	MEDIUM Already detected in glasshouse crops in Netherlands. Growers need to be aware of this if control measures break down
https://www.rhs.org.uk/science/pdf/plant-health/Biosecurity-2019-Pest-Alerts.pdf https://platform.cabi.org/isc/datasheet/53354 Netherlands took statutory action in 2018: https://www.eppo.int/ACTIVITIES/plant_quarantine/alert_list_insects/tetranychus_mexicanus Aguilar H, Murillo P, 2012. New hosts and records of plant feeding mites for Costa Rica: interval 2008-2012. (Nuevos hospederos y registros de ácaros fitófagos para Costa Rica: período 2008-2012.) Agronomía Costarricense, 36(2):11-28. http://www.mag.go.cr/rev_agr/index.html							

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Task 2.3. Ability of *Orius* to predate the capsid, *Lygus rugulipennis* juvenile stages (Year 1, Lead; NIAB)

Introduction

The AHDB Soft Fruit Panel identified capsids as a key pest of soft fruit crops in the UK. Capsids, such as the European Tarnished Plant Bug (*Lygus rugulipennis* Poppius), cause direct crop damage by feeding on developing fruits (Easterbrook, 2000). This results in deformation known as 'cat-facing', making the fruit unmarketable. Chemical Plant Protection Products (cPPP) are typically relied on to supress capsid populations. However, conventional use of broad-spectrum insecticides for capsid control may disrupt biological-based Integrated Pest Management strategies used for other major pests, such as Western Flower Thrips *Frankliniella occidentalis* (Pergande) (WFT). SCEPTREplus Review SP 39 highlighted the sector's comments that capsid damage has become more frequent and of higher impact because of cPPP withdrawals (e.g. chlorpyrifos, thiacloprid), increased reliance on biological controls for other pests, and increasing mean UK temperatures.

These changes in the UK soft fruit industry, including uncertain pesticide approvals, a reduced range of active ingredients, and associated insecticide resistance, increase the need for effective, new and novel, non-pesticide control methods. Providing growers with a range of alternative control measures is essential to prevent reliance on a single strategy and to allow them to choose the most appropriate method to achieve robust and satisfactory capsid control in a variety of situations. More recently as part of AHDB funded, SF 174, a capsid repellent has been investigated and is now available commercially to disrupt/prevent capsids entering soft fruit crops (Fountain et al., 2021).

The enhanced use of commercially available biocontrols has been identified as one potential method to reduce capsid numbers in crops. Anecdotal information from UK growers suggested that the presence of *Orius laevigatus* (Say), used to control WFT in the summer months, may also reduce capsid numbers. This was supported by data collected in project SF 174 where fewer *L. rugulipennis* were found in tap samples of crops in which *Orius* had been released.

The aim of the first year of this study was to investigate the possible role of *Orius* in capsid predation in soft fruit crops, and specifically to determine the ability of *O. laevigatus* to predate juvenile stages of *L. rugulipennis* in the laboratory.

Whilst not significant, there was a reduction in the number of *Lygus* nymphs that emerged from eggs in the presence of *Orius*. It appears that *Orius* nymph predation was higher than that of *Orius* adults, but again, this was not significant. Using behaviour tracking software, EthoVision, *Orius* spent more time in the vicinity of green beans which contained *Lygus* eggs over those that did not. This indicated there was potentially an attraction to the eggs or where Lygus females have previously visited, implying there may be semiochemical signals to which the *Orius* is orientating.

Where *Orius* was introduced into Petri dishes containing *Lygus* nymphs, there was a significantly higher probability of *Lygus* death compared to the untreated controls at both 24- and 72-hours of exposure. This was regardless of the stage of the *Orius* and instar of *Lygus.* After 24-hours of exposure there was a significant difference in probability of death in *Orius* treated 1st and 2nd instar *Lygus*. After 72-hours exposure, 1st, 2nd and 4th instar nymphs had a higher probability of death compared to 3rd and 5th. However, even the highest probability was only 12.7% probability of *Lygus* (4th instar) death in the presence of *Orius*. Hence, while it appears *Orius* presence does impact *Lygus* survival, it is minimal in its efficacy.

The first year experiments were done in Petri dishes and hence in the second year we studied the interaction in a more realistic setting in strawberry plants. The aim was to investigate the possible role of *Orius* in capsid predation in strawberry. We tested whether 1) *Orius* introduced to strawberry plants reduced the numbers of *Lygus*, 2) *Orius* reduced the level of fruit damaged caused by *Lygus* and finally 3) whether the presence of an alternative prey would diminish the impact that *Orius* had on *Lygus* control and fruit protection.

Methods

Site: The trial was conducted at NIAB East Malling in the westerly polytunnel on 'Ditton Rough', between July and September 2022. Within the tunnel were 30 cages (BugDorm-6E620 – 60 x 60 x 120 cm). Four flowering, *Fragaria x ananassa* plants (cv. Amesti) in 4L pots were transferred into each of cages, which were arranged into 6 blocks (6 replicates of each treatment), one block per irrigation line (Figure 2.3.1 and 2.3.2), with each block containing the 5 treatments (Table 2.3.1). Any unwanted pests were removed by hand. In cases where aphids were found, parasitoid wasps were deployed (Aphiline Bioline). Temperature and humidity were recorded using EL-USB-2 data loggers within the tunnel and within the cages.

Table 2.3.1. Treatments with combinations of insects in each.

Treatment number	***L. rugulipennis***	***F. occidentalis***	***O. laevigatus***
1	Yes	-	Yes
2	-	Yes	Yes
3	Yes	Yes	Yes
4 (control)	Yes	-	-
5 (control)	Yes	Yes	-

Culture Establishment: L. rugulipennis were collected by sweep-netting areas of wild host plants (including *Chenopodium*), adjacent to cultivated strawberry at the field site. Three sweep events were conducted: 11/07/2022, 29/07/2022 and 01/08/2022.

Male and female *L. rugulipennis* adults were identified by visual assessment in the laboratory and stored within a cage (6E610 Insect Rearing BugDorm, 60 x 60 x 60 cm) (Figure 2.3.1 & 2.3.2). The cage contained damp paper to provide humidity, a 5% sucrose solution for water and carbohydrates and bee-collected pollen for protein. Collections of adults were made until a minimum of 100 females had been collected.

Once *L. rugulipennis* had been collected, adult *F. occidentalis* were removed from a culture maintained in a temperature-controlled facility at East Malling, on *Chrysanthemum sp.* flowers. Using a vacuum powered pooter connected to a pipette tip, 720 *F. occidentalis* were gathered into groups of ten (Figure 2.3.4). *F. occidentalis* were collected into pipette tips which were sealed at one end with a filter paper, allowing airflow to draw the *F. occidentalis* into the tip. After 10 *F. occidentalis* had been collected, the open end was removed from the pooter and sealed with parafilm. The groups of *F. occidentalis* were released directly onto each plant within cages (Table 2.3.1) immediately after collection, resulting in 40 thrips released into each cage (Figure 2.3.3).

Two *L. rugulipennis* females were added to each cage (Table 2.3.1) at the point at which the *F. occidentalis* were released (12/07/2022). Additional releases of two female *L. rugulipennis* were made on 29/07/2022 and 02/08/2022 in cages where no adults or nymphs were detected during tap sampling prior to the release of *O. laevigatus.*

Subsequently, *O. laevigatus* were purchased from Bioline (Oriline L 250 ml bottle, containing 2000 nymphs). Upon arrival, the *O. laevigatus* were sexed under a microscope. One female *O. laevigatus* was released per cage in line with AHDB recommendations (0.25 *O. laevigatus* per plant). Releases were made on 03/08/22 and again on 18/08/22.

Figure 2.3.1. Insect cages containing four strawberry plants, with irrigation lines installed via the sleeves. Metal twist ties are wrapped tightly around the sleeves to ensure invertebrates cannot enter/ escape.

Figure 2.3.2. Insect cages laid out in the 'Ditton Rough' polytunnel. Blocks consisted of 5 cages with individual irrigation line.

Figure 2.3.3. *L. rugulipennis* culture from which two females were selected for release into each trial cage.

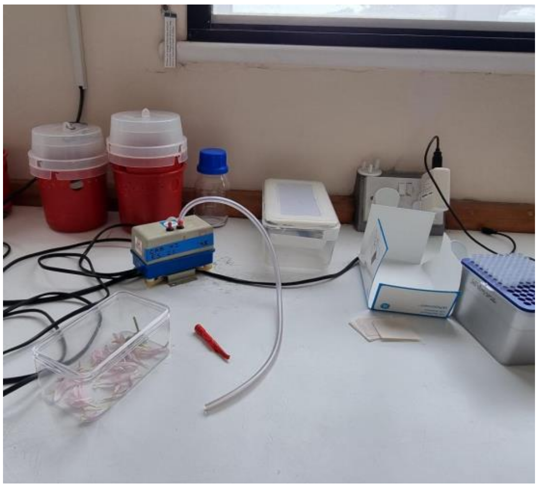


Figure 2.3.4. *F. occidentalis* collection. An electric pooter was used to remove *F. occidentalis* from *Chrysanthemum sp.* flowers.

Assessment

Tap Sample Assessments

Tap sampling was performed to assess the numbers of *F. occidentalis*, adult and nymph *L. rugulipennis*, *O. laevigatus* and other pests (e.g. aphids) and predators (e.g. predatory spiders). Each cage was opened, and a white tray placed beneath the canopy of the plants. A padded wooden stick was used to knock invertebrates off the plants onto the tray. All invertebrates were counted, including pests and predators not introduced into the cages. After counting, invertebrates were tapped back onto their original host plants and the cage closed. Pre assessment tap samples were done prior to *O. laevigatus* introduction 20/07/20, 25/07/22 and 01/08/22 to ensure pest population establishment. Following introduction of *O. laevigatus*, tap samples were done weekly (10/08/22, 17/08/22, 24/08/22 and 01/09/22).

'Cat-Facing' Assessments

Four strawberry damage assessments were undertaken to assess the impact *O. laevigatus* and *F. occidentalis* releases had on fruit 'cat-facing' caused by *L. rugulipennis*. Ten fruits were collected per plot, visually inspected, and scored between zero and three (zero being no 'cat-facing' and three being severe 'cat-facing') (Figure 2.3.5). The first assessment was done 7-days post 1st *O. laevigatus* introduction on 10/08/22. Subsequent assessments were taken weekly on three occasions (17/08/22, 24/08/22 and 01/09/22).

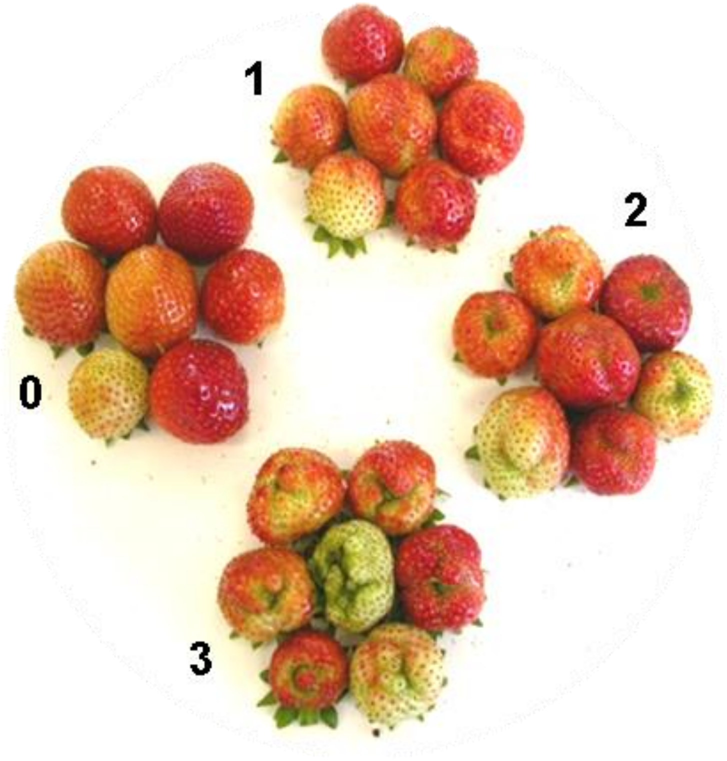


Figure 2.3.5. Scale used for capsid cat-facing assessments of strawberry fruit, from left working clockwise, 0 = no damage, 1 = low damage, 2 = moderate damage, 3 = high damage.

F. occidentalis *Assessments*

Two *F. occidentalis* assessments were made during the trial (10/08/22 and 01/09/22) to confirm thrips being recorded during tap sampling were *F. occidentalis* and not other species. Ten flower samples were collected per cage prior to tap sampling to ensure thrips had not been dislodged. Thrips were extracted from flowers using ethanol as described by Fountain et al. (2022). Following extraction thrips were assessed under a microscope and were confirmed as *F. occidentalis,* then adults and nymphs were counted.

Statistical analysis

All statistical analysis was carried out in R 4.1.1. Tap samples thrip nymphs in flowers were analysed using mixed models with Poisson distribution. A mixed model was used to account for the non-independence of measurements taken from the same plot (repeated measures). For *L. rugulipennis* nymphs the counts were 0 for certain treatments (Fig. 2.3.7); to enable a model to fit the data a Bayesian mixed model was used. Adult thrips in flowers were analysed using a standard generalised linear model (GLM) as modelling showed the repeated measures were independent of each other. Post-hoc analysis was used to calculate estimated means from the models, and to identify treatments which significantly differed from each other. All post-hoc p-values were adjusted for multiple testing using the Tukey method.

Results

Meteorological data

Generally, the mean temperature was 1.1°C warmer within the cages than within the tunnel (Figure 2.3.6). Temperature reached a maximum of 46.5°C within the cages while in the tunnel maximum temperature reached 43.0°C.

Humidity within the cages was on average 2.8% lower than in the tunnel itself. Maximum humidity rose to 94% in the tunnel while it only reached a maximum of 89.5 in the cages.

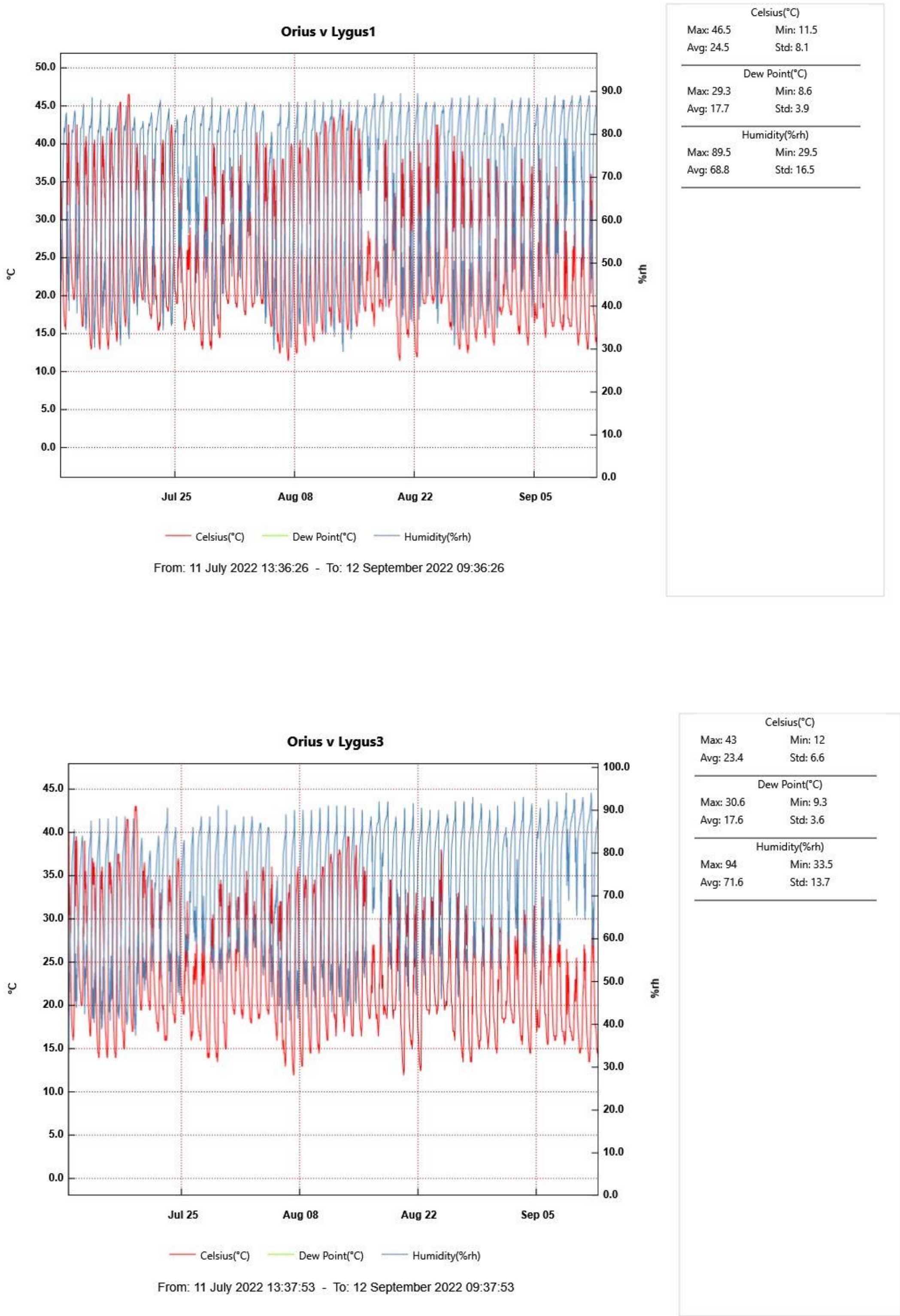


Figure 2.3.6. Environmental conditions collected within the cage (top) and within the tunnel (bottom) during the semi-field trial. Red line indicates temperature. Blue line indicates humidity.

L. rugulipennis numbers in cages

O. laevigatus introductions to cages did not significantly reduce numbers of *L. rugulipennis* regardless of whether *F. occidentalis* were present. Significantly more *L. rugulipennis* nymphs were present at assessment 1 in the *L. rugulipennis* vs *O. laevigatus* treatment compared to the *L. rugulipennis* alone treatment (p=0.049).

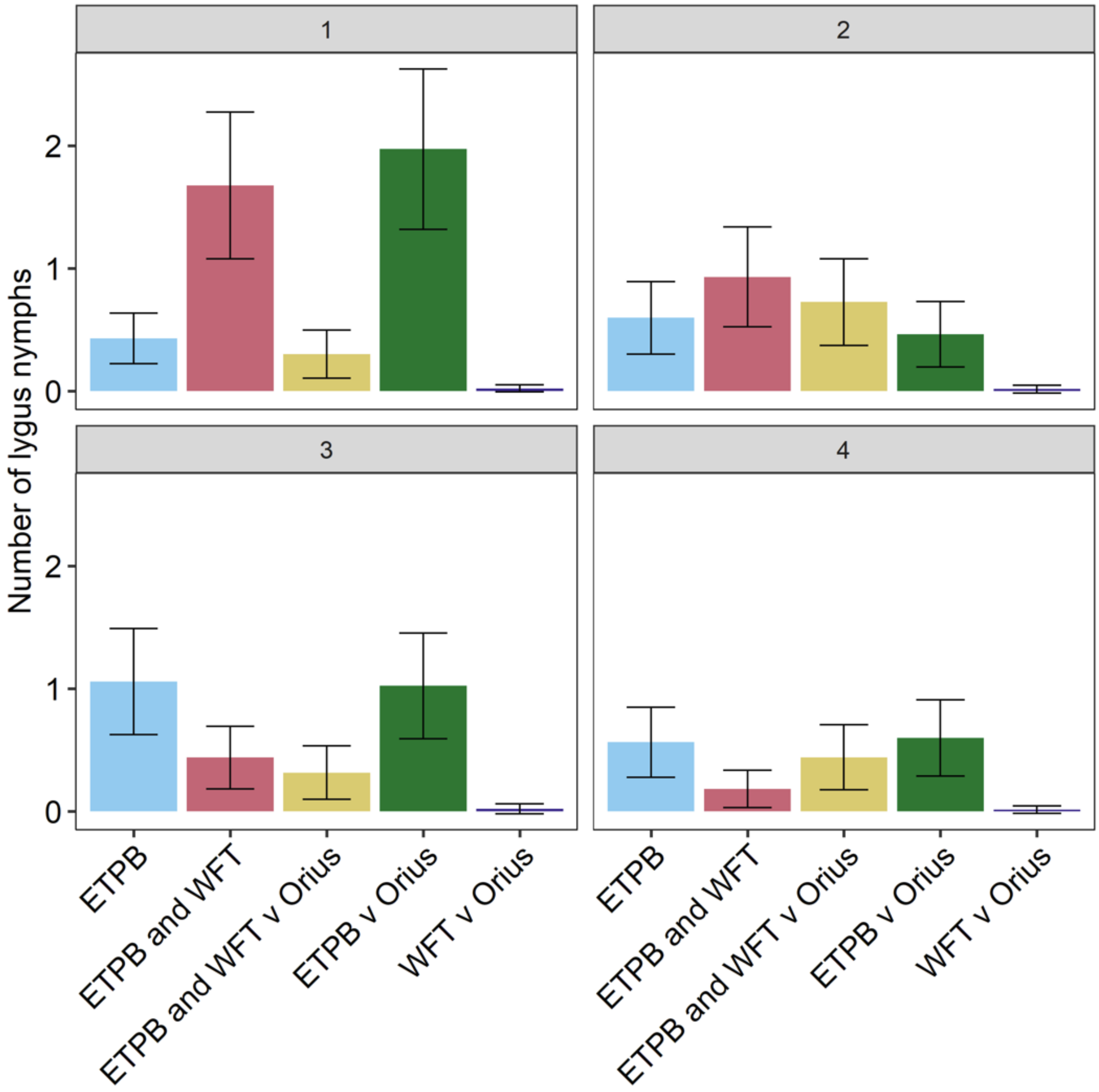


Figure 2.3.7. Mean (±SE) number of *L. rugulipennis* nymphs found in tap samples in the treatments on the four assessment events (1=10/08/22, 2=17/08/22, 3=24/08/22 and 4= 1/09/22). ETPB= *L. rugulipennis,* WFT= *F. occidentalis,* Orius = *O. laevigatus.* Please note, no ETPB were released in the WFT v Orius treatment.

There was no overall significant effect of treatment on fruit quality, damage score, however there was one interaction. There was significantly more damage in the *L. rugulipennis* plus *O. laevigatus* treatment than in *L. rugulipennis* alone (p=0.010) at assessment 4 (Figure 2.3.8).

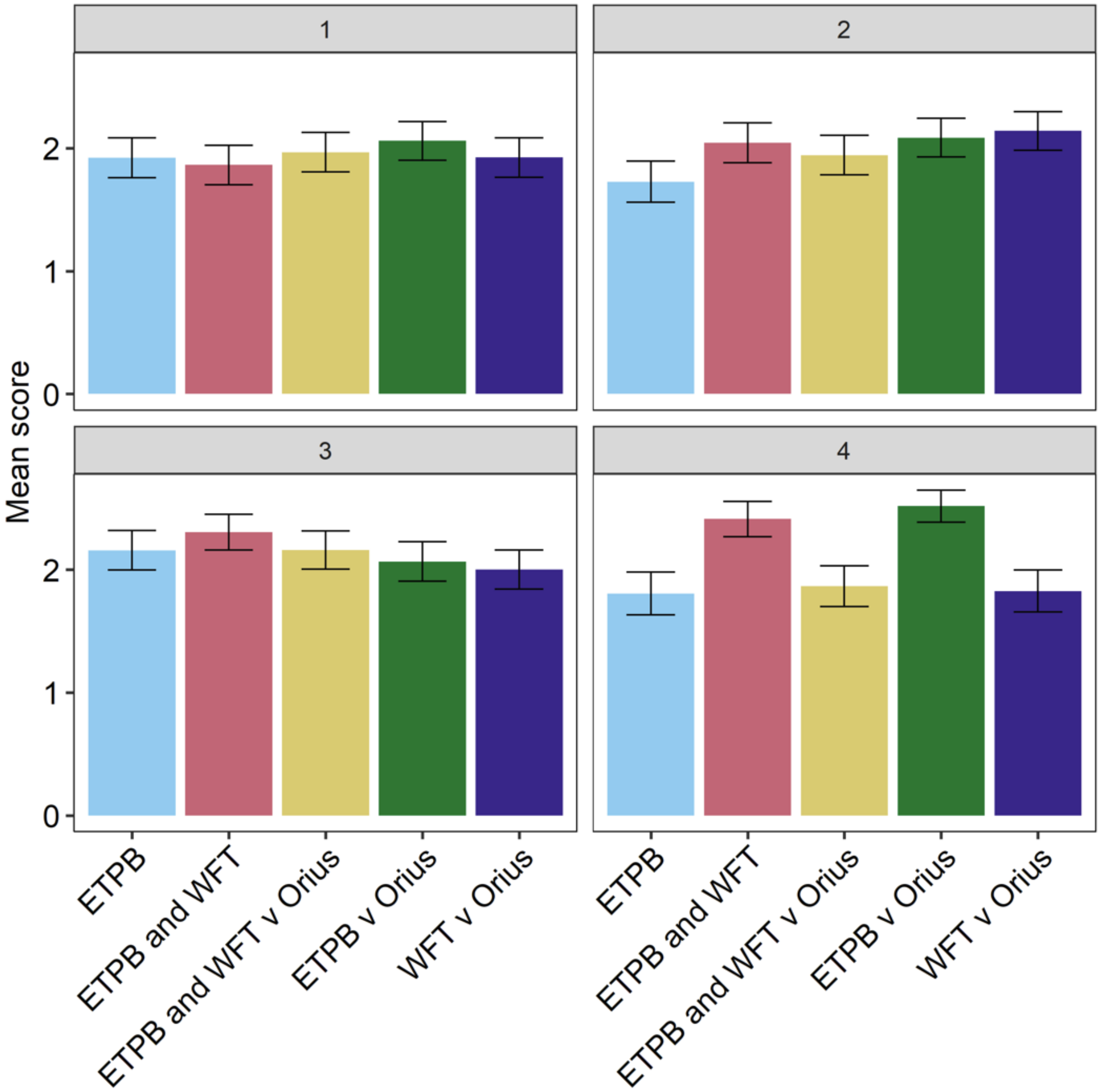


Figure 2.3.8. Mean (±SE) score of fruit damage of 10 fruits collected per plot, per assessment on the four assessment events (1=10/08/22, 2=17/08/22, 3=24/08/22 and 4= 1/09/22). ETPB= *L. rugulipennis,* WFT= *F. occidentalis,* Orius = *O. laevigatus.*

F. occidentalis assessments

Plants were screened prior to deployment in the cages and those which did not have *F. occidentalis* were used in the two non-thrips treatment. However, by the start of the trial, *F.*

occidentalis were found in all treatments (even those in which they were not introduced). The cages used for this trial were chosen to be thrips-proof, but clearly small numbers of thrips may have been present and undetectable on the plants at the beginning. There was no significant difference in *F. occidentalis* numbers between treatments although there were significantly higher overall numbers of *F. occidentalis* assessment 4 compared to assessments 2 (p=0.028) and 3 (p=0.023).

Other non-targets

There was no significant difference in the number of spiders, ants, aphids, parasitoids or predatory thrips between treatments which were all very low in number. While all precautions were taken to prevent insects from entering the cages, clearly the plant material and substrates were harbouring other invertebrates.

Discussion

The aim of this experiment was to further investigate the impact of *O. laevigatus* on *L. rugulipennis* following indications in year one that *O.* laevigatus had a positive effect on *L. rugulipennis* mortality. In addition, we aimed to assess the subsequent capsid damage caused to strawberry fruit and the impact the presence of an alternative prey source had on *L. rugulipennis* control by *O. laevigatus*. Unfortunately, the positive effects that were observed in Petri dishes in the laboratory in 2021 were not evident in the tunnel trial using strawberry plants in 2022. No reduction in the number of adult or nymph *L. rugulipennis* was observed and unexpectedly there was an increase in fruit damage in the cages which contained *L. rugulipennis* nymphs and *O. laevigatus* treatment compared to the control.

The lack of impact on *L. rugulipennis* fruit damage and numbers in tap samples was the result of insufficient *O. laevigatus* releases in treated cages. In tap sampling, only 8 individual *O. laevigatus* adults were detected in total in all assessments even though a total of 36 were introduced. As there were *F. occidentalis* in all cages we would have expected this to sustain the *O. laevigatus* in places where *L. rugulipennis* had not been introduced but it is likely that more inoculations were required to impact the population of all pests. Originally more *O. laevigatus* were not introduced to prevent cannibalism. This would have taken the density per plant higher than commercially recommended (0.25 per plant- taken from AHDB recommendations), hence two inoculations two weeks apart were made.

The first introduction of *L. rugulipennis* and *F. occidentalis* were made on 12 July and when the temperature reached 41.0°C within the cages. Additional introductions of *L. rugulipennis* were made once temperatures dropped and pest establishment was confirmed in subsequent tap sampling. *O. laevigatus* establishment could have been impacted by the high temperatures experienced after introduction as temperature exceeded 40.0°C on several occasions. It may be that the temperatures were too high for *O. laevigatus* survival. *O. laevigatus* thrive in temperatures between 20-30°C, with optimum temperatures identified at 26°C (Cocuzza et al., 1997). Above this temperature, high mortality occurs.

Although care was taken to prevent pest infestation prior to our artificial inoculations, the strawberry plants had several non-target species, primarily aphids, before the trial started. Non-targets were removed by hand and aphid parasitoids were introduced. It was decided not to use chemical interventions as this could have impacted the target organisms. However, there was no significant difference in the number of non-target invertebrates between the treatments, meaning any impact this could have had on predation of the target species was even across all treatments.

Future research could investigate how *O. laevigatus* interacts with other non-target species, but careful consideration would be required to ensure optimum experimental design was executed. While other non-target invertebrates will be present in field conditions, more evidence is required to demonstrate the in-field interaction between *L. rugulipennis* and *O. laevigatus*.

