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Location of project:	NIAB EMR, growers' holdings
Industry Representative:	**Chairman:** Stephen McGuffie **Industry representatives:** Andrey Ivanov, Steve Greenaway, Cristian Marmandiu, Richard Harnden
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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

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

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GROWER SUMMARY

The UK soft fruit industry is experiencing a period of change which offers opportunities for new and novel pest control options. Brexit, coupled with uncertain crop protection product approvals, losses of actives (and associated product resistance), emerging and invasive pests, and climate change offer the industry an opportunity to explore and exploit novel 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.

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

In the first three years of this project we will: 1) research and report on 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) test 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) investigate the ability of Orius to predate the capsid juvenile stages for use under warmer, summer, temperatures; 4) determine 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) determine 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) gain 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 test a ‘push-pull’ method to prevent non-western flower thrips entering strawberry crops and causing fruit damage; 8) develop 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 test a semiochemical push pull strategy for control of midges in cane fruit.

For ease of reading, this Grower Summary report is split into sections for each of the work packages listed above.

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 and expected deliverables

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). 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, native and non-native species (Hulme 2016). Increased movement of plant material around the globe (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.

Summary of the project and main conclusions

The team of scientists working on this project attended national and international meetings to report back potential new and invasive pests of soft fruit crops. This has been summarised in the tables listed in the Science Section of this report, along with selected references and web links. There has been liaison with AHDB, Fera, Defra's Animal and Plant Health Agency (APHA) and the Royal Horticultural Society (RHS). EPPO and CABI databases have also 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 Science Section of this 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.

Current threats include:

- two species of thrips; Japanese flower thrips and flower thrips
- a true bug; Brown Marmorated Stink Bug
- a whitefly; honeysuckle whitefly
- a scale insect; white peach scale
- two beetles; Japanese flower beetle and whitefringed weevil
- 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 in the Science Section. Another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*).

Financial benefits

Native and non-native pests are increasing as a result of increased transport of goods around the world and fewer approved broad-spectrum products. These are likely to have a financial impact on fruit growers. Spotted wing drosophila is a good example of an invasive pest which has arrived in the UK in recent years, resulting in significantly increased management and control costs for soft fruit growers.

Action points for growers

- Growers and their agronomists should remain 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 Defra's Animal and Plant Health Agency: 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 employed by growers should be checked with a BASIS qualified adviser.

Task 2.1. To investigate the efficacy of the *Lygus rugulipennis* repellent compound for control of capsid species in cane fruits

Headline

- The synthetic semiochemical push (previously tested as part of a push-pull system in commercial strawberry) also reduces numbers of capsid nymphs (common green capsid, *Lygocoris pabulinus*) and capsid damage to fruit and leaves in commercial raspberry.

Background and expected deliverables

Recently, during two years of replicated field trials, successful control of the European tarnished plant bug *Lygus rugulipennis* was achieved in strawberry, using a synthetic semiochemical push-pull approach. A semiochemical 'push' was deployed in the crop in combination with a semiochemical 'pull' in green cross vane funnel traps at regular intervals around the crop perimeter (AHDB Project SF 156). The approach significantly reduced numbers of *L. rugulipennis* (adults and nymphs) in the crop and reduced fruit damage by up to 90% in organic strawberry. Cane fruits are also damaged by *L. rugulipennis*, along with the common green capsid, *Lygocoris pabulinus.*

Capsid control usually requires routine spray control treatments. However, the current plant protection products (PPP) employed to control capsids can disrupt biological control agents and increase product residues in fruits. Moreover, there are continuing restrictions on chemical PPP use (pan-europe.info. 2008) and a trend to promote the use of non-chemical alternatives (eur-lex.europa.eu. 2009). A semiochemical push-pull approach could therefore offer a useful alternative to growers.

The main aim of this trial was to find out whether the semiochemical push can reduce capsid numbers in the crop and damage to fruit in cane fruits. In summer 2020 a trial was set up in a commercial raspberry crop. The trial also studied whether distributing the semiochemical at alternating heights throughout the crop canopy improved efficacy.

Summary of the project and main conclusions

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 in 2017

and 2019. The raspberry plantation was divided into six replicates, each divided into the following three equal sized plots to test two methods of deploying the semiochemical push;

- Capsid repellent sachets deployed every 2 m along the row at 1 m height
- Capsid repellent sachets deployed every 2 m along the row, but at alternating staggered heights 0.5, 1.0 and 1.5 m
- 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
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 as well as 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, so 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.

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.

Action points for growers

- 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.
- The semiochemical repellent used in these studies is not currently approved for pest control by CRD and this should be a focus for the AHDB, working with the industry to secure some form of registration and approval.
- 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 as these can outcompete undesirable weeds.

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 commercial product to repel capsids from crops is under development.

Background and expected deliverables

In previous work under AHDB Project SF156, successful control of *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, will require registration with CRD before it can be used by commercial growers. It is a component of the sex pheromone of several *Lygus* species, is registered as a food additive and is a GRAS compound (Generally Regarded as Safe), although it does not fall into the straight-chain Lepidopteran pheromone (SCLP) category given fast-track registration by the EU. To date, monitoring of crops containing the repellent has not revealed any adverse effects on natural enemies but this will continue to be monitored in all future experiments. Thus, there is a good prospect that registration will be relatively straightforward and the requirements for this are being explored by Russell IPM and CRD.

The objective of this work package is to develop commercial formulations of the capsid repellent and to evaluate them in the field. As well as formulations of hexyl butyrate alone, blends with methyl salicylate are being evaluated. Formulations are being optimised through laboratory release rate measurements during 2020 with the aim of developing a suitable formulation(s) for evaluation in field trials during 2021.

Summary of the project and main conclusions

Following discussion and feedback between NRI and Russell IPM, candidate commercial formulations of hexyl butyrate with and without methyl salicylate were prepared by Russell IPM using blister-pack technology. Release rates from these were compared with rates from low density polyethylene (LDPE) sachet formulations prepared at NRI and used in the previous trials to date. The "standard" sachet was 5 cm x 5 cm x 120 µm sachet containing hexyl butyrate (1 ml) impregnated onto a cotton dental roll. The "long-life" dispenser was the same sachet containing 5 ml hexyl butyrate impregnated on two dental rolls. Samples were tested for longevity under laboratory conditions.

Initial studies compared release rates from two blister pack formulations of hexyl butyrate (HB) alone with those from NRI standard and long-life sachets at 22°C. Release rates were

unexpectedly higher than those originally measured (21 mg/d), with the two Russell IPM formulations releasing at half the rate of the standard NRI formulation. Although the laboratory temperature during these 2020 measurements was nominally 22°C, the very hot weather meant that this was very variable, occasionally reaching 34°C. Thus, all further experiments were carried out in a temperature-controlled room at a more reliable 27°C.

In the next series of experiments, release rates were measured from the standard Russell IPM blister pack formulation of hexyl butyrate and two new formulations designed to increase the release rate to match that from the standard NRI sachet. Also provided were blister pack formulations containing blends of hexyl butyrate with methyl salicylate at 50:50, 95:5, and 0:100, respectively. The standard formulation of HB, the increased release rate (HET 1) and the formulations with methyl salicylate all released at a similar rate (80-100 mg/d) to that of the NRI standard sachet (107 mg/d). The fast release rate formulation released at over three times the rate, but all these formulations lasted less than 10 days under the wind tunnel conditions. Blending the hexyl butyrate with ethanol apparently gave a more sustained release.

As the blister pack containing hexyl butyrate in ethanol seemed to give a more persistent formulation, in the third series of experiments two formulations of hexyl butyrate in ethanol were compared with a blister pack containing ethanol only. The 4:1 blend of hexyl butyrate and ethanol released hexyl butyrate rapidly (520 mg/h) and lasted less than 10 d. The 1:4 blend of hexyl butyrate and ethanol was more persistent and was still releasing hexyl butyrate after 15 d at approximately 50 mg/d allowing for the concomitant release of ethanol.

The Russell IPM blister packs provide a convenient, commercially available formulation of HB for use in control of capsids by a push-pull approach. The studies show that the standard blister pack formulation containing 1 g HB in 4 g paraffin oil releases the HB at a rate (approx. 80 mg/d) comparable to that from the standard NRI polyethylene sachets (approx. 100 mg/d) used in all previous push-pull field trials. Furthermore, the HB could be combined with methyl salicylate (hoverfly attractant), in a single formulation with release rate proportional to the proportion of compound in the blend.

However, both the blister pack and polyethylene sachet formulations had an unexpectedly short lifetime at 27ºC and 8 km/h windspeed. Preliminary studies suggest this can be extended by mixing the hexyl butyrate with ethanol which is released simultaneously.

Financial benefits

The capsid repellent is being formulated with and without hoverfly attractant into a commercially affordable product. The 2021 trials will test increasing the spacing of the devices to further reduce cost.

Action points for growers

Whilst a commercial repellent product for capsids is being developed, there are no specific action points for growers.

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 are a source of natural enemies and pollinators and should be considered for sowing adjacent to soft fruit crops to hasten the influx of beneficials to the neighbouring crop.

Background and expected deliverables

A literature review has recently been prepared for the AHDB on the impact of organic treatments and floral margins for pest and disease control in orchards. In addition, an Interreg project (BEESPOKE) is aiming at designing bespoke floral margins to encourage pollinating insects into flowerings crops. In 2019, a replicated experiment of floral margins was sown around the WET Centre at NIAB EMR not only to reduce run-off from polytunnel structures but provide secondary benefits of boosting natural enemies and pollinators in the vicinity of the tunnel (Holistic Water for Horticulture, HWH).

Several research studies, and growers themselves, 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.

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 could provide a food source for natural enemies in the form of alternative prey, pollen and nectar, and as a shelter and overwintering habitat.

In the first year of this study, we aimed to;

1. Compare three 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. Establishing floral margins in commercial farms in the vicinity of soft fruit crops for 2021 trial.

Summary of the project and main conclusions

NIAB EMR WET Centre

In the first year the replicated plots (unsown, sainfoin, chicory, perennial meadow mix (EM1)) that had established around the WET Centre (strawberry crop) at NIAB EMR in 2019, were surveyed for soft fruit natural enemies and pest species in May, June, July, and August of 2020. Records of vegetation cover were also made in July. Floral units were identified, and invertebrates extracted using the extraction device, developed in AHDB Project SF 156, along with 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.

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 also 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 thought to be from genus *Nysius* (not a soft fruit pest).

Herbivores in floral margins

Most arthropod herbivores or potential soft fruit pests found during this trial were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in May and June and were particularly widespread in sainfoin plots. Capsid were thought to be 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 found in high numbers in all treatments except in chicory. The meadow mix (EM1) was less attractive to capsids than the unsown treatment.

Thrips on flower heads

Unsown species like dandelion, bindweed, hawkbit, white clover and yarrow had, on-average, greater numbers of thrips (two 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 two thrips per flower or had thrips species not found on soft fruit.

In sown plots chicory, sainfoin, oxeye daisy, common knapweed and wild carrot were the flowering species with more than two thrips per flower (Park et al. 2007) on at least 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 developed in AHDB Project SF 156 provided very good recovery of adult thrips (at least 90%) but was less efficient at extracting larval thrips (around 50%) from flower heads.

Beneficials on flower heads

Predatory thrips (*Aeolothrips*), parasitoids, ground beetles and *Orius* nymphs and adults were present in flower heads. No significant numbers were recorded on any plant species. There was a more diverse and abundant community of pollinators in May than September, probably a reflection of floral resource. Bumblebees were frequent visitors to sainfoin flowers, including many wild species, but more research is needed to see if commercial bumblebees are distracted by wildflower margins. 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 2020, floral margins were successfully established in two commercial farms. A third farm was sourced from a previous project where floral margins were implemented in 2017. All sites will be monitored for beneficials and pests in 2021.

Financial benefits

At this stage in the work, no financial benefits from sowing wildflower strips in the vicinity of soft fruit crops have been identified or calculated. However, it is hoped that if the use of wildflower sowings is demonstrated to enhance pest control in soft fruit crops, then the exact financial benefits may be better understood in future.

Action points for growers

- There are currently no action points arising for growers from this work, but growers might consider implementing wildflower strips around soft fruit farms to encourage the biodiversity of pollinating insects and natural enemies in the landscape.
- Once established, wildflower margins may be able to help to 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

Headline

- Rose thrips (*Thrips fuscipennis*) was the predominant species at both sites used for push-pull trials, but numbers were too low to determine whether the strategy led to lower numbers of thrips in flowers.

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 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.

This study proposed to test a push-pull strategy 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 are found on strawberry in the UK; the rose thrips, *Thrips fuscipennis* and the flower thrips, *Frankliniella intonsa*. However, it has been tested predominately in countries that lack these species.

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.

Summary of the project and main conclusions

- Despite best-efforts with site selection, thrips numbers per flower were low overall in the untreated and treated plots at both sites used on the three assessment dates, and there were no significant differences between treatments.
- At Site 1 there was less than a mean of one adult thrips per flower on all three dates. At Site 2 there was a mean of five adults per flower on the set-up date but only one and 1.5 per flower on the second and third dates.
- Thrips adults found on both sites were predominantly rose thrips (*T. fuscipennis*) but particularly at Site 2.
- Rubus thrips (*Thrips major*) was the second most common species of thrips adult, especially at Site 1.
- No WFT were seen at either site, and only small numbers of flower thrips (*F. intonsa*).
- Low numbers of larvae were recorded in flowers. Rubus thrips (*Thrips major*) was the main species of thrips larvae confirmed at both sites. Onion thrips (*Thrips tabaci*) was also confirmed at both sites and flower thrips (*F. intonsa*) at Site 1 only. No rose thrips (*T. fuscipennis*) larvae were found in flowers at either site, despite this being the predominant species of thrips adults at both sites. There is no evidence that rose thrips (*T. fuscipennis*) breeds in strawberry flowers.
- Some fruit bronzing was seen early on when setting up the trials, but little bronzing seen overall at both sites.
- There were no significant differences between treatments in mean numbers of thrips on traps in 'pull' or 'push-pull' plots.
- Thrips species on the traps were confirmed at Site 2 and were the same as those in the flowers.
- Low numbers of beneficial insects were caught on the traps.

Financial benefits

No financial benefits are apparent from this work so far.

Action points for growers

- There are no action points arising from this work at this stage.

Task 4.2. Culture of thrips species other than WFT for future biological and control studies

Headline

- Attempts to set up a culture of rose thrips were unsuccessful and will require further work.

Background and expected deliverables

As there is little information on the biology and behaviour of thrips species other than western flower thrips (WFT) on strawberry, work to fill key gaps in knowledge on other species would require a pure species culture, such as rose thrips (*Thrips fuscipennis*). Western flower thrips can be reared in the laboratory both on host plants such as pot chrysanthemum and also on French bean pods. It is likely that other thrips species can be reared on bean pods, as most are polyphagous, however it is difficult to source single species females to initiate the culture as they can only be identified after killing and mounting on glass slides.

To overcome this difficulty, females could be collected from strawberry flowers and individual females allowed to lay eggs on French beans together with a pollen source. Once larvae have developed from any eggs laid, the original female could be killed and identified to species. The larvae of the selected species (e.g. *T. fuscipennis*) could then be allowed to develop into the next generation adults to develop a pure species culture. This would allow further work to fill key selected gaps in the knowledge of the biology of the species (e.g. experiments to test fruit damage by adults and larvae, reproductive rate on strawberry, colour attraction, predation of adults by *Orius* and the predatory thrips *Aeolothrips*) in future years of the project.

Summary of the project and main conclusions

We aimed to establish a pure species laboratory culture of a *Thrips* species from strawberry flowers, to allow further work on filling key gaps in biology.

- A standard laboratory method was initially tested using WFT which were successfully reared from adults to 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, 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*.

Financial benefits

No financial benefits can be identified from this work at present.

Action points for growers

- No action points have arisen from this work so far.

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

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). 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 (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.

Materials and methods

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 (APHA, Rachel Barker; Plant Health Risk Register (PHRR) status of pests in new UK legislation: https://www.legislation.gov.uk/uksi/2020/1527/made/data.pdf) (including a

meeting with Rachel Yale), RHS (Andrew Salisbury), and EPPO and CABI databases have been searched to identify and alert growers and agronomists to potential new pest problems.

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 include two species of thrips; Japanese flower thrips, and flower 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*).