WP3. Enhance and augment biological control agents to target early aphid in protected crops

Task 3.1. Promoting the control of early aphid in strawberry by augmenting and retaining aphidophagous hoverflies in the crop (Year 3, Lead; NIAB EMR, Contributors; NRI, Russell IPM, Koppert UK

Introduction

Many species of hoverflies (Family: Syrphidae) are important predators of aphids. Adults have a high fecundity and larvae are voracious predators. However, they often only migrate into crops as pest populations increase. Plant produced volatile organic compounds (VOCs) can encourage beneficial insects, including hoverflies, into crops (James and Price 2004; James 2005, 2006; Mallinger et al. 2011; Zhu and Park 2005). There is also considerable potential to improve the attractiveness of commercially available volatiles for beneficial insects, including hoverflies, using readily available chemicals, with the added benefit that such lures do not require regulatory approval. At least three companies (e.g. http://polyfly.es/en/, https://www.flypollination.com/ (Olombria), Koppert, and www.bionostrum.com) have been successful in mass producing hoverflies for release in commercial crops.

In 2021, a field trial was established in polytunnel grown June bearer strawberry, to test whether deployments of commercially produced aphidophagous hoverflies (*Episyrphus balteatus*) could reduce populations of pest aphids (*Macrosiphum euphorbiae*) early in the spring and whether this interaction could be enhanced using 2 types of volatile dispensers to retain aphidophagous hoverflies in the crops. Unfortunately, trial findings were inconclusive. Sentinel plants, infested with equal numbers of *M. euphorbiae*, were deployed for 4 to 11 days in hoverfly treated or untreated plots, then plants were collected from the field. Numbers of hoverfly life stages and aphids on plants were counted to compare hoverfly egg laying and aphid feeding between treatments. However, aphid numbers were too variable to find a treatment effect, potentially due to the sentinel plants being on the ground, where other predators (e.g. Carabidae) may have reduced aphid numbers in all plants.

Nevertheless, there was some evidence supporting that hoverfly activity is positively correlated to aphid abundance. This was observed within the plot where highest numbers of *M. euphorbiae* were observed in the crop, indicating that this strategy might be better suited to strawberry crops with higher aphid numbers.

In 2022, two experiments were done in strawberry crops with a history of aphid abundance. The objective of trial 1 was to test whether the attraction of hoverflies and other natural enemies to plant VOCs could be improved compared to a commercial standard lure. Trial 2 investigated whether; 1) a commercially available VOC lure (MagiPal^{TM}) could retain commercially released hoverflies (*Sphaerophoria rueppellii*) and attract naturally occuring aphidophagous hoverflies into crops, 2) the combination of the MagiPal^{TM} volatile and releases of hoverflies could reduce numbers of aphid in the crop and, 3) the MagiPal^{TM} dispenser attracts other natural enemies of pest aphids.

Materials and methods

Trial sites:

Trial 1 (comparing hoverfly volatiles) was done on two farms in Kent to increase numbers of hoverfly species detected. At each farm the trial was set up in a ~2 ha. commercial strawberry crop.

Trial 2 (grower trial) was done on two farms in Kent. At each farm the trial was set up in two ~1 ha commercial strawberry crops, separated by buffer crops (≥ 300 m).

All strawberries were conventional polytunnel grown, everbearer (cv. Murano), in bags on tabletops (Fig. 3.1.1).

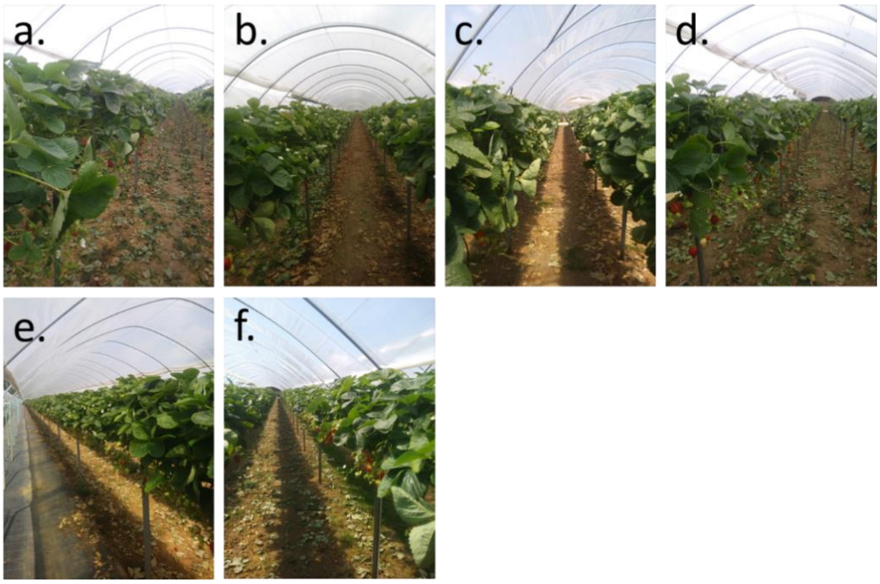


Figure 3.1.1. Photos of strawberry crops (cv. Murano) used during the aphidophagous hoverfly trial 2022; a) Trial 1 blocks 1 to 5 and b) Trial 1 blocks 6 to 10, c) Trial 2, block 1 control, d) Trial 2, block 1 treated, e) Trial 2, block 2 control, f) Trial 2, block 2 treated.

Experimental design:

Trial 1: A randomised block design was used with ten replicate blocks (5 blocks per farm). Each block was a polytunnel sub-divided into five 15 m L x 8 m W plots with a treatment randomly assigned to each plot to prevent position effect bias (Fig. 3.1.2).

Trial 2: At each farm a treatment was randomly assigned to each crop to prevent position effect bias. The trial served as a large-scale demonstration with only two replicates (Fig. 3.1.3).

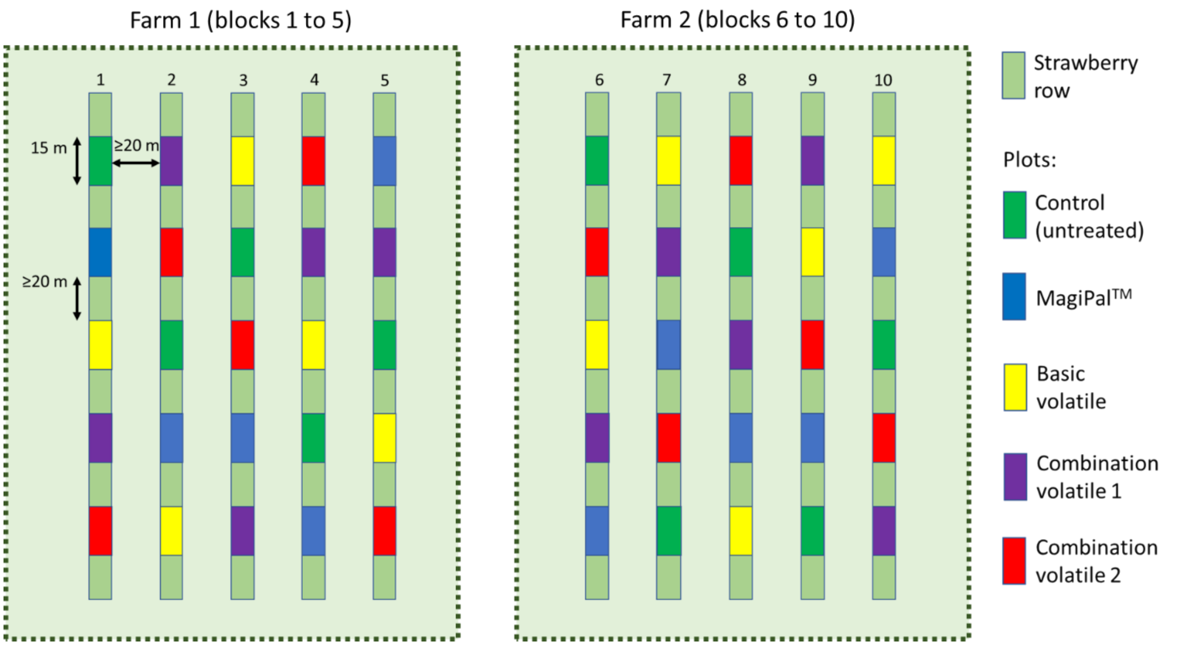


Figure 3.1.2. Schematic of Trial 1 (volatile trial) block and plot layout during the aphidophagous hoverfly trial 2022. Each block was a polytunnel sub-divided into five plots with a treatment randomly assigned to each plot. There was ≥20 m between plots and blocks.

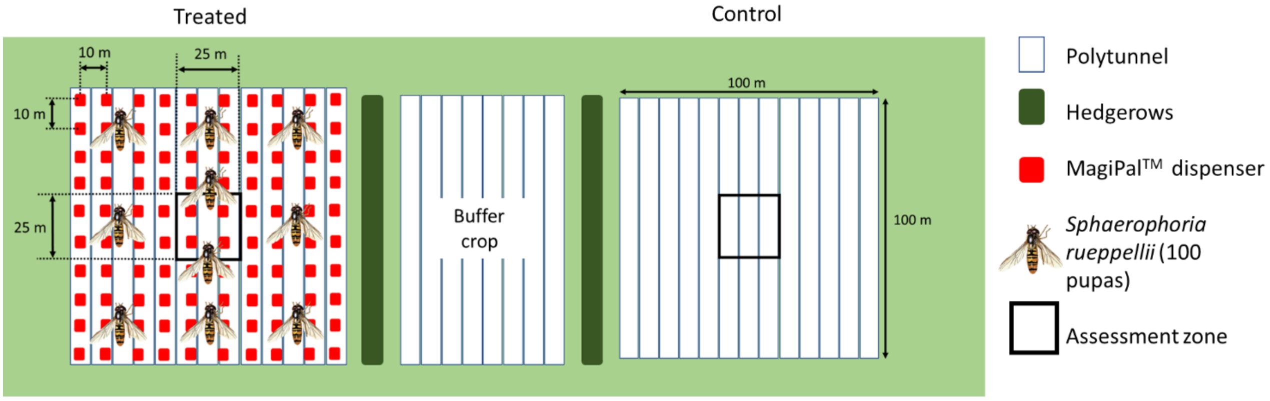


Figure 3.1.3. Schematic of Trial 2 (grower trial) layout in 2022. Each farm consisted of two ~1 ha strawberry crops separated by buffer crops (≥ 300 m).

Treatments:

Trial 1: In May, immediately after pre-assessments, a white Delta Trap® (Agralan Ltd) was hung below the tabletop in the centre of all plots (Fig. 3.1.4a). For plots with a volatile assigned, the volatile dispenser was suspended inside the Delta Trap® using a paper clip (Fig. 3.1.4b). No volatile dispenser was suspended inside the control (untreated) Delta Trap®. Volatiles consisted of; 1) MagiPal™, 2) Basic (single volatile), 3) Combination 1 (3 volatile blend), 4) Combination 2 (alternative 3 volatile blend). Volatiles dispensers were removed at the end of the 2-week trial, but Delta Traps® remained in position. Then in July, immediately after pre-assessments, volatile dispensers were re-suspended in Delta Traps® and the trial repeated.

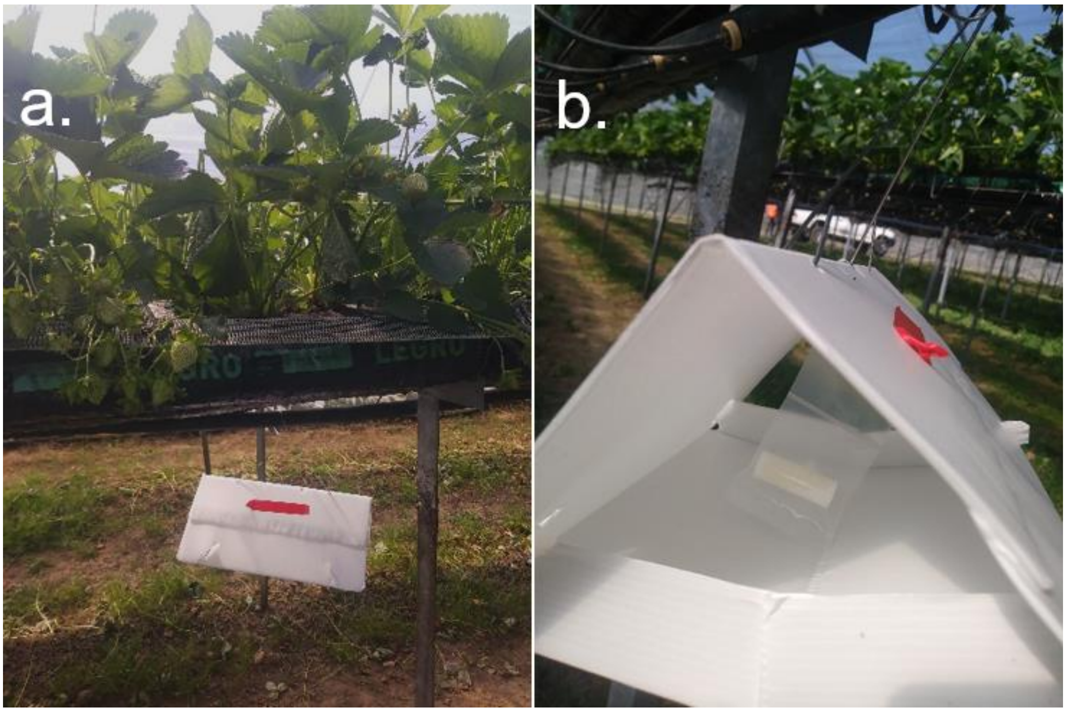


Figure 3.1.4. a) Position of a white Delta Trap® suspended below the tabletop in the centre of all plots during Trial 1 of the aphidophagous hoverfly trial 2022 and b) volatile dispenser suspended inside the Delta Trap® using a paper clip.

Trial 2: In May, immediately after pre-assessments, a grid of 100 MagiPal™ volatile dispensers were secured to growbags at 10 m intervals within and between rows in each treated crop (100 per ha) (Fig. 3.1.5a). Then, 10 tubes of 100 *S. rueppellii* hoverfly pupae (PredaNostrum, Koppert UK Ltd) (1000 hoverfly pupae per ha) were wedged between grow bags at regular intervals throughout the crop (Fig. 3.1.5b). Aphidophagous hoverfly tubes were renewed every 4 weeks (3 deployments total) as advised by Jasper Hubert at Koppert UK Ltd.

Russell IPM and The Natural Resources Institute – University of Greenwich (NRI) produced the hoverfly volatile dispensers. The treatments are coded to protect future Intellectual Property. Clare Sampson at Russell IPM recommended that the MagiPal™ dispensers would release throughout the 12-week trial period.

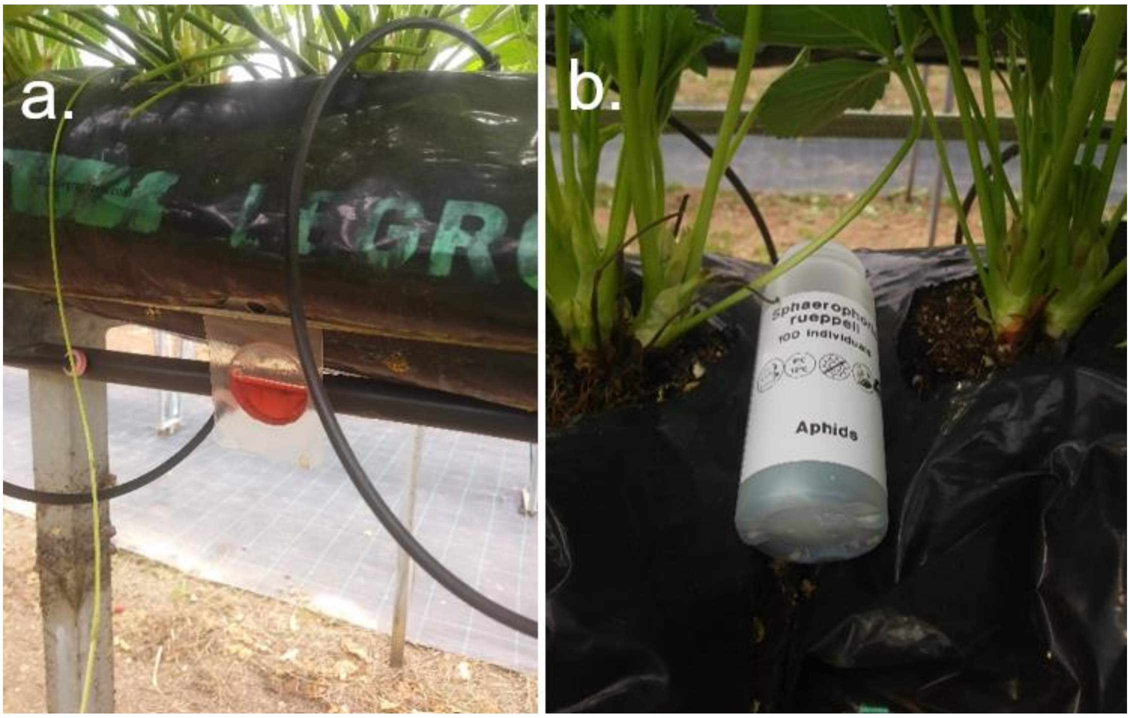


Figure 3.1.5. a) MagiPal™ volatile dispenser secured to a strawberry growbag during Trial 2 of the aphidophagous hoverfly trial, 2022 and b) tube of 100 *Sphaerophoria rueppellii* hoverfly pupae (PredaNostrum, Koppert UK Ltd) wedged between strawberry grow bags.

Assessments:

On each date adult hoverfly assessments were done between 11:00 and 14:00.

Trial 1: Farms and blocks were assessed in a random order to prevent bias. For hoverfly counts and plant inspections a pre-assessment was done in May (Table 3.1.1), before volatile dispensers were suspended in white Delta Traps®, then again in July immediately before volatile dispensers were re-suspended in white Delta Traps®.

Hoverfly counts in the crop: Each assessment involved a 5-minute crop walk survey of the central 10 m in each plot. Numbers of adult hoverflies observed during each crop walk were recorded. Hoverfly species were identified when possible. Hoverflies were not removed from plots to avoid reducing hoverfly numbers. This assessment was repeated 7 days after volatile dispensers were deployed in May and 7 days after volatile dispensers were redeployed in July (4 times total during the trial including May and July pre-assessments).

Plant inspections: At each assessment, 10 plants in the central 10 m of each plot were inspected. All hoverfly (life stages) and other beneficial arthropods and life stages per plant were counted and recorded. This assessment was repeated 14 days after volatile dispensers were deployed May and 14 days after volatile dispensers were redeployed July (4 times total during the trial including May and July pre-assessments).

Hoverfly counts on white Delta Trap® sticky inserts: Immediately after the day 7 hoverfly count in the crop (May and July), sticky inserts were placed in the base of all white Delta Traps®, including control plots (Fig. 3.1.6). Seven days later, sticky inserts were removed, labelled (with plot number and date collected), then brought back to NIAB East Malling where all hoverfly species were identified, counted and recorded.

Figure 3.1.6. White Delta Trap® with sticky insert in the base during Trial 1 of the aphidophagous hoverfly trial 2022.

Trial 2: Farms and respective crops (treated and control) were assessed in a random order to prevent bias. Assessments were done throughout the central 25 x 25 m assessment zone of each crop (Fig. 3.1.3). A pre-assessment was done in May, just before MagiPal™ dispensers and aphidophagous hoverfly tubes were deployed. Then weekly during the 11-week trial period (12 times total, including the pre-assessment).

Hoverfly counts in the crop: This involved a 30-minute crop walk, during which numbers of adult hoverflies were recorded. Hoverflies were identified to species where possible.

Plant inspections: 40 plants were inspected and aphid numbers per plant recorded.

Tap samples: 50 plants were tap sampled and numbers of hoverfly (life stages), aphid and beneficial arthropod life stages per tap sample were recorded.

Hoverfly counts on blue sticky traps: On the day of the penultimate assessment, 12 blue sticky traps were deployed evenly throughout each crop (48 total). The position of each numbered trap was noted. Traps were positioned alternating above and below the tabletop, to mitigate against losses due to traps above being dislodged by the boom sprayer. After 7 days, blue stick traps were collected, then brought back to NIAB East Malling where hoverfly species caught were identified and recorded.

Data loggers recorded temperature and humidity inside polytunnels throughout the experimental period in each crop (Table 3.1.6 and Appendix 3.1.1).

Table 3.1.1. Trial 1 and 2 assessments and timings during the aphidophagous hoverfly trial 2022.

	Hoverfly counts in the crop	Hoverfly counts on sticky inserts	Plant inspections	Tap samples	Hoverfly counts on blue sticky traps
May (pre-assessment)	Trial 1 & 2	-	Trial 1 & 2	Trial 2	-
May (7 days after pre-assessment)	Trial 1	-	-	-	-
May (14 days after pre-assessment)	-	Trial 1	Trial 1	-	-
May to July (weekly for 12 weeks)	Trial 2	-	Trial 2	Trial 2	-
July (pre-assessment)	Trial 1	-	Trial 1 & 2	-	-
July (7 days after pre-assessment)	Trial 1	-	-	-	-
July (14 days after pre-assessment)	-	Trial 1	Trial 1	-	-
July (final assessment)	-	-	-	-	Trial 2

Statistical analyses

Trial 1

All data was analysed in R version 4.2.2 (R Core Team 2022).

Hoverfly counts in the crop: A glm with Poisson distribution was fitted to the data. Fixed effects were timing, treatment and their interactions with block. Significance of fixed effects was tested by Analysis of Deviance (chisquare). Post hoc tests were used to estimate means and contrasts between each treatment and the untreated.

Plant inspections: A glm with poisson distribution or negative binomial, if there was overdispersion, was fitted to the data. Fixed effects were timing, treatment and their interactions with block. Significance of fixed effects was tested by Analysis of Deviance (chisquare). Post hoc tests were used to estimate means and contrasts between each treatment and the untreated.

Hoverfly counts on white Delta Trap® sticky inserts: A glmm with negative binomial distribution was fitted to the data using blmer from the R package 'blme' (Chung et al. 2013). This was used to account for the separation within the data. Fixed effects were timing, treatment and their interactions with block. Random effects were plot, used to account for the non-independence of repeated measures. Significance of fixed effects was tested by likelihood ratio tests (chisquare). Post hoc tests were used to estimate means and contrasts between each treatment.

Trial 2 data was not analysed as it was primarily for demonstration purposes with only 2 replicates.

Results

Trial 1

Hoverfly counts in the crop

More adult hoverflies were observed in plots July than May (grand mean = 2.49 and 0.72 respectively). There were no significant differences in numbers of adult hoverflies observed during crop walks in plots with or without volatile dispensers in both May (grand mean = 0.75 and 0.60 respectively) and July (grand mean = 2.64 and 1.90 respectively).

Most identifiable hoverfly species in both months were *E. corollae* (7% and 11% respectively), *E. balteatus* (3% and 8% respectively) and *S. rueppellii* (1% and 8% respectively). The other species identified was *E. latifasciatus* (0% and 3% respectively). Most adult hoverflies caught could not be identified to species (89% and 73%) (Table 3.1.2).

Table 3.1.2. Means and percentages of hoverfly species observed per plot during 5-minute crop surveys May and July Trial 1 of the aphidophagous hoverfly trial, 2022.

	May (mean per plot)	May %	July (mean per plot)	July %
Eupeodes corollae	0.05	7	0.27	11
Episyrphus balteatus	0.02	3	0.2	8
Sphaerophoria rueppellii	0.01	1	0.2	8
Eupeodes latifasciatus	0	0	0.01	0
Unidentified adult Syrphidae	0.64	89	1.81	73

Plant inspections

Overall, numbers of hoverfly life stages (larvae and pupae) per plant throughout plots were too low to analyse (grand mean = 0.003 combined). Other natural enemies and life stages with suitable numbers for statistical analysis were Orius (nymphs and adults combined) (grand mean = 2.64) and lacewing eggs (grand mean = 1.9), in July. There were no significant differences in numbers of Orius in plots with and without a volatile dispenser (mean = 2.81 and 2.86 respectively) nor lacewing eggs (mean = 4.07 and 3.56 respectively).

Other natural enemies or activity counted per plant included predatory Araneae spp. (grand mean = 0.05), parasitoid Hymenoptera spp. (grand mean = 0.006) mummified aphids (grand mean = 0.04), Chrysopidae spp. (nymphs and adults) (grand mean = 0.009 combined) and Aeolothripidae (grand mean = 0.004).

Hoverfly counts on white Delta Trap® sticky inserts

Overall (May and July combined), significantly more wild adult hoverflies were caught in traps containing a volatile dispenser than without (grand mean = 0.39 and 0.02 per trap respectively, $P < .001$, Fig. 3.1.7). There were no significant differences in catches between MagiPal™, basic volatile, combination volatile 1 and combination volatile 2 dispensers (mean = 0.53, 0.38, 0.43 and 0.23 respectively).

More adult hoverflies were caught per trap in July than May (grand mean = 0.62 and 0.16 respectively). No hoverflies could be identified to species in May due to the poor condition of adult hoverflies on traps. Most hoverfly species identified in July were *Melanostoma mellinum* (33%) and *Eupeodes corollae* (21%). Other species identified were *E. balteatus* (3%), *S. rueppelliii* (3%), *Eupeodes latifasciatus* (3%) and *Chrysotoxum festivum* (3%). Many adult hoverflies caught (36%) could not be identified to species (Table 3.1.3).

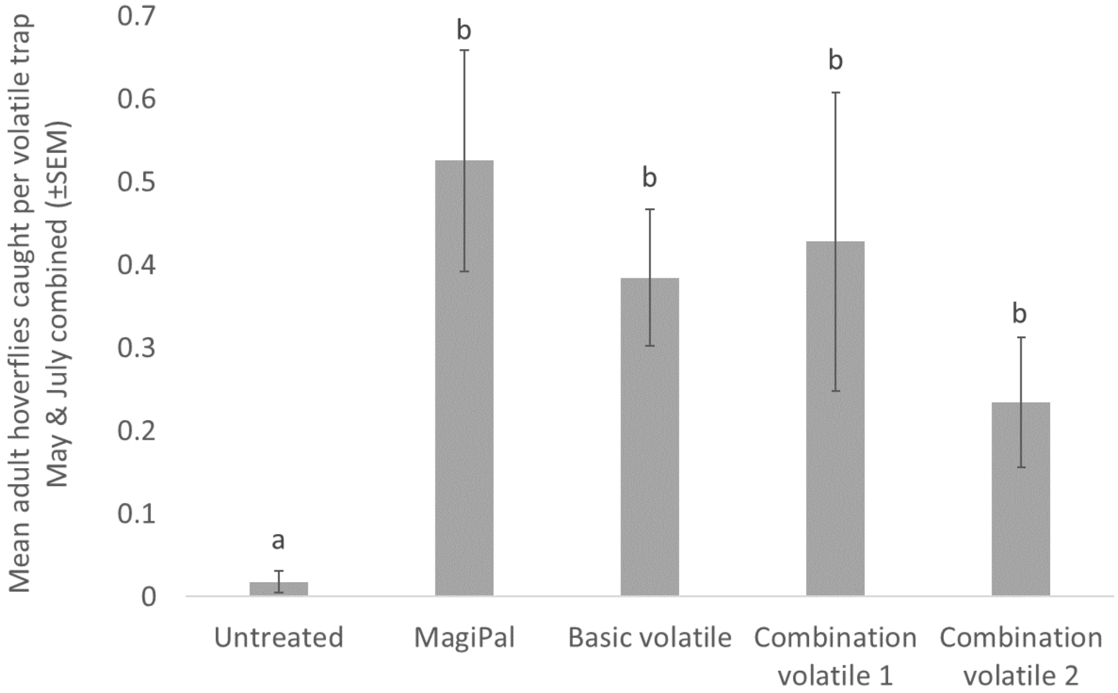


Figure 3.1.7. Mean adult hoverflies caught on white Delta Trap® sticky inserts over a 7-day period during Trial 1 of the aphidophagous hoverfly trial, 2022. Letters denote significant differences at *P* = .05.

Table 3.1.3. Means and percentages of hoverfly species caught per white Delta Trap® sticky insert over a 7-day period in July during Trial 1 of the aphidophagous hoverfly trial, 2022. Hoverflies in May were not identified with a mean of 0.2 per trap.

	July (mean per trap)	July %
Melanostoma mellinum	0.26	33
Eupeodes corollae	0.16	21
Episyrphus balteatus	0.02	3
Sphaerophoria rueppellii	0.02	3
Eupeodes latifasciatus	0.02	3
Chrysotoxum festivum	0.02	3
Unidentified adult Syrphidae	0.28	36

Release rates

Release rates from the lures were assessed by exposing the lures in a fume hood at 22°C and periodic measuring of weight loss. Results in Fig. 3.1.8 confirmed release would have continued during the trial periods.

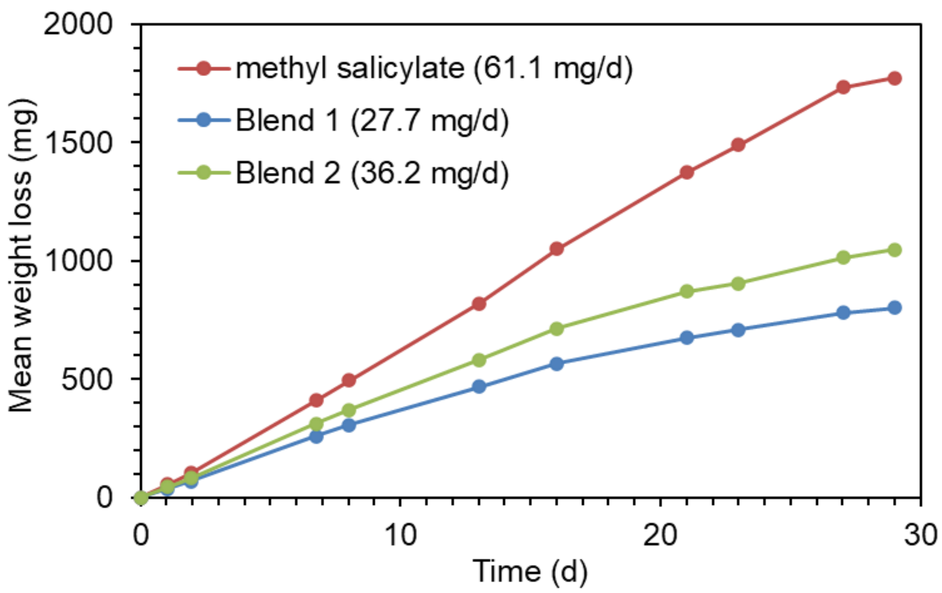


Fig. 3.1.8. Release rates from NRI sachets measured by weight loss at 22°C; the Russell IPM MagiPal lure released methyl salicylate at 67.5 mg/d under the same conditions.

Trial 2

Hoverfly counts in the crop

Numbers of adult *S. rueppellii* (commercial species released) observed per assessment were higher, overall, at farm 2 than farm 1 (grand mean = 2.3 and 0.7 respectively). At farm 2, more adult *S. rueppellii* were observed in treated than control crops (mean = 3.7 and 0.8 respectively) (Table 3.1.4 and Fig. 3.1.8). The same trend was observed at farm 1 (mean = 1 and 0.3 respectively) although numbers were lower than farm 2 (Table 3.1.4).

Numbers of adult hoverflies (including unidentified adult Syrphidae) were similar between treated and control crops at farm 2 (mean = 21.9 and 21.8 respectively), but lower in treated than control crops at farm 1 (mean = 8.0 and 17.5 respectively). Most other species of hoverfly identified at both farms were *E. corollae* and *E. balteatus* followed by *E. latifasciatus* (See Table 3.1.4 for means).

Plant inspections

Numbers of aphid per plant were higher, overall, at farm 2 than farm 1 (grand mean = 18.2 and 3.6 respectively). At farm 2, fewer aphids were observed in treated crops than the untreated control (mean per plant = 1.3 and 35, respectively) (Table 3.1.4 and Fig. 3.1.8). At farm 1, the opposite was observed (mean = 6.9 and 0.4 respectively) (Table 3.1.4). The most abundant species of aphid observed and formally identified were *Aphis fabae*. *Macrosiphum euphorbiae* were also present, but sporadically and in much lower numbers (not formally identified).

Table 3.1.4. Mean adult hoverflies observed during 30-minute crop surveys Trial 2 of the aphidophagous hoverfly trial, 2022.

	Farm 1			Farm 2		
	Control (mean)	Treated (mean)	Grand mean	Control (mean)	Treated (mean)	Grand mean
Eupeodes corollae	4.3	1.3	2.8	4.1	4.0	4.0
Episyrphus balteatus	1.6	1.3	1.4	4.1	1.4	2.8
Sphaerophoria rueppellii	0.3	1.0	0.7	0.8	3.7	2.3
Eupeodes latifasciatus	0.1	0.3	0.2	0.0	0.2	0.1
Unidentified adult Syrphidae	11.2	4.1	7.6	12.8	12.6	12.7
Aphid	0.4	6.9	3.6	35.0	1.3	18.2

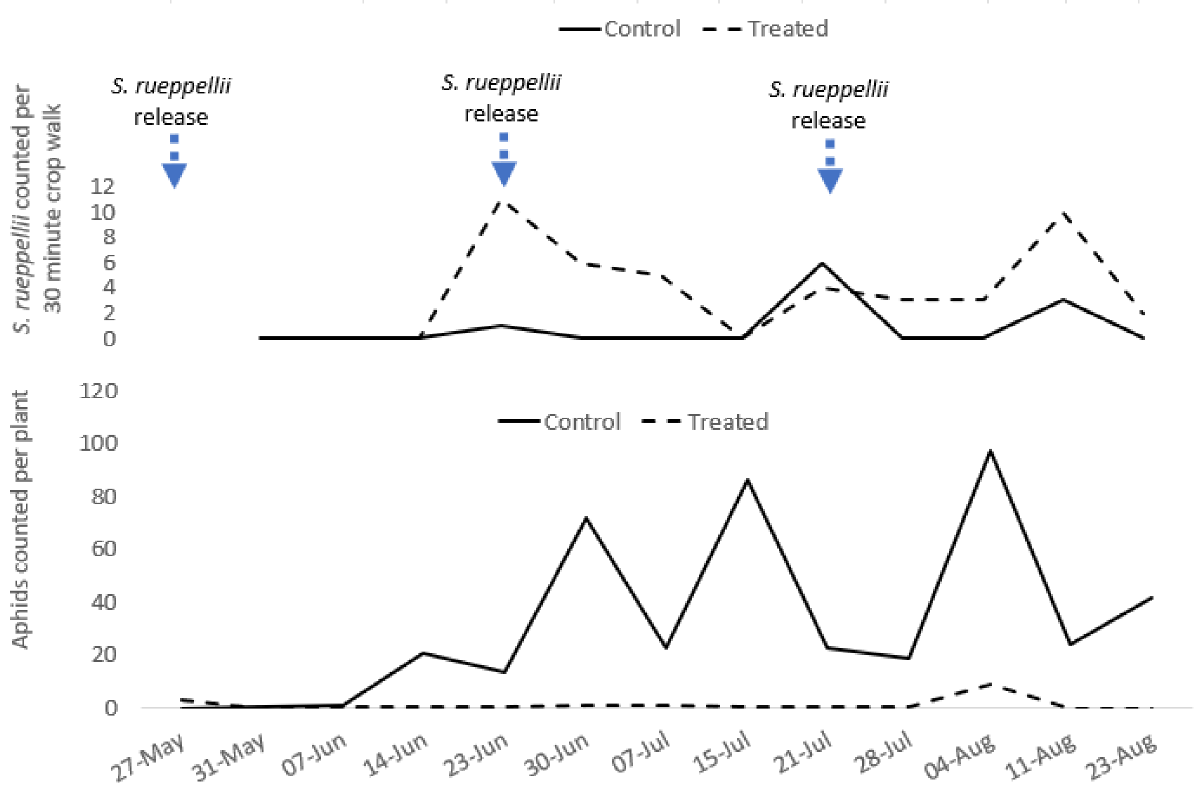


Figure 3.1.9. Farm 2; a) Number of *Sphaerophoria rueppellii* (released hoverfly species) observed per 30-minute crop walk – arrows indicate dates of hoverfly release, b) number of aphids counted per plant during Trial 2 of the aphidophagous hoverfly trial, 2022.

Tap samples

Numbers of aphid per plant were higher at farm 2 than farm 1 (grand mean = 0.7 and 0.42 respectively). At farm 2, fewer aphids were observed in treated than control crops (mean = 0.058 and 1.34 respectively) (Table 3.1.5). At farm 1 the opposite was observed (mean = 0.627 and 0.217 respectively) (Table 3.1.5).

Other natural enemies counted per tap sample included predatory Orius, predatory Araneae spp., parasitoid Hymenoptera spp., Chrysopidae spp. life stages, Coccinellidae spp. life stages and Syrphidae spp. life stages (see Table 3.1.5 for means).

Table 3.1.5. Mean aphid and natural enemies observed per tap sample during Trial 2 of the aphidophagous hoverfly trial, 2022.

	Farm 1			**Farm 2**		
	Control (mean)	Treated (mean)	Grand mean	Control (mean)	Treated (mean)	Grand mean
Aphid	0.217	0.627	0.422	1.342	0.058	0.700
Orius	0.838	0.792	0.815	0.452	0.603	0.528
Predatory Areneae spp.	0.090	0.105	0.098	0.177	0.135	0.156
Parasitoid Hymenoptera spp.	0.047	0.043	0.045	0.033	0.067	0.050
Chrysopidae spp. life stages	0.048	0.050	0.049	0.038	0.045	0.042
Coccinellidae spp. life stages	0.007	0.018	0.013	0.018	0.005	0.012
Syrphidae spp. life stages	0.002	0.015	0.008	0.007	0.005	0.006

Hoverfly counts on blue sticky traps:

Numbers of adult *S. rueppellii* (commercial species released) caught per trap were low overall (grand mean = 0.08), most adult hoverflies caught were *E. corollae* (grand mean = 0.31).

Other species included *E. balteatus* (grand mean = 0.06), *E. latifasciatus* (grand mean = 0.06), *S. ribesii* (grand mean = 0.04) and *S. pipiens* (grand mean = 0.02). Most species caught could not be identified due to the poor condition on sticky traps (grand mean = 0.9).

Polytunnel environment:

Diurnal fluctuations in air temperature and relative humidity among the polytunnel raspberry plants are shown in Table 3.1.6 and Appendix 3.1.1.

Table 3.1.6. Temperature and relative humidity among polytunnel strawberry plants during the aphidophagous hoverfly trial, 2022.

Timing	Trial	Farm	Field	Mean Temperature °C	Maximum Temperature °C	Minimum Temperature °C	Mean Humidity % rh	Maximum Humidity % rh	Minimum Humidity % rh
May	1	1	1	15	28	4.5	73.8	95	33.5
		2	2	14.9	28	5	68.8	87	34.5
July/August		1	1	20.5	41	10	65.9	95.5	28.5
		2	2	20.6	32.5	10.5	66.5	87	35
May to September	2	1	Control	20	45	5.5	69.8	98	24.5
			Treated	19	38.5	5.5	72.4	97	25.5
		2	Control	19.4	39.5	5.5	71.1	96.5	24
			Treated	19.1	38.5	4.5	69.3	95	27

Discussion

The objective of trial 1 was to test whether the attraction of hoverflies and other natural enemies to VOCs could be improved compared to a commercial standard lure.

Almost twenty times more hoverfly adults were captured on sticky traps with volatile organic compounds (VOCs) compared to control traps without VOCs. However, our four different VOC dispensers with additional VOCs compared to the commercial standard dispenser did not improve the attraction hoverflies in strawberry crops. More than 50% of the hoverfly species on sticky traps were *M. mellinum* and *E. corollae*. Other species were identified as *E. balteatus*, *S. rueppelliii*, *E. latifasciatus* and *C. festivum* in roughly equal numbers. Larvae of all species identified are aphidophagous and adults are nectar feeding. As shown in previous AHDB projects more hoverflies were present in strawberry crops in July compared to May; in this study almost 4-fold. In a previous AHDB project (TF 218), Blend 1 proved more attractive to hoverflies than methyl salicylate alone, but in those experiments the major species present was *Episyrphus balteae*.

Despite sticky trap catch results, crop walk surveys did not detect an increase in numbers of adult hoverflies where VOCs were deployed. Identifiable, free-flying hoverflies in order of highest abundance were *E. corollae*, *E. balteatus*, *S. rueppelliii*, with very few *E. latifasciatus.* Hence, although we mostly identified *M. mellinum* on sticky traps we did not observe them free in the crop. The majority (73%) of free-flying adult hoverflies observed in the crop could not be identified with a high level of certainty and hence certain species are likely under-represented.

Other natural enemies present in the strawberry crop included Orius, Chrysopidae spp., predatory Araneae spp., parasitoids (Hymenoptera) and Aeolothripidae. However, there was no evidence that our VOC treatments increased numbers.

The first objective of trial 2 was to investigate whether the commercially available VOC lure (MagiPal™) can retain commercially released adult *S. rueppellii* and attract natural aphidophagous hoverflies into 1 ha commercial strawberry crops. The trial was limited due to its large scale across two farms and so results should be interpreted with caution.

Crop surveys found more *S. rueppellii* in crops where they had been released and where the MagiPal™ had been installed at both farms compared to the untreated (control) crops from 27 to 34 days after release. This is a positive finding as it demonstrates that at least some released *S. rueppellii* remained in the crop. Numbers of other native species of adult hoverflies were higher in the treated crop than the untreated control at one farm, but lower at the other. As with trial 1, most species of wild hoverfly identified in the field at both farms were

E. corollae and *E. balteatus*. Numbers of hoverfly species caught on blue sticky traps deployed at the penultimate assessment were low with no clear trends. These included, in order of highest abundance, *E. corollae, S. rueppelliii*, *E. balteatus, E. latifasciatus*, *S. ribesii* and *S. pipiens*. However, due to the condition of the hoverflies on the sticky cards most species could not be identified, and it is conceivable that some species were missed.

The trial also investigated whether hoverfly releases and MagiPal™ dispensers could reduce numbers of aphids in commercial strawberry crops. The result of this trial was inconclusive; one farm had fewer aphids in the treated crop and the other had fewer aphids in the untreated control. The same trend was observed during aphid tap sample assessments at each farm. Overall, aphid numbers per plant were higher at farm 2 than farm 1 during plant inspections and this may go some way to explaining why higher numbers of *S. rueppellii* were observed at farm 2. Female hoverflies are more likely to remain and lay eggs where there are high numbers of aphids for their offspring to feed on.

Finally, there was no evidence that MagiPal™ attracted other aphid natural enemies into the studied crops on the two farms.

Conclusions

- Synthetic VOCs deployed in strawberry crops attracted wild aphid feeding hoverflies and possibly helped to retain commercially released *S. rueppellii.*
- However, no clear difference in wild hoverfly numbers was found between different blends of VOCs compared to the commercial standard MagiPal™.
- It is possible that our survey area was too small to detect differences between hoverfly numbers as these are highly mobile adult flying insects.
- Results of the larger scale trial differed between the two farms, however where there were substantial aphid colonies, higher numbers of the commercially released hoverfly (*S. rueppellii*) were observed.
- This indicates hoverflies should probably be released once aphid numbers build up because hoverflies are unlikely to lay eggs in small aphid colonies.
- Besides pollination and aphid control, there is also potential for hoverfly species such as *E. corollae* to be used to entomovector biological control agents of grey mould (*Botrytis cinerea*) as an alternative to spray application of fungicides. The hoverfly species could be used as a multitool in strawberry production combining biological control of aphids, grey mould, as well as pollination services (Petig 2022).

Tasks 3.4. Parasitoids for aphid control in overwintered protected strawberry

Introduction

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years. Unfortunately, potato aphid populations can persist in over-wintered crops, surviving at temperatures below freezing and continuing to grow and develop very slowly when the temperature exceeds just 1°C. With the first warmer days of spring, the aphids start to grow and reproduce much more rapidly, leading to early outbreaks and damage. The withdrawal of chlorpyrifos and thiacloprid leaves soft fruit growers with fewer conventional options for early season aphid control, especially when temperatures are too low for biopesticide efficacy. In addition, aphid colonies can be difficult to target with contact-acting PPPs in strawberry, early in the season, because they are often out of spray range in the crown of strawberry plants.

With limited insecticide options now available, growers are increasingly relying on releases of parasitoid wasps in early spring for aphid biocontrol. Two parasitoid species (*Aphidius ervi* and *Praon volucre*) can be particularly effective at parasitizing potato aphid. Both species are present in the mixed parasitoid products available to growers for aphid control on soft fruit (e.g., FresaProtect from Viridaxis, Aphiline Berry from Bioline), and *A. ervi* is also available separately from some biocontrol companies. However, there are three main possible areas of risk and uncertainty associated with release of parasitoids for early-season aphid control:

- Failure of parasitism due to low temperature
- Impact of insecticide residues on parasitism
- Failure of parasitism due to resistance

We aim to address some of these potential risks, so that growers can be better informed in releasing parasitoids appropriately (in terms of species and timing) for effective early season biocontrol of aphids. In addition, it was observed from work in SF 156 that some parasitoids may be surviving in aphids over the winter and ready to emerge the following spring giving a head-start to biological aphid control. However, it is difficult for growers to observe this hidden biocontrol and PPP harmful to emerging parasitoids may be applied risking early season aphid control. In this study we aimed to look at the possibility of parasitoids using aphids in the crop to overwinter. We also investigate if the release of additional parasitoids in early spring had an impact on parasitism and aphid diversity and numbers in the crop.

Materials and methods

In 2021 three grower's sites that over-wintered strawberry crops were selected. Two farms were in Kent, England and one in Angus, Scotland (Table 3.4.1).

Table 3.4.1. Crop, variety, and growing systems of trial sites 2021.

Site code	Crop	Variety	Growing system	Location
1	Strawberry	Majestic	Tabletop	Kent
2	Strawberry	Malling Centenary	Tabletop	Kent
3	Strawberry	Magnum	Tabletop	Scotland

At each site, 4 tunnels with aphids were selected, each tunnel representing a plot. Plots (i.e., tunnels) were numbered 1 to 12 across the 3 sites (Fig. 3.4.1). In 2021, no parasitoid treatment was applied to the plots. Aphids were sampled in August and September to determine parasitism levels before the winter. In 2022, there was one assessment per month, in February and March before any parasitoid release (Fig. 3.4.3). After these samplings and depending on the spray programme of each farm a first release of a parasitoid mix product was made at a rate of 0.25 parasitoids per plant. Approximately 2.5 weeks after the first release there was another sampling occasion, followed by a second parasitoid release after a further 2 weeks. As before, we aimed to sample the aphid population 2.5 weeks after the second release. Two more sampling occasions were taken at approximately 3-week intervals thereafter.

At each plot the tabletop plants were examined and colonies of aphids from different random plants were sampled when possible. We aimed to collect a maximum of 20 colonies of aphids where aphid abundance was sufficient. Where aphid abundance was very low, as many samples as possible were collected in the allocated time. Aphid colonies were sampled from different vegetative material including leaves, flower trusses, and runners.

Immediately after collection, each sample was placed in an individual 15 cm Petri dish. The cut petioles were inserted in a cotton ball soaked in 2% sucrose solution (Fig.3.4.2) and labelled with plot (1-12) and sample numbers (1-20).

Aphids were brought back to the laboratory and incubated at 20-23°C for 3 weeks. In the first 24 hours after collection, parasitoids and other aphid predators were removed from the petri dishes. On each assessment, and for each sample, the following was recorded: i) vegetative material sampled; ii) aphid colony size; iii) number of parasitoids emerged at 7, 14 and 21 days of incubation; iv) number of mummies present at 0, 7, 14 and 21 days of incubation; v) number of other aphid predators.

All parasitoids emerging during the incubation period were collected and stored in 70% ethanol for subsequent identification. Other natural predators found at each assessment were recorded and removed from the petri dish. Parasitoids were identified to family or assigned to morphologically similar groups by examination under a microscope. Representative samples were selected for molecular taxonomic identification by JHI.

Visual identification of aphids and parasitoids

Visual identification was carried out using a Leica M165C microscope (NIAB) and a VWR VisiScope SZTL360 (Hutton). Identification was primarily based on Royal Entomological Society books and keys. Aphids – Pterocommatinae and Aphidinae (Aphidini) Vol. 2, part 6 was used to confirm the family of the aphids and Hymenoptera Vol. VI, part 1 (2nd edition) was used to confirm the family of parasitoids. Additional scientific papers were used to identify the aphids and parasitoids to species and genera, respectively, as well as entomological websites and online pictures of key features of species. Only adult specimens were used for identification.

Molecular taxonomic identification at JHI

Aphids from sites 1, 2 and 3 were sampled and DNA extracted using a sodium hydroxide technique (modification of Klimyuk et al., 1993 and Stanton et al., 1998) and 1 µl of the extract was amplified using PCR ready-to go beads (GE Healthcare). A 658bp region in the gene encoding the cytochrome c oxidase I (COI) was amplified using insect barcoding primers LCO1490 and HC02198 (Folmer et al., 1994; Herbert et al., 2003). Representative samples of parasitoid morphotypes were selected from each site and subjected to the same molecular identification procedure.

PCR products were purified using Qiagen PCR purification and sequenced directly using the BIGdye Terminator V3.1 kit (Applied Biosystems) and an AB13730XL sequencer. The sequence editing software Bioedit 7.0.5 was used to produce consensus sequences, and these were used to search the NCBI databases (GenBank, PubMed) for regions of sequence similarity using BLASTn.

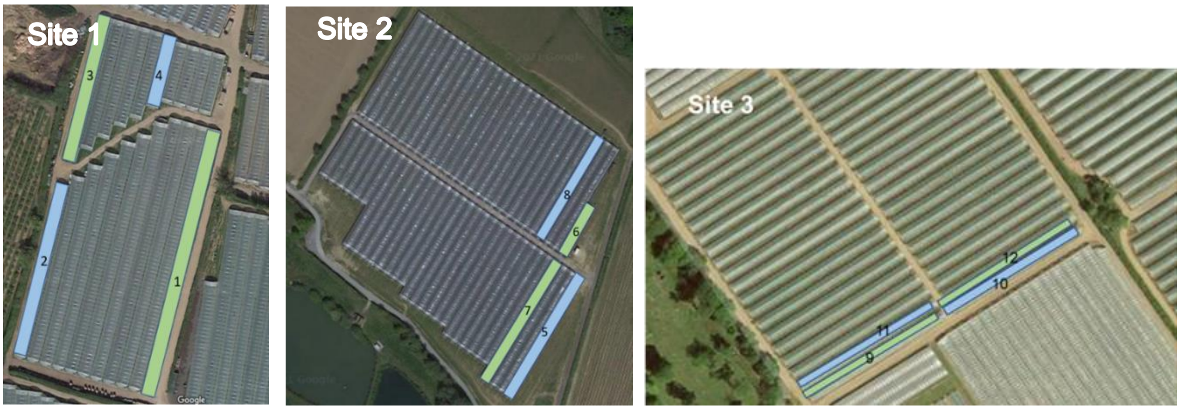


Figure 3.4.1. Aerial view and plot representation of the 3 sites used in this trial. Site 1 and 2 in Kent, England and Site 3 in Angus, Scotland. Plots are numbered and in 2022 were subject to parasitoid releases (blue) or no parasitoid releases (green).

Figure 3.4.2. Mesocosm used for parasitoid rearing with cotton ball soaked in 2% sucrose solution (left). Incubated leaf infested with aphids (right).

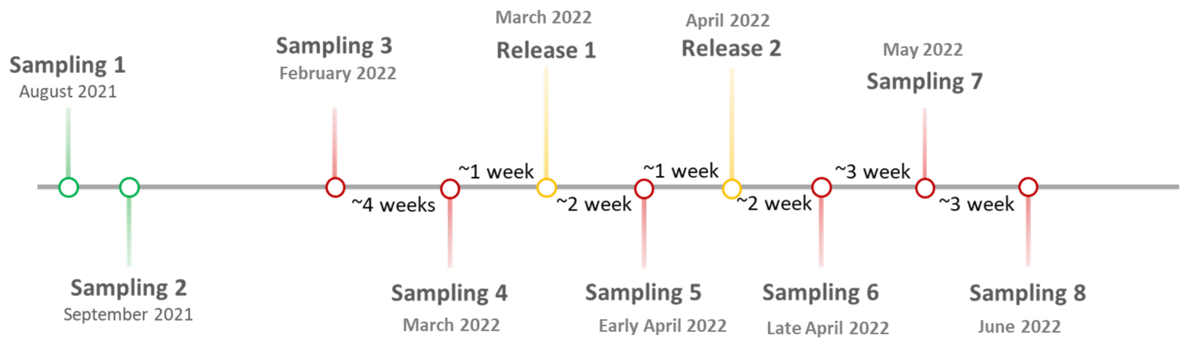


Figure 3.4.3. Timeline of sampling and treatments of the aphids in 2021 and 2022.

Results

In 2021 no parasitoid treatment was applied to the plots. Species of aphids collected in Angus were mostly *Chaetosiphon fragaefolii* with a few *Macrosiphum euphorbiae* and in Kent mostly *Aphis fabae* and some *Myzus ornatus*. Levels of parasitism before winter were higher in August than September 2021 (Fig. 3.4.4) and were highest at Sites 1 and 3. Levels of parasitism were lowest in February, then rose to highest levels in late March (before parasitoid release). There was no clear change in parasitism levels following parasitoid release (Figure 3.4.4) and parasitism levels tended to decline towards the summer (Fig. 3.4.4).

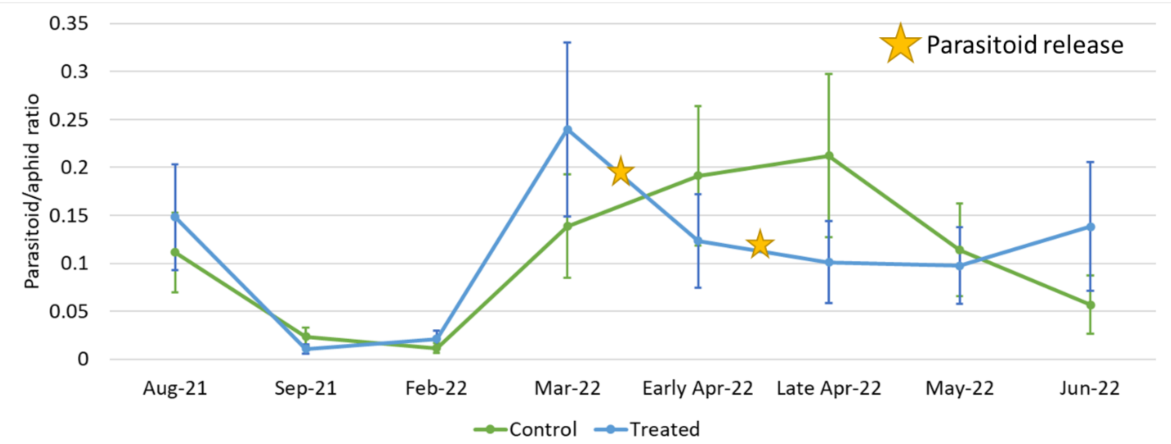


Figure 3.4.4. Ratio of parasitoids:aphids averaged across the three sites during the experimental period.

Parasitoid retention in the crop over the winter

To investigate the possibility of parasitoid overwintering in aphids present in the crop during winter, we started sampling the crop in August 2021. Figure 3.4.5 shows the variation of parasitoid/aphid ratio from August 2021 to March 2022. The green line represents the control plots, and the blue line represents the treated plots used for parasitoid release. No treatment application was done before March 2022, thus all plots remained untreated for the period below (Fig. 3.4.5).

In August 2021, the ratio of parasitoids per aphid was between 0.11 and 0.15. This implies up to 1.5 parasitoid emerging per 10 aphids. The ratio decreased close to zero in September 2021 ($Ratio_{green}$= 0.024, $Ratio_{blue}$= 0.011) and was still very low when sampled in February 2022 ($Ratio_{green}$= 0.012, $Ratio_{blue}$= 0.021). However, ratio of parasitoids per aphid increased substantially without any biocontrol release in March 2022 when compared with February 2022. We recorded between 0.14 and 0.24 parasitoids per aphids. This represents up to 2.4 parasitoids emerging per 10 aphids.

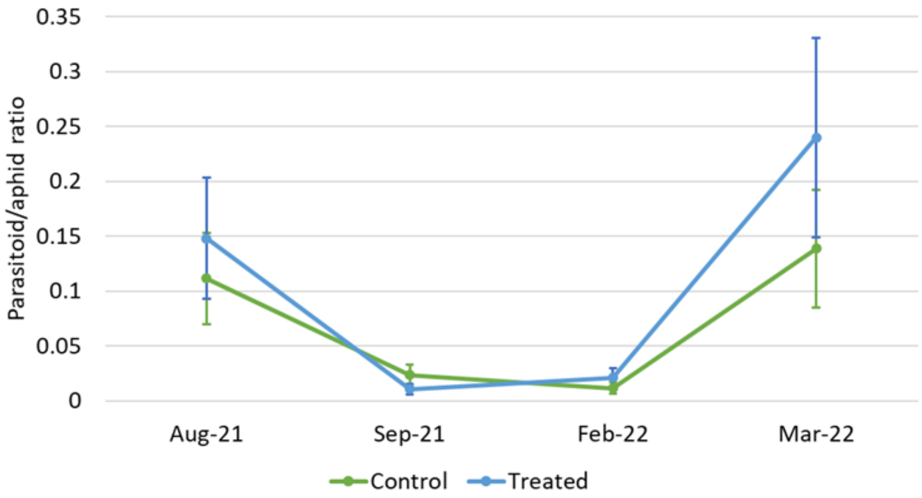


Figure 3.4.5. Ratio of emergence of parasitoid per aphid in control (green) and future treated (blue) plots from August 2021 to March 2022 with respective error bars. No treatment application was done before March 2022, thus all plots remained untreated for the period illustrated in this figure.

Treatment impact

The first release of parasitoids, done after sampling 4, did not significantly increase the overall number of parasitoids per aphid (ratio) in the treated plots (Fig. 3.4.6). In sampling occasion 5, we recorded a mean ratio of 0.15 parasitoids per aphid per plot in the control plots and a mean ratio of 0.12 parasitoids per aphid per plot in the treated plots. The same trend was seen at sampling occasion 6 after the second release and no increase of parasitism was observed (Fig. 3.4.7). Mean ratio of parasitoids per aphid per plot were similar to the previous sampling; mean ratio of 0.16 in control plots and 0.13 in treated plots. All mean values account for the baseline data collected in sampling 4 before treatment was applied (for the sampling date 4 numbers were used as a covariate in the model). This included already existing parasitoid numbers and colony size in each plot.

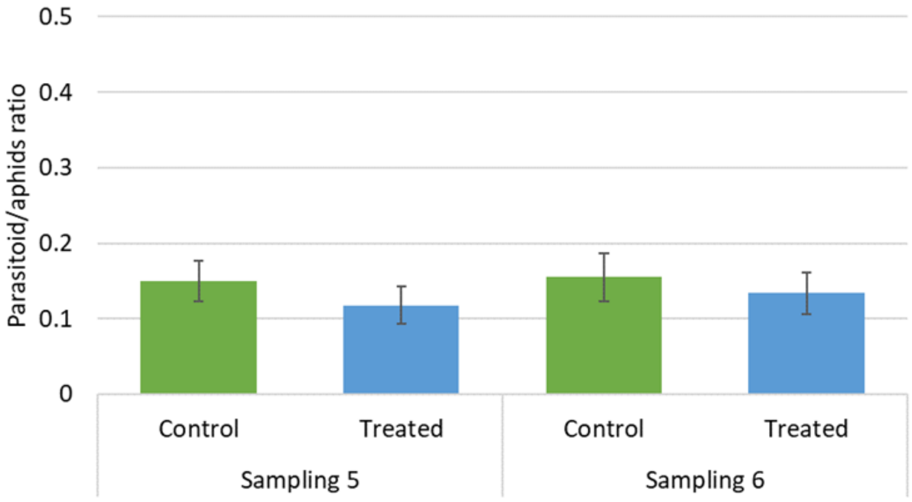


Figure 3.4.6. Ratio of emergence of parasitoid per aphid in control (green) and treated (blue) plots observed in sampling 5 (after first treatment) and 6 (after second treatment) with respective error bars. Mean values are standardized with the existing parasitoid numbers and colony size in each plot before treatment application.

The overall mean number of parasitoids emerging per plot, at sampling occasion 5, did not show a significant difference between the control and treated plots (Fig. 3.4.7). A mean of 19.9 parasitoids per plot in the controls and a mean of 20.9 parasitoids in the treated plots was recorded. Likewise, there was not an increase in numbers of parasitoids in treated plots in sampling 6 when compared to control plots. A slight decrease in parasitoid numbers was recorded when compared to sampling 5. In sampling occasion 6, there was a mean of 14.0 parasitoids per control plot and 9.9 parasitoids per treated plot.