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) Spread through cut flower imports.	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 south coast of England (Bennison Pers. Comm)	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. Does not feed on pollen. RR review concluded that damage is “not thought to be any more significant than those of other thrip species”	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) Current thrips control measures should also be effective against this species.	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 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

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=22136

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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	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	Body and legs variable, mainly brown with head and pronotum often paler than abdomen, tibiae, and tarsi largely yellow;	Natural enemies: Ceranisus menes (parasite), Misumenops tricuspidatus, Orius sauteri (predators)		MEDIUM In UK, not yet reported causing significant damage. Risk

	Thailand, Bangladesch, Northern India and Pakistan) Presence in UK: present (CABI)		TSWV, TCSV, GRSV	antennal segments III–IV yellow with apices shaded; fore wing pale with setae dark. Very similar to WFT, but intonsa has considerably shorter postocular setae than WFT and lacks campaniform sensilla on the metanotum			with warmer summers. 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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https://www.cabi.org/isc/datasheet/24423

https://keys.lucidcentral.org/keys/v3/thrips_of_california/identify-thrips/key/california-thysanoptera-2012/Media/Html/browse_species/Frankliniella_intonsa.htm

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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	More than 100 plant species, primarily fruit trees, nuts, and woody ornamentals, but also field crops. Citrus, apple, mulberries,	Adults feed on fruit, nymphs feed on leaves, stems, and fruit. Leaf feeding characterized by small lesions (3	Eggs: elliptical (1.6 x 1.3 mm) light green-blue, in groups of 20-30. Five nymphal inasterisks, 2.4-	Pyrethroid insecticides (e.g. deltamethrin and lambda-cyhalothrin). Insect exclusion mesh.	Hitchhiker on packing material or via plant imports or passenger luggage.	MEDIUM Detected active in UK in 2020, not yet at high numbers.

	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.	blueberry, apricot, sweet cherry, plum, pear, raspberry, grapevine. Also, field crops and woodland trees.	mm diameter) which become necrotic and coalesce. Fruit: small necrotic spots (corky spots) or blotches, grooves, and brownish discolorations to severely disfigured ('cat-facing') and unmarketable. Nuisance to humans because of aggregation in buildings.	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. 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.	Ghost nets – attract and kill. 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 species recently reported in Europe.	Eggs: underside of leaves. Aggregation pheromone traps and tap sampling.	PHRR information: No statutory action against findings. Management by industry. Legislative status: not in GB legislation
IDENTIFICATION and significance to UK: Powell, G., Barclay, M.V.L., Couch, Y. & Evans, K.A. 2020. Current invasion status and potential for UK establishment of the brown marmorated stink bug, Halyomorpha halys (Hemiptera: Pentatomidae). British Journal of Entomology and Natural History (in press).							

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Species / Common name	Geographic distribution	Hosts / Crops	Symptoms	Description	Control	Monitoring	Risk for soft fruit
Aleyrodes lonicerae honeysuckle whitefly	Native and widespread species in the U.K. Found throughout Europe and east into Russia; Israel, Turkey, Iran, and Korea.	*Lonicera periclymenum* and *Rubus fruticosus.* 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. Papaveraceae—*Chelidonium*	Overwintered as adults on *R. fruticosus* on the woodland floor, spreading onto spring growth of *L. periclymenum, Geum urbanum* and other minor hosts to reproduce, before retreating to *R. fruticosus* in the autumn.	PUPA: 1 mm long, light yellow in color, oval and dorsally ADULTT: 1 mm 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 ring of wax	parasitoids *Euderomphale chelidonii* and *Encarsia tricolor* and the specialist 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 recorded from Florida.		LOW

		majus, Dicentra spectabilis Rosaceae—*Crategus microphylla, Filipendula ulmaria, Fragaria* spp.; *Geum rivale, Prunus dulcis, Rubus chamaemorus* Urticaceae—*Urtica* spp. Violaceae—*Viola* spp.		residue can be seen on the leaf surface after the pupal exuviae are removed			

https://www.nhm.ac.uk/our-science/data/uk-species/species/aleyrodes_lonicerae.html

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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, *Malus, Prunus, Pyrus, Ribes, Rubus, Sorbus,* and *Vitis* *Catalpa bignonioides* Kiwi fruit lilac (*Syringa*) dogwood (*Cornus*)	Foliage of infested trees may become sparse and yellow. Fruit size may be reduced, and premature fruit drop is likely to 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	Adult female scale covers are convex, circular to oval, dull white with a subcentral yellow spot (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.	Infested hosts can be trimmed/pruned to remove infested parts, which can then be burned. Chemical options are available, but 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	Visual inspection. Sticky tape erected with its stickiness facing outwards on the trunk and branches can help to optimise spray of young larvae ('crawlers') timings. In the spring.	MEDIUM Easily spread from imported material. Lack of good controls. Wide host range.

			die very quickly after infestation.	The male tests often occur in conspicuous masses occasionally smothering the bark and turning it white. The adult males are winged and mobile in order to locate a mate.			

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

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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. Presence in UK: no (EPPO GD)	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.	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. Dug up by badgers and foxes in turf.	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. Larvae: typical chafer, C-shape form, well developed legs and head capsule.	Native generalist predators and birds. Plant Protection Products, broad spectrum including pyrethroids. Insect excluding mesh. Entomopathogenic nematodes; *Steinernema* and *Heterorhabditis*. *Metarrhizium anisopliae*	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 + eugenol + geraniol) and sex attractant (Japonilure)	LOW (long life cycle in UK – 2 years) PHRR information: Action: Statutory action against findings. Awareness raising. Already listed in legislation, but stakeholders may wish to monitor for possible presence. EPPO protocol has been developed which sets out measures needed in the event of an outbreak.

							Legislative status: GB QP

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 / whitefringed weevil	South Africa, Europe (not UK), North America, Oceania, South America	*Brassica* *Daucus carota subsp. sativus* Fabaceae *Fragaria x ananassa* *Pisum sativum*	Eggs, larvae, pupae (on roots, stems and lower leaves and in growing media) Adults (on foliage)	Eggs: Oval approximately 0.9 mm long and 0.6 mm wide, laid in clusters of approximately 10–60. Milky-white when first	Natural enemies: *Conoderus exsul* *Heterorhabditis Hexamermis* *Paecilomyces farinosus*	Phytosanitary inspections	LOW Not yet identified in UK.

		Rubus *Solanum tuberosum* *Trifolium* vegetable plants *Vigna unguiculata* *Zea mays*		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 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	*Passer domesticus* *Rhabditis hambletoni* *Steinernema feltiae* Phytosanitary measures Soil fumigation Crop rotation Nematodes and EPFs		

				hairs which are longer on the elytra.			

https://efsa.onlinelibrary.wiley.com/doi/full/10.2903/j.efsa.2020.6104

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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	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 torticid 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 inedium-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

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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 Madeira. Belgium (2017). Established and expanding its range. Presence in UK: present (CABI)	Wide host range including leaf-litter, vegetation, and stored products. Strawberry, apple, pear.	Scalloping of epidermis of fruit, weep and are sometimes covered by a sticky mass of black frass. Webbing and tenting of foliage, with foliar damage and frass. In strawberry under calyx and feed superficially on berries.	Wingspan 18-21 mm. Adults: quite variable some being very plain, 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.	1-2 sprays of methoxyfenozide - protective deposit. Chlorantraniliprole applied during egg-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	Tap sampling	LOW In UK, sporadic occurrence in crops. Causes significant damage when it occurs, reducing control options available. Not on PHRR. Legislative status: not in GB legislation

					highly effective.		
IDENTIFICATION: https://britishlepidoptera.weebly.com/blacticolella-vs-badustella.html https://ukmoths.org.uk/species/blastobasis-lacticolella https://apples.ahdb.org.uk/blastobasis.asp							

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.	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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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

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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
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 area is dark grey. Hindwings are brownish grey.	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. Legislative status: GB QP

				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.			

IDENTIFICATION: https://bugguide.net/node/view/58615/bgimage

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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
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

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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	Like other spider mites. Feeding punctures lead to whitening or yellowing of leaves, followed by desiccation, and eventually defoliation.	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

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Task 2.1. To investigate the efficacy of the *Lygus rugulipennis* repellent compound for control of capsid species in cane fruits

Introduction

Synthetic semiochemicals have the potential to control capsids that damage cane fruits. Recently, during two years of replicated field trials, successful control of the European tarnished plant bug *Lygus rugulipennis* was achieved in strawberry, using a synthetic semiochemical push-pull approach. A hexyl butyrate (HB) 'push' was deployed in the crop in combination with a 'pull' consisting of *Lygus* sex pheromone and phenylacetaldehyde in green cross vane funnel traps spaced at regular intervals around the crop perimeter (SF 156). The approach significantly reduced numbers of *L. rugulipennis* (adults and nymphs) in the crop and reduced fruit damage by up to 90% in organic strawberry. Cane fruits are also damaged by *L. rugulipennis* and the common green capsid, *Lygocoris pabulinus*. Chemical plant protection products (PPP), including pyrethroids, are typically used to control capsids, however these can disrupt biological control agents and increase pesticide residues in fruits. Moreover, there are continuing restrictions on chemical PPP use. For example, in the EU there has been an ongoing review and phase-out of chemical PPPs since the 1980s (pan-europe.info. 2008) and a continuing trend to promote the use of non-chemical alternatives (eur-lex.europa.eu. 2009). In summer 2020, a trial was set up in a commercial raspberry crop to assess whether:

1. Capsid numbers and damage caused to the crop are reduced using the HB repellent sachets (push)
2. Distributing HB repellent sachets at staggered heights in the crop improves efficacy
3. HB causes any side effects on numbers of beneficials in the crop
4. HB causes any noticeable phytotoxicity to the crop

Materials and methods

Trial site: The trial was setup in a commercial raspberry crop in Kent, consisting of 68 adjoining Polytunnels, each ~8m wide and 70m long, with 3 rows of canes per tunnel (row spacing 2.4m). Raspberries were grown in soil beds, variety Grandeur (Fig. 2.1.1a). Polytunnel ends were open for most of the trial (Fig. 2.1.1b). Weeds noted adjacent to crops at all blocks that could be hosts for capsids were nettle (*Urtica dioica* L, Urticaceae), groundsel

(*Senecio vulgaris*) and mayweed (*Matricaria*) (Fig. 2.1.1c). Others may have been present, but a habitat assessment was not made.

a)  b)  c) 

Figure 2.1.1. Photos of the trial site used for the capsid repellent trial 2020, showing a) rows of raspberries grown in soil beds, variety Grandeur; b); the north facing polytunnel ends and; c) patches of weeds east side of the polytunnels.

Block layout: A block design was used with each treatment occurring twice at north and south open ends of polytunnels where there was highest pest pressure. The raspberry crop was divided into 6 replicate blocks, each sub-divided into 3 plots (Fig. 2.1.2). All plots were 16 m x 16 m (2 Polytunnels wide) and ordered randomly to avoid position affect bias. The minimum distance between plots was 30m to avoid interaction between the treatments.

Treatments (Fig. 2.1.3):

1. *Control;* No HB push
2. *Push, HB level height;* A push consisting of 6 rows of 8 standard concentration HB repellent sachets (16 x 16 m grid) fastened to the supporting string, 1 every 2 m (48 total), at a constant 1m height along the crop canopy
3. *Push, HB staggered heights;* A push same as treatment 2, except with HB at staggered heights along the crop canopy; 0.5m, 1m and 1.5m

HB was formulated in polyethylene sachets (1 ml HB on a dental roll sealed in a polyethylene sachet 50 mm x 50 mm x 120 µm thick, HB release rate 18 mg/d at 22°C). Sachets were fastened to the supporting string using wire ties (Fig. 2.1.4) 24 June, then renewed once during the trial, mid-July (Table 2.1.1).

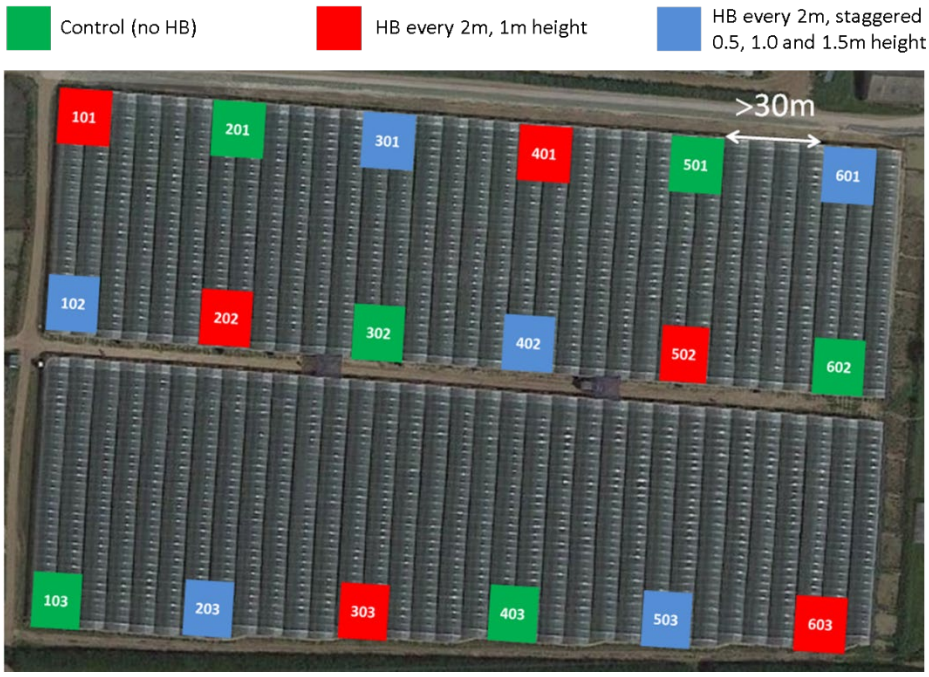


Figure 2.1.2. Block and plot layout of the capsid repellent trial 2020, showing 1. Control with no push; 2. Push with HB repellent sachets at a constant 1m height along the crop canopy; and 3. Push with HB repellent sachets at staggered heights along the canopy, at 0.5 m, 1 m and 1.5 m. Minimum distance between plots was 30 m.

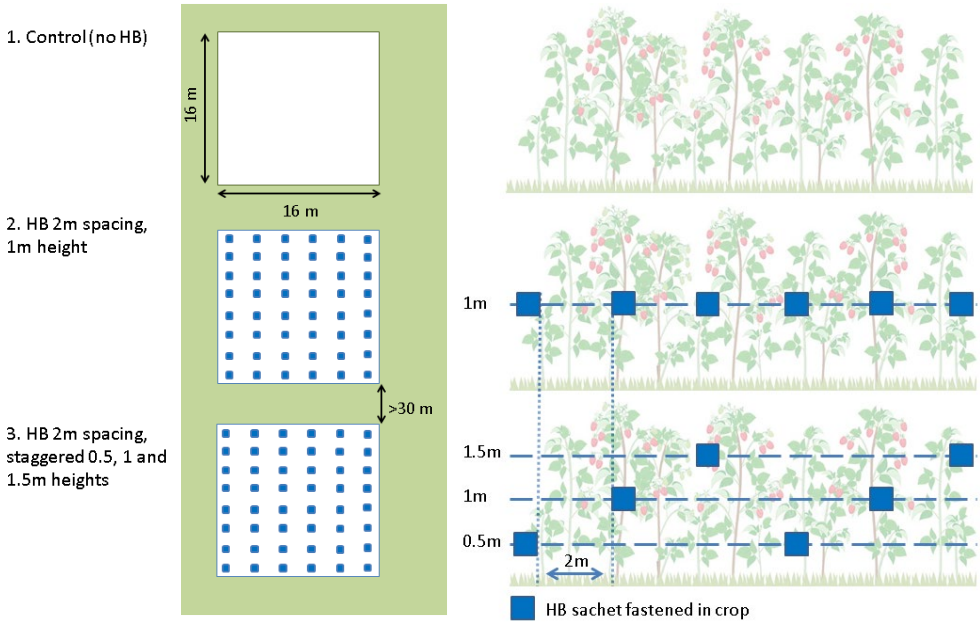


Figure 2.1.3. Diagrammatic representation of an experimental block of the capsid repellent trial 2020, showing 1. Control with no push; 2. Push with HB repellent sachets at a constant 1m height along the crop canopy; and 3. Push with HB repellent sachets at staggered heights along the canopy, at 0.5 m, 1 m and 1.5 m.

Figure 2.1.4. A standard concentration HB repellent sachet fastened to raspberry supporting string using a wire tie.

Crop husbandry involved the standard grower practices, including the growers' standard spray programme (Appendix 2.1.1). No spray was applied to target capsids, but Calypso was applied for leaf curling midge 7 August. Data loggers recorded temperature and humidity throughout the experimental period in each crop (Appendix 2.1.2).