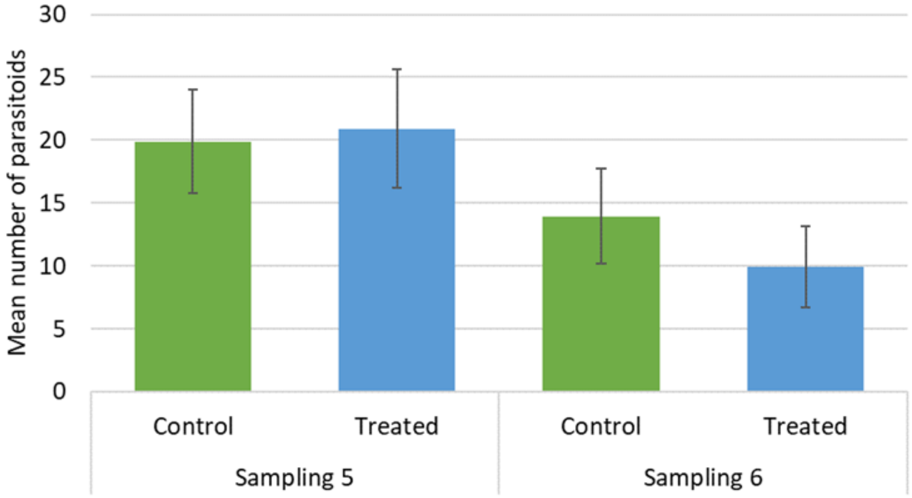


Figure 3.4.7. Mean numbers of parasitoids in control (green) and treated (blue) plots observed in sampling 5 (after first treatment) and 6 (after second treatment) with respective error bars. Mean values are standardized with the existing parasitoid numbers and colony size in each plot before treatment application.

Impact of parasitism on aphid numbers

The number of aphids recorded per plot after treatment applications did not significantly vary between the control and treated plots (Fig. 3.4.8). At the time of sampling occasion 5, we found a mean of 222 aphids per plot in control and a mean of 241 aphids per plot in the treated areas. Aphid numbers decreased in sampling 6 when compared with sampling 5. In sampling 6 we recorded a mean of 107 aphids per control plot and a mean 103 aphids in the treated plots.

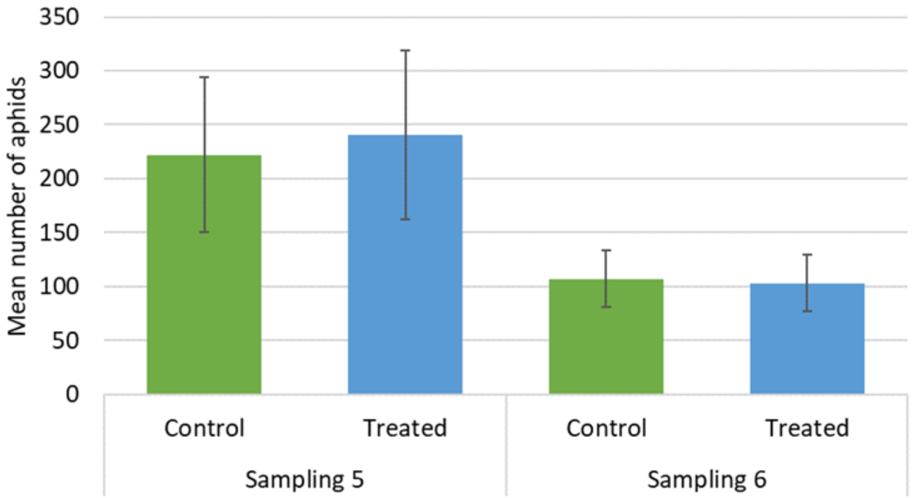


Figure 3.4.8. Mean number of aphids in control (green) and treated (blue) plots observed in sampling 5 (after first treatment) and 6 (after second treatment) with respective error bars. Mean values are standardized with the existing colony size in each plot before treatment application.

The overall numbers of aphids between sites were different and impacted the number and size of colonies available for collection. There were significantly lower numbers of aphids in site 2 compared to site 1 (p<0.0001) and site 3 (p=0.0015). Figure 3.4.9 shows the overall mean number of aphids per colony collected per site from sampling 5 to sampling 8.

Overall parasitoid numbers emerging per 100 aphids did not follow the same trend as aphid numbers. There were significantly fewer parasitoids emerging in site 3 when compared to site 1 (p=0.0115) (Fig. 3.4.10).

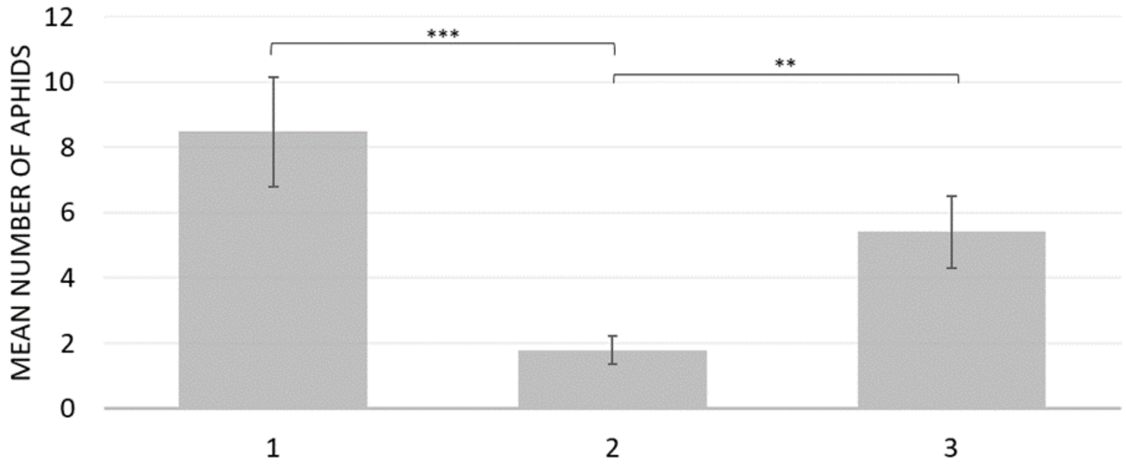


Figure 3.4.9. Overall mean number of aphids per colony collected, observed in site 1, 2 and 3, between sampling 5 and sampling 8, with respective error bars.

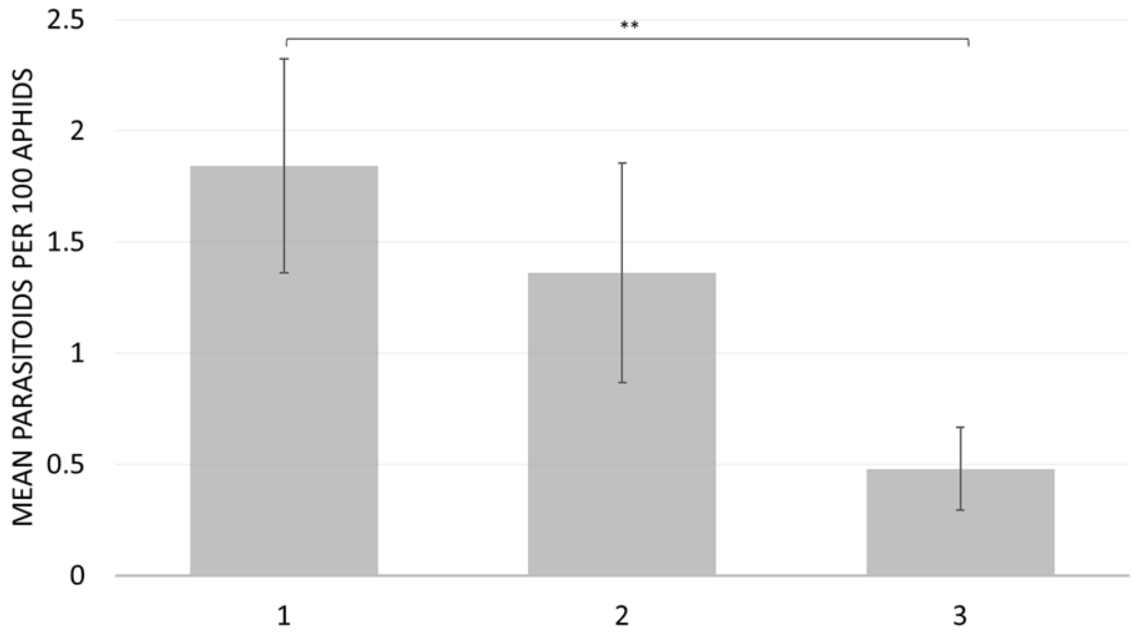


Figure 3.4.10. Overall mean number of parasitoids per 100 aphids collected, observed in site 1, 2 and 3, between sampling 5 and sampling 8, with respective error bars.

Treatment impact on parasitoid and aphid species

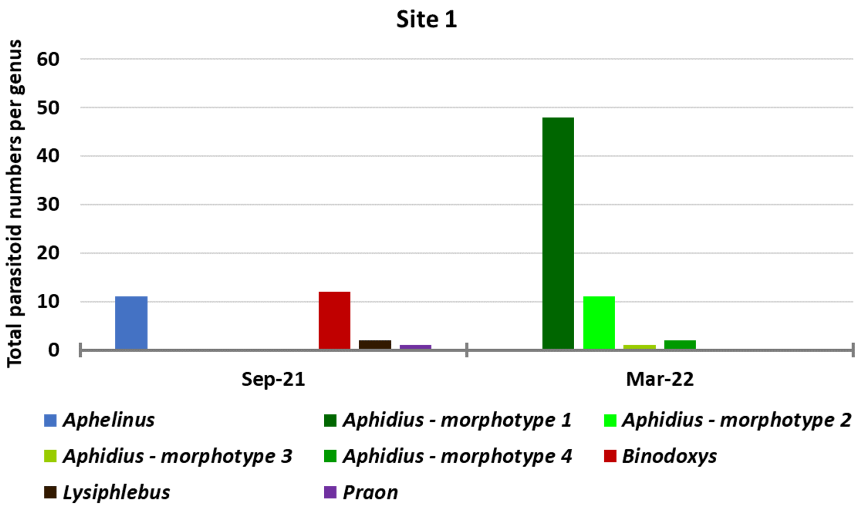
Data collected for the parasitoid species was analysed separately for each site as some genus/species were only recorded at specific sites.

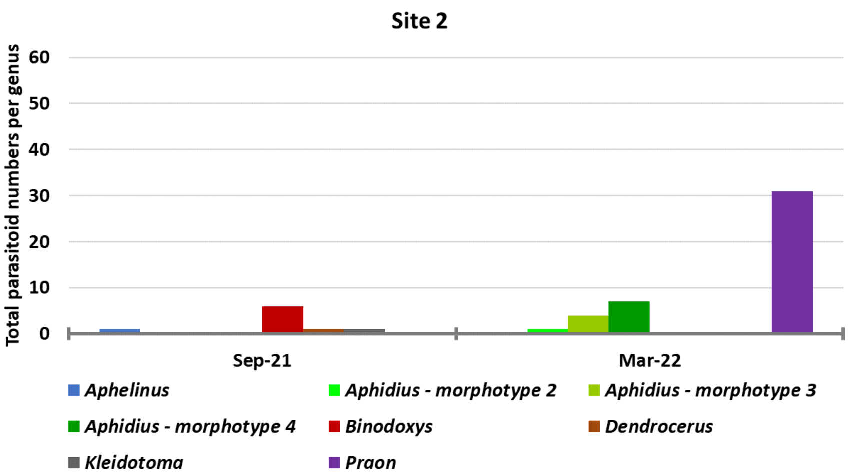
Parasitoids collected were taxonomically identified to family or genus and divided into morphotypes when distinct morphological features were observed. A sub-sample of each family, genus or morphotype was subsequently identified through molecular analyses. Although molecular analyses confirmed the previous visual identification for most families and genera, the accurate identification to species was not possible. PCR amplification generated poor quality sequence data for some specimens and sequence matches to the database were therefore unreliable.

However, good quality sequence data was obtained for *Dendrocerus, Kleidotoma, Praon and Aphelinus* genera and a match with a good percentage of certainty was possible (respectively 83%, 94%, 96% and 94%). Parasitoids from *Aphidius* morphotype 1 and 2 were also a good match for *Aphidius ribis* (respectively, 97% and 98%), probably males and females.

The following matches were also made however the accuracy of the match is based on a poor-quality sequence data and cannot be relied upon without further analyses. *Aphidius ervi* was the closest match for Aphidius morphotype 3 while *Aphidius microlophii* was the closest match for *Aphidius* morphotype 4. *Binodoxys* genus collected was matched with *Binodoxys angelicae* and *Lysiphlebus* genus matched to *Lysiphlebus fabarum*. *Megaspilidae* morphotype 6 was also matched with data belonging to *Megaspilidae* species. Note that the % match for these samples with existing sequence data in the NCBI database was low (63-73%)

Genera recorded on the three different sites are represented in Figures 3.4.11 and shows the total of individuals per genera sampled in September 2021 and March 2022; these sampling points represent before and after overwintering timings. Sites 1 and 2 seemed to support more diversity of wild parasitoid genera than site 3. Genera observed in September differed from genera observed in March at sites 1 and 2. However, at site 3 we recorded the presence of the same *Aphidius* genus before and after overwintering samplings. As mentioned before in this report no application of biocontrol products was done before the sampling occasion in March 2022 (sampling 4). On site 1 the dominant genera observed in September were *Aphelinus* and *Binod*oxys (as the closest match) while in March, two morphotypes of the *Aphidius* genus were the most abundant. On site 2 *Binodoxys* was the genus recorded in higher numbers in September while *Praon* was the main genus in March. *Aphidius* genus (morphotype 1) was the only genus observed in September on site 3 and was observed again in March in very high numbers. Note that the y axis in the graph for site 3 is much larger (fig. 3.4.11).





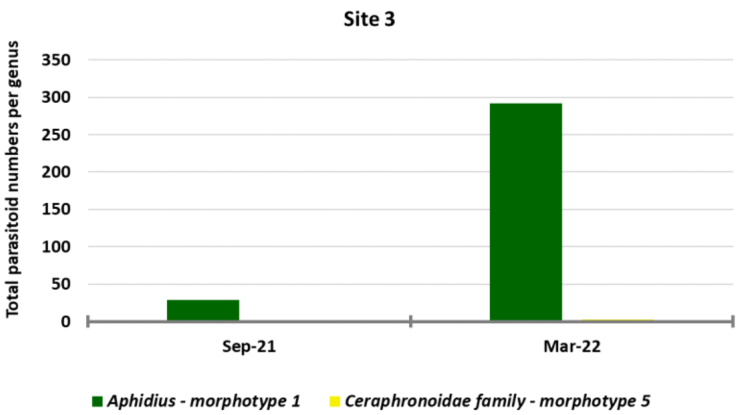


Figure 3.4.11. Total number of parasitoids per genera recorded on site 1 (top), 2 (middle) and 3 (bottom) at sampling occasion 2 (September 2021) and 4 (March 2022). All scientific names refer to genera unless stated otherwise.

When looking at parasitoids sampled before and after treatment applications, trends seem to vary between sites. We observed higher numbers of mean parasitoids per colony emerging at site 1 and 3 when compared with site 2 (Fig. 3.4.12).

At site 1, sampling 4 (pre-treatment) was done on 24 March, sampling 5 (after 1st treatment) on 7 April and sampling 6 (after 2nd treatment) on 27 April. No major differences in trends were observed between control and treated plots however *Aphidius* morphotype 1 and 2 increased slightly in mean parasitoids emerging per colony between sampling 4 (pre-treatment) (Mean= 2.0±0.33 *Aphidius* morphotype1 per colony, Mean = 0.7±0.33 *Aphidius* morphotype2 per colony) and sampling 5 (after 1st application) (Mean = 3.0±0.45 *Aphidius* morphotype1 per colony, Mean= 3.9±2.28 *Aphidius* morphotype2 per colony). In both control and treated overall numbers of parasitoids seem to slightly increase at sampling 6.

At site 2, mean numbers of each genus were low in both control and treated plots. A spray of Batavia was applied to crop by the farm after sampling 4 and before any parasitoids biocontrol products were deployed. This may have affected aphid availability and prevented parasitoids from finding a suitable host to increase numbers. Sampling 4 (pre-treatment) was done on 22 March, sampling 5 (after 1st treatment) on 21 April and sampling 6 (after 2nd treatment) on 11 May.

At Site 3, a high mean number of *Aphidius* morphotype 1 was observed in both control and treated plots before the release of parasitoid biocontrol was done (Fig. 3.4.12). However, these numbers drastically decreased after sampling 4 (pre-treatment). Mean numbers of *Aphidius* morphotype 1 per colony in control plots decreased from 6.33±1.07 in sampling 4 (pre-treatment) to 1.31±0.47 in sampling 5 (after 1st treatment). In treated plots, *Aphidius* morphotype 1 decreased from 10.47±1.30 in sampling 4 (pre-treatment) to 1.50±0.37 in sampling 5 (after 1st treatment). Sampling 4 (pre-treatment) was done on 22 March, sampling 5 (after 1st treatment) on 6 April and sampling 6 (after 2nd treatment) on 28 April.

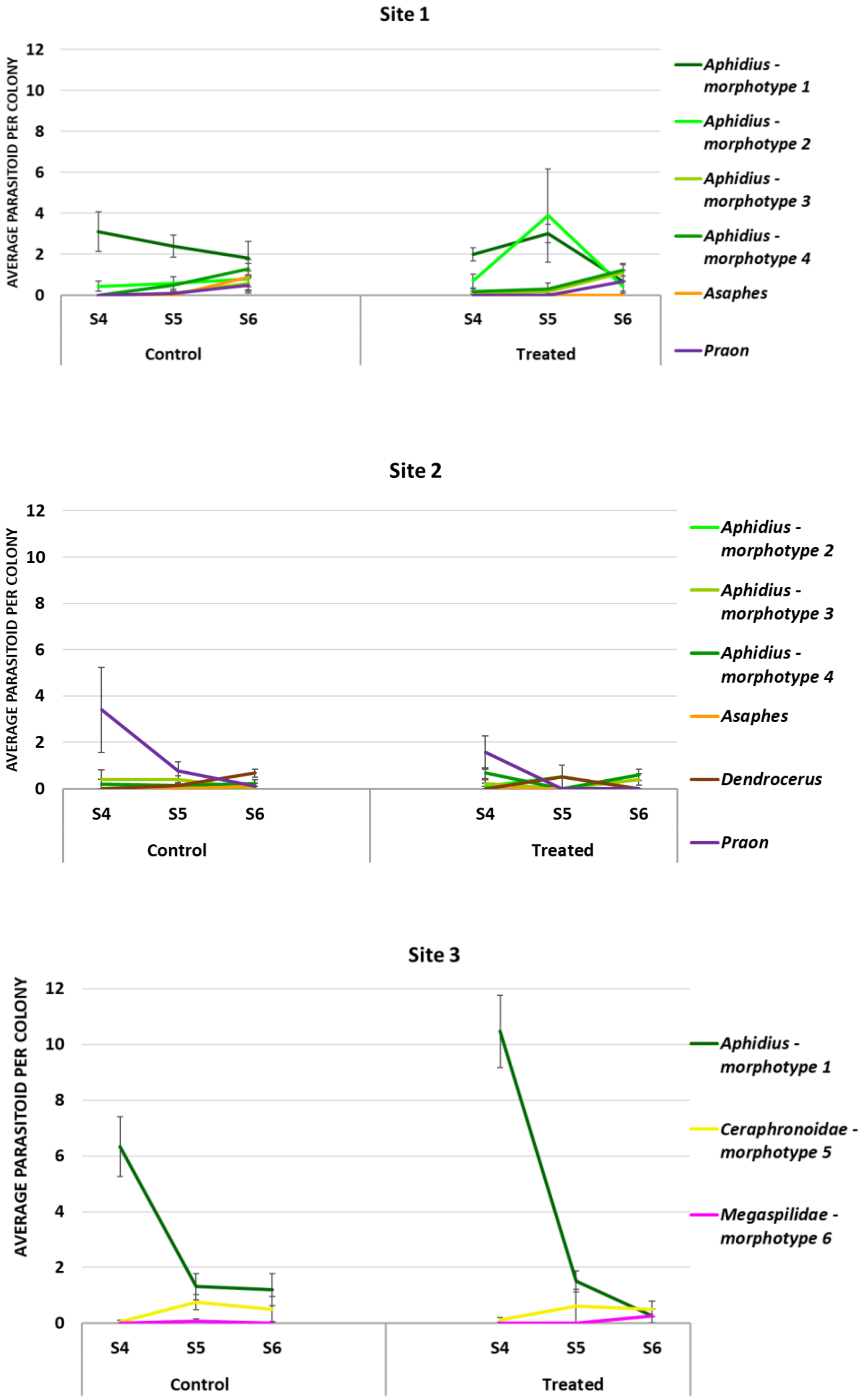


Figure 3.4.12. Mean number of parasitoids of each genus per colony collected at site 1 (top), 2 (middle) and 3 (bottom) before and after the two releases of parasitoid biocontrols, with respective error bars. Left side of the graph shows data collected at sampling 4 (S4, pre-treatment), 5 (S5, after 1st treatment) and 6 (S6, after 2nd treatment) in control plots. And right side shows data collected at sampling 4, 5 and 6 in treated plots. All referenced scientific names are genera except for the families *Ceraphronoidae* and *Megaspilidae.*

As shown in figure 3.4.13 four different aphid species were sampled across the 3 sites in this trial.

Some of the parasitoid genera seem to prefer an aphid species. Specimens of *Aphelinus* and *Binodoxys* genus (closest match) only emerged from *Aphis fabae* colonies. *Aphidius* morphotype 1 and 2 and parasitoids from the *Ceraphronoidae* family were mostly found in *Chaetosiphon fragaefolii* colonies. *Aphidius* morphotype 2 and 4 were recorded in *Macrosiphum euphorbiae* colonies. *Myzus ornatus* is not viewed as a major pest on strawberry crops and was observed scarcely through the crop. Parasitoids of the *Asaphes* genus (closest match) were mostly recorded from *Myzus ornatus.*

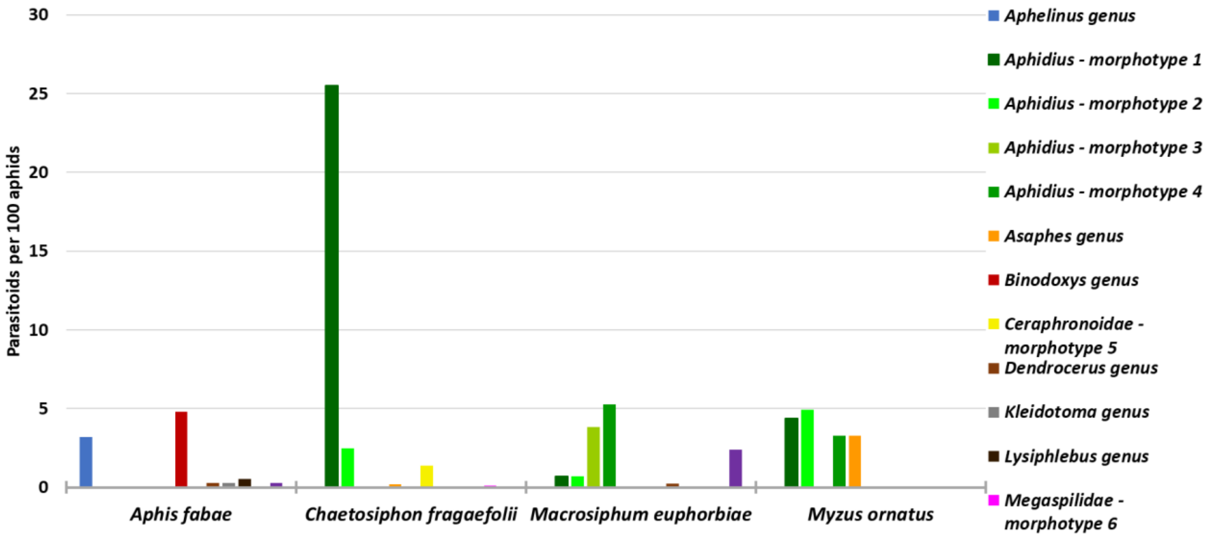


Figure 3.4.13. Number of each parasitoid genus emerging per aphid species collected on sampling occasions 2 (September), 4 (March), 5 (April) and 6 (April). All referenced scientific names are genera with the exception of the families *Ceraphronoidae* and *Megaspilidae.*

Discussions and Conclusions

- Parasitoids overwinter in aphids present on the crop and emerge in early spring as aphid numbers increase.
- Parasitoid genera/species composition seems to vary greatly before and after winter indicated that they may overwinter in the crop until conditions are adequate for emergence.
- In this study, the parasitoid release had no impact on the overall number of parasitoids in the treated plots. Similar parasitoid genera/species were observed in control and treated plots.

- Identification of parasitoids to species was not possible for all specimens and thus detection of parasitoids introduced by the biocontrol mix was not possible.
- Aphid numbers in treated plots did not decrease significantly when compared to the control plots.
- Specific parasitoid genera/species seem to have preferred aphid hosts and the establishment in each parasitoid population may vary according to host availability.
- Due to the high numbers of parasitoids collected throughout this trial and the time-consuming process of visual and molecular identification, more time and resources would be needed to analyse all samples collected and gain more information on the species present at all 3 sites.

WP 4 Control thrips species other than western flower thrips damaging to strawberry crops

Introduction

Successful IPM programmes for management of western flower thrips (WFT), *Frankliniella occidentalis* on strawberry have been developed using knowledge of its biology and behaviour. These programmes are based primarily on the release of the predatory mites, *Neoseiulus cucumeris* and predatory bugs, *Orius laevigatus*. Both small monitoring traps and larger 'mass-monitoring' blue roller traps are frequently included in WFT-targeting IPM programmes, with growers typically hanging the traps below tabletops to avoid potential interference with horizontal spray booms. Monitoring sticky traps can provide valuable information to growers about WFT populations such as early detection of thrips to support decisions on control measures such as release times of *Orius* or lowering of thrips netting at the ends of tunnels. While often deployed without lures, blue roller traps are sometimes combined with WFT aggregation pheromone lures which can lead to significantly increased trap catch of *F. occidentalis* and reduced fruit damage (Sampson and Kirk, 2013; Sampson *et* al, 2014; Sampson, 2014; Harnden *et al*. 2015; Raffle *et al*. 2015). *Frankliniella intonsa* is also known to be attracted to the WFT aggregation pheromone (Zhang *et al*., 2011).

While this IPM approach can be very effective for controlling WFT on strawberry, it has proved less effective against other, native pest thrips species in strawberry crops. Despite WFT-focussed IPM, other thrips species continue to migrate into strawberry crops leading to typical thrips bronzing damage to fruit and reducing marketability (Brown & Bennison, 2017; Bennison *et al.*, 2020).

It is likely that the failure of WFT-targeted IPM strategies against other thrips species is due to several factors that may include the failure of *N. cucumeris* to control immigrant thrips adults (this predator feeds only on young thrips larvae). Unlike WFT which breeds and produces larvae in strawberry flowers, only low numbers of larvae of native thrips species and no *T. fuscipennis* larvae have been found in strawberry flowers. In this project we evaluated two commercially available semiochemical lures, Lurem-TR and Thripnok, in combination with industry standard blue 'dry' sticky traps relative to unbaited sticky traps mounted below tabletops as per commercial practice. An additional small-scale pilot trial tested whether unbaited traps mounted just above the crop or below the tabletops caught different numbers and species of thrips.

Lurem-TR is a non-pheromone lure containing methyl isonicotinate (MI), which is the most widely internationally studied non-pheromone semiochemical used as a thrips attractant. Lurem-TR has been found to increase catches of 12 different species of thrips, including WFT (*F. occidentalis*), rubus thrips (*Thrips major*), and onion thrips (*Thrips tabaci*) (Teulon, 2017). However, there is no published evidence, yet that Lurem-TR attracts rose thrips (*Thrips fuscipennis*) or flower thrips (*Frankliniella intonsa*). Thripnok is also a non-pheromone lure containing two floral scents to attract thrips. Thripnok has been reported to increase thrips catches of WFT and onion thrips by a factor of three in glasshouse and polytunnel strawberry crops relative to control traps.

In this project in 2021, both Lurem-TR and Thripnok were evaluated in combination with blue sticky traps at the same site as the 2022 trial. The 2021 trial was undertaken from 15 July to 3 August during a period of high thrips density. Blue sticky traps in 2021 (above tabletop traps) baited with Lurem-TR or Thripnok caught significantly more thrips than unbaited traps (2.8x and 1.3x respectively). Higher numbers of thrips were caught on the Lurem-TR baited traps than on the Thripnok baited traps (2.1x more). In the 2021 trial, thrips species identified on the traps were a mix of *Thrips fuscipennis* (rose thrips), *Thrips major* (rubus thrips), *Thrips tabaci* (onion thrips) and *Frankliniella intonsa* (flower thrips) however the number of thrips identified were insufficient to statistically assess any significant increases in specific species on traps relative to the control.

The objectives of this trial were:

1. To gain a second year's data on whether the thrips lures Lurem TR and Thripnok increase sticky trap catches of the thrips species mix that damage strawberry, deploying traps earlier in the season than in 2021 and thus presenting them with a potentially different thrips species composition and lower thrips density.
2. To test the effect of Lurem TR and Thripnok on trap catches of flying predators and pollinators.
3. To evaluate whether there is a difference in thrips sticky trap catches above the crop or below tabletops in a commercial strawberry crop.

The results could be used immediately by growers to aid early detection of low densities of thrips in order to time control methods such as release of *Orius* predators or lowering thrips netting at the ends of tunnels to reduce immigrant thrips.

The results could also be used by growers to aid 'mass' precision monitoring of thrips

The researchers could use the results to explore further future research funding for developing improved IPM strategies for thrips management such as lure and infect and luring to trap plants.

Materials and methods

This trial was undertaken at a commercial strawberry nursery in Worcestershire (Figure 4.1). The trial was set up in a second year protected everbearer crop cv. Prize (*Fragaria* x *ananassa* 'Prize') which was grown in open-ended Spanish tunnels with six tabletops per tunnel and ground cover matting beneath the tabletops.

This site was selected based on investigations undertaken in 2021, where thrips species were sampled and identified at nine potential sites. The thrips at this site were found to be a mixture of native thrips species including *Thrips fuscipennis*, *Thrips major*, *Thrips tabaci* and *Frankliniella intonsa*. Trials in 2021 indicated that of these species, *T. fuscipennis* (rose thrips) and *Frankliniella intonsa* (flower thrips) were the most prevalent, with only one individual of WFT confirmed at this site. At this site, bumblebee hives are placed in tunnels to aid pollination, thus tunnels without hives were selected to minimise bumblebee bycatch.

Figure 4.1: Trial site

Semiochemical trial

Treatments:

1. Untreated control (dry blue sticky trap only)
2. Lurem-TR sachet + dry blue sticky trap
3. Thripnok (kairomone lure) sachet + dry blue sticky trap

Trial design: Twenty replicates of each of the three treatments were undertaken. Each of the replicates was a single 'dry glue' blue sticky trap, 25 x 10cm, mounted below the tabletops, with the appropriate treatment sachet cable-tied to the top edge of the trap. A buffer space of 10 m was left between each trap to avoid the semiochemicals mixing.

The traps were set up early in the season, on 14 June, aiming to coincide with first non-WFT activity. The individual traps were mounted vertically in a portrait orientation with the tops of the traps approximately 5 cm below tabletops using two cable ties and aligned at right angles to the tabletops (Figure 4.2). The traps were left in position for three weeks, then carefully mounted onto thick clear plastic wallets (Figure 4.4) and returned to the laboratory on 5 July.

Figure 4.2: Sticky trap and Thripnok sachet mounted below tabletops using cable ties.

Above and below tabletop pilot trial

Treatments:

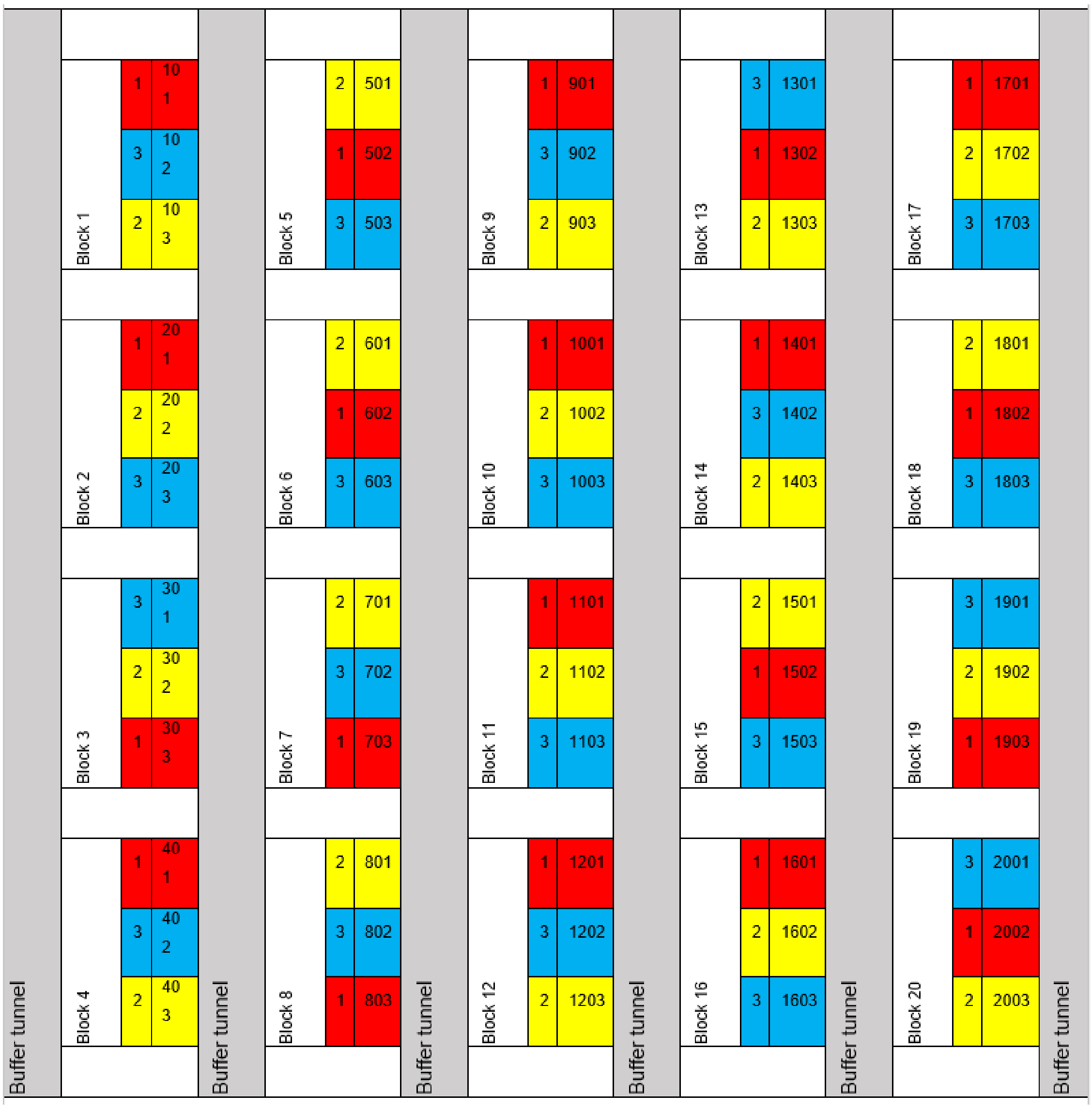
1. Dry blue sticky traps above crop and tabletop (10 cm above soil level)
2. Dry blue sticky traps below tabletop (10 cm below tabletop)

Trial design: Five replicates of each treatment were undertaken. Each of the replicates was a pair of 'dry glue' blue sticky trap, 25 x 10 cm, one mounted above the tabletop on a green pea stick and a second trap cable tied below tabletops, A buffer space of 10 m was left between each pair of traps (Figure 4.3).

This trial was set up and taken down on the same dates as the semiochemical trial (14 June – 5 July). The individual traps were mounted vertically in a portrait orientation approximately 10 cm above or below tabletops and traps were oriented to face NE-SW (Figure 4.3). The traps were left in position for three weeks, then carefully mounted onto thick clear plastic wallets and returned to the laboratory (Figure 4.4).

Figure 4.3: Trial setup for above and below tabletop pilot study.

Figure 4.4: Sticky traps being mounted onto plastic wallet.



1	No lure
2	Lurem-TR lure
3	Thripnok lure

Figure 4.5: Semiochemical trial layout. Experimental blocks were spread across five tunnels, with a buffer tunnel between each. Each tunnel contained four randomised blocks, with each block containing one plot of each of the three treatments.

Assessments

Flower counts:

During both trial set-up and take down (14 June and 5 July), in the central plot in 10 of the 20 blocks (1, 4, 6, 7, 11, 12, 13, 14, 19, 20), five plants were selected in the field and the numbers of flowers on each plant recorded.

Flower sampling:

A week prior to trial set-up (7 June), a non-replicated pre-trial assessment of the incidence of thrips in strawberry flowers at the extreme ends of the tunnels and in flowers of surrounding crops/hedgerow plants and weeds (hogweed, wild rose, elder, wheat and yellow coltsfoot) was undertaken. Non-standardised numbers of flowers from each were tapped out onto a white dish, collected using a fine paintbrush and put into 70% ethanol in labelled screw-top tubes. Thrips samples were then returned to the laboratory and mounted onto microscope slides using a clearing medium. Thrips were then identified to species using a morphological key and diagnostic features under a high-power microscope (Mound *et al*., 1976; Mound and Kibby, 1998). Incidence of thrips species were recorded.

During trial takedown (5 July), a methodical assessment of the numbers of thrips in flowers (in all plots in the same 10 of the 20 blocks as flower counts were performed) was undertaken (30 plots total). In each plot, 20 systematically selected flowers (fully open and upward facing) were tapped out onto a white dish and number of thrips counted and recorded. All thrips present (adults and larvae) were collected using a fine paintbrush and put into 70% ethanol in labelled screw-top tubes. Thrips samples were then returned to the laboratory and the following were recorded:

- Numbers of *Thrips* spp. and *Frankliniella* spp. adult females and numbers of adult male thrips (it was not possible to assign males to genus as males of both genera look similar under a low power dissecting microscope i.e., yellow and smaller than females).
- Numbers of thrips larvae
- Numbers of *Aeolothrips* spp. (predatory thrips) adults
- Numbers of *Orius* spp. adults and nymphs, and numbers of other beneficial insects such as lacewings, hoverflies, and bumblebees

A subsample of 10 adult female thrips from each plot was then mounted onto microscope slides using a clearing medium and identified to species level using a morphological key and diagnostic features under a high-power microscope (Mound *et al*., 1976; Mound and Kibby, 1998). Where fewer than 10 thrips were present in the sample, all thrips in that sample were mounted. Numbers of each species were recorded.

All remaining thrips adults and larvae in ethanol were kept in the laboratory to be used for further identifications if needed. All tubes were labelled with the date, site, tunnel or row and plot number.

Identification of thrips and beneficials on sticky traps - semiochemical trial and above and below tabletop pilot trial

In the laboratory, each trap was examined under a low power binocular microscope and the total number of thrips adults and beneficials on each side of the trap was recorded. Numbers of the following categories were recorded:

- *Thrips* spp. females
- *Frankliniella* spp. females
- Males (of either *Thrips* spp. or *Frankliniella* spp. as both are smaller than females and yellow, thus difficult to identify to genus on a sticky trap under a low power binocular microscope)
- Total pest thrips species (*Thrips* spp. females + *Frankliniella* spp. females + males)
- Predatory thrips (*Aeolothrips* spp.)
- *Orius* spp.
- Other anthocorid bugs
- Bees
- Hoverflies
- Lacewings
- Ladybirds

Species Identification of thrips on sticky traps - semiochemical trial and above and below tabletop pilot trial

All pest thrips were removed from the semiochemical trial individual traps using white spirit. To do this, sticky traps were examined down the microscope and all thrips circled. Portions of traps with thrips were then removed from traps using a hole punch. The individual circular portions of trap with thrips were immersed in separate glass beakers containing a small volume of white spirit, agitated, and left overnight. The following day, the now liberated thrips were transferred from the white spirit into water to wash away excess white spirit, before being mounted onto slides with the clearing medium for identification.

Data analysis

Flower counts:

The mean number of flowers per plant was calculated and analysed between dates using a two-sample t-test and between blocks on the same date using ANOVAs. Analysis was undertaken in Genstat 16 by Chris Dyer, the ADAS statistician.

Flower sampling:

Mean numbers of adult thrips and larvae collected from flowers at trial take down were evaluated using Analysis of Variance (ANOVA) in Genstat 16 with plot and treatment as factors. Analysis was undertaken by Chris Dyer, the ADAS statistician.

Identification of thrips and beneficials on sticky traps - semiochemical trial

Following completion of counts of thrips and beneficials on sticky traps, results were analysed using analysis of variance. ANOVAs were performed on Log_{10}-transformed data for each counted category, with block and treatment as factors. All analyses were completed by Chris Dyer, the ADAS statistician.

Identification of thrips and beneficials on sticky traps - above and below tabletop pilot trial

Following completion of counts of thrips and beneficials on sticky traps, results were analysed using paired T-tests on untransformed data. All analyses were completed by Chris Dyer, the ADAS statistician.

Data loggers: temperature and humidity

One datalogger was used to monitor temperature and humidity for the trial duration. The datalogger was attached underneath the tabletops using cable ties.

Results

Semiochemical trial results

Mean number of flowers per plant

At trial setup on 14 June, the mean number of flowers per plant was 1.40 with a maximum of four and minimum of zero. At trial takedown on 05 July, the mean number of flowers per plant was 1.86 with a maximum of five and a minimum of zero (Figure 4.6). A two-sample T-test revealed no significant difference in the number of flowers per plant between trial setup and takedown ($t(98)=1.78$, $P=0.079$).

Analysis of variance tests showed no significant differences between plots in the number of flowers per plant at trial set-up ($F(9,40)=0.740$, P=0.674) and trial takedown ($F(9,40)=0.680$, $P=0.718$).

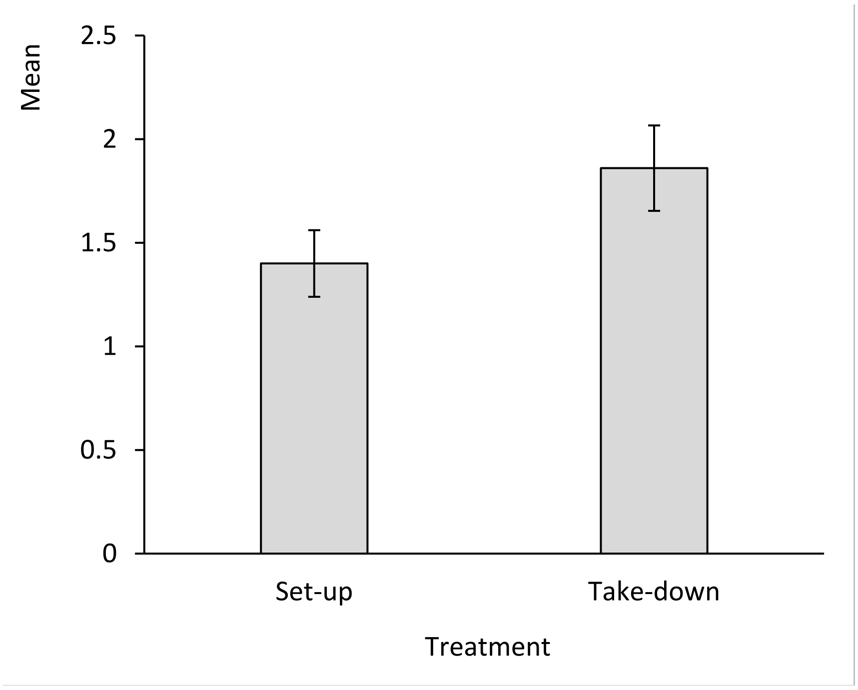


Figure 4.6: Mean numbers (±SE) of flowers per plant (± standard error) in all treatments combined, (untreated plots, Lurem-TR treated plots and Thripnok treated plots). No significant difference was identified in numbers of flowers per plant between plots at trial set-up (14 June) and trial take-down (05 July) ($P>0.05$).

Species of thrips in flowers: one-week prior to trial setup

Prior to trial setup, a non-replicated initial evaluation of thrips incidence was undertaken. This revealed that in the strawberry flowers, *T. major*, *T. fuscipennis* and *T. tabaci* were all present on 07 June – with an indication that at this time *T. fuscipennis* may have been the most prevalent thrips species. On flowering weeds, hedgerow plants and a wheat crop in the immediate area surrounding the strawberry tunnels, additional species of thrips were also present; *F. occidentalis*, *F. intonsa*, *T. vulgatissimus* and *Limothrips cerealium* (Table 4.1). *Thrips major* was found in the flowers of all plant species except for wheat and was the only species found in elder flowers.

Mean number of thrips per flower: At trial takedown

During trial takedown, an evaluation of thrips in strawberry flowers was undertaken. Across all blocks, an overall mean of 0.56 thrips were found per flower, with a maximum individual block mean of two thrips per flower and a minimum individual block mean of 0.15 thrips per flower (Figure 4.7). In blocks subject to (1) dry blue stick-trap treatment alone, (2) dry blue sticky-traps with a Lurem-TR lure, or (3) dry blue sticky traps with a Thripnok lure, the mean numbers of thrips per flower were (1) 0.48, (2) 0.61 and, (3) 0.59 respectively (Figure 4.7).

Analysis of variance revealed no significant difference in the total number of thrips per flower in plots subject to (1) dry blue stick-trap treatment alone, (2) dry blue sticky-traps with a Lurem-TR lure, or (3) dry blue sticky traps with a Thripnok lure ($F(2,48)= 0.37$, $P=0.694$). A significant difference in thrips catch was however noted between blocks ($F(9,48)=3.00$, $P=0.029$).

Table 4.1: Summary of the number and proportion of identified thrips species adults in flowers of strawberry and weed/hedgerow species and wheat a week prior to experimental setup (07.06.22).

Thrips species	**Host plant**						
	Strawberry North-end	**Strawberry South-end**	**Hogweed**	**Wild Rose**	**Elder**	**Wheat**	**Yellow Coltsfoot**
Total thrips	**5**	**12**	**9**	**5**	**15**	**4**	**4**
F. occidentalis	0	0	1 (11.1%)	0	0	0	0
F. intonsa	0	0	**5 (55.5%)**	0	0	0	0
T. major	1 (20%)	2 (16.7%)	1 (11.1%)	**4 (80%)**	**15 (100%)**	0	**2 (50%)**
T. fuscipennis	**3 (60%)**	**10 (83.3%)**	0	1 (20%)	0	0	0
T. tabaci	1 (20%)	0	1 (11.1%)	0	0	0	0
T. vulgatissimus	0	0	0	0	0	0	1 (25%)
Limothrips cerealium	0	0	1 (11.1%)	0	0	**4 (100%)**	1 (25%)

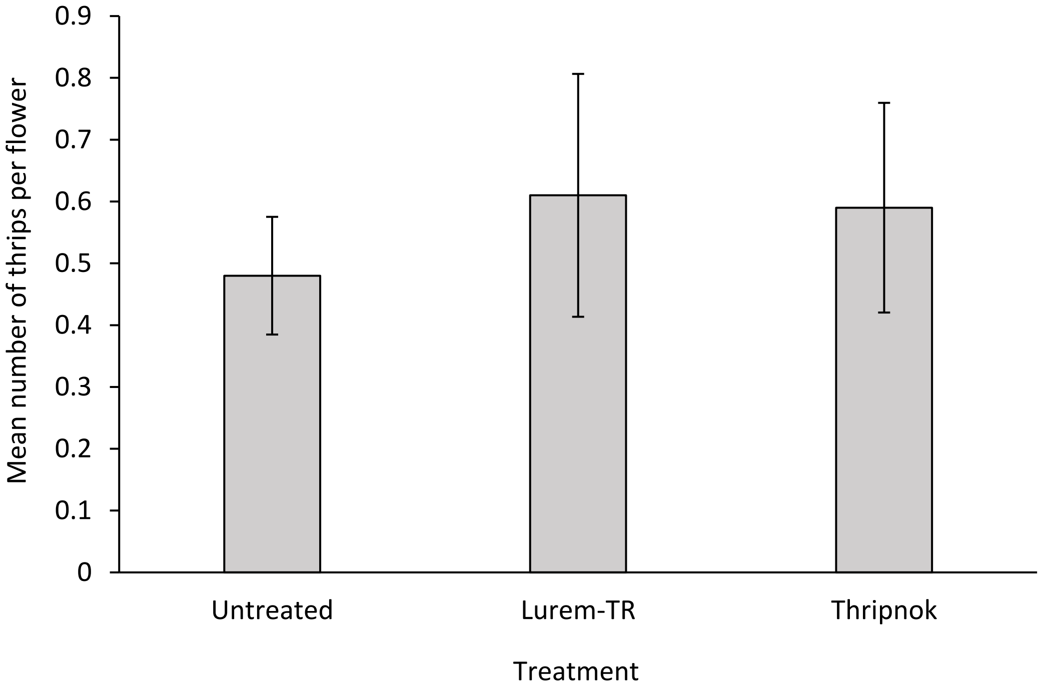


Figure 4.7: Mean (±SE) numbers of combined thrips adults (*Thrips* spp. females, *Frankliniella* spp. females and male thrips) per flower (± standard error). No significant differences in numbers of total thrips between treatments were noted in tapped flower samples (*P*>0.05).

Genera of thrips in strawberry flowers: At trial takedown

Of the thrips sampled from strawberry flowers at trial takedown, 92.02% were *Frankliniella* spp. (173 of 188). By treatment, a mean of 0.32 *Frankliniella* spp. per flower were seen in untreated blocks, a mean of 0.29 per flower in Lurem-TR treated blocks, and a mean of 0.34 per flower in Thripnok treated blocks. In contrast, a mean of 0.06 *Thrips* spp. per flower were seen in untreated blocks, a mean of 0.01 per flower in Lurem-TR treated blocks, and a mean of 0.02 per flower in Thripnok treated blocks (Figure 4.8).

Analysis of variance revealed no significant differences in the number of *Thrips* spp. or *Frankliniella* spp. between treatments ($F(1,48)=0.36$, $P=0.699$). However, there were significantly more *Frankliniella* spp. per flower than *Thrips* spp. across all treatments ($F(5,48)=64.80$, $P=<0.001$).

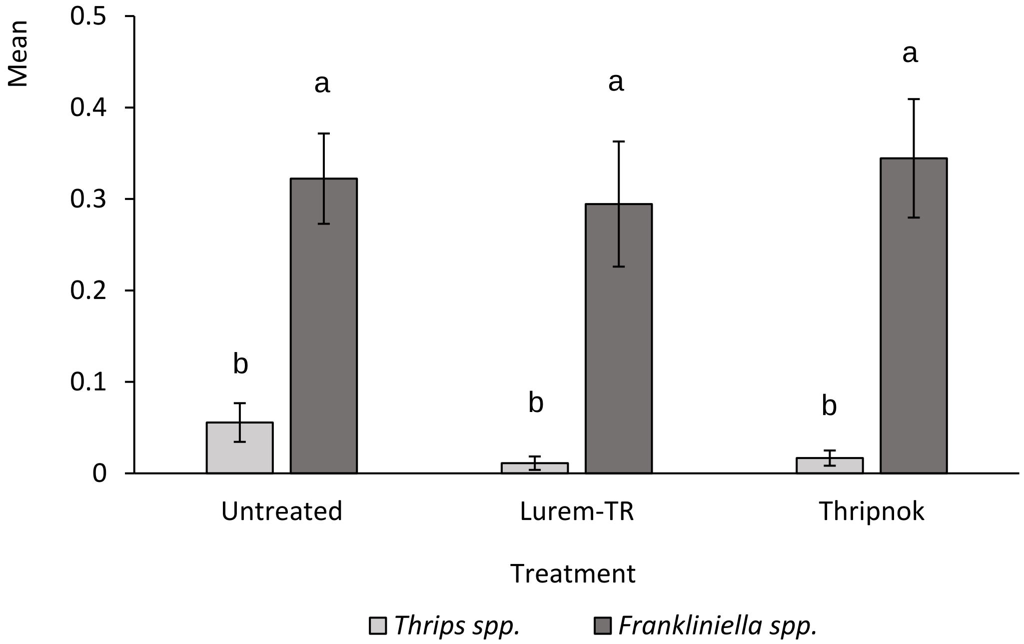


Figure 4.8: Mean (±SE) numbers of *Thrips* spp. and *Frankliniella* spp. female adults per flower (± standard error). There were significantly more *Frankliniella* spp. than *Thrips* spp. in tapped flower samples (P<0.05). However, post-hoc analysis revealed no differences in mean number of *Thrips* spp. or *Frankliniella* spp. between treatments (P>0.05).

Species of thrips in strawberry flowers: At trial takedown

Of the *Franklinkella* species collected, 170 of 173 were identified as WFT (*F. occidentalis*) while the remaining three *Frankliniella* specimens were identified as *F. intonsa*. Of the *Thrips* species collected, six individuals of *T. major*, five *T. tabaci* and four *T. fuscipennis* were identified (Figure 4.9 and Table 4.2). Owing to low incidence of *Thrips* spp., these results were only evaluated statistically for *F. occidentalis*. ANOVA revealed no significant difference in flower catch of WFT in blocks subject to blue sticky trap treatment alone, blue sticky trap in combination with a Lurem-TR lure or a blue sticky trap in combination with a Thripnok lure ($F(2,24)=0.13$, $P=0.879$).

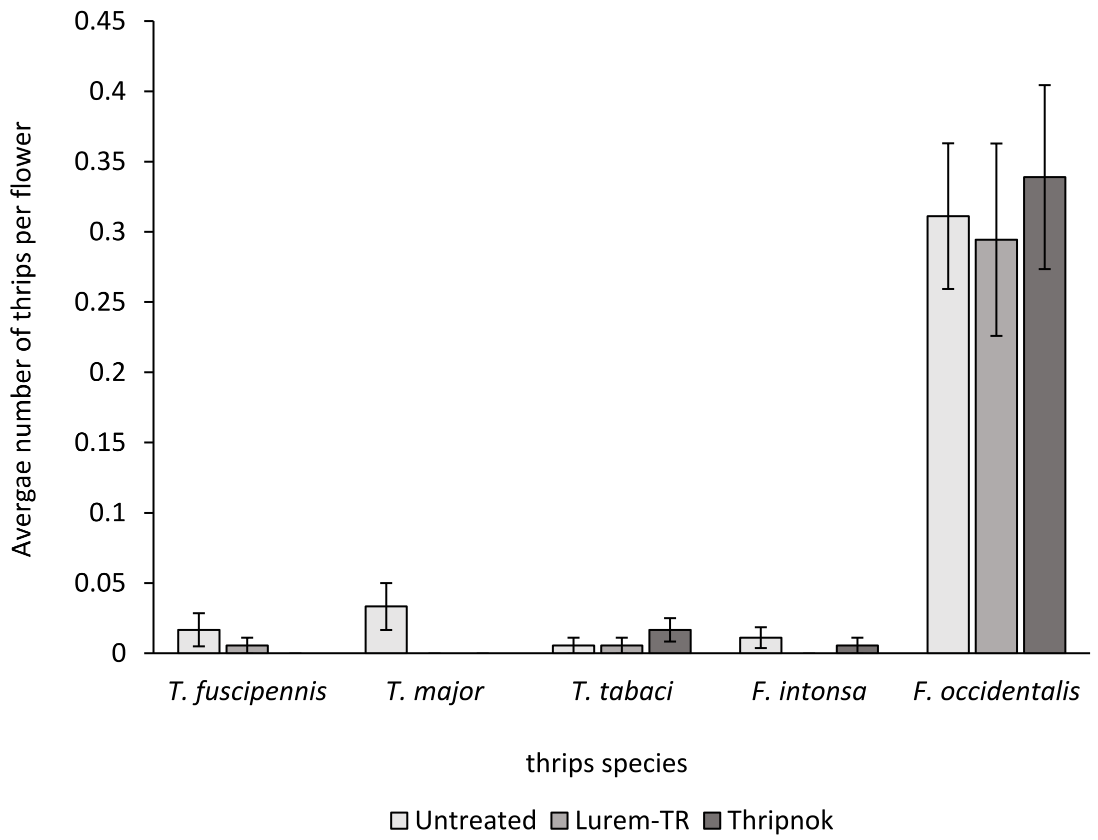


Figure 4.9: Mean (±SE) numbers of thrips adults by species per strawberry flower at trial takedown, 05.07.22 (+/- standard error). ANOVA revealed no significant difference in *F. occidentalis* catch between treatments (P>0.05).

Table 4.2: Summary of the number and proportion of identified thrips species adults in flowers during trial takedown (05.07.22). From each plot of ten randomly selected blocks,

Species	**Metric**	**Date 05.07.22**
T. fuscipennis	Number identified	4
	% of total	2.1%
T. major	Number identified	6
	% of total	3.2%
T. tabaci	Number identified	5
	% of total	2.7%
F. intonsa	Number identified	3
	% of total	1.6%
F. occidentalis	Number identified	170
	% of total	90.4%
Total thrips adults identified		188

Sticky trap thrips catch (all placed below tabletops)

Total pest thrips catch (**Thrips** ***spp. and*** **Frankliniella** ***spp. combined)***

When considering pest thrips species collectively (*Thrips* spp. and *Frankliniella* spp. females and male thrips), the combination of blue sticky traps with Lurem-TR or Thripnok lures did not lead to any significant difference in thrips trap catch per trap (0.05 m^2) relative to blue sticky trap alone over the 3-week period ($F(2,48)=2.66$, $P=0.083$) (Figure 4.10). Thrips catches on untreated traps (blue sticky traps alone), averaged 18.4 thrips per trap (Table 4.3; Figure 4.10). Where Lurem-TR and Thripnok lures were used, thrips catch increased to a mean of 24.3 (1.32x higher than control) and 24.9 (1.35x higher than control) respectively per trap, however, these increases were not significant ($P>0.05$). The maximum number of thrips seen per individual trap was 33 (blue sticky trap + Thripnok lure) while the minimum number of thrips seen per trap was two (blue sticky trap alone).

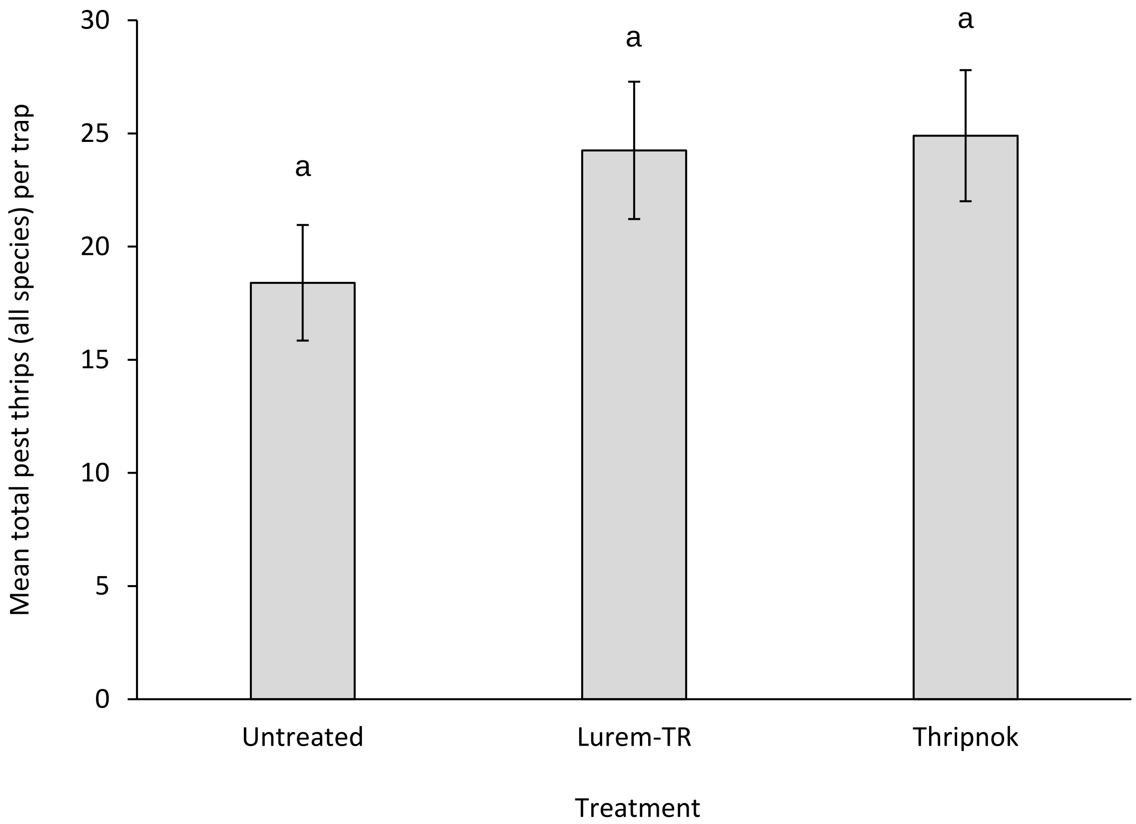


Figure 4.10: Mean (±SE) numbers of total thrips (*Thrips* spp., *Frankliniella* spp. and male thrips) per trap (both sides of a trap 10 x 25 cm, total of 0.05 m^2) after a 3-week period, ± standard error. Bars sharing a letter are statistically similar, those not sharing a letter are significantly different (P<0.05).