Capsid repellent trial WET centre: In addition to the main capsid repellent trial in raspberry, a small-scale capsid repellent trial was set up beside the floral margins surrounding the WET centre at NIAB EMR (Fig. 2.1.5, see Task 3.2. below for composition of plant species, pests, herbivores and beneficials in floral margin plots). The variety of strawberry in the WET centre was Malling Champion. Between 8 and 19 June 2020, at four floral plots, two treatments were compared; 1) control with *Lygus* sex pheromone only; 2) *Lygus* sex pheromone and HB. Semiochemical dispensers were attached to a blue sticky trap hung on a metal cane (50-60cm height) to catch capsids (Fig 2.1.6). Every 2 to 3 days, blue sticky traps were renewed, then treatments were rotated a position to ensure each was tested at the same floral plot.

The synthetic *Lygus* sex pheromone was formulated in 1 ml disposable pipette tips containing 10 mg hexyl butyrate + 0.3 mg (*E*)-2-hexenyl butyrate + 2 mg (*E*)-4-oxo-2-hexenal + 1 mg Waxoline Black in 100 µl sunflower oil on a cigarette filter, with release rate of HB 0.93 ± 0.05 (S.E.) µg/hr at 27°C.

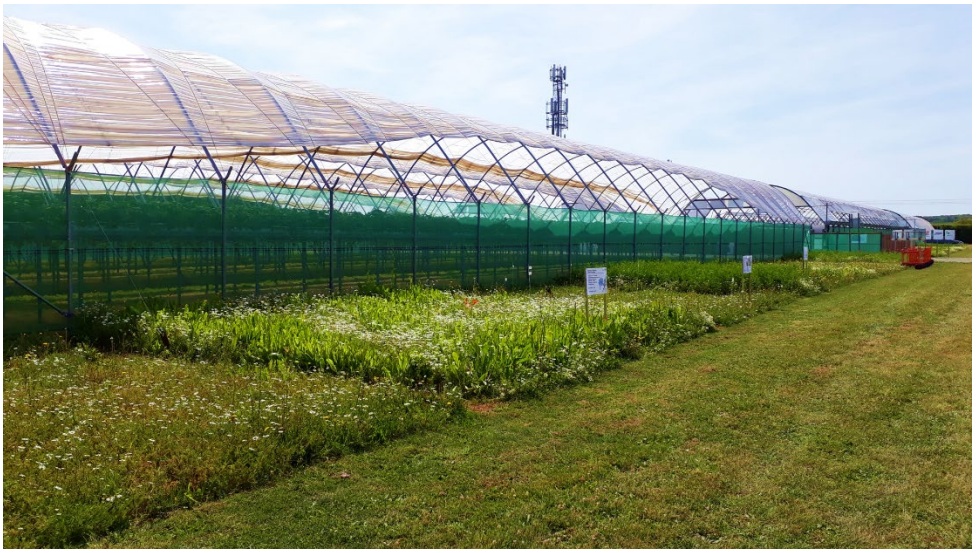


Figure 2.1.5. Floral margin plots surrounding the WET centre 2020, used for the capsid repellent (HB) small-scale trial.

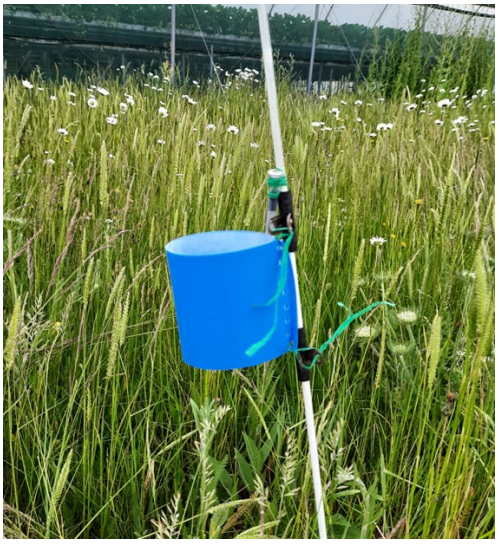
a)  b) 

Figure 2.1.6. Blue sticky traps used to catch capsids during the capsid repellent (HB) small-scale trial 2020. Two treatments were compared; a) control, consisting of blue sticky trap with *Lygus* sex pheromone only; b) treatment, consisting of blue sticky trap with *Lygus* sex pheromone and HB.

Assessments: For the main trial in raspberry, assessments were done between June and August and included a pre-assessment, before HB repellent sachets were deployed and 4 post assessments, when HB was deployed (only in plots with a push treatment). See Table 2.1.1 for HB deployment and renewal dates.

Tap sampling; To compare numbers of capsids and beneficials in control and treatment plots, 100 laterals were tap sampled fortnightly in the central 10 x 10 m of each plot per block and invertebrate numbers counted. See Table 2.1.1 for tap sample assessment dates.

Fruit assessment: To compare capsid damage to raspberry fruit in control and treatment plots, in the central 10 x 10 m of each plot, approximately 100 fruits were categorised according to capsid damage score; 0 (zero), 1 (slight), 2 (moderate) and 3 (severe) (Fig. 2.1.7a). Moving along each row, fruit was assessed alternately from the top, middle and bottom of the canopy to find out if both HB treatments can prevent capsid damage throughout the canopy. See Table 2.1.2 for fruit damage assessment dates.

Leaf assessment: Raspberry leaves on young lateral stems were assessed following the same sampling method as used to assess fruit and were also categorised according to capsid damage score (Fig. 2.1.7b). See Table 2.1.2 for leaf damage assessment dates.

Phytotoxicity; To determine if HB can cause leaf phytotoxicity in raspberry, at a separate crop on the same farm, 10 July 2020; 10 standard concentration HB sachets (release rate 18 mg/d at 22°C) and 10 sachets containing dental roll soaked in 1ml water, were attached to young lateral stems on separate raspberry canes at 5 m intervals. A further 10 young lateral stems were tagged with no sachets attached. On 4 September 2020, the 3 groups of 10 lateral stems were assessed according to the phytotoxicity key (Appendix 2.1.3) (onlinelibrary.wiley.com. 2006).

The water sachet was formulated in polyethylene sachets (1ml deionised water on a dental roll sealed in a polyethylene sachet 50 mm x 50 mm x 120 µm thick).

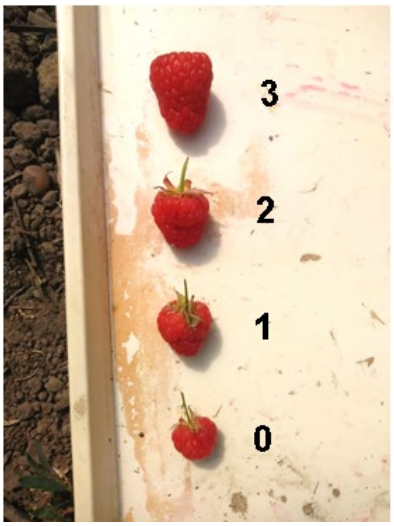
HB repellent trial WET centre: Each collection (treatment rotation day), blue sticky traps were brought back to the lab at NIAB EMR and capsid species identified and counted.

Table 2.1.1. Dates for capsid repellent trial set-up, HB deployment and renewal and tap assessments at each block, 2020.

Location	Date of experiment set-up	Tap sample pre-assessment (then HB deployment)	Tap sample assessment 1	Tap sample assessment 2 (HB renewal)	Tap sample assessment 3	Tap sample assessment 4
Block 1	24-Jun	24-Jun	10-Jul	21-Jul	05-Aug	20-Aug
Block 2	24-Jun	24-Jun	10-Jul	21-Jul	05-Aug	20-Aug
Block 3	24-Jun	25-Jun	10-Jul	22-Jul	05-Aug	20-Aug
Block 4	24-Jun	25-Jun	10-Jul	22-Jul	05-Aug	20-Aug
Block 5	24-Jun	25-Jun	10-Jul	22-Jul	05-Aug	20-Aug
Block 6	24-Jun	25-Jun	10-Jul	23-Jul	05-Aug	20-Aug

Table 2.1.2. Dates for capsid repellent trial raspberry and leaf damage assessments at each block, 2020.

Location	Damage pre-assessment	Damage assessment 1	Damage assessment 2	Damage assessment 3	Damage assessment 4
Block 1	24-Jun	10-Jul	21-Jul	10-Aug	20-Aug
Block 2	24-Jun	10-Jul	21-Jul	10-Aug	20-Aug
Block 3	25-Jun	10-Jul	22-Jul	10-Aug	20-Aug
Block 4	25-Jun	10-Jul	22-Jul	10-Aug	20-Aug
Block 5	25-Jun	10-Jul	22-Jul	10-Aug	20-Aug
Block 6	25-Jun	10-Jul	23-Jul	10-Aug	20-Aug

a) 

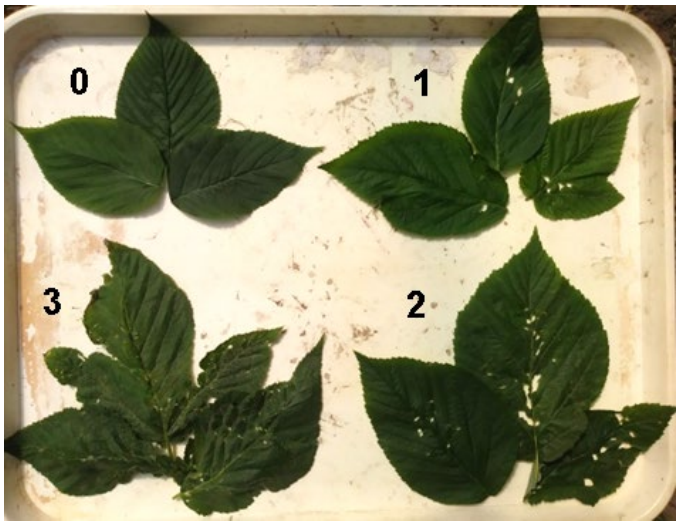
b) 

Figure 2.1.7. Capsid damage categories for a) raspberry fruits; and b) raspberry leaves, 0 = no damage, 1 = slight damage, 2 = moderate damage, 3 = severe damage.

Statistical analyses

Tap samples; invertebrate counts between treatment and control plots were analysed using glmm. Pre-assessment counts were used as an offset.

Fruit and Leaf damage assessments: % undamaged fruit/leaves, was analysed using two models - a mixed model to account for the repeated measures and standard glm to account for over dispersion. Damage score data was analysed separately for each assessment by fitting to an ordinal model.

HB repellent trial WET centre: Numbers of capsids caught in traps were analysed using a repeated measures ANOVA.

Results

The mean daily temperature between the pre-assessment and assessment 1 was 19.5ºC, between assessments 1 and 2 was 20.1ºC, between assessments 2 and 3 was 21.6ºC and between assessments 3 and 4 was 23.3ºC (Fig. 2.1.16).

Tap sample assessments (per 100 raspberry laterals)

Overall, the mean number of capsid nymphs was significantly lower in plots with HB at staggered heights than control plots with no HB (mean = 4.16 and 10.76 respectively, *P* = 0.003). There was no difference in capsid nymphs between HB at 1 m height (mean = 7.1) and the control (*P* = 0.300). There was also no significant difference between the two HB treatments (*P* = 0.190) (Fig. 2.1.8).

At assessment 1 (2 weeks after HB deployment) there were significantly fewer capsid nymphs in plots with an HB treatment (HB 1 m height and HB at staggered heights) compared to the control (mean = 9.5, 13.5 and 37.5 respectively, *P* = 0.003 and 0.001 respectively) and at assessment 2 there were significantly fewer capsid nymphs in plots with HB at staggered heights compared to HB at 1 m height and control (mean = 14.3, 21.5 and 30.7 respectively, *P* = 0.02 and 0.01 respectively). There were no significant differences at the other assessments when numbers of capsid nymphs were lower in general (Fig. 2.1.9).

Overall, fewer adult *L. pabulinus* were observed in plots than capsid nymphs (mean = 1.4 and 7.34 respectively). There was no significant difference in numbers of adult *L. pabulinus* between control and the two HB treatments (HB 1 m height and HB staggered heights) (mean = 1.32, 1.48 and 1.5 respectively, *P* = 0.70), or each assessment (Fig. 2.1.10).

Only 2 species of adult capsid were observed in the plots during the trial; *L. pabulinus* and *L. rugulipennis*. Mean numbers of adult *L. pabulinus* were higher than *L. rugulipennis* (mean = 3.3 and 0.01, respectively).

Beneficials in numbers high enough for statistical analysis included *Atractotomus mali*, lacewing larvae and adults, *Orius* spp., parasitoid Hymenoptera spp. and predatory spiders spp. There were significantly fewer *Atractotomus mali* in plots with HB at 1 m height compared to plots with HB at staggered heights and the control (mean = 0.07, 0.3 and 0.2 respectively, *P* = 0.040) and significantly fewer predatory spiders in plots with HB at staggered heights compared to plots with HB at 1 m height and control (mean = 0.384, 0.782 and 0.903 respectively, *P* = 0.008).

Fruit assessments

There was no overall difference in fruit damage between the treatments (HB 1 m height and HB at staggered heights) and the control plots (mean % = 85.8%, 86.6% and 74.3% respectively; *P* = 0.096) (Fig. 2.1.11). Over the course of the trial, mean damage scores of raspberries sampled was significantly higher in control plots than plots with an HB treatment (Fig. 2.1.12 and Table 2.1.3).

There was no difference in damage to fruits at different heights in the crop (mean % = bottom 86.9, middle 83.3 and top 77.3 respectively; *P* = 0.302).

Leaf assessments

Overall, there were more raspberry leaves with zero capsid damage in plots with an HB treatment (HB 1 m height and HB staggered heights) than control plots (mean % = 97.1%, 95.8% and 89.5% respectively). The difference from control was significant for HB 1 m height, but not HB at staggered heights (*P* = 0.046 and 0.148 respectively). There was no significant difference between treatments (Fig. 2.1.13). Over the course of the trial, mean damage scores of raspberry leaves sampled was significantly higher in control plots than plots with an HB treatment, except assessment 4 when there was no significant difference (Fig. 2.1.14 and Table 2.1.4).

There was no significant difference in capsid damaged leaves at the bottom, middle or top of the canopy (mean % = 96.16, 94.26 and 94.07 respectively; *P* = 0.631).

Phytotoxicity

Following 2 months attachment to young lateral stems on separate raspberry canes, the HB sachets used in the 2020 push had no clear adverse effect on raspberry foliage compared to foliage where water sachets and no sachets were applied (Fig. 2.1.15). During the attachment period mean temperature in the polytunnel was 20.96°C ranging from 6°C to 50.5°C (Fig. 2.1.17) and mean humidity was 66.8 %RH ranging from 21.5 to 90.5 %RH (Fig 2.1.18).

HB repellent trial - WET centre

Four capsid species were observed on blue sticky traps, including *L. pabulinus, L. rugulipennis,* potato capsid*; Closterotomus norvegicus and Orthops kalmia*, but mean numbers caught per trap were generally below 1. Numbers of *L. pabulinus*, *L. rugulipennis*, and *O. kalmia* captured on traps with HB were 0.45, 0.63 and 0.3 respectively, compared to the controls with no HB; 2.5, 0.16 and 0 respectively, and not statistically different. For *C. norvegicus*, catches were similar between treatments (mean = 0.63 and 0.66 respectively).

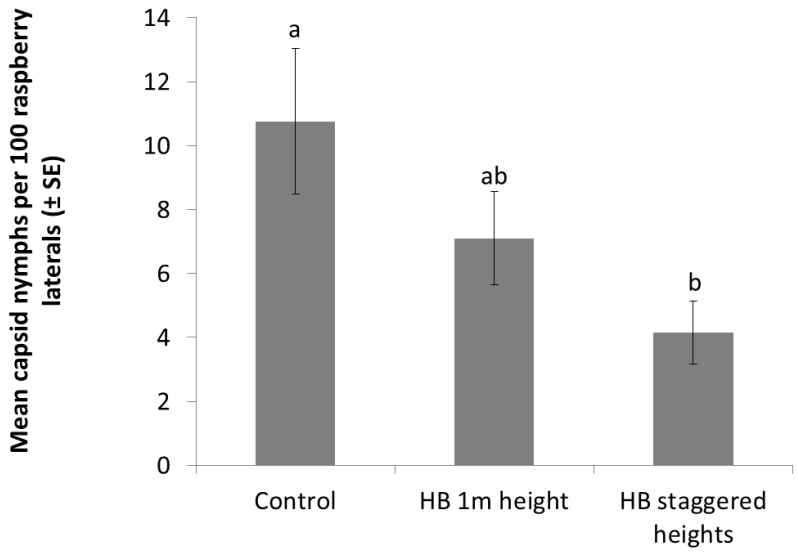


Figure 2.1.8. Mean numbers (+/-SE) of capsid nymphs per 100 raspberry laterals from tap assessments in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020 ($P \leq 0.05$).