***Trap catch of* Thrips *spp. and* Frankliniella spp. separately (all placed below tabletops)**

When considering thrips species females by genus (*Thrips* spp. and *Frankliniella* spp.) Lurem-TR and Thripnok semiochemical lures resulted in significant increases in *Frankliniella* spp. catch relative to untreated control traps (F(2,19)=3.44, P=0.042). Across all three treatments *Frankliniella* spp. proved the most prevalent genus, representing 41.8% of the total thrips catch on untreated traps (7.7 mean per trap), 47.4% of total thrips catch on blue sticky traps combined with a Lurem-TR lure (11.1 mean per trap), and 45.2% of total thrips catch on blue sticky traps combined with a Thripok lure (11.3 mean per trap). The semiochemical lures Lurem TR and Thripnok increased *Frankliniella* spp. female catch by 1.49x and 1.46x respectively relative to blue sticky traps alone and these increases were not significantly different from each other. However, no significant between-treatment differences were seen in *Thrips* spp. catch (F(2,19)=0.65, P=0.527) or male thrips catch (F(2,19)=1.51, *P*=0.234). For *Thrips* spp., catches averaged 4.0, 4.4 and 3.6 per blue sticky traps alone, with a Lurem-TR lure or with a Thripnok lure respectively (Figure 4.11; Table 4.3). For male thrips, blue sticky traps alone caught a mean of 6.7 relative to 8.4 and 10.1 when blue sticky traps were deployed with Lurem-TR or Thripnok respectively.

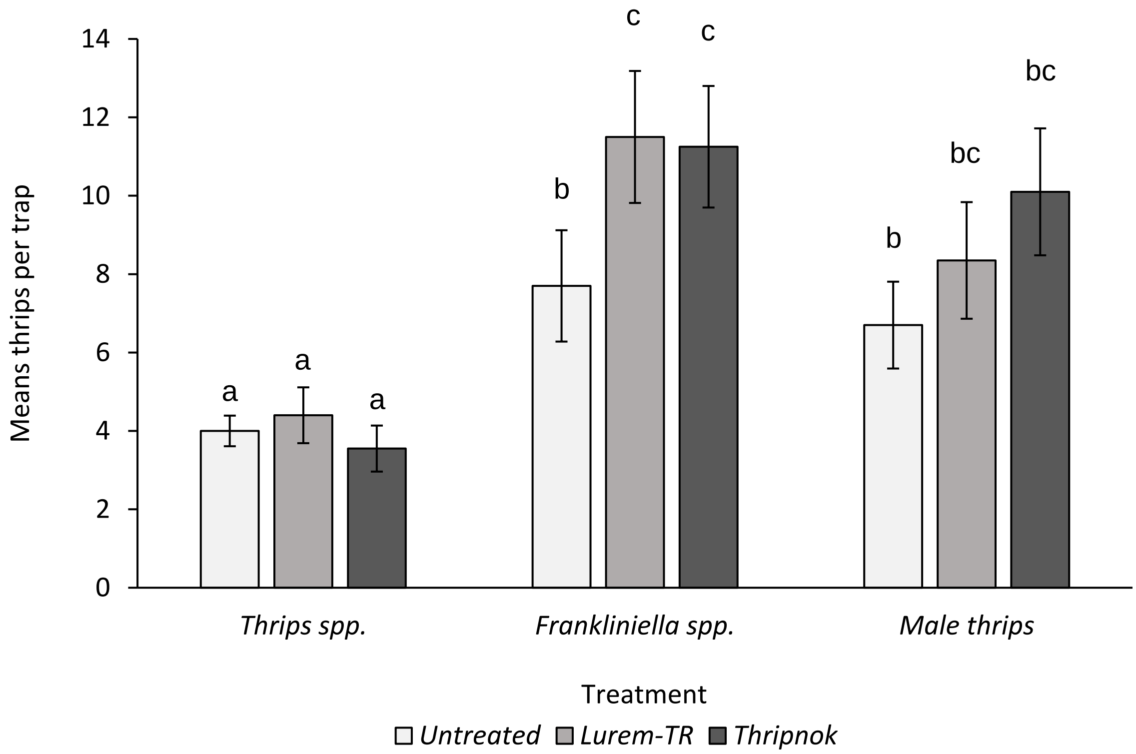


Figure 4.11: Mean (±SE) number of *Thrips* spp., *Frankliniella* spp. (females) and all species males per trap (both sides of a trap 10 x 25 cm, total of 0.05 m^2) after a 3-week period, ± standard error. Bars sharing a letter are not significantly different, those not sharing a letter are significantly different (*P*<0.05).

Table 4.3: Mean number of thrips and beneficial insects found per trap (after a 3-week period) and analysis of variance results on Log_{10}-transformed counts of each thrips or beneficials grouping. Values in columns sharing a letter are not significantly different. Values in colums not sharing a letter are significantly different. Values significantly different from those in the untreated controls indicated in bold and underlined.

Treatment		Thrips				Beneficials
		***Thrips* and *Frankliniella* spp. (males and females)**	***Thrips* spp. females**	***Frankliniella* spp. females**	**Male thrips**	**Bees**
Untreated		18.40	4.00 a	7.70 b	6.70 b	1.40 a
Lurem-TR		24.25	4.40 a	**<u>11.50 c</u>**	8.35 bc	**<u>3.05 b</u>**
Thripnok		24.90	3.55 a	**<u>11.25 c</u>**	10.10 bc	**<u>13.20 c</u>**
One-way ANOVA						
Treatment	dof	2,19	2,19	2,19	2, 19	2,19
	Test stat. (F)	2.66	0.65	**<u>3.44</u>**	1.51	**<u>58.26</u>**
	Prob (p)	0.083	0.527	**<u>0.042</u>**	0.234	**<u><0.001</u>**

'Dark' thrips species identified from sticky traps (all traps placed below tabletops)

Owing to the considerable amount of existing research and literature exploring the attractiveness of *F. occidentalis* to different colours of sticky traps and semiochemical lures, thrips species identification from sticky traps in this study focussed instead upon species commonly grouped together as 'dark' thrips species by growers – for which much less information is available about the efficacy of semiochemical lures. Following removal of thrips from traps, 112 thrips were identified to species level. A notable majority of 'dark' thrips present were identified as cereal thrips (*Limothrips* spp., 72.3% of all 'dark' thrips across all treatments). Of the remaining species, *T. tabaci* and *T. major* were the second and third most abundant species respectively (16.8% and 9.8% of total dark thrips catch respectively) (Figure 4.12). Only three individuals of *T. fuscipennis* and two individuals of *F. intonsa* were recorded in total (Table 4.4). Owing to low dark thrips catch across all treatments and a predominance of *Limothrips* spp. these data were not statistically analysed.

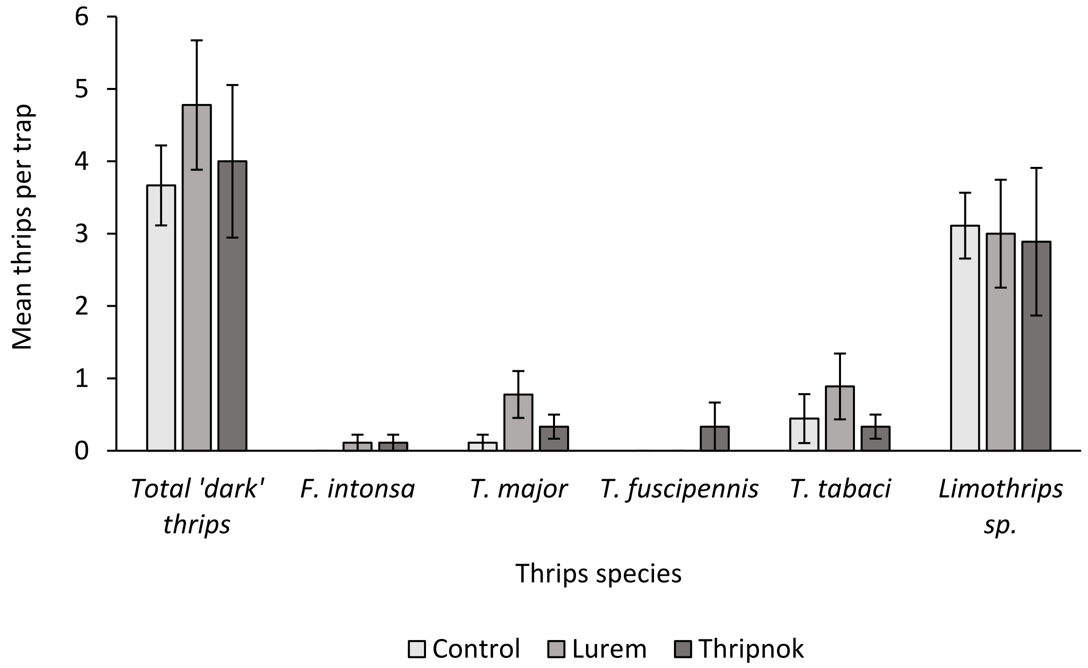


Figure 4.12: 'Dark' thrips species identification (mean (±SE))after removal from sticky traps with no semiochemical lure, a Lurem-TR lure or a Thripnok lure. Owing to low dark thrips catch across all treatments and a predominance of *Limothrips* spp. these data were not statistically analysed.

Table 4.4 'Dark' thrips species identification after removal from sticky traps.

Treatment	*T. fuscipennis*	*T. major*	*T. tabaci*	*F. intonsa*	*Limothrips* spp.	Total
Untreated	0	1 (3.0%)	4 (12.1%)	0	28 (84.8%)	33
Lurem-TR	0	7 (16.3%)	8 (18.6%)	1 (2.3%)	27 (62.8%)	43
Thripnok	3 (8.3%)	3 (8.3%)	3 (8.3%)	1 (2.8%)	26 (72.2%)	36
All	3 (2.7%)	11 (9.8%)	15 (16.8%)	2 (1.8%)	81 (72.3%)	112

Beneficials catch

Bee catch

On blue sticky traps alone (no lure), a mean of 1.40 bees (predominantly bumblebees) were caught per trap (Figure 4.13a). On traps with a Lurem-TR lure, the catch of bees was significantly greater, with a mean of 3.05 per trap (2.2x increase relative to untreated traps). On traps with a Thripnok lure, there was a larger significant increase in bee catch, with a mean of 13.20 (9.4x increase relative to untreated traps, 4.3x increase relative to Lurem-TR treated traps) (Table 4.8; Figure 4.14). Analysis of variance confirmed significant variation in bee catch between treatments ($F(2,48)=58.26$, $P<0.001$), with post-hoc testing showing that significantly more bees were caught on both Lurem-TR and Thripnok traps compared with untreated traps ($P<0.05$ for all pairwise contrasts).

Other beneficials catch

Very few predatory thrips (*Aeolothrips* spp.), *Orius* spp., other anthocorid spp., or hoverflies were recorded on sticky traps, with catches of each group averaging less than 0.5 per trap (Figure 4.13b). Across treatments, the mean *Aelothrips* spp. per trap ranged from 0.20-0.40, with the highest numbers on untreated and Lurem-TR treated traps. Across treatments, the mean *Orius* spp. other anthocorid spp., and hoverflies per trap ranged from 0-0.49, 0.37-0.55, and 0.31-0.59 respectively. For other anthocorid spp. and hoverflies, Thripnok treatment led to the greatest mean trap catch (0.25 and 0.35 respectively). No *Orius* spp. however were recorded on Thripnok treated traps – with the greatest mean per-trap catch of *Orius* spp. seen on Lurem-TR treated traps (0.15). Except for *Aeolothrips* spp., untreated traps led to the lowest (or joint lowest) mean catch for every observed beneficials group. Owing to low numbers of these beneficials, statistical analyses were not undertaken.

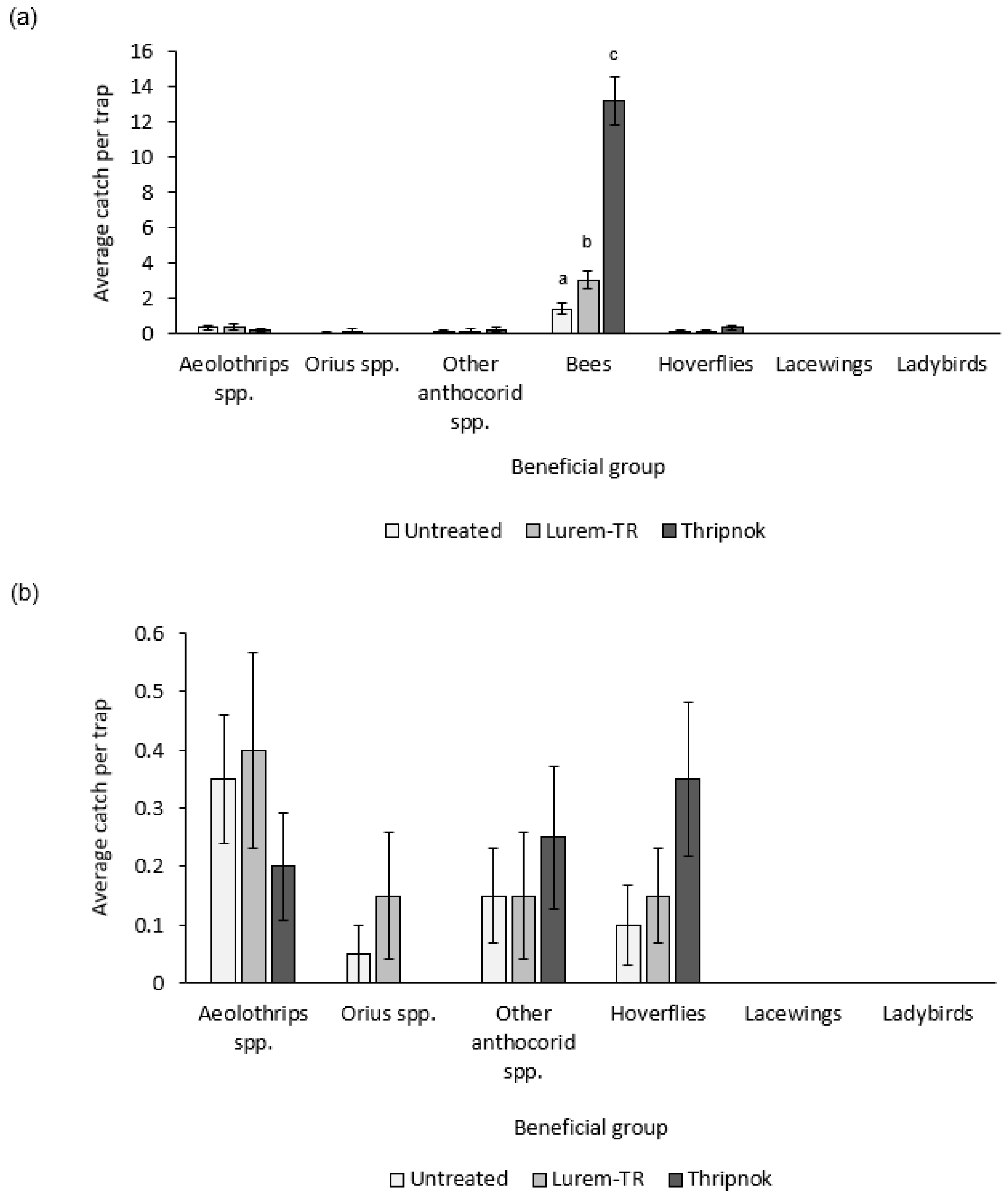


Figure 4.13: Mean (±SE) number of beneficial insects caught per trap (both sides of a trap 10 x 25 cm, total of 0.05 m^2) after a 3-week period, ± standard error (a) including bees and (b) excluding bees. Bars sharing a letter are not significantly different, those not sharing a letter are significantly different (P<0.05).

Above and below table-top mini trial sticky trap catch

Pest thrips catch above and below tabletops

Pest thrips species caught in the above and below tabletop catch trial were considered both overall (grouped as ‘pest thrips’) and grouped into *Thrips* spp. and *Frankliniella* spp. females and male thrips. Analysis of variance revealed significant differences in total pest thrips on traps above and below the tabletop ($F(1,4)=62.72$, $P=0.001$), with a mean of 2.0 pest thrips below the table-top relative to a mean of 16.2 above the tabletop (8.1x more above the tabletop) (Figure 4.14). Significantly higher catches above the tabletop were also given with *Thrips* spp. females, *Frankliniella* spp. females and male thrips (*Thrips* spp. $F(1,4)=90.00$, $P<0.001$; *Frankliniella* spp. $F(1,4)=17.16$, $P=0.014$; males. $F(1,4)=16.41$, $P=0.015$). The mean *Thrips* spp. females per trap below the tabletops was 1.0, relative to 7.0 above the tabletop (7.0x increase). For *Frankliniella* spp. females the mean below tabletop catch was 0.6 per trap relative to 3.7 above the tabletop (6.2x increase). For males, the mean below tabletop catch was 0.4 relative to 5.5 above (13.8x increase).

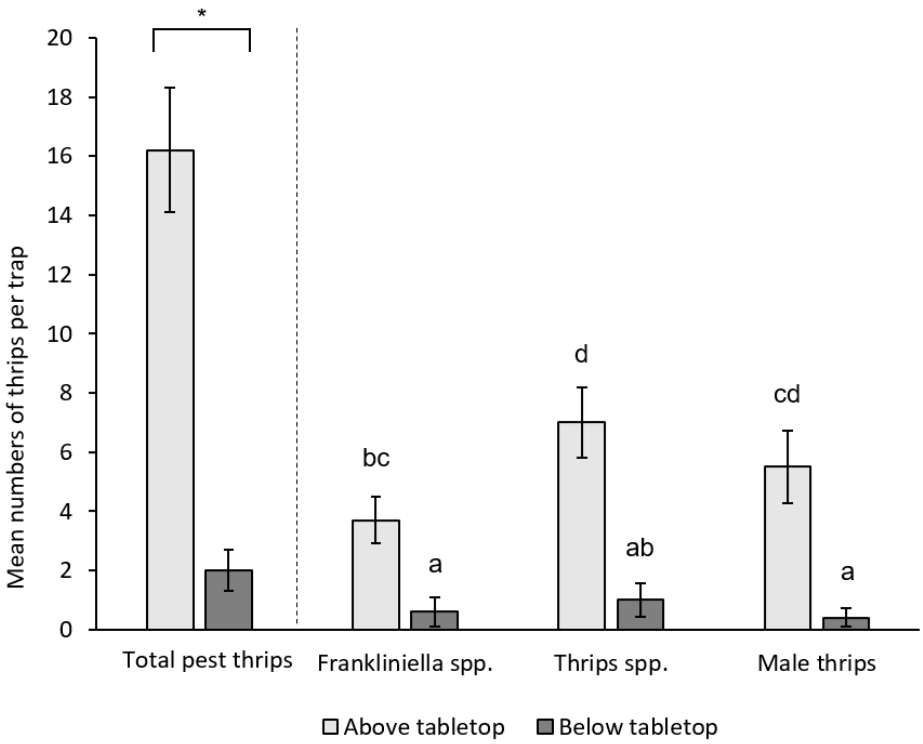


Figure 4.14: Mean (±SE) thrips catch (total and by genus) on un-baited blue sticky traps placed above or below strawberry tabletops. ANOVAs revealed significantly more of each thrips grouping above tabletops relative to below (P<0.05). Bars sharing a letter are not significantly different, those not sharing a letter are significantly different.

Pest thrips catch above and below tabletops – species identification

Following identification to genus level using a microscope, all thrips present on above and below tabletop sticky traps were removed, mounted, and identified to species level. On above tabletop sticky traps, *T. major* and *F. intonsa* were the most prevalent species, representing 29.2% (26/89) and 23.6% (21/89) of the thrips catch respectively (table 4.5, Figure 4.15). *Thrips tabaci* and *F. occidentalis* were also abundant on above-tabletop traps, representing 16.9% (15/89) and 13.5% (12/89) of the thrips caught. The least abundant species on above-tabletop traps was *T. fuscipennis*, with only one individual being caught on traps. Significantly fewer thrips in total were caught on below-tabletop traps than above tabletop traps ($t(4)=7.92$, $P=0.001$). The most prevalent strawberry pest thrips species on below tabletop traps was *T. tabaci*, representing 24.0% (6/25) of the catch. *Frankliniella occidentalis* and *T. major* were also present on these traps, however only three and one individual thrips of these species were caught respectively. Among the clearest difference in thrips catch above and below tabletops was in incidental cereal thrips (*Limothrips* spp.), which represented 6.7% (6/89) of the thrips caught above the tabletop relative to 52.0% (13/25) of the thrips caught on below-tabletop traps. Paired *t*-test analyses revealed significantly more *T. major*, *F. occidentalis* and *F. intonsa* were caught on traps above the tabletops than on those below. Significantly more *Limothrips* spp. were found on traps below the tabletops (Table 4.5). No significant difference in sticky trap catch above and below tabletop however was noted for *T. tabaci* ($t(4)=1.41$, $P=0.233$), while insufficient *T. fuscipennis* were caught to assess locational differences (Table 4.5; Figure 4.15).

Table 4.5: Thrips species identification after removal from sticky traps placed either above or below strawberry crop tables.

Treatment	*T. fuscipennis*	*T. major*	*T. tabaci*	*F. occidentalis*	*F. intonsa*	*Limothrips* spp.	Male thrips	**Total**
Above tabletop	1 (1.1%)	21 (23.6%)	15 (16.9%)	12 (13.5%)	26 (29.2%)	6 (6.7%)	8 (9.0%)	89
Below tabletop	0	1 (4.0%)	6 (24.0%)	3 (12.0%)	0	13 (52.0%)	2 (8.0%)	25
All	1 (0.88%)	22 (19.30%)	21 (18.4%)	15 (13.2%)	26 (22.8%)	19 (16.7%)	10 (8.8%)	114
Paired two-sample T-tests								
Test statistic (*t*)	n/a	**3.65**	1.41	**3.09**	**6.04**	**3.50**	**4.05**	**7.92**
Probability (*P*)	n/a	**0.022**	0.233	**0.037**	**0.004**	**0.025**	**0.015**	**0.001**

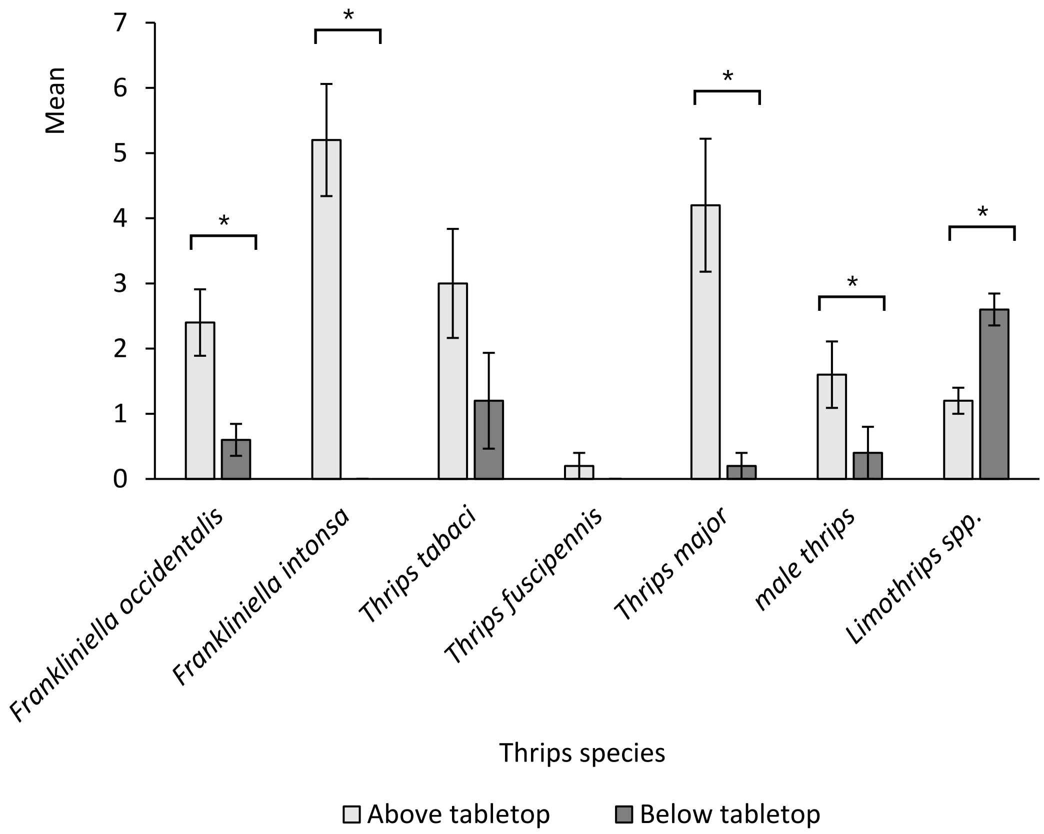


Figure 4.15: Mean (±SE) thrips catch per trap of different thrips species above or below strawberry growing tabletops. Thrips species groups with an asterisk (*) had a significant difference in above and below tabletop sticky trap catch for this group (*P*<0.05).

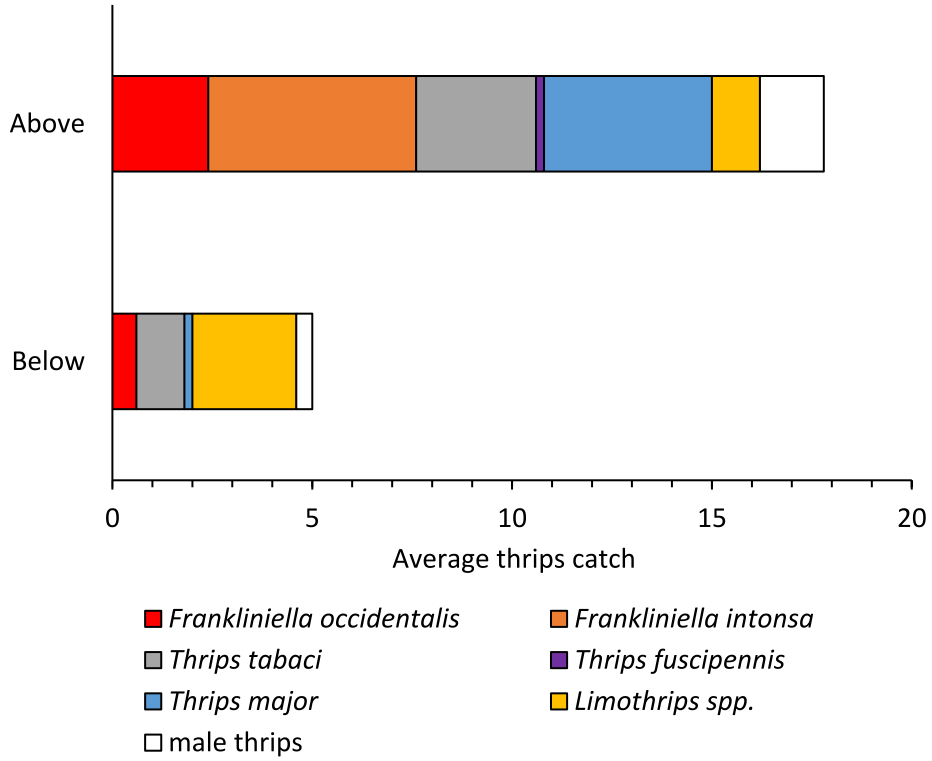


Figure 4.16: Total per trap mean thrips catch of different thrips species above or below strawberry growing tabletops.

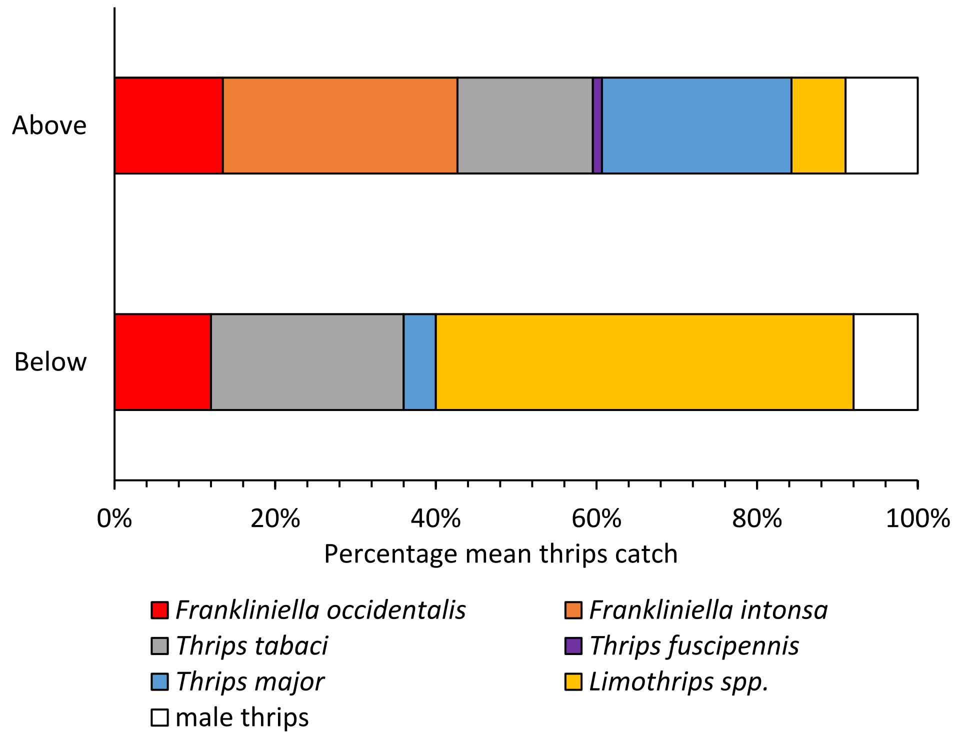


Figure 4.17: Mean percentage of catch each thrips species caught on above or below strawberry tabletop sticky traps.