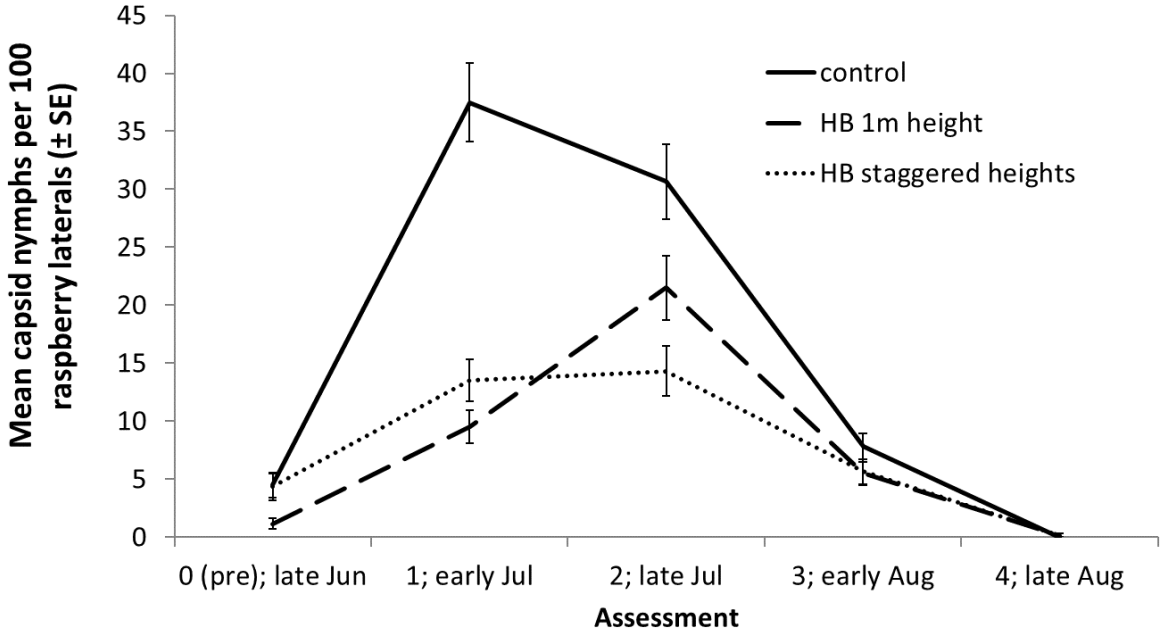


Figure 2.1.9. Mean number of capsid nymphs per 100 raspberry laterals each tap assessment, in Control, HB 1m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020.

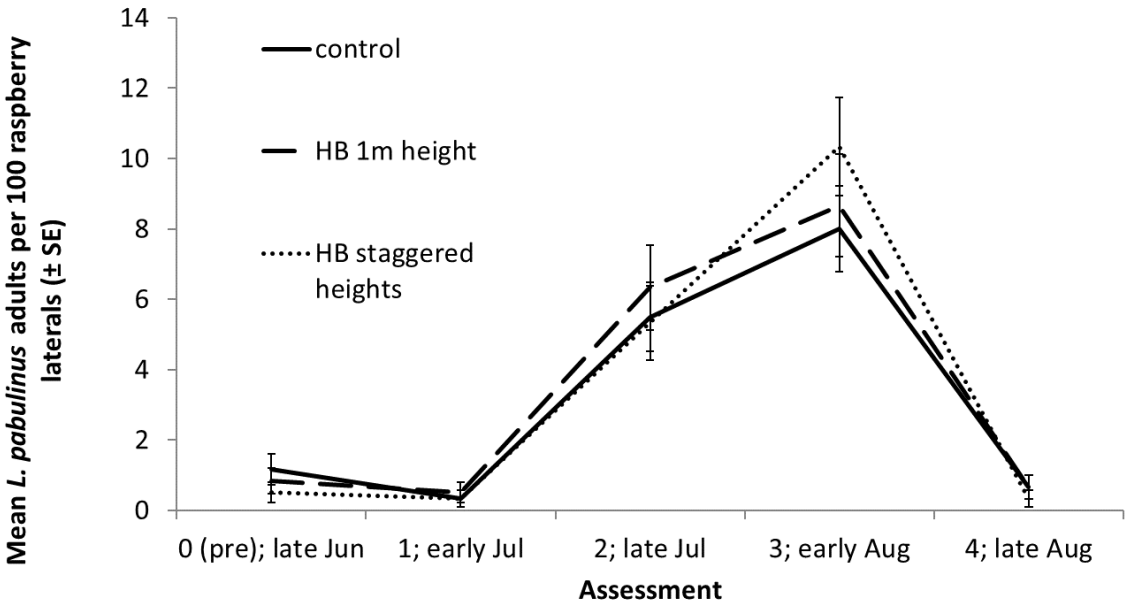


Figure 2.1.10. Mean number of *L. pabulinus* adults per 100 raspberry laterals each tap assessment, in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020.

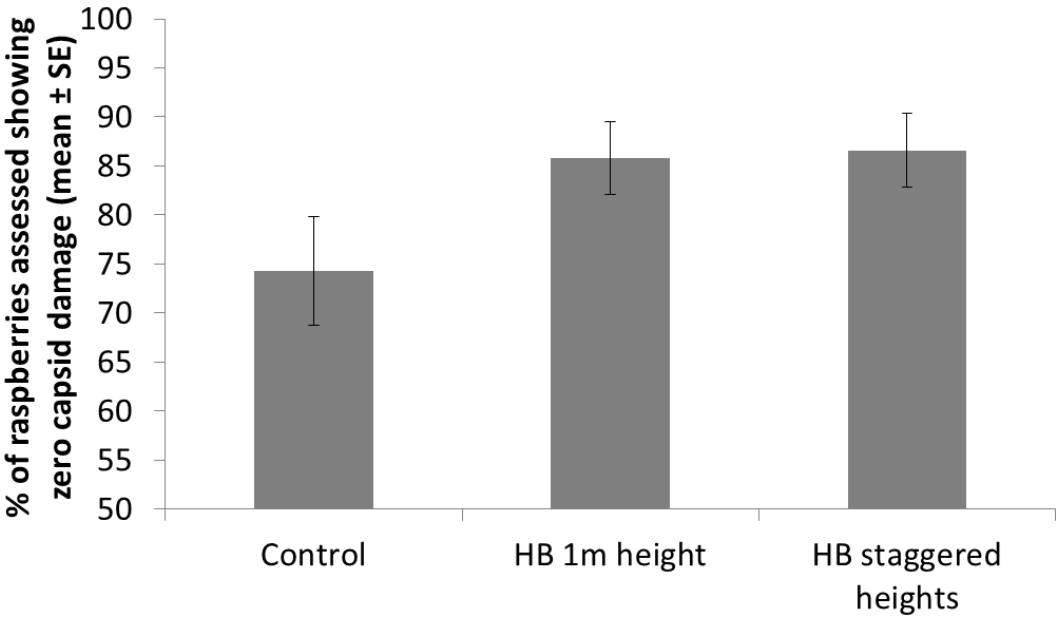


Figure 2.1.11. Mean % of raspberry fruit sampled showing zero capsid damage in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020.

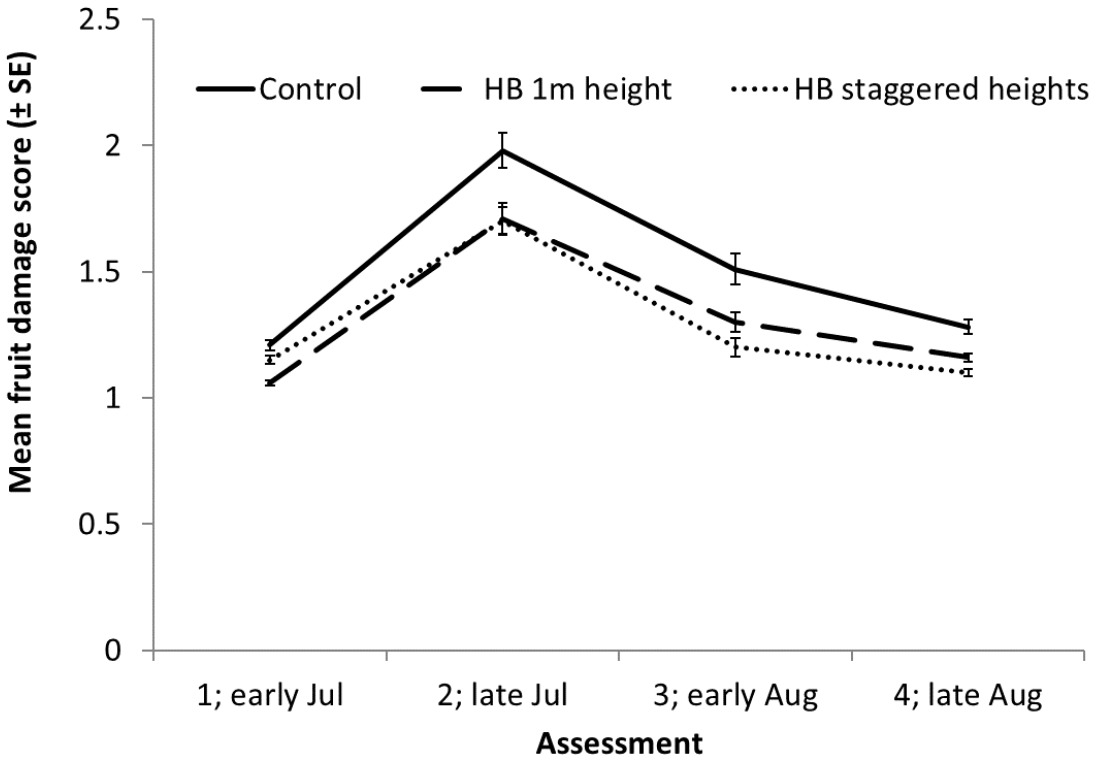


Figure 2.1.12. Mean fruit damage scores of raspberries sampled each assessment in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020.

Table 2.1.3. Mean fruit damage scores of raspberries each assessment in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020. Different letters are significantly different at $P \leq 0.05$.

Assessment	Treatment	Mean damage score (SE)		z ratio from control	Significance from control
1; early Jul	Control	1.21 (0.020)	a	-	-
	HB 1 m height	1.06 (0.010)	b	6.654	<.0001
	HB staggered heights	1.15 (0.017)	b	2.642	0.016
2; late Jul	Control	1.98 (0.070)	a	-	-
	HB 1 m height	1.71 (0.062)	b	3.291	0.002
	HB staggered heights	1.70 (0.055)	b	3.379	0.0014
3; early Aug	Control	1.51 (0.063)	a	-	-
	HB 1 m height	1.30 (0.038)	b	3.301	0.0019
	HB staggered heights	1.20 (0.0350)	b	4.453	<.0001
4; late Aug	Control	1.28 (0.0286)	a	-	-
	HB 1 m height	1.16 (0.0173)	b	3.899	0.0002
	HB staggered heights	1.10 (0.0139)	b	6.057	<.0001

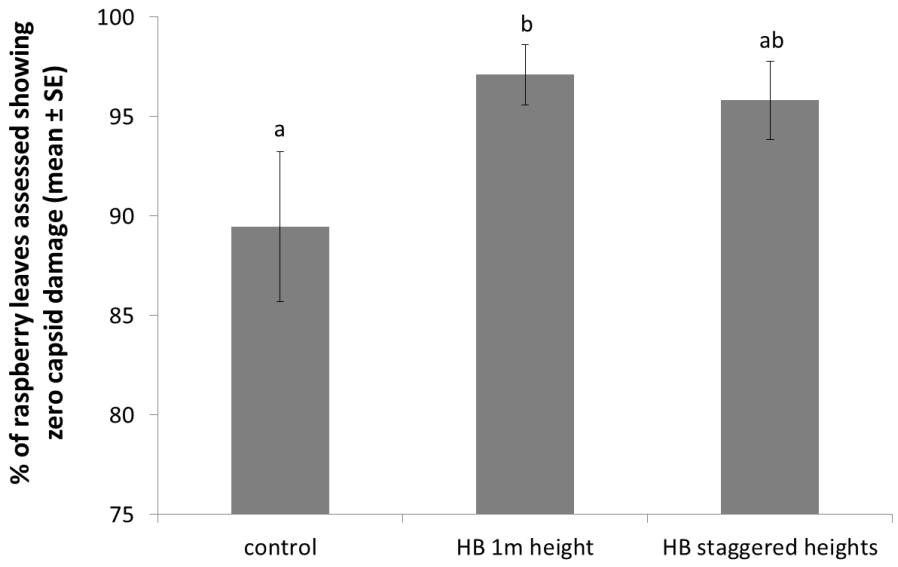


Figure 2.1.13. Mean % of raspberry leaves sampled showing zero capsid damage in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020 ($P \leq 0.05$).

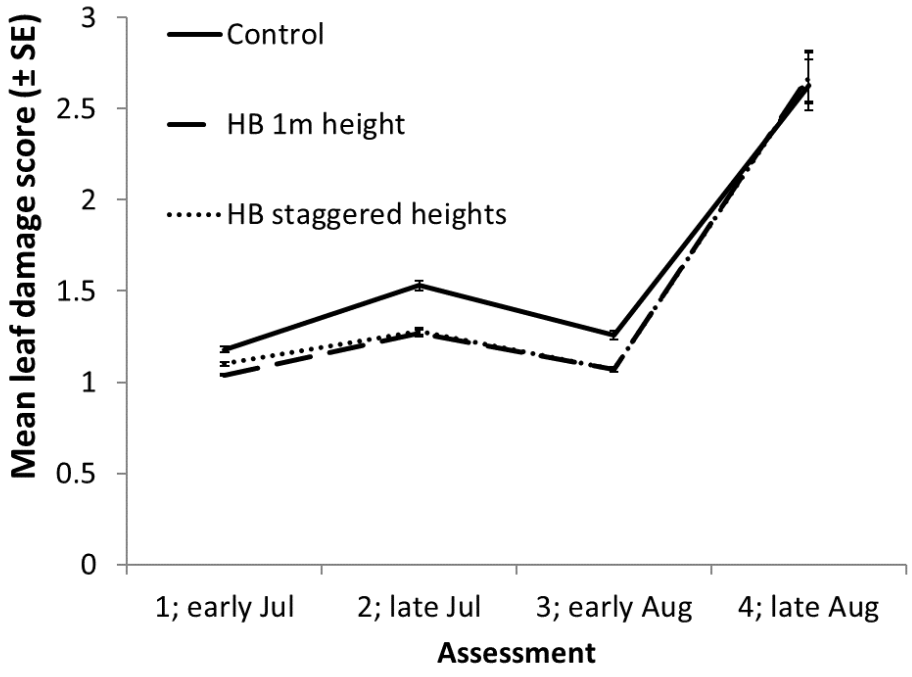


Figure 2.1.14. Mean leaf damage scores of raspberries sampled each assessment in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020.

Table 2.1.4. Mean leaf damage score of raspberries each assessment in Control, HB 1 m height and HB staggered heights (0.5 m, 1 m and 1.5 m) plots during the capsid repellent trial 2020. Different letters are significantly different at $P \leq 0.05$.

Assessment	Treatment	Mean damage score (SE)		z ratio from control	Significance from control
1; early Jul	Control	1.18 (0.017)	a	-	-
	HB 1m height	1.04 (0.007)	b	7.669	<.0001
	HB staggered heights	1.10 (0.012)	b	3.861	0.0002
2; late Jul	Control	1.53 (0.027)	a	-	-
	HB 1m height	1.27 (0.019)	b	8.008	<.0001
	HB staggered heights	1.28 (0.019)	b	7.596	<.0001
3; early Aug	Control	1.26 (0.025)	a	-	-
	HB 1m height	1.07 (0.011)	b	6.949	<.0001
	HB staggered heights	1.07 (0.011)	b	6.984	<.0001
4; late Aug	Control	2.63 (0.140)	a	-	-
	HB 1m height	2.68 (0.139)	a	0.248	0.9444
	HB staggered heights	2.67 (0.140)	a	0.219	0.9548

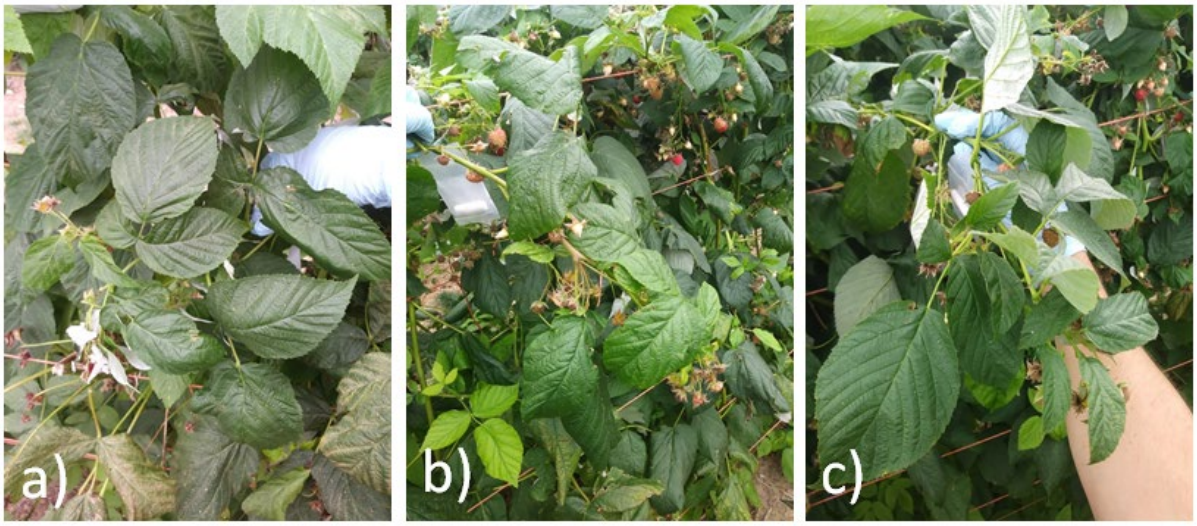


Figure 2.1.15. Sample photos from HB phytotoxicity assessment comparing plant foliage following ~2 months exposure to the HB repellent sachet used in the capsid repellent trial 2020: a) Control - no sachet; b) Sachet containing dental roll soaked in 1 ml water; c) Standard concentration HB sachet.

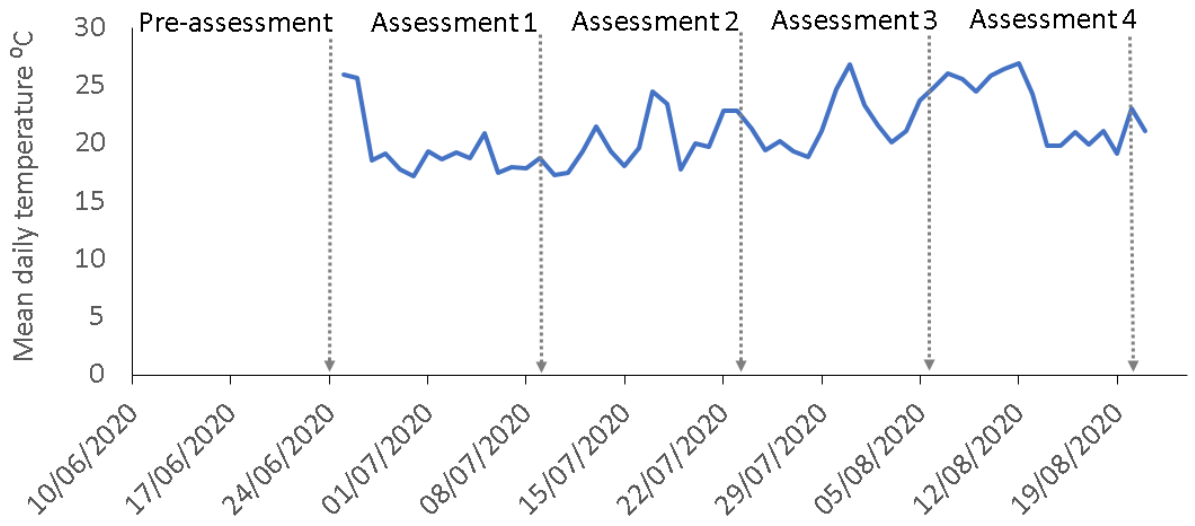


Figure 2.1.16. Mean daily temperature (°C) in trial polytunnels from pre-assessment; 24 June to assessment 4; 20 August, during the capsid repellent trial 2020. HB repellent sachets were deployed 24 June and renewed 23 July.

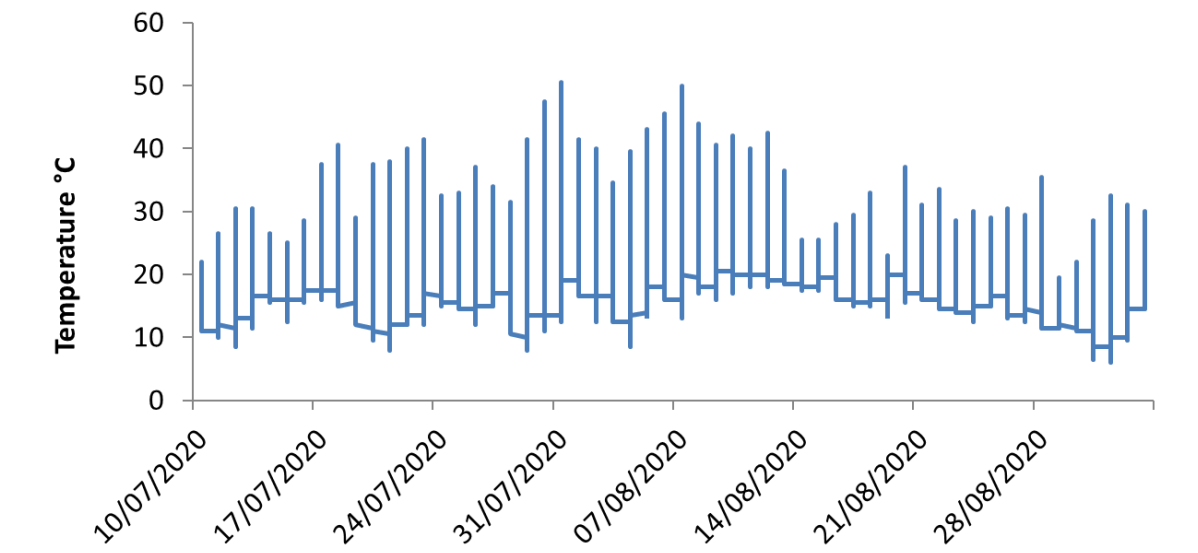


Figure 2.1.17. Temperature (°C) in the polytunnel during the HB phytotoxicity experiment between 10 July (sachet attachment) and 4 September (phytotoxicity assessment). Daily peaks are highest temperatures during daylight hours, troughs are lowest temperatures during the night.

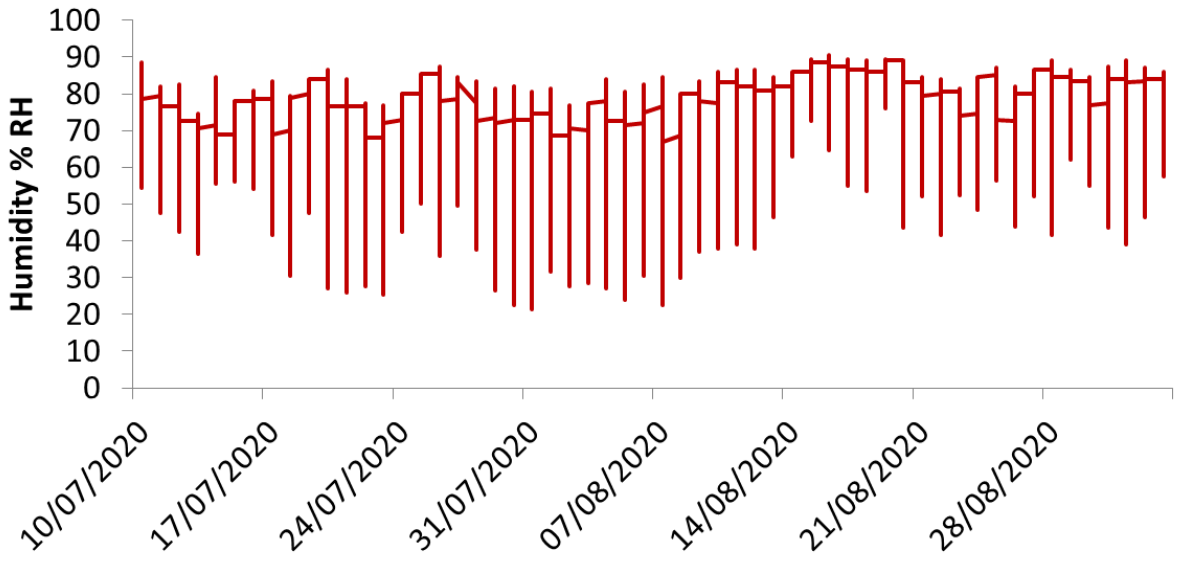


Figure 2.1.18. Humidity (%RH) in the Polytunnel during the HB phytotoxicity experiment between 10 July (sachet attachment) and 4 September (phytotoxicity assessment). Daily peaks are highest %RH during the night, troughs are lowest %RH during daylight hours.

Discussion

During the 2020 trial in commercial raspberry, the synthetic HB push significantly reduced numbers of capsid nymphs and capsid damage to fruit and leaves in the crop.

Two methods of deploying HB were tested alongside an untreated control (HB sachets at 1m height every 2 m along the crop canopy and HB at staggered heights). On 10 July, two weeks after HB was first deployed, numbers of capsid nymphs were at least 3 times higher in control plots than HB plots (HB 1 m height and HB at staggered heights) (mean = 37.5, 9.5 and 13.5 respectively). Between 21 and 23 July, four weeks after first HB deployment, there were more capsid nymphs in control plots than plots with an HB treatment, but statistical analysis found significantly fewer capsid nymphs in plots with HB at staggered heights compared to HB at 1 m height and control (mean = 14.3, 21.5 and 30.7 respectively). Numbers of capsid nymphs had decreased in all plots at the two final assessments (10 and 20 August; Fig. 2.1.9).

The reduction in nymphs may have been due to mating disruption or repellence of the adults or repellence of the nymphs upon hatching, or a combination of effects. However we did not show significant repellence of adult capsids in the HB treated plots. However, numbers were generally low and hence statistical analyses may not be robust enough to detect differences. The post prevalent species in the raspberry crop was the common green capsid, *L. pabulinus*. Previously it has been suggested HB inhibits sex pheromone release in *L. pabulinus* females (Groot et al. 2001). During our trial this may explain why fewer capsid nymphs were observed

in HB plots than control, despite similar numbers of adults between plots. In future, a perimeter pull may further improve the effects of the HB push observed during this trial, by removing adults too. But this would need further investigation and would require blue sticky traps for this species.

Results from the additional capsid repellent small-scale trial around the WET centre at NIAB EMR were encouraging but numbers were low and no statistical difference in adult catches were found between pheromone traps with or without additional HB added.

Previous results in strawberry show when HB is in the crop, there are significantly fewer *L. rugulipennis* nymphs and adults and respective damage to fruit (SF156 annual report 2017 and 2019). This study was published in a peer reviewed journal in 2021 (Fountain et al. 2021).

HB treatments (HB 1 m height and HB staggered heights) also reduced foliar damage compared to the control. This was the case all fruit assessments following HB deployment (Fig. 2.1.12 and Table 2.1.3) and all leaf assessments except assessment 4, when there was no significant difference between treatments and control (Fig. 2.1.14 and Table 2.1.4). There was no significant difference in fruit and leaf damage between HB treatments any assessment. Capsid damage was also assessed at different heights in the raspberry canopy to find out if one method of HB deployment gave broader reduction of capsids and respective damage. Statistical analysis found no significant interaction between HB treatment and capsid damage at different levels in the canopy. Therefore, either method of deployment is considered sufficient to reduce capsid damage, but our recommendation is that HB is deployed at 1 m height to speed the operation.

Beneficials observed in plots in numbers high enough for statistical analysis included *Atractotomus mali,* lacewing (larvae and adults), *Orius* spp., parasitoid Hymenoptera spp. and predatory spiders spp. (mean = 0.2, 0.3, 0.4, 0.9 and 0.7 respectively). Of these, there were significantly fewer *Atractotomus mali* in plots with HB at 1 m height compared to plots with HB at staggered heights and control (mean = 0.07, 0.3 and 0.2 respectively), and significantly fewer predatory spiders in plots with HB at staggered heights compared to plots with HB at 1 m height and control (mean = 0.384, 0.782 and 0.903 respectively). However, numbers of both were less than 1 per 100 laterals, and predatory spiders were not identified to species, so these findings are inconclusive and may need further investigation.

Following 2 months attachment to young lateral stems on separate raspberry canes, the HB sachets used in the 2020 push (standard sachet used during 2017 and 2019 push-pull trials) had no clear adverse effect on raspberry foliage compared to foliage where water sachets and no sachets were applied (Fig. 2.1.15).

Management of weeds that host pest capsids in and around the crop is recommended. Weeds that host *L. pabulinus* include nettles and dock. *L. pabulinus* overwinter as eggs in young shoots of various shrubs and trees. Nymphs of the first generation emerge in April or May (Blommers et al. 1997).

Conclusions

- The HB push significantly reduces numbers of capsid nymphs (most likely common green capsid, *L. pabulinus*) and capsid damage to fruit and leaves in commercial raspberry.
- These effects may be due to mating disruption and/or repellence although numbers of *L. pabulinus* adults in the crop were not reduced.
- A perimeter pull for *L. pabulinus* in raspberry might enhance the effect by creating a push-pull strategy, but this would need investigation.
- Deploying HB at 1 m height along the crop canopy reduced fruit and leaf damage throughout the canopy similar to deploying HB at staggered heights.
- HB had no phytotoxic effects when attached to young raspberry laterals for 2 months.
- Low numbers of beneficials were counted in the crop, making it difficult to conclude if HB had any adverse effect.
- Early season management of weeds that host capsids in and around the crop is recommended but avoid cutting weeds once the crop is in production, later on in the season, as this may force pests into the crop.

WP2. Control of capsids in soft fruit using new and novel technology and biological control.

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)

Introduction

In previous work under SF156, successful control of *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, will require registration with CRD. It is a component of the sex pheromone of several *Lygus* species, is registered as a food additive and is a GRAS compound (Generally Regarded As Safe), although it does not fall into the straight-chain Lepidopteran pheromone (SCLP) category given fast-track registration by the EU. To date, monitoring of crops containing the repellent has not revealed any adverse effects on natural enemies but this will continue to be monitored in all future experiments. Thus, there is a good prospect that registration will be relatively straightforward and the requirements for this are being explored by Russell IPM and CRD.

The objective of this work package is to develop commercial formulations of the capsid repellent and to evaluate them in the field. As well as formulations of hexyl butyrate alone, blends with methyl salicylate are being evaluated. The latter is the active component of "Magipal", an established Russell IPM product to attract beneficial insects into a crop. Formulations are being optimised through laboratory release rate measurements during 2020 with the aim of developing a suitable formulation(s) for evaluation in field trials during 2021.

Materials and Methods

Following discussion and feedback between NRI and Russell IPM, candidate commercial formulations of hexyl butyrate with and without methyl salicylate were prepared by Russell IPM using blister-pack technology (Fig. 2.2.1). Release rates from these were compared with rates from low density polyethylene (LDPE) sachet formulations prepared at NRI and used in the previous trials to date. The "standard" sachet was 5 cm x 5 cm x 120 µm sachet containing hexyl butyrate (1 ml) impregnated onto a cotton dental roll. The "long-life" dispenser was the same sachet containing 5 ml hexyl butyrate impregnated on two dental rolls.

Samples were exposed in a windtunnel maintained at 8 km/h windspeed and 27°C. Release rates were measured at NRI primarily by periodic weighing of duplicate samples.