Beneficials catch above and below tabletops

As was seen in the main semiochemical trial, bees and *Aeolothrips* spp. were the most abundant beneficials seen on sticky traps in the above and below tabletop pilot trial. Owing to low numbers of all other beneficials caught, statistical analyses were undertaken for only these groups. No significant differences were identified in bee catch per trap above and below tabletops ($t(4)=0.78$, $P=0.477$). A significant difference was however identified in *Aeolothrips* spp. catch, with a mean of 1.2 per trap being caught above the tabletops than below, where mean *Aeolothrips* spp. trap catch was 0.3 ($t(4)=3.09$, $P=0.037$) (Figure 4.17).

Beneficials catch in the above and below tabletop pilot trial were broadly consistent with below-tabletop untreated traps in the main semiochemical trial. *Aeolothrips* spp., bees, and hoverfly catches below tables tops in this trial averaged 0.30, 1.30, and 0.20 relative to means of 0.35, 1.40, and 0.10 in the untreated blocks of the semiochemical trial.

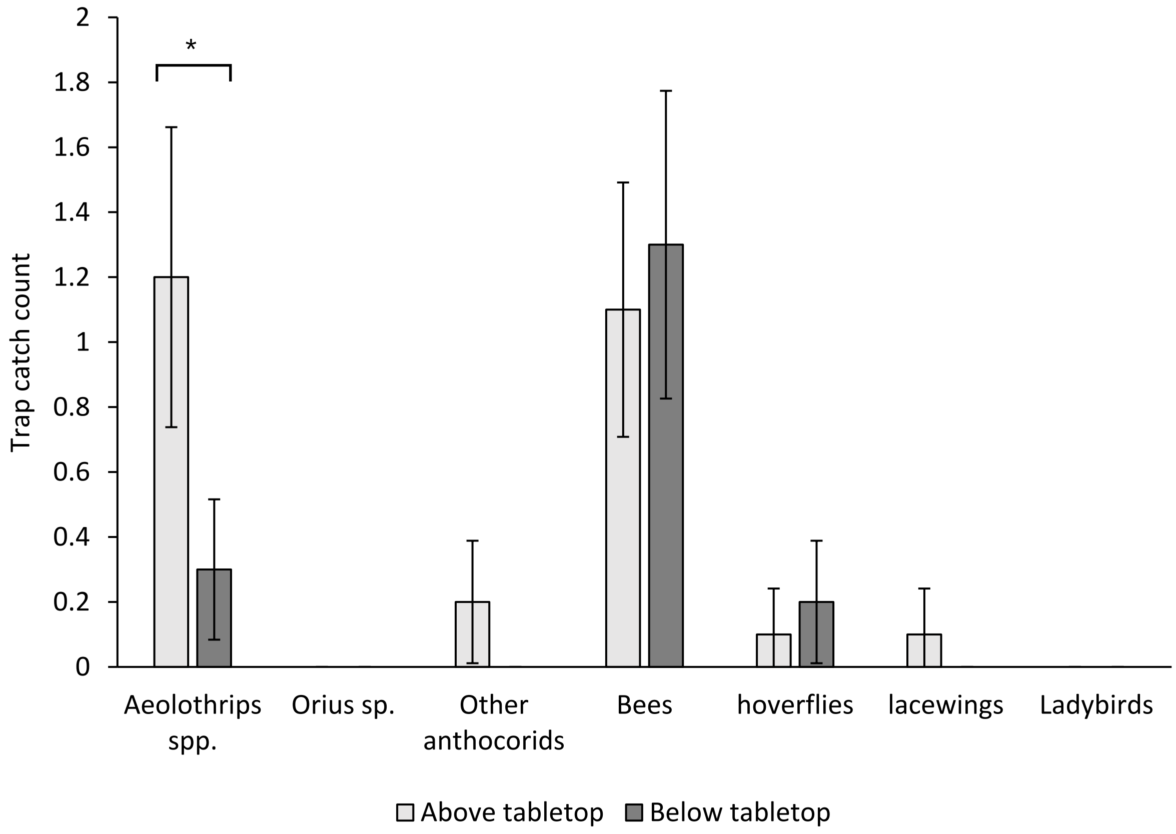


Figure 4.18: Mean (±SE) beneficials catch per trap on unbaited blue sticky traps placed above or below strawberry tunnel tabletops. Paired T-tests were undertaken for bees and *Aeolothrips* spp., revealing no significant differences in catch of bees on sticky traps above or below tabletops ($P>0.05$), but a significant increase in *Aeolothrips* spp. catch on sticky traps above the tabletops relative to below ($P<0.05$).

Temperature and Humidity

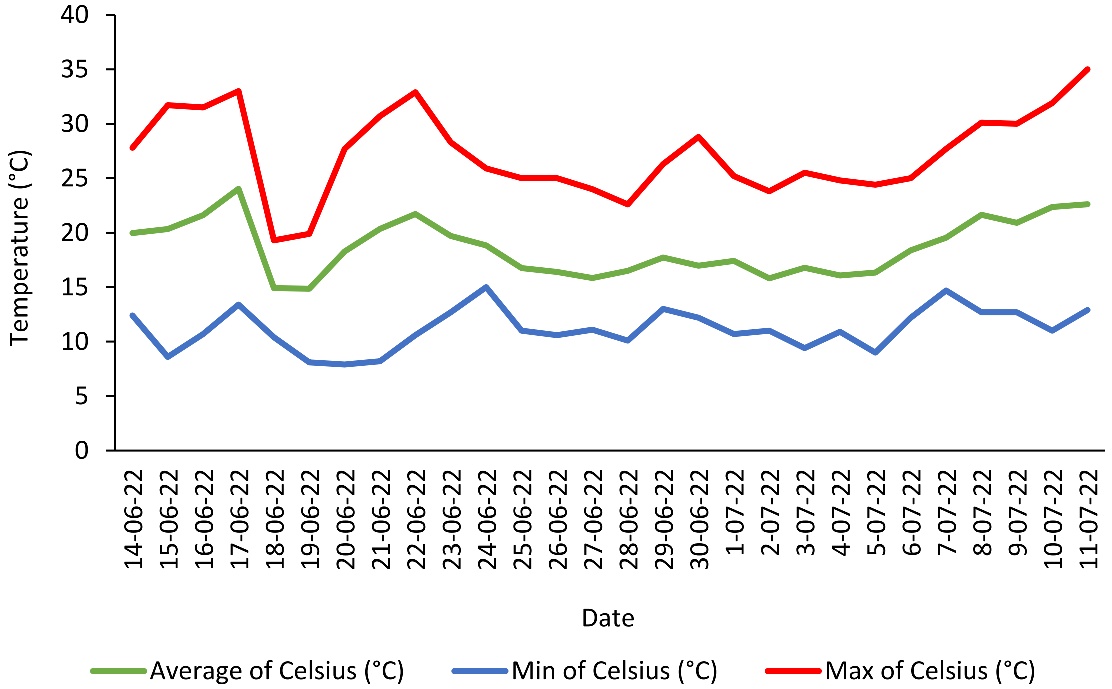


Figure 4.19: Mean maximum, minimum and mean daily temperatures (°C) from data logger under the tabletop.

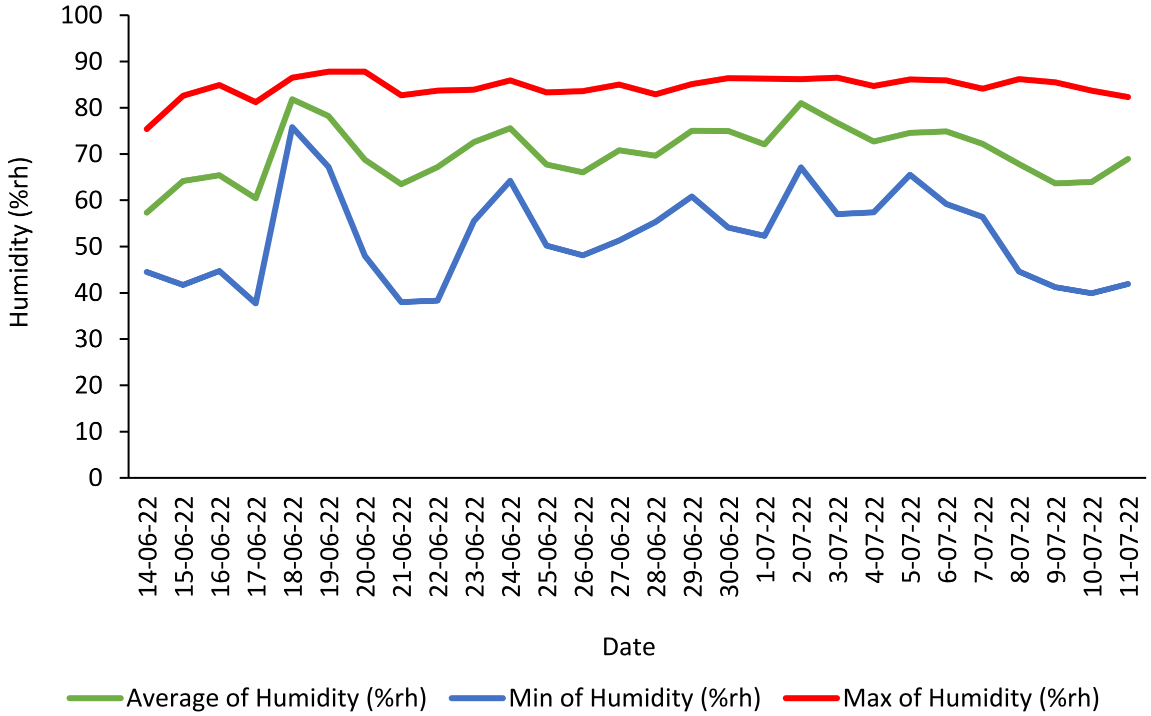


Figure 4.20: Mean maximum, minimum and mean humidity (%rh) from data logger under the tabletop.

Grower IPM programmes

Table 4.6: Biological control agents released in semiochemical trial area.

Date	Biological control agent	Release rate
07.05.22	*Neoseiulus cucumeris*	50/plant
10.05.22	*Phytoseiulus persimilis*	2/plant
19.05.22	*N. cucumeris*	25/plant
26.05.22	*N. cucumeris*	25/plant
06.06.22	*N. cucumeris*	25/plant
16.06.22	*N. cucumeris*	25/plant
24.06.22	*P. persimilis*	2/plant
01.07.22	*N. cucumeris*	25/plant

Table 4.7: Plant protection products applied in semiochemical trial area.

Date	Active ingredient	Trade name
13.03.22	Deltamethrin	Decis
	Silicon wetter	SW7
08.04.22	Spirotetramat	Batavia
	Silicon wetter	SW7
23.04.22	Azoxystrobin	Amistar
	Fenhexamid	Teldor
	Silicon wetter	SW7
04.05.22	Myclobutanil	Systhane
	Silicon wetter	SW7
17.05.22	Boscalid and Pyraclostrobin	Signum
	Silicon wetter	SW7
25.05.22	Myclobutanil	Systhane

	Silicon wetter	SW7
30.05.22	Azoxystrobin	Amistar
	Cyprodinil and Fludioxonil	Switch
	Silicon wetter	SW7
06.06.22	Myclobutanil	Systhane
	Silicon wetter	SW7
09.06.22	Propamocarb hydrochloride	Karma
14.06.22	Mepanipyrim	Frupica
	Cyflufenamid	Takumi
	Silicon wetter	SW7
23.06.22	Penconazole	Topas
	Silicon wetter	SW7
27.06.22	Propamocarb hydrochloride	Karma
03.07.22	Lambda cythalothrin	Robin
	Silicon wetter	SW7
11.07.22	Proquinazid	Talius
	Silicon wetter	Silicon wetter

Discussion

Semiochemical trial - thrips species in flowers

One-week prior to trial setup

One week prior to trial setup (07 June), non-replicated sampling revealed that three pest thrips species were present in strawberry flowers: rose thrips (*Thrips fuscipennis*), rubus thrips (*Thrips major*) and onion thrips (*Thrips tabaci*). A further four thrips species were also identified in tapped flower samples from wheat, hedgerow plants and weeds in the immediate area surrounding the strawberry-growing Spanish tunnels: WFT (*Frankliniella occidentalis*), flower thrips (*Frankliniella intonsa*), white-flower thrips (*Thrips vulgatissimus)*, and cereal thrips (*Limothrips cerealium*). These thrips species are consistent with previously identified thrips species in strawberry crops in SF156 and SF174 trials in 2020 and 2021, and other studies evaluating pest and incidental thrips species in strawberry crops (Brown & Bennison, 2017; Seymour, Bennison & Kirk, 2020; Nielsen *et al*, 2021).

In the thrips samples collected from strawberry flowers on 07 June, *T. fuscipennis* was the most prevalent species. In SF174 trials in 2020 and 2021, *T. fuscipennis* was consistently found to be the most abundant thrips species earlier in the summer season, before later being superseded by *T. tabaci* and *F. intonsa*. Findings in these pre-trial flower evaluations therefore indicate that *T. fuscipennis* is either among the earliest pest thrips species to migrate into strawberry crops or is the first pest thrips species to become active within the strawberry crop following winter.

While only a small number of samples were collected in this pre-trial thrips evaluation, the presence of *F. occidentalis*, *F. intonsa*, and *T. vulgatissimus* within weeds and hedgerows surrounding the strawberry tunnels but not in strawberry flowers may indicate a potential source of these pest thrips species later in the season. It is unclear however whether these weeds and hedgerow plants represent an overwintering host for these thrips species or are more favoured hosts earlier in the season prior to any migration into strawberry crops. Whereas WFT is known to overwinter in strawberry crops on overwintered plants, weeds, crop debris and substrate (Sampson *et al*., 2019), *T. fuscipennis* and *T. major* are recorded as overwintering under tree bark and *T. tabaci* and *F. intonsa* are recorded as overwintering on vegetation (Bennison *et al.,* 2020). Previous research in UK-grown outdoor strawberries indicates that both overwintered strawberry crops and surrounding weeds (including chickweed, *Stellaria media*, groundsel, *Senecio vulgaris*, and dandelion, *Taraxacum officinale*) can serve as overwintering sites for *F. occidentalis* and other potential thrips pests (Sampson *et al*, 2019). While weeds surrounding strawberry-growing tunnels may therefore represent a reservoir for these potentially damaging thrips species, it remains unknown whether their removal would limit influx of these species into the crop, with such measures also likely to negatively affect the influx of thrips predators including *Orius* and *Aeolothrips* species.

Trial takedown

At trial takedown (05 July), a more comprehensive evaluation of thrips species in strawberry flowers was undertaken. A markedly different cohort of thrips was identified on this date relative to the pre-trial investigation (07 June), with *F. occidentalis* dominating (90.4% of total identified thrips species). The three thrips species found in flowers prior to trial setup (*T. fuscipennis*, *T. major*, and *T. tabaci*) were still present in flowers at trial take-down however only small numbers of each were found – representing 2.1%, 3.2%, and 2.7% of total thrips collected respectively. These results are notable owing to this site having been selected as a site on which *F. occidentalis* has in recent years been uncommon, and where non-WFT species are thought to cause most of the thrips-related damage within the strawberry crop.

In 2021 in this project, on 08 July, 56.1% of the thrips catch at this site was *T. fuscipennis*, 37.8% was *T. major*, 4.9% was *T. tabaci*, and 1.2% was *F. intonsa* – with no *F. occidentalis* present. These significant differences in thrips species composition at the same site, one year apart highlights the challenge that growers face in controlling thrips on strawberry crops – with thrips species compositions changing markedly both within and between years. This variety and variation in thrips species complex within strawberry crops is likely to underlie continued damage by 'non WFT species' in strawberry crops even where WFT-focussed IPM is used - including the release of the predatory mites, *N. cucumeris*, and predatory bugs, *O. laevigatus*.

One of the main factors in the lower number of *Thrips* species in strawberry flowers at trial take-down could be that an application of lambda-cyhalothrin was made on 03 July, two days before the flowers were assessed for thrips at trial take-down on 05 July. Western flower thrips and some populations of *T. tabaci* are known to be resistant to pyrethroids but no information is yet available for other species infesting strawberry.

Owing to the thrips catch on blue sticky traps in this trial being recorded on only one date after three weeks with no interim recording of thrips catch, it is unknown when during the three-week experimental period *F. occidentalis* first arrived within the crop. Such an influx of *F. occidentalis* may indicate a large migration into the crop from an adjacent removed crop, however no such crop removal was reported by the grower. It is most likely therefore that the influx of *F. occidentalis* during this period is related to a smaller influx coinciding with ideal conditions for rapid *F. occidentalis* population build-up. These findings highlight that even where *F. occidentalis* has been well controlled through IPM, ideal conditions and influx events due to various factors can nonetheless lead to significant infestations of *F. occidentalis*, highlighting the value of effective monitoring to understand the particular species and abundance of thrips present within a crop. This is particularly important with *F. occidentalis* owing to its widespread insecticide resistance, apparent high interspecific competitive abilities, demonstrating the ability to dominate many other thrips pests when present, frequently leading to a significant reduction in the abundance of other pest thrips species (Wu *et al*, 2021).

Semiochemical trial

Pest thrips

During the semiochemical trial, when all traps were placed below the tabletops, over the three-week experiment period and across all three treatments, a mean of 22.5 thrips were recorded per 25 x 10 cm trap (front and back, 0.05 m^2 trap area). The highest number of thrips on an individual trap was 33, and the lowest two. Where all strawberry pest thrips species were considered together, statistical analysis revealed that use of the semiochemical lures Lurem-TR and Thripnok did not significantly increase sticky trap thrips catch relative to blue sticky traps alone. This finding is contrary to semiochemical trial results at the same site in 2021 – where sticky traps (mounted above tabletops) with a Lurem-TR lure or a Thripnok lure were found to have caught significantly more thrips relative to blue sticky traps alone (2.8x and 2.1x control traps respectively).

Further differences between 2022 and 2021 semiochemical trial results also occurred where pest thrips genera were considered separately (*Thrips* spp. and *Frankliniella* spp.). In 2022, sticky traps below tabletops with a Lurem-TR or Thripnok lure were found to have caught significantly more *Frankliniella* spp. relative to blue sticky traps alone (1.49x and 1.46x increase respectively). In 2021, a similar trend was seen for above tabletop sticky traps with a Thripnok lure, with a significant increase seen only for *Frankliniella* spp. catch (1.51x increase relative to blue sticky trap alone). Blue sticky traps with a Lurem-TR lure in 2021 however led to a significant increase in both *Thrips* spp. and *Frankliniella* spp. catch – with 1.27x and 3.52x increases in catch respectively.

The mixture of thrips species present within the strawberry crop in 2021 and 2022 however were markedly different, as confirmed through flower-tapped samples and thrips identified on sticky traps.

Frankliniella spp.:

In 2022, at trial takedown most thrips present within flowers were *F. occidentalis* (>90%), with only three *F. intonsa* individuals identified in tapped flower samples relative to 170 *F. occidentalis*. A similar trend was seen on sticky traps (all placed below the tabletops), with only two *F. intonsa* individuals identified on sticky traps across all treatments. In 2021 conversely, across the five timepoints that thrips were tapped from flowers for assessment, only one *F. occidentalis* individual was found while a total of 43 *F. intonsa* specimens were collected, with 38 of these collected on a single date (03 August 2021). On the sticky traps, only three *Frankliniella* spp. were identified from sticky traps in 2021, with all three being *F. intonsa*. These findings thus indicate that in 2021 almost all *Frankliniella* spp. were *F. intonsa* whereas in 2022 almost all *Frankliniella* spp. were *F. occidentalis*. It is therefore of note that both Lurem-TR and Thripnok led to significant increased *Frankliniella* spp. catch on sticky traps in both 2021 and 2022 –indicating that both lures may offer significant improvements in *F. occidentalis* and *F. intonsa* catch. However, in the 2021 trial all the traps were placed just above the crop whereas in 2022, all were placed below the tabletops, and this is likely to have affected the species caught, as shown by the 'above and below' tabletop pilot trial in 2022.

Thrips spp.:

Relative to *Frankliniella* spp., there was greater consistency in the *Thrips* spp. observed in flower-tapped samples and sticky trap caught samples in the 2021 and 2022 trials. In 2021, *T. fuscipennis* and *T. major* were the most prevalent *Thrips* species in flower-tapped samples on 23 June, 08 July, and 21 July before being superseded by *T. tabaci* on 03 August. A similar trend was seen in flower-tapped samples in 2022, with *T. fuscipennis* the most abundant *Thrips* spp. on 07 June and *T. major* the second most abundant. On 07 July 2022, *T. fuscipennis*, *T. major*, and *T. tabaci* were all present in strawberry flowers in low but relatively even numbers.

On sticky traps placed just above the crop in 2021 *T. fuscipennis* and *T. tabaci* were the most prevalent species – with the highest catch of both species occurring where a Lurem-TR lure was used. Owing to low numbers of thrips identified from sticky traps in 2021 however, it is unknown whether the increased catches of these species on traps with a Lurem-TR lure was statistically significant.

On sticky traps placed below the tabletops in 2022, *T. major* and *T. tabaci* were found to be the most prevalent *Thrips* species – with a Lurem-TR lure in combination with the sticky trap again leading to the highest observed catch of both species. *Thrips* spp. in 2022 however were notably uncommon on traps – with conclusion regarding the efficacy of both Lurem-TR and Thripnok in attracting *Thrips* spp. therefore difficult to draw.

Identification of 'dark' thrips on traps in 2022 did however reveal a high incidence of *Limothrips* spp. on traps mounted beneath tabletops – a trend which was not seen in 2021 where traps were mounted above tabletops. While thrips were removed from sticky traps and mounted for identification allowing for the differentiation of *Limothrips* spp. from other thrips, it would prove challenging for growers or agronomists in the field to differentiate *Limothrips* spp. and 'dark' pest thrips species, particularly *T. fuscipennis*, *T. major*, and *F. intonsa*. This could lead to inaccurate estimates of 'dark' strawberry thrips pest species abundance within strawberry crops.

Differences in semiochemical lure efficacy in 2021 and 2022

While some consistencies were present between the results of semiochemical lure efficacy trials in 2021 and 2022, most notably both lures significantly increasing *Frankliniella* spp. catch in both trials, the efficacy of these lures in increasing overall thrips catch and *Thrips* spp. were found to be inconsistent between trials in 2021 and 2022. While variation in lure efficacy between trials is not uncommon, several key differences in trial design and random sampling effects between 2021 and 2022 may in part also account for the observed differences in efficacy. These underlying factors include: (1) Trial dates, (2) Presence or absence of WFT (*F. occidentalis*), and (3) Location of traps within the crop i.e. just above the crop in 2021 and below the tabletops in 2022.

(1) Trial dates

The semiochemical trial in 2022 was undertaken between 14 June and 05 July, while the semiochemical trial in 2021 was undertaken later in the season from 15 July to 03 August. As has been reported in the literature and was noted in both SF 156 and the results of SF 176 trials in 2020 and 2021, the relative abundance of different thrips species throughout the year changes significantly, particularly during the early to late summer season (Nielsen *et al*, 2021). Flower trapping and sticky trap catch results in 2020 and 2021 indicated that in early summer, species including *T. fuscipennis* and *T. major* are the most prevalent in strawberry crops while as the season progresses, the abundance of these species diminishes, being superseded by species including *F. intonsa* and *T. tabaci*, and in 2022, *F. occidentalis*. Both Lurem-TR and Thripnok are currently on the market with advertised efficacy in attracting WFT (*F. occidentalis*) and *T. tabaci.* – Lurem-TR is also known to attract *T. major* (Teulon *et al*, 2008; Kirk *et al*, 2021). While neither Lurem-TR nor Thripnok are reported to attract *F. intonsa*, the WFT aggregation pheromone is also reported to attracts *F. intonsa* (Zhang *et al*, 2011; Kirk, 2017).

Given the thrips species recorded in flower tapping samples earlier and later in the season, alongside species-specific claims for lure efficacy, it would therefore be expected that both Lurem-TR and Thripnok would have more significant efficacy in trials undertaken later in the summer season in strawberry crops. This could in part explain the differences in observed Lurem-TR and Thripnok efficacy in increasing sticky trap catches – with notably greater lure efficacy observed in 2021 (when the trial ran in mid-summer) relative to the trial in 2022 which ran earlier in the summer season.

(2) Presence or absence of WFT (*F. occidentalis)*

While the relative ratio of thrips species present in strawberry crops changes throughout the season, results from SF 156 and in this project in 2021 at this site indicate that there is year-on-year consistency in the presence of *T. fuscipennis*, *T. major*, *T. tabaci*, and *F. intonsa* within the strawberry crop at this site. The trial in 2022 marks the first occasion in trials at this site that WFT became established and dominant in the strawberry crop, resulting in a notable difference in the ratios of thrips present (>90% on 5 July being WFT). *Frankliniella occidentalis* has many times been noted as a highly competitive thrips species, with reproduction and development outpacing many UK native thrips species, often leading WFT to outcompete and dominate among thrips pests where present (Wu *et al*, 2021). However, as already discussed, in this 2022 trial, the application of lambda-cyhalothrin towards the end of the trial is likely to have killed some *Thips* species and this will have affected the species ratios.

In this 2022 trial, the dominance of WFT seemed to affect the observed efficacy of Lurem-TR and Thripnok in attracting pest thrips overall, pest thrips genera (*Frankliniella* spp. and *Thrips* spp.) and pest thrips species. With both Lurem-TR and Thripnok well-demonstrated and sold as attractive to WFT however, the dominance of WFT in this trial would be assumed to have led to a significant difference between control traps and traps baited with Lurem-TR and Thripnok on total pest thrips caught. Such an effect however was not noted, with the significant influence of Lurem-TR and Thripnok on trap catch only noted where *Frankliniella* spp. were considered alone, with the increase of trap catch increase being of a similar magnitude for Thripnok and a lesser magnitude for Lurem-TR to those noted in 2021. This could indicate that *F. occidentalis* dominance in the strawberry crop occurred late into the 3-week period where sticky traps were present in the crop.

(3) Location of traps within the crop

The most significant difference in semiochemical trial experimental design between 2021 and 2022 trials was the location of the blue sticky traps – with traps cable-tied in a portrait orientation beneath strawberry tabletops in 2022, while in 2021 traps were mounted in a landscape orientation on green pea sticks just above the crop level above the strawberry tabletops. Where grower advice is offered regarding trap location for monitoring thrips pests, the recommendation is usually to place traps just above the strawberry crop canopy (Raffle, Bennison & Sampson, 2014). Few studies however have been undertaken evaluating the optimal height for sticky traps for monitoring thrips in tabletop-grown strawberry crops (Shin *et al*, 2020), with no studies being identified where the quantitative difference in blue sticky trap catch below tabletops (common current grower practice) and above tabletops (grower advice) was evaluated alone or in combination with lures.

While the semiochemical lure trials were undertaken on different dates in 2021 and 2022, and while *F. occidentalis* dominated other thrips species late into the 2022 trial, the results of these studies taken together indicate two findings with respect to sticky trap location: (1) Significantly more thrips appear to be caught on sticky traps above the crop relative to below, and (2) semiochemical lures appear to lead to more significant increases in thrips catch overall when used in combination with sticky traps above the crop relative to sticky traps below the crop. Owing to further discussed differences between the 2021 and 2022 trials, further research is required to confirm this finding. However, based upon these results, if growers intend to use lures to supplement sticky trap monitoring, results of 2021 and 2022 trials suggest that it may be beneficial to ensure sticky traps are located above the crop to maximise lure efficacy, if this does not interfere with horizontal spray booms.

Beneficials

In the semiochemical trial, sticky trap catches of predatory thrips (*Aeolothrips* spp.), predatory bugs (*Orius* spp., other anthocorid spp.), and hoverflies were uniformly low – with no significant difference in catch between treatments (blue sticky trap alone, trap with a Lurem-TR lure or trap with a Thripnok lure) and catch counts of each of these beneficial groups averaging fewer than 0.5 per trap. Furthermore, no lacewings or ladybirds were noted across all 60 traps in this trial.

Bees were the most prevalent beneficial caught on sticky traps. On untreated traps, a mean of 1.4 bees were caught in the 3-week experimental period. Significantly more bees however were caught when semiochemical lures were used, increasing mean sticky trap bee catch to 3.1 bees with a Lurem-TR lure (2.2x control) and 13.2 with a Thripnok lure (9.4x control). A similar trend was also observed in 2021, with significant differences in beneficials catch between treatments (traps with and without semiochemical lures) seen only in bee catch.

In 2021, Lurem-TR was found to significantly increase bee catch (2.1x control), with a further significant increase in bee catch with a Thripnok lure (4.1x control). As was noted in 2021, the increased catch of bees on traps with Lurem-TR and Thripnok is likely to be due to these two lures containing floral volatiles, with these findings indicating that these volatiles are significantly attractive to bees as well as thrips. As was also the case in 2021, the traps used in this trial were 'dry glue' traps which are reported to catch an increased number of bees than equivalent 'wet glue traps' – with evidence from growers who deploy wet glue roller traps indicating that bees may be able to escape from the wet glue (Sampson, personal communication, 2022).

Bee catches aside, catch of all other recorded beneficials groups in 2022 was uniformly lower than in 2021 – particularly for other anthocorid spp., hoverflies, and predatory thrips (*Aeolothrips* spp.) - for which mean trap catch in 2021 averaged 25-30 per trap relative to 0.2-0.4 per trap in 2022. With no difference in semiochemical efficacy for each beneficial group between 2021 and 2022, the notably lower beneficial catch in 2022 could result from the same factors which likely influenced thrips catches which varied between the 2021 and 2022 trials, chiefly (1) The date the trials were undertaken (2021:15 July - 03 August, 2022: 14 June - 05 July) and (2) the location of sticky traps in the trial (2021: above/within the crop in a landscape orientation, 2022: hung below the crop in a portrait orientation).

Among the most notable of the differences between beneficial catches in 2021 and 2022 was that of predatory thrips *(Aeolothrips* spp.). *Aeolothrips* spp. are naturally occurring thrips predators which are commonly found in the flowers of strawberries – particularly where IPM strategies are used in place of synthetic chemical pesticides (Seymour, Bennison & Kirk, 2020). While it is currently unknown whether *Aeolothrips* spp. feed on thrips adults, they are recorded as feeding on thrips larvae (Bennison *et al.*, 2020), though the scale of positive impact this feeding has in a commercial strawberry crop is unknown. It would be useful to carry out research to establish whether *Aeolothrips* spp. feed on thrips adults and at what rate.