Fig. 2.2.1. Russell IPM blister pack formulations

Some formulations were assessed by collection of volatiles by placing the formulation in a Kilner jar (5 litre) and drawing air in through an activated charcoal filter and out through a collection filter consisting of a Pasteur pipette (4 mm i.d.) containing purified Porapak Q (200 mg, 50-80 mesh) held between plugs of silanised glass wool. Trapped volatiles were eluted with dichloromethane (1 ml; Pesticide Residue Grade) and decyl acetate (5 µg) added as internal standard. Solutions were analysed by gas chromatography (GC) with flame ionisation detection. A polar DBWax column (30 m x 0.32 mm i.d. x 0.25 µm film thickness) was used with helium carrier gas (2.4 ml/min) and oven temperature programmed from 50°C for 2 min then at 10°C/mn to 250°C.

Results

Initial studies compared release rates from two blister pack formulations of hexyl butyrate (HB) alone with those from NRI standard and long-life sachets Fig. 2.2.2) in a laboratory fumehood, nominally at 22°C. Release rates were unexpectedly higher than those originally measured (21 mg/d) as shown in Fig. 2.2.3, with the two Russell IPM formulations releasing at half the rate of the standard NRI formulation.

Although the laboratory temperature during these 2020 measurements was nominally 22°C, the very hot weather meant that this was very variable, occasionally reaching 34°C. Thus, all further experiments were carried out in a temperature-controlled room at a more reliable 27°C.

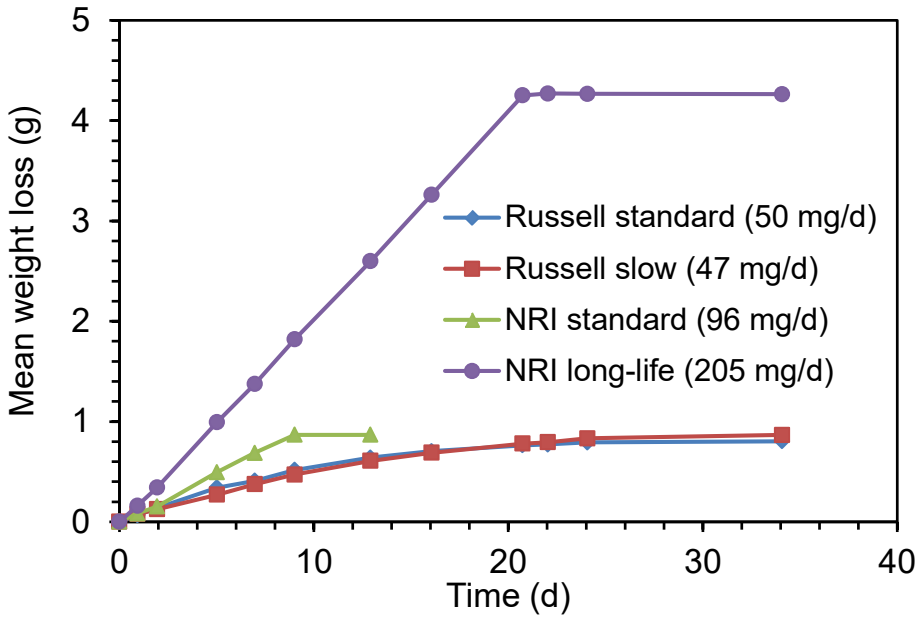


Fig. 2.2.2. Release rates of hexyl butyrate from two NRI LDPE sachet formulations and two Russell IPM blisterpack formulations measured by periodic weighing of duplicate samples (laboratory fumehood 22-34°C)

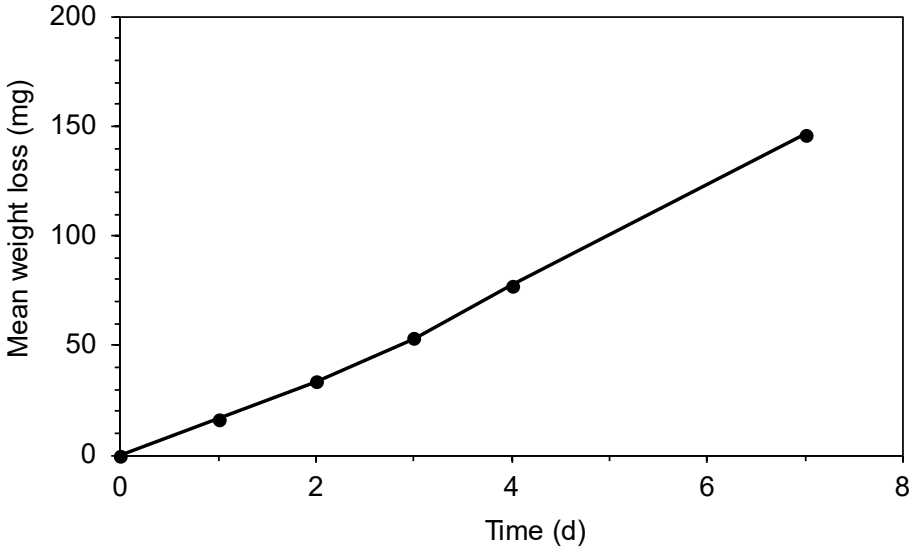


Fig. 2.2.3. Release rate of hexyl butyrate from standard NRI LDPE sachet formulation measured in 2010 (20.9 mg/d; laboratory fumehood 20-22°C)

In the next series of experiments, release rates were measured from the standard Russell IPM blister pack formulation of hexyl butyrate and two new formulations designed to increase the release rate to match that from the standard NRI sachet. Also provided were blister pack formulations containing blends of hexyl butyrate with methyl salicylate at 50:50, 95:5, and 0:100, respectively.

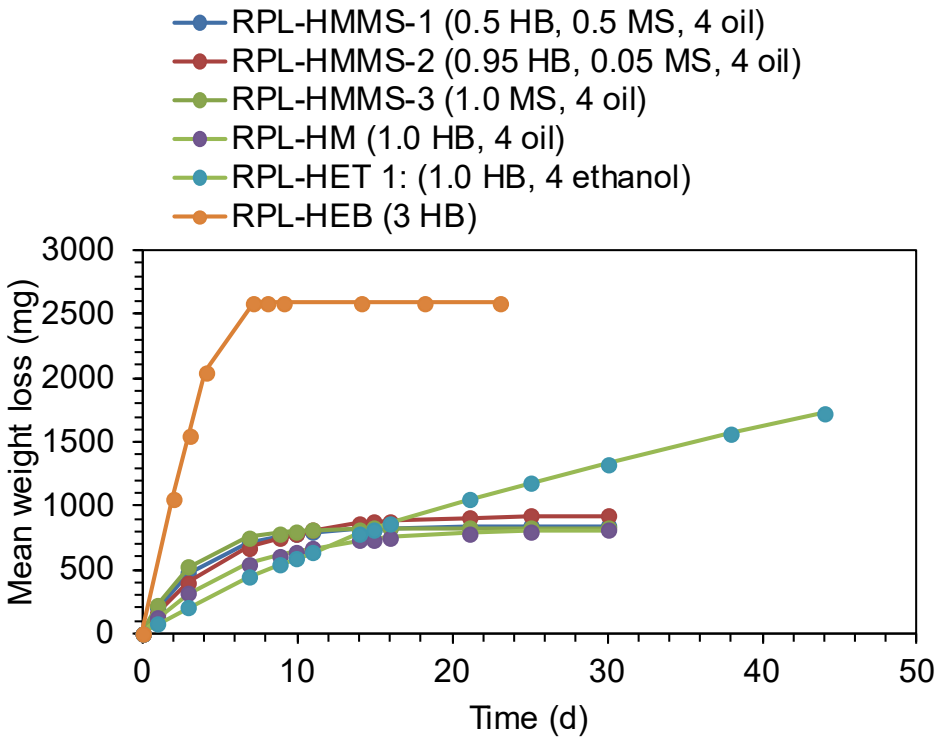


Fig. 2.2.4. Release rates from Russell IPM blister pack formulations of hexyl butyrate with and without methyl salicylate as measured by weight loss (27°C, 8 km/h windspeed)

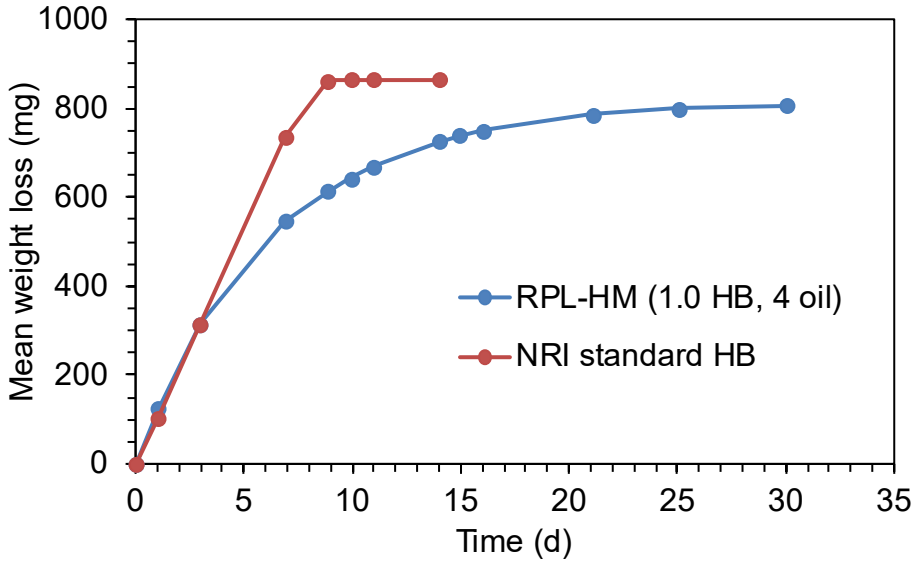


Fig. 2.2.5. Release rates from Russell IPM blister pack formulations of hexyl butyrate with and without methyl salicylate as measured by weight loss (27°C, 8 km/h windspeed)

Fig. 2.2.4 shows that the standard formulation of hexyl butyrate (HM), the increased release rate (HET 1) and the formulations with methyl salicylate (HMMS-1, HMMS-2, and HMMS-3) all released at a similar rate (80-100 mg/d) to that of the NRI standard sachet (107 mg/d).

The fast release rate formulation (HEB) released at over three times the rate, but all these formulations lasted less than 10 days under the windtunnel conditions. Blending the hexyl butyrate with ethanol apparently gave a more sustained release (HET-1). The release rates are summarised in Table 2.2.1.

Table 2.2.1. Laboratory release rates from Russell IPM blister packs and NRI sachets (windtunnel at 27°C and 8 km/h windspeed)

Formulation	Release Rate (mg/d)	Linear Period (d)	Lifetime (d)	Amount released (g)
NRI standard HB	107.1	6.87	8.85	0.85
NRI long-life HB	228.2	6.87	25.03	4.3
RPL-HMMS-1 (0.5 HB, 0.5 MS, 4 oil)	104.0	6.87	10.97	0.85
RPL-HMMS-2 (0.95 HB, 0.05 MS, 4 oil)	98.6	6.87	10.97	0.85
RPL-HMMS-3 (1.0 MS, 4 oil)	109.7	6.87	10.97	0.85
RPL-HM (1.0 HB, 4 oil)	79.5	6.87	16.03	0.85
RPL-HET 1: (1.0 HB, 4 ethanol)	64.2	6.87	29.99	1.73
RPL-HEB (3 HB)	362.5	7.15	7.15	2.59

As the blister pack containing hexyl butyrate in ethanol seemed to give a more persistent formulation, in the third series of experiments two formulations of hexyl butyrate in ethanol (HET-1 1 g : 4 g; HET-3 4 g : 1 g, respectively) were compared with a blister pack containing ethanol only. Results in Fig. 2.2.6 show that the 4:1 blend of hexyl butyrate and ethanol released hexyl butyrate rapidly (520 mg/h) and lasted less than 10 d. The 1:4 blend of hexyl butyrate and ethanol was more persistent and was still releasing hexyl butyrate after 15 d at approximately 50 mg/d allowing for the concomitant release of ethanol.

These results were confirmed by collection of volatiles from the sachets and quantitative GC analysis.

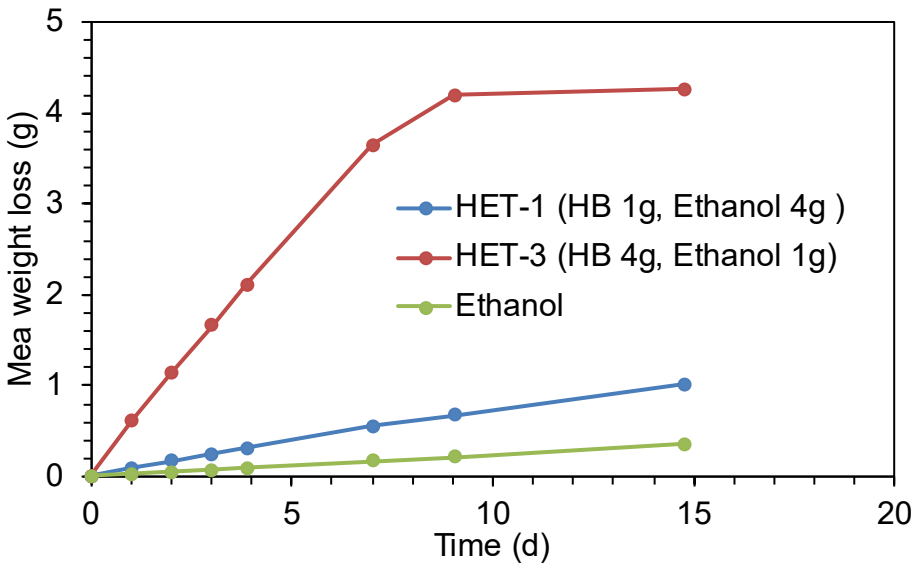


Fig. 2.2.6. Release rates from Russell IPM blister pack formulations of hexyl butyrate in ethanol as measured by weight loss (27ºC, 8 km/h windspeed)

Discussion

The Russell IPM blister packs provide a convenient, commercially-available formulation of hexyl butyrate for use in control of capsids by a push-pull approach. The studies described here show that the standard blister pack formulation containing 1 g hexyl butyrate in 4 g paraffin oil releases the hexyl butyrate at a rate (approx. 80 mg/d) comparable to that from the standard NRI polyethylene sachets (approx. 100 mg/d) used in all previous push-pull field trials. Furthermore, the hexyl butyrate could be combined with methyl salicylate, in a single formulation with release rate proportional to the proportion of compound in the blend.

However, both the blister pack and polyethylene sachet formulations had an unexpectedly short lifetime at 27ºC and 8 km/h windspeed. Preliminary studies suggest this can be extended by mixing the hexyl butyrate with ethanol which is released simultaneously.

Conclusions

- The Russell IPM blister packs provide a convenient, commercially-available formulation of hexyl butyrate for use in control of capsids by a push-pull approach.
- A standard blister pack formulation releases hexyl butyrate at a similar rate to that from the NRI standard polyethylene sachets used in previous field trials.
- The hexyl butyrate can be combined with methyl salicylate.
- The blister packs and polyethylene sachets showed an unexpectedly short lifetime under laboratory conditions and experiments are under way to extend this.

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

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)

Introduction

Currently, a literature review is being prepared for the AHDB on the impact of organic treatments and floral margins for pest and disease control in orchards. In addition, an Interreg project (BeeSpoke) has begun, aimed at designing bespoke floral margins to encourage pollinating insects into flowerings crops. In 2019, a replicated experiment of floral margins was sown around the WET Centre at NIAB EMR 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 BeeSpoke will facilitate surveys of pollinating insects.

Several research studies, and growers themselves, 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 plots in the HWH project at the NIAB EMR Wet Centre (funded by the Rivers Trust in 2019) will remain in place for 2020 when the perennial flower plots will flower for the first time. This wildflower resource offers an ideal opportunity to monitor margins for beneficial and pest species of soft fruit crops including ladybirds, lacewings, and hoverflies, but also capsids, and thrips.

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 have been shown to be effective in increasing the abundance of pollinators and natural enemies. 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 could provide a food source for natural enemies in the form of alternative prey, pollen, and nectar, and as a shelter and overwintering habitat.

In this trial we aimed to:

1. Estimate the impacts of 3 floral treatments on pests, natural enemies and pollinators in compared to an unsown control

2. Monitor the establishment and floral resource in the margins
3. Establish and begin to monitor floral margins on commercial farms in the vicinity of soft fruit crops

Materials and Methods

In 2019-2020, we began to work with growers to establish floral margins adjacent to soft fruit crops (Table 3.5.1). These will begin to be monitored in 2021, firstly for establishment and then for natural enemies both in the floral margins and at distances into the crop.

Table 3.5.1. Farms (blocks), growers, crop and starting assessment dates for the floral margin trial 2020.

Code	Address	Field	Crop	Floral resource	Assessed from
7	Hugh Lowe Farm	Adamswell	Strawberry	Margin	2021
10	Hugh Lowe Farm	Hopper Huts	Raspberry	Margin	2021
14	NIAB EMR	WET Centre	Strawberry	Margin	2020
B1F	Roughways Farm	-	Raspberry	Margin	2021

Site 14:

Site 14 was established in 2019 and could be assessed in 2020. Single species (Chicory or Sainfoin) and a species mix (EM1, sourced from Emorsgate Seeds) of wildflowers was sown (broadcast, rolled and irrigated in 2019) around WET centre polytunnels. Tunnels were 50 m in length and 8.5 m wide (Fig. 3.5.1). An untreated (no sowing) control was included and allowed to establish as 'tumbledown'. There were 8 replicates of each treatment. The tunnel was divided into two – one half had water capture, so very little water runs off the polythene onto the ground, and the other half was normal commercial practice.

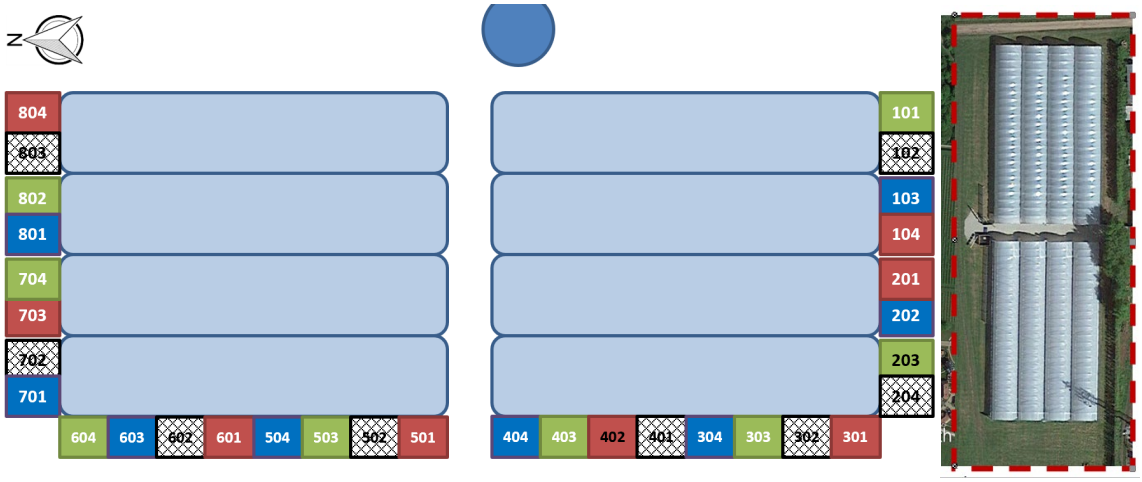


Figure 3.5.1. Left: Schematic of WET centre polytunnels at NIAB EMR with commercial practice and advanced water capture and treatment practice. North & South plot are approx. 4x4 m and West plots 6x6 m. Green = untreated, Red = sainfoin, Blue = chicory and White/black = Meadow mix EM1. Right: Water Efficient Technologies (WET) Centre polytunnels.

There was one assessment per month between May and August (4 assessments total);

1. The percentage **vegetation coverage** in all plots was assessed once in July. Photographs of plots were taken at each visit. Sown and unsown species ground coverage were assessed in 2 replicates of 50x50 cm quadrat per plot.
2. **Floral units** were measured by placing a 50x50 cm quadrat at flower height in each plot and recording the number and identification of flowering heads.
3. **Pests, herbivores and beneficials** were sampled using a sweep net. Three sweeps were taken in each plot. The net was then slowly unfolded, and arthropods recorded. In addition, an alternative method using a bug vacuum was tested to sample the floral plots. Suction was applied for 10 second and all invertebrates collected into a sample cup. Ethanol (70%) was added to samples after collection to avoid predation between Arthropods. For all samples, macro-arthropods were identified into broad groups e.g., spiders, lacewings, ladybirds, ground beetles, all considered natural enemies in strawberry. Insects considered a potential pest were identified further, e.g., capsids (adults and juveniles), aphids, blossom weevil, SWD, etc.
4. **Thrips** were sampled from flower heads from each flowering species in each plot. A standard number of flower heads for each species was determined depending on flower size. Between 1 and 5 flower heads were sampled per plot. Flowers were stored in 70% ethanol immediately after picking until sample could be processed.

5. To assess the **MIK extraction device** (SF 156) efficacy on different flower structures, on the first sampling occasion (May), flower heads were collected into the device. Flowers were left in the device for 10 minutes. After this time insects collected in the bottom compartment of the device were preserved in 70% ethanol for later identification. The flower heads used in the extraction device were also preserved in 70% ethanol for later extraction by washing (NIAB EMR SOP 780). Total numbers of adult thrips and larvae in each sample were counted and a sub-sample (a third of the thrips from each sample with a minimum of 5 and a maximum of 15 specimens) mounted on microscope slide in Polyvinyl alcohol media. Only species recognised as potential strawberry pests were identified to species.

Results

Vegetation cover

Quadrat counts of flower heads (a proxy for floral resource) demonstrated that the single species plots, sainfoin and chicory, had shorter flowering periods than the multi-species plots, EM1 (meadow mix) and unsown (Fig. 3.5.2). Sainfoin flowered from May to July, with a peak in May. Chicory flowered from June to August. Both unsown and EM1 plots flowered May until August following the same trend. In August unsown plots had slightly more flowers than EM1 plots. It was noted that after most sown flowers had ceased flowering hawkbit because the predominant floral resource (September).

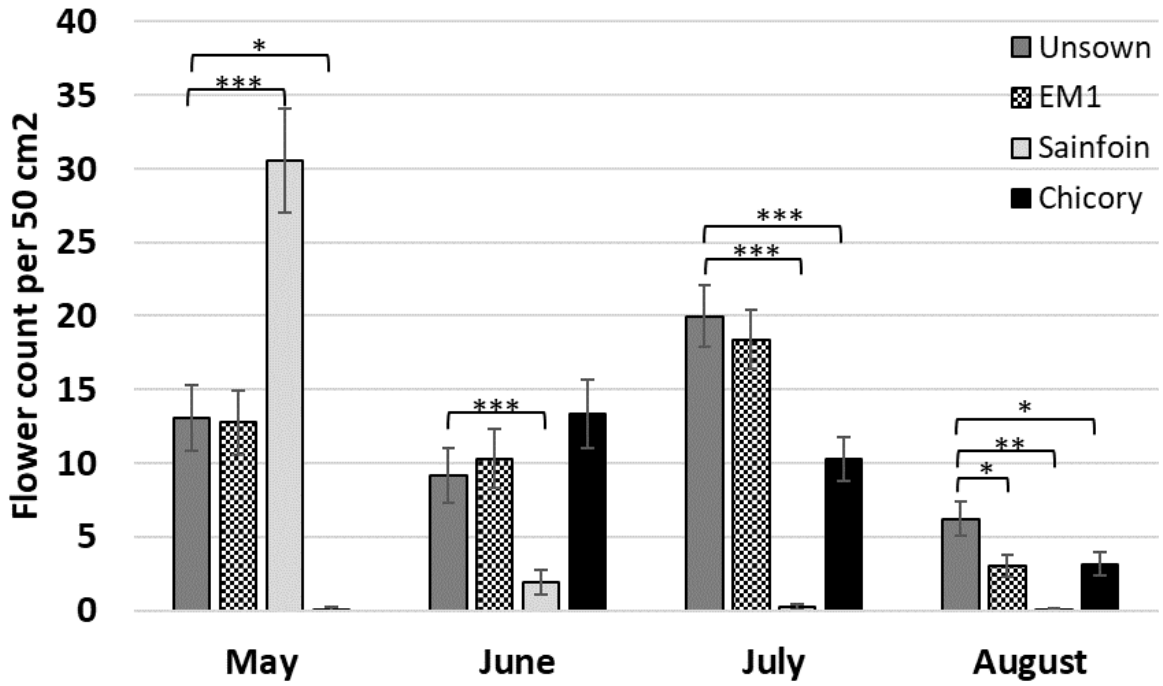


Figure 3.5.2. Mean number (±SE) of flower heads per 50 cm^2 in chicory, unsown, meadow mix (EM1), and sainfoin plots between May and August, at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

In July, the most common plant species in the unsown plots were hawkbit (14%), yarrow (20%), and ribwort plantain (17%). Dead or dry vegetation (20%) and bare ground (14%) was also observed (Fig. 3.5.3). Chicory plots (95%) also had bare ground (4%) and ribwort plantain (1%). Sainfoin plots (92%), had dead or dry vegetation (3%), ribwort plantain (3%), bare ground (1%) and yarrow (1%) (Fig. 3.5.3). The EM1 seed mix establishment was successful. Sown species accounted for 72%, with wild carrot (29%), common bent (23%), smaller cat's tail (8%), common knapweed (8%), and fescue grasses (4%).

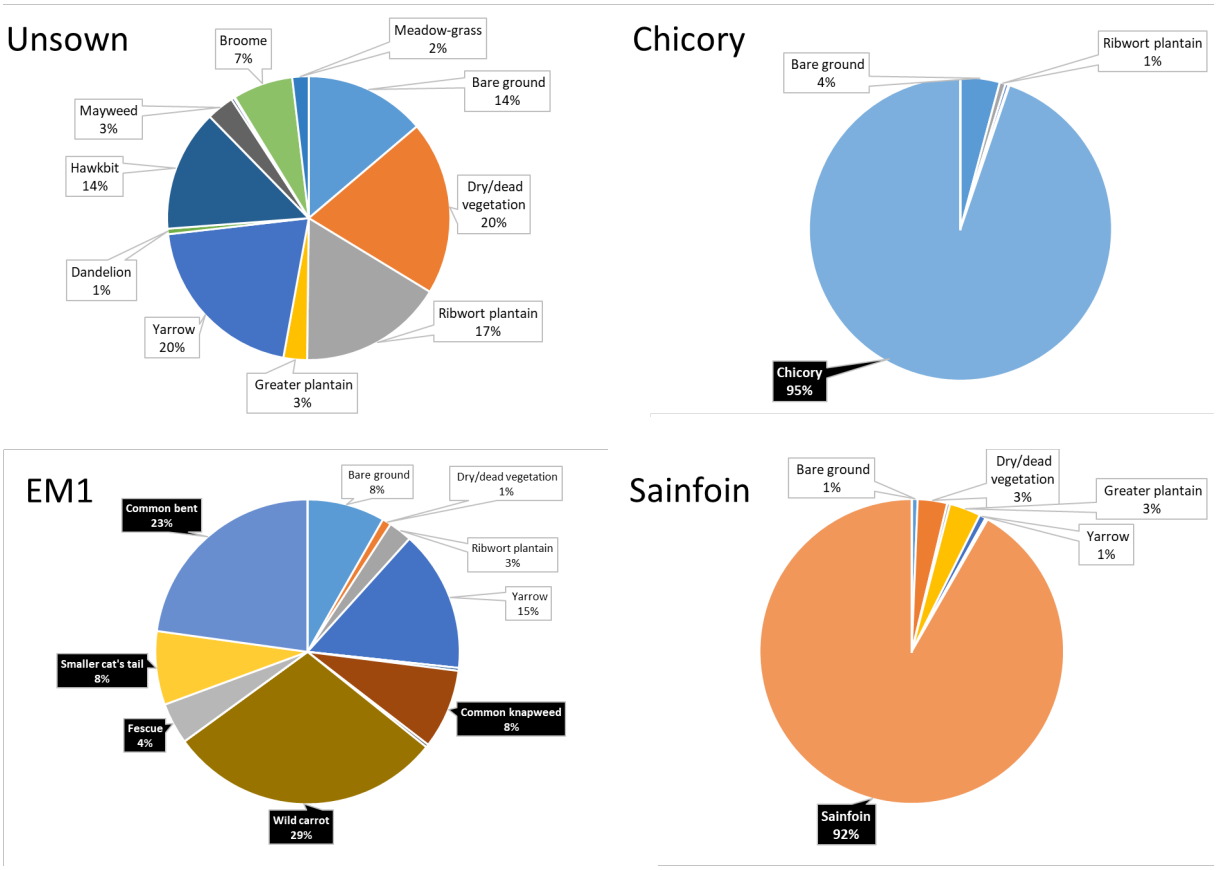


Figure 3.5.3. Mean percentage ground coverage of plant species in each treatment unsown, meadow mix (EM1), chicory, and sainfoin in July at site 14. Measurements were taken with a 50 x 50 cm quadrat and purpose sown species are highlighted in black.

Arthropods in sweep net samples

Sweep net samples covered an area of approximately 1.5 m^2 on each plot. A higher diversity of arthropods was recorded in May and June compared to July and August (Fig. 3.5.4).

In May, the number of anthocorids (p= 0.008), and ants (p= 0.002) were significantly higher in EM1 plots compared to unsown (control) plots. Ants were also significantly higher in sainfoin plots (p=0.019). A weevil, not identified as a strawberry pest, was found in the unsown plots in significantly higher numbers when compared with all sown plots (p<0.001). Unsown and EM1 plots had a more spiders compared with chicory and sainfoin. In May, parasitoids, ladybirds, moths, hoverflies, and soldier beetles were also recorded, but numbers were too low to analyse.

In June, chicory plots had significantly fewer spiders (p= 0.007), ground-bugs (p= 0.003) and weevils (p<0.001) compared with unsown plots. Most of the ground-bugs were from the genus *Nysius*, known as false chinch bugs or seed bugs. Sainfoin plots had significantly fewer pollen

beetles (p= 0.005), and weevils (p<0.001). EM1 plots had significantly more parasitoids (p<0.001), and beetles from the genus *Oedemera* (p= 0.004) and fewer pollen beetles (p= 0.034), and weevils (p= 0.015) compared with unsown plots. The number of ladybirds and moths was higher in June than in May, but no significant difference was observed between treatments.

In July, the number of arthropods was very low in chicory plots. Unsown plots had a higher number of arthropods followed by EM1, and sainfoin plots (Fig. 3.5.5). Unsown plots recorded significantly more parasitoids ($p_{chicory}$< 0.001, p_{EM1}= 0.012, $p_{sainfoin}$< 0.001), and anthocorids (p<0.001) on this occasion, compared with other treatments. Sainfoin plots had significantly fewer ground-bugs (p= 0.042), whilst chicory had significantly fewer weevils (p= 0.002) compared with unsown plots. The numbers of *Oedemera*, pollen beetles, and ladybirds were too low to analyse.

In August, the numbers of ground-bugs, and spiders increased in unsown and EM1 plots compared to July (Fig. 3.5.5). Only ground-bugs were recorded with significantly higher numbers on unsown plots when compared with all other treatments ($p_{chicory}$<0.001, p_{EM1}=0.017, $p_{sainfoin}$<0.001).