As was observed in 2021, no significant difference was seen in *Aeolothrips* spp. trap catch with different semiochemical treatments. The presence of notably more on sticky traps in 2021 semiochemical trial relative to 2022 however may indicate either lower *Aeolothrips* spp. activity earlier in the summer season (commonly observed in UK strawberry crops) or that

Aeolothrips spp. are localised within the strawberry crop itself and do not fly below strawberry-growing tabletops. These findings in 2021 and 2022 are most likely a consequence of the preferred sources of food for *Aeolothrips* spp. (i.e., the larvae of thrips and pollen) being present only within the crop/above the tabletops. Thus, while the bycatch of *Aeolothrips* spp. is lower below the tabletops, this is likely indicative that monitoring traps are better placed just above the crop, as the presence of *Aeolothrips* spp. could be assumed to be directly related to the presence of pest thrips - the intended target of monitoring sticky traps in strawberry crops. Some bycatch of *Aeolothrips* spp. on monitoring sticky traps is thus unavoidable and could be indicative to growers that their sticky traps are best placed to monitor pest thrips species. It may therefore be useful for growers and those assessing sticky traps to learn to differentiate larger predatory thrips (with black and white bands on the wings) from often smaller pest thrips species (without black and white bands on the wings) to ensure accuracy of monitoring.

Above and below tabletop pilot trial

Thrips

Among UK strawberry growers using monitoring sticky traps, the most common placement of traps is hung or mounted beneath strawberry tabletops, with this primarily being driven by concerns that placement of traps above the crop could interfere with horizontal spray boom operation. Advice to growers however typically recommends the placement of traps above the crops due to the presence of thrips in flowers (Raffle, Bennison & Sampson, 2014). To date, few studies have evaluated quantitatively the degree of difference in thrips catch both overall and at a species scale between traps mounted above or below the strawberry crop (Shin *et al*, 2020). Growers currently opt for the more practical option of mounting traps beneath tabletops.

The results of this study demonstrate significantly higher total thrips catch on blue sticky traps above the crop – catching 8.1x more pest thrips relative to identical traps mounted beneath tabletops. This significant increase of total thrips catch is also present where *Frankliniella* spp. females, *Thrips* spp. females and male thrips are considered individually – with 6.2x, 7.0x, and 13.8x increases in thrips catch respectively on traps above the crop relative to below. Beyond simply increasing thrips catch however, sticky traps above the crop also caught five different strawberry pest thrips species compared with only three strawberry pest thrips species caught on traps below the tabletops, with no *F. intonsa* or *T. fuscipennis* identified on below-tabletop traps. Taken together, these findings suggest a significant increase in the sensitivity of sticky traps mounted above the strawberry crop to strawberry pest thrips relative to below-tabletop sticky traps, offering considerable improvements where traps are deployed as an early thrips monitoring system.

A further difference observed between above and below-tabletop mounted sticky traps was the catch of incidental (non-pest) cereal thrips – as was also noted as a difference on sticky traps in 2021 (above tabletop) and 2022 (below tabletop) semiochemical trials. On traps above tabletops, a mean of 1.2 cereal thrips were caught per trap in the 3-week monitoring period, representing approximately 7% of the total thrips catch. On traps below tabletops however, a mean of 2.6 cereal thrips were caught per trap, representing approximately 50% of the total thrips catch. A significant difference was therefore present between sticky trap locations for non-target cereal thrips. Upon visual inspection, cereal thrips (*Limothrips* spp.) can be difficult to distinguish from many strawberry pest thrips species, particularly the darker pigmented species including *T. fuscipennis*, *T. major*, and *F. intonsa*. A high catch of cereal thrips on monitoring sticky traps could thus undermine pest thrips monitoring where traps are monitored in-situ in the crop, thus a reduced catch of grain thrips on traps above tabletops relative to below further increases the sensitivity of sticky traps to pest thrips. Throughout both 2021 and 2022 trial, no cereal thrips (*Limothrips* spp.) were recorded from strawberry-flower tapped samples, further highlighting the value of evaluating thrips in flowers to complement sticky trap monitoring.

Beneficials

Trap catches of all beneficials in the trial evaluating above or below tabletop traps were low – with each assessed group averaging fewer than 1.5 per trap. No naturally occurring *Orius* spp. or ladybirds were present on traps either above or below tabletops (*Orius* were not released by the grower).. Bees (predominantly bumble bees which the grower used through boxed hives) were the most abundant beneficial found on both above tabletop and below tabletop – however no significant difference was seen in bee catch between different trap locations. Similarly, no significant difference was seen between trap placement locations upon hoverfly trap catch. Other Anthocorid spp. and lacewings were only found on sticky traps above the tabletop, however only a mean of 0.2 and 0.1 per trap respectively, thus the significance of these observations cannot be confirmed.

As indicated in semiochemical trial results, the most significant difference in above and below tabletop beneficials trap catch was predatory thrips (*Aeolothrips* spp.), with 4.0x more being caught on traps above strawberry tabletops relative to below. While an increased catch of *Aeolothrips* spp. is undesirable for growers given that these species predate pest thrips larvae, the increased catch of *Aeolothrips* spp. was in this trial less than half the increased catch of pest thrips (8.1x increase of pest thrips on sticky traps above strawberry tables relative to below). In light of the significantly improved catches of pest thrips (both count and number of species) and no significant increase in any other observed beneficial groups aside from predatory thrips, it is therefore clear that the placement of monitoring traps even without lures represents a significant increase in sticky trap monitoring effectiveness and sensitivity.

Conclusions

Semiochemical trial (all traps placed below tabletops)

- Flower-tapped samples revealed that rose thrips (*T. fuscipennis*) were likely to be the most abundant thrips species at trial setup on 14 June, while at trial takedown on 5 July western flower thrips (*F. occidentalis*) were the most abundant.
- Numbers of *Thrips* species in flowers at take-down are likely to have been reduced by an application of lambda-cyhalothrin two days earlier.
- Thrips pressure in the flowers remained low throughout the monitoring period, with a mean of fewer than one adult per flower at trap take-down.
- On traps hung below the tabletops, sticky traps with either a Lurem-TR or Thripnok lure did not catch significantly more total adult pest thrips (*Frankliniella* spp. females, *Thrips* spp. females, male thrips) relative to blue sticky traps alone.
- When *Frankliniella* spp. females, *Thrips* spp. females, and male thrips were considered separately, significantly more *Frankliniella* spp. females were caught on traps with a Lurem-TR lure (1.49x increase) or Thripnok lure (1.46x increase) than on untreated traps.
- Lurem-TR and Thripnok performed equally in increasing female *Frankliniella* spp. catch relative to untreated traps.
- On traps hung below tabletops, there was no significant difference seen in total ‘dark’ thrips species on traps between treatments – with uniformly low numbers of ‘dark’ thrips species.
- The most prevalent dark thrips species seen on the traps were incidental cereal thrips (*Limothrips* spp.), which accounted for >50% of total dark thrips catch (sticky traps below tabletops).
- No cereal thrips were found in strawberry flowers, and they are not considered to be a pest of strawberry.
- As was also seen in 2021, thrips species composition and abundance on traps did not match those seen in flower-tapped sample, highlighting the value of supplementing sticky trap monitoring with regular flower-tapping thrips assessments.

- Relative to the 2021 semiochemical trial, total thrips catch in 2022 was markedly lower. This may have resulted from (1) The 2021 trial being undertaken later in the season (2021: 15 July – 3 August, 2022: 14 June – 5 July), (2) sticky traps in 2021 being mounted just above the strawberry crop rather than in 2022 where traps were mounted below tabletops, and (3) In 2022, flower tapping samples indicated a significantly higher number of WFT than other thrips species which may have outcompeted other pest thrips species, reducing their numbers, (4) Natural variation in thrips species incidence and numbers and (5) application of lambda-cyhalothrin two days before the traps were collected which is likely to have killed some thrips species.
- *Frankliniella* species were the dominant species on traps and WFT, *Frankliniella occidentalis* being the dominant species in flowers on the date traps were collected.
- Beneficials catch on traps were uniformly low, with catch of *Aeolothrips* spp., *Orius* spp., other anthocorid spp., hoverflies, lacewings, and ladybirds averaging fewer than 0.5 per trap.
- Bee catches (predominantly bumble bees) on traps was notably higher on traps relative to all other assessed beneficials, with a mean of 1.4 bees per trap on untreated traps. Significant increases in bee catch relative to control were seen with both a Lurem-TR lure (2.2x control) and a Thripnok lure (9.4x control).
- Sticky traps with a Thripnok lure caught significantly more bees than sticky traps with a Lurem-TR lure – increasing catch by 4.3x. 'Dry' sticky traps were used in this trial which are reported to catch more bees than 'wet' traps which allow some bees to escape.
- Sticky traps catch of all observed beneficial groups in 2022, most notably predatory thrips (*Aeolothrips* spp.), were substantially lower than in 2021; with trap location and trial date again the factors most likely to be underlying these differences.

Above/below tabletop trial

- Sticky traps mounted above the strawberry crop caught significantly more total strawberry pest thrips than sticky traps hung below tabletops (8.1x increase in total thrips catch).
- Sticky traps mounted above the crop caught a wider range of pest thrips species than sticky traps hung below strawberry tabletops (five species above, three species below). *Frankliniella intonsa* and *Thrips fuscipennis* were only detected on traps above the crop.

- Below-tabletop sticky traps caught significantly more cereal thrips than above-tabletop traps (>50% of total thrips compared with approximately 7% of total thrips catch on traps above tabletop). Visual similarity of 'incidental' cereal thrips and dark pigmented pest thrips (e.g., *T. fuscipennis*, *T. major* and *F. intonsa*) may lead to inaccurate estimates of the presence and abundance of strawberry species.
- Significantly more predatory thrips (*Aeolothrips* spp.) were caught on traps above the crop tabletops compared to below the tabletops.
- No significant differences in catch of other observed beneficial species (*Orius* spp., other anthocorid spp., bees, hoverflies, lacewings, and ladybirds) above and below the tabletops.
- A notable difference was seen in *Thrips* species composition between semiochemical trial and above and below tabletop trial – highlighting the potential variation in thrips species even within a blocks of tunnels.

Knowledge and Technology Transfer

2020

AHDB Soft Fruit Day, Technical Webinar on Soft Fruit Research, Thursday 18 November 202

- The use of floral margins to support natural enemies in strawberry, (Celine Silva, NIAB EMR)
- A novel push/pull approach to capsid control in strawberry (Adam Walker, NIAB EMR)
- Novel approaches to thrips control in strawberry (Peter Seymour, ADAS)

Fountain - 30 Jan 20 Herefordshire Hop Discussion Group, Plough Inn, Stoke Lacy, Herefordshire TTSM, floral interventions, capsid control

Fountain - 06 Feb 20 HSE Chemicals Regulation Division (CRD) to NIAB EMR

Overview of R&D on novel crop protection products

Fountain - 29 Jul 20 Katrina Hayer's visit BBSRC – Entomology research at NIAB EMR

Fountain - 9 Sep 20 Fruit Focus – Enhancing beneficial insect in orchards

2021

Mozūraitis R, Hall D, Trandem N, Ralle B, Sigsgaard L, Baroffio C, Fountain MT, Cross JV, Wibe A, Borg-Karlson A-K (2021) Composition of Strawberry Floral Volatiles and their Effects on Behavior of Strawberry Blossom Weevil, Anthonomus rubi. Journal of Chemical Ecology, 46:1069–1081.

Fountain MT, Deakin G, Farman D, Hall D, Jay C, Shaw B, Walker A (2021) An effective “push-pull” control strategy for European tarnished plant bug, Lygus rugulipennis (Heteroptera: Miridae), in strawberry using synthetic semiochemicals. Pest Management Science. DOI 10.1002/ps.6303

Fountain, M.T. Impacts of Wildflower Interventions on Beneficial Insects in Fruit Crops: A Review. Insects 2022, 13, 304.

NIAB EMR Soft Fruit Day - Technical Webinar on Soft Fruit Research, Tuesday 16 November 2021

- The use of Orius as a predator for capsid bugs (Michelle Fountain, NIAB EMR)
- Push/pull strategies for midge control in cane fruit (Elysia Bartel, ADAS)
- A push/pull approach to control of thrips in strawberry (Peter Seymour, ADAS)

- The use of floral margins to harbour predators of thrips and other pests (Celine Silva, NIAB EMR)
- New approaches to aphid control (Ross George, Harper Adams University)

Jude Bennison gave a presentation on the aims and preliminary results of the thrips trials at the International Symposium on Thysanoptera in 2021 and the Nordic Berry Conference in January 2022.

Fountain 07 Apr 21 Worshipful Company of Fruiterers - Innovations in fruit pest control and how WCoF kick-started recent pollination research at NIAB EMR

Fountain, Raffle 29 Apr 21 AHDB Horticulture - New IPM approaches to aphid and capsid control in strawberry

Fountain 1-5 May 21 IX International Strawberry Symposium Rimini (Italy) - Synthetic push-pull strategy for controlling capsids in commercial strawberry

Fountain 26 May 21 BIFGA Cryals Farm, Matfield, Kent TN12 7HN - Pollinator Identification Guides and Records plus How to Successfully Establish Perennial Wildflower Areas

Fountain, Silva Jul 21 Fruit Focus – Follow the Bees

<u>2022</u>

NIAB Soft Fruit Technical Webinar - 30 Nov 22

- Improved methods for monitoring thrips in strawberry (Andrew Gladman, ADAS)
- Employing parasitoids in aphid control strategies (Celine Silva, NIAB)
- Attracting and retaining hoverflies in soft fruit crops (Adam Walker, NIAB)

25-29 Sep 2022 PHEROFRUITS 2022 – IPM in the XXI century: new tools, tactics and

strategies to improve sustainability from old and new pests and diseases. Joint Meeting of the IOBC/WPRS Working Groups “Pheromones and other semiochemicals in integrated production” and “Integrated Protection of Fruit Crops”, held in Girona from September 25th to 29th, 2022 (Michelle Fountain, *The road to mirid control* – Keynote)

24 Nov 2022 Berry Garden Growers Research and Agronomy Conference (Michelle Fountain, *Wildflowers and hoverflies*)

Fruit Focus – 13 July 2022

- Controlling capsids using the Russell IPM push-pull system (Adam Walker, NIAB, Clare Sampson Russell IPM)

Association of Applied Biologists Conference - Improving Global and Local IPM - 17 – 18 November 2021

- An effective synthetic semiochemical ‘push–pull’ control strategy for pest Miridae, in strawberry and raspberry crops (Adam Walker, NIAB)

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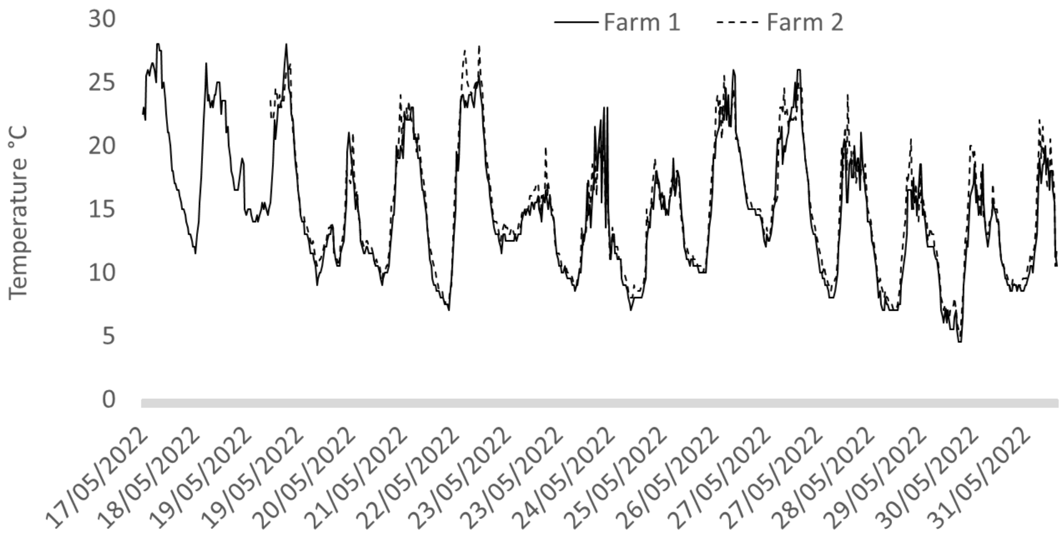
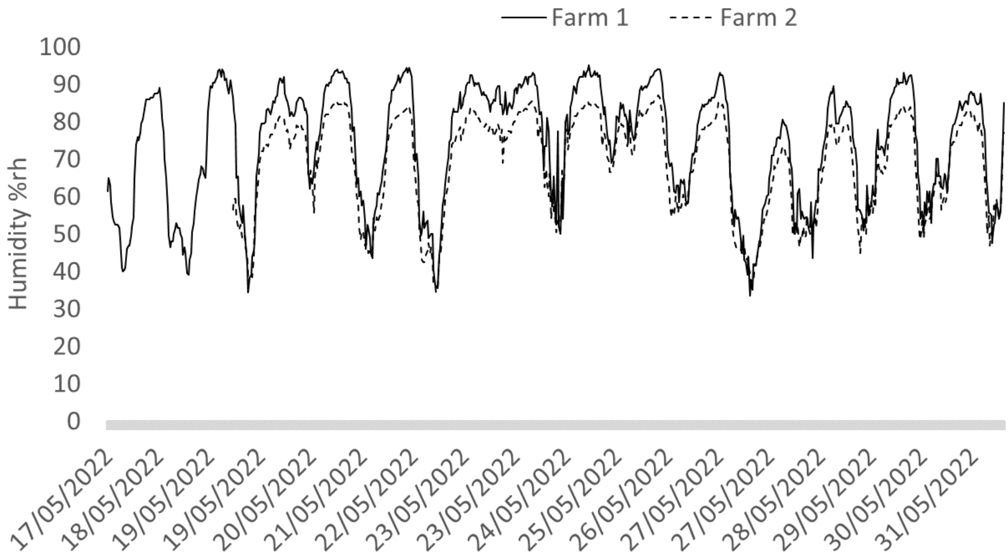
Appendices

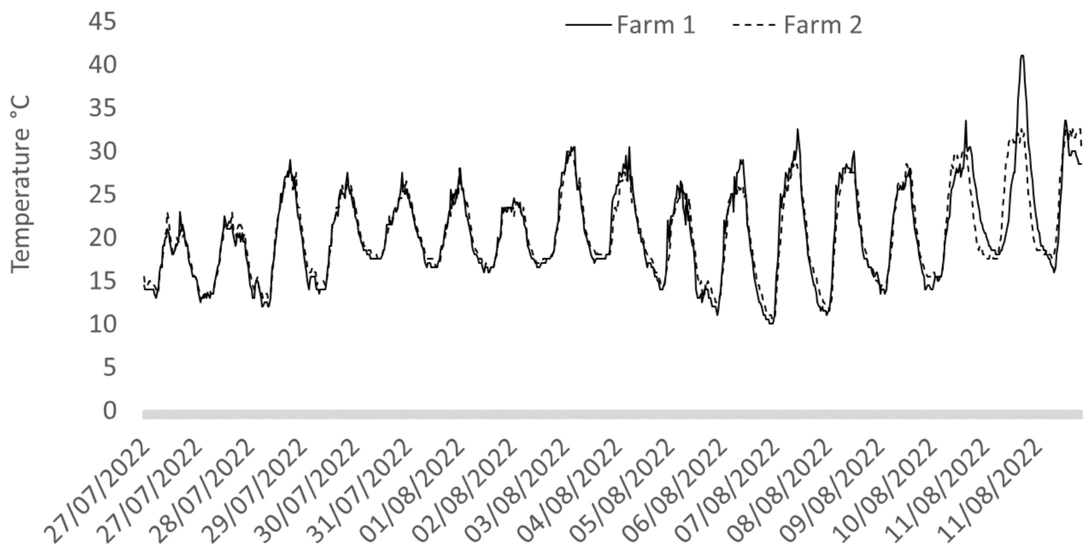
Appendix 3.1.1.

Daily temperature (°C) and humidity (%rh) among polytunnel strawberry plants during the aphidophagous hoverfly trial 2022; a) Trial 1 temperature May; b) Trial 1 humidity May; c) Trial 1 temperature July/August; d) Trial 1 humidity July/August; e) Trial 2 temperature farm 1; f) Trial 2 temperature farm 2; g) Trial 2 humidity farm 1; h) Trial 2 humidity farm 2.



a) b)




Farm 1
Farm 2
Temperature °C
45
40
35
30
25
20
15
10
5
0
27/07/2022
27/07/2022
28/07/2022
29/07/2022
30/07/2022
31/07/2022
01/08/2022
02/08/2022
03/08/2022
04/08/2022
05/08/2022
06/08/2022
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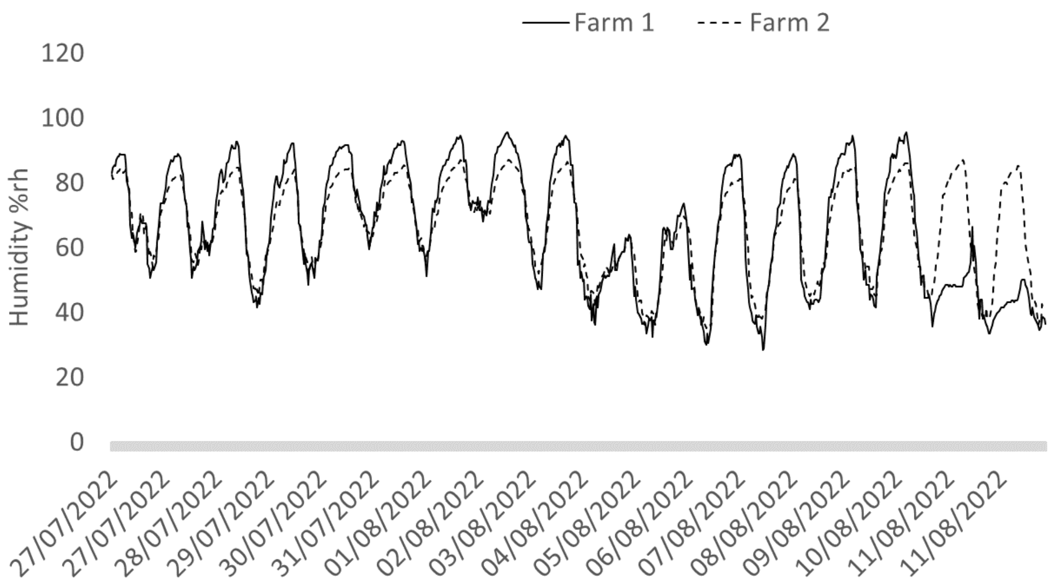
08/08/2022
09/08/2022
10/08/2022
11/08/2022
11/08/2022

c)


Farm 1
Farm 2
Humidity %rh
120
100
80
60
40
20
0
27/07/2022
27/07/2022
28/07/2022
29/07/2022
30/07/2022
31/07/2022
01/08/2022
02/08/2022
03/08/2022
04/08/2022
05/08/2022
06/08/2022
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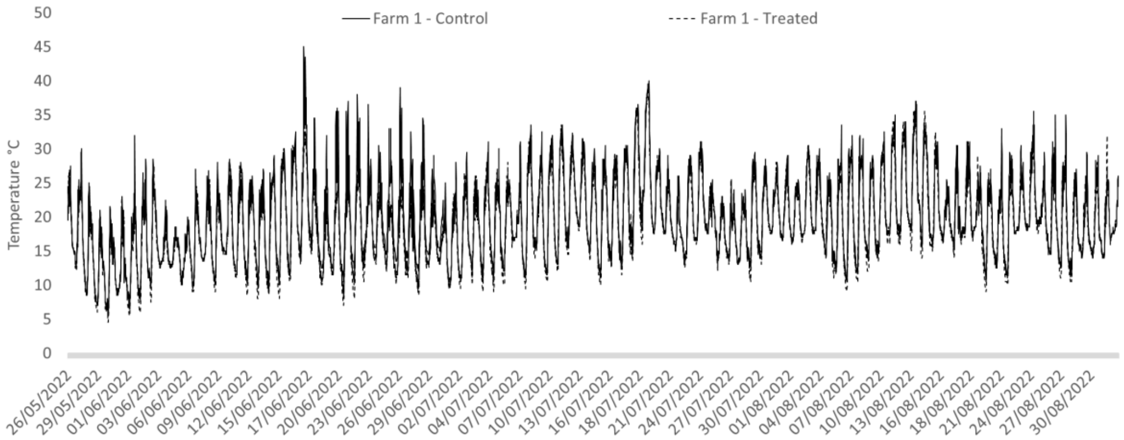
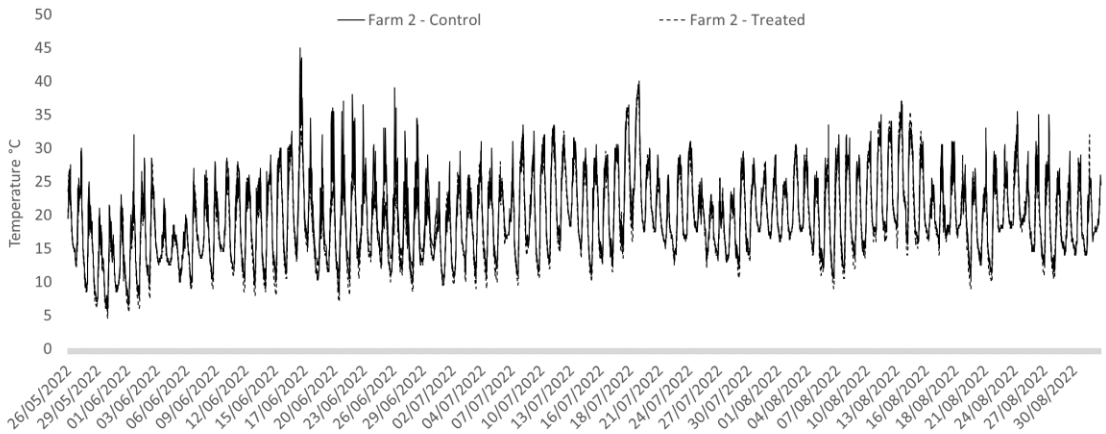
08/08/2022
09/08/2022
10/08/2022
11/08/2022
11/08/2022

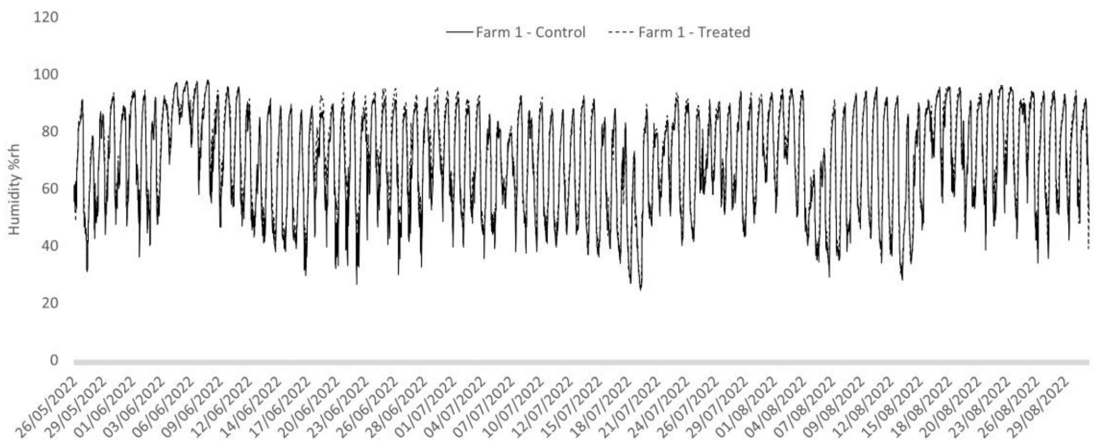
d)


Farm 1 - Control
Farm 1 - Treated
Temperature °C

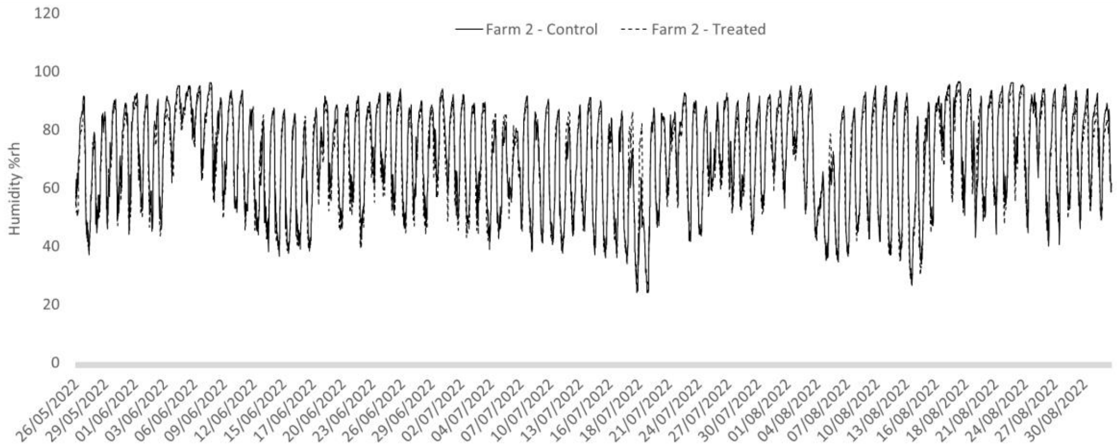
e)


Farm 2 - Control
Farm 2 - Treated
Temperature °C

f)


Farm 1 - Control
Farm 1 - Treated
Humidity %rh

g)


Farm 2 - Control
Farm 2 - Treated
Humidity %rh
120
100
80
60
40
20
0
26/05/2022
29/05/2022
01/06/2022
03/06/2022
06/06/2022
09/06/2022
12/06/2022
15/06/2022
17/06/2022
20/06/2022
23/06/2022
26/06/2022
29/06/2022
02/07/2022
04/07/2022
07/07/2022
10/07/2022
13/07/2022
16/07/2022
18/07/2022
21/07/2022
24/07/2022
27/07/2022
30/07/2022
01/08/2022
04/08/2022
07/08/2022
10/08/2022
13/08/2022
16/08/2022
18/08/2022
21/08/2022
24/08/2022
27/08/2022
30/08/2022

h)