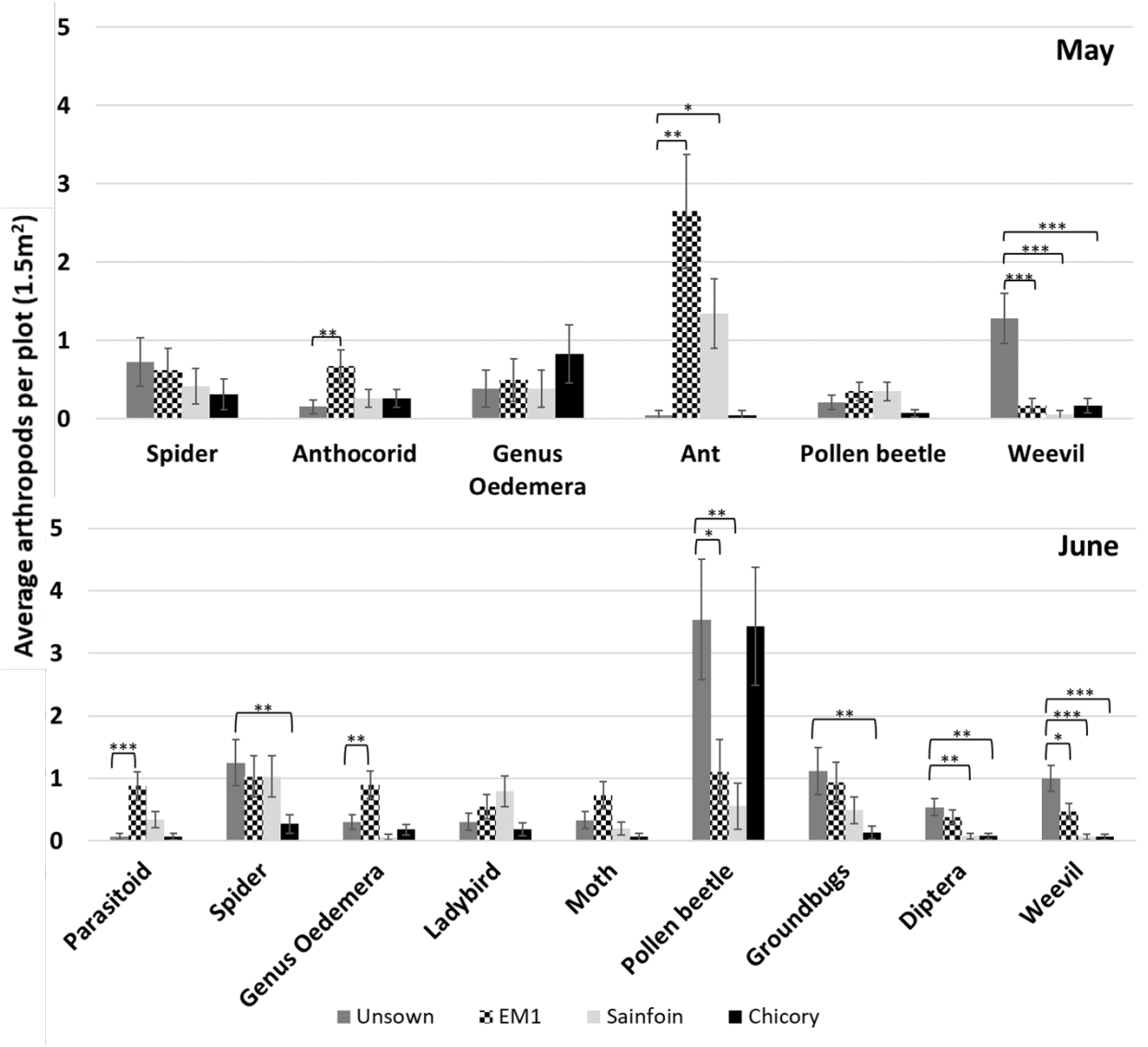


Figure 3.5.4. Mean number (±SE) of beneficial Arthropods per sweep net sample (1.5 m^2) unsown, meadow mix (EM1), chicory and sainfoin plots sampled in May and June at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

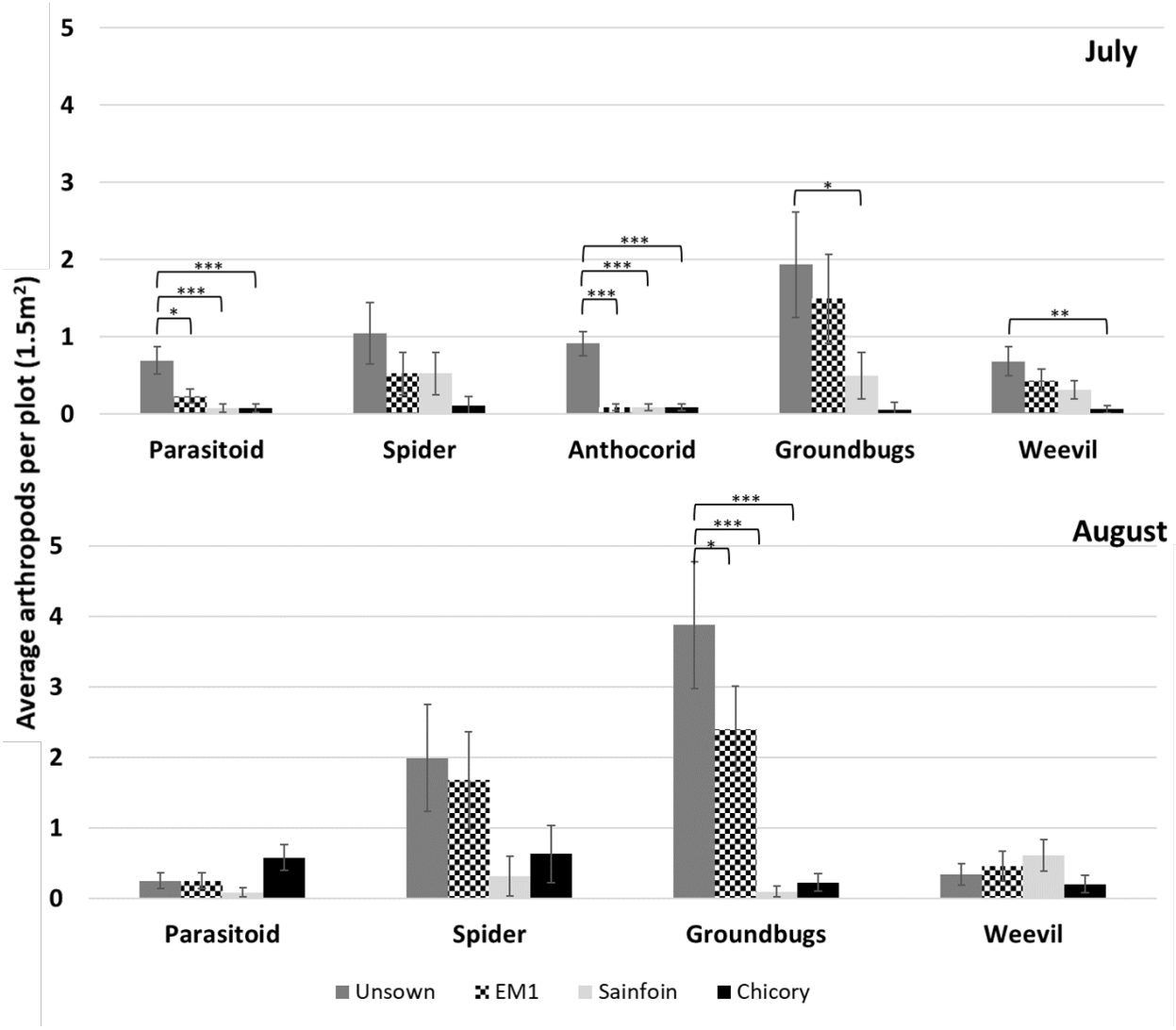


Figure 3.5.5. Mean number (±SE) of beneficial arthropods per sweep net sample (1.5 m^2) unsown, meadow mix (EM1), chicory and sainfoin plots sampled in July and August at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Pests and herbivores

Most herbivores or potential strawberry pests in all plots were capsids and aphids. Aphids were not species recognised as strawberry pests and were dominated by one species suspected to be pea aphids (to be confirmed in 2022).

In May, significantly fewer capsid adults were found in chicory (p=0.014), and EM1 (p=0.014) plots when compared with unsown plots (Fig. 3.5.6). Similar numbers of aphids were observed in unsown, EM1, and sainfoin plots. As with beneficials, very few herbivorous arthropods were recorded in chicory plots.

In June, the numbers of adult capsids were similar to those observed in May (Fig. 3.5.6). Although there was a slight increase in capsid nymphs in EM1 plots, in sainfoin plots numbers almost tripled (p= 0.001) compared with unsown plots. The number of aphids decreased in unsown and EM1 plots from May to June. However, in June, numbers of aphids remained similar in sainfoin plots, having significantly more aphids (p= 0.002) than unsown plots.

In July and August, the numbers of capsid nymphs and aphids were too low to analyse (Fig. 3.5.6). The number of adult capsids recorded in July were significantly lower on chicory (p= 0.006), and sainfoin (p= 0.006) plots compared with unsown plots.

The strawberry crop was tap sampled on 3 occasions between mid-June and mid-July, when numbers were higher in floral margins. No capsid species were recorded in the crop.

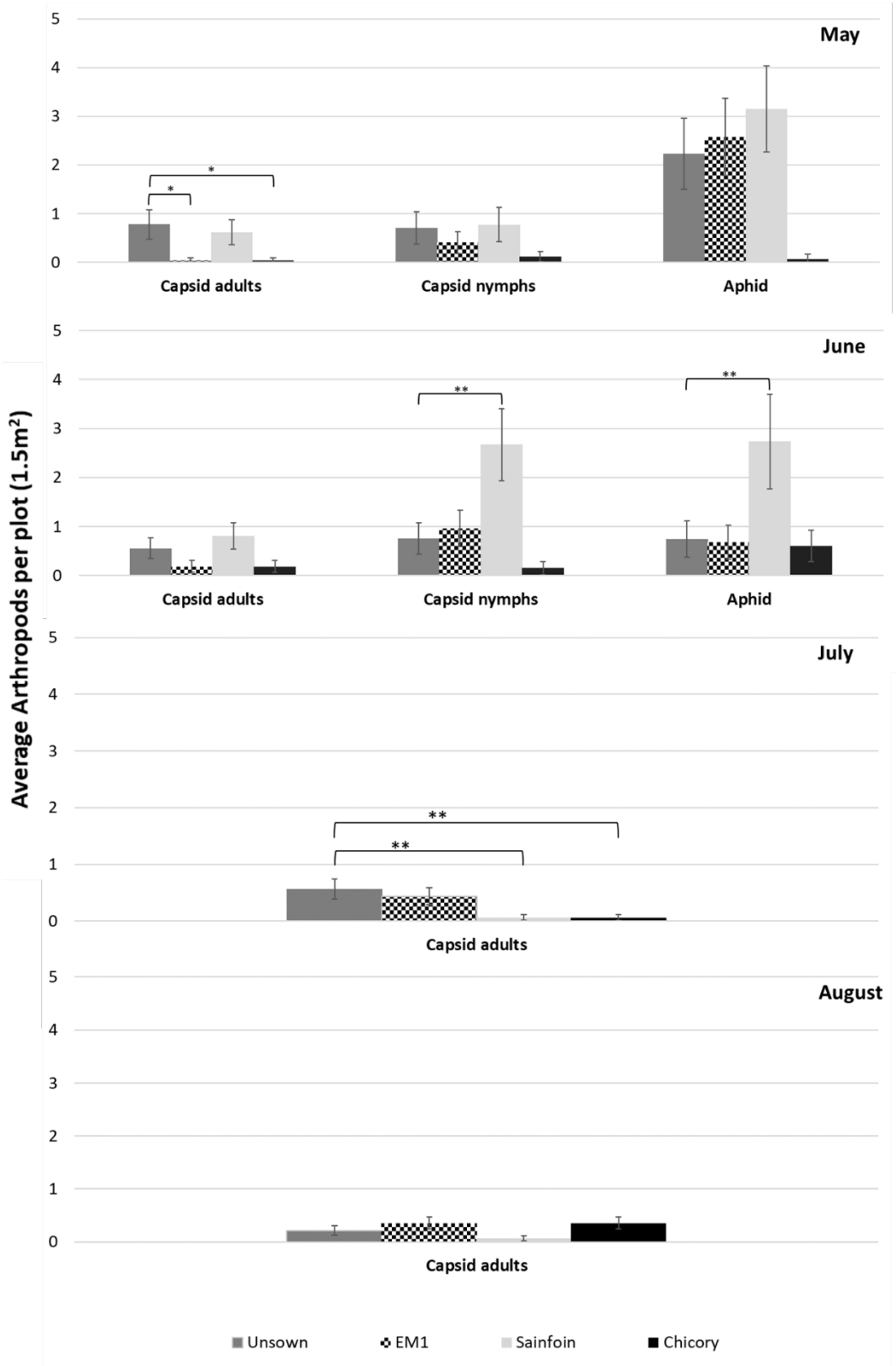


Figure 3.5.6. Mean (±SE) of pests and herbivores per sweep (1.5 m^2) sweep net sample (1.5 m^2) unsown, meadow mix (EM1), chicory and sainfoin plots sampled in May, June, July, and August at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Capsid identification

Three capsid species were identified in the floral margins: Common Green capsid (*Lygocoris pabulinus*), European Tarnished plant bug (*Lygus rugulipennis*), and Potato capsid (*Closterotomus norvegicus*). Unsown and sainfoin plots had higher numbers of Common Green capsid (1.8 ±0.5 per 1.5 m^2). The numbers of European Tarnished plant bug were low and similar across all treatments (Fig. 3.5.7). Overall, lower numbers of capsids were observed in chicory (0.2 ±0.2) and EM1 (0.9 ±0.3) plots compared to unsown plots (2.0 ±0.5), but this was not significant. Only chicory (p=0.032) plots had significantly fewer common green capsid when compared with unsown plots.

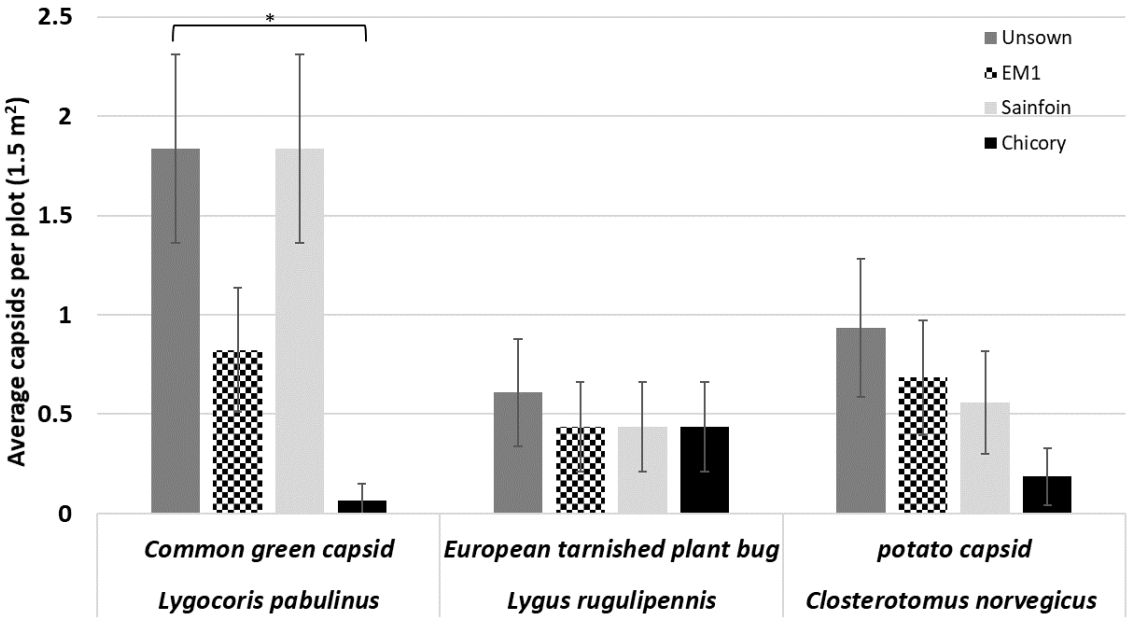


Figure 3.5.7. Mean (±SE) of capsid species in unsown, meadow mix (EM1) chicory and sainfoin plots assessed in June at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Thrips in flower heads

In May, thrips adults and/or larvae were found in all sown and unsown plant species (Fig. 3.5.8). Dandelion (5.8), and sainfoin (3.8) contained the highest average number of adult thrips per flower, while oxeye daisy (3.8 ±0.7) had significantly higher numbers of larvae per flower than all other plant species. Only oxeye daisy and red campion had higher larval numbers than adults per flower. Dandelion had significantly more adult thrips than oxeye daisy. Larvae were not identified as part of this project.

In May, we recorded the presence of *Frankliniella occidentalis* (Western Flower thrips), *Thrips tabaci* (Onion thrips), and *Frankliniella intonsa* (Flower thrips) and other thrips species that were not considered soft fruit pests. These thrips are referred to in the results as “Other thrips” (Fig. 3.5.9). Less than 2 thrips per flower were recorded in all plant species for *F. occidentalis*, *T. tabaci* and *F. intonsa*. Numbers of other thrips in dandelion were significantly higher when compared with oxeye daisy ($p=0.014$), red campion ($p<0.001$) and sainfoin ($p<0.001$) sampled in May. Other thrips in oxeye daisy were significantly higher when compared with red campion ($p=0.002$) and sainfoin ($p=0.005$). Oxeye daisy had, on average, 1.8 ‘other thrips’ per flower, of these 0.5 were an *Haplothrips* sp., suspected to be *Haplothrips leucanthemi*; known to feed and lay eggs in oxeye daisy. Numbers of *F. occidentalis* were significantly higher in sainfoin when compared with oxeye daisy ($p<0.001$), red campion ($p=0.014$) and white clover ($p=0.001$).

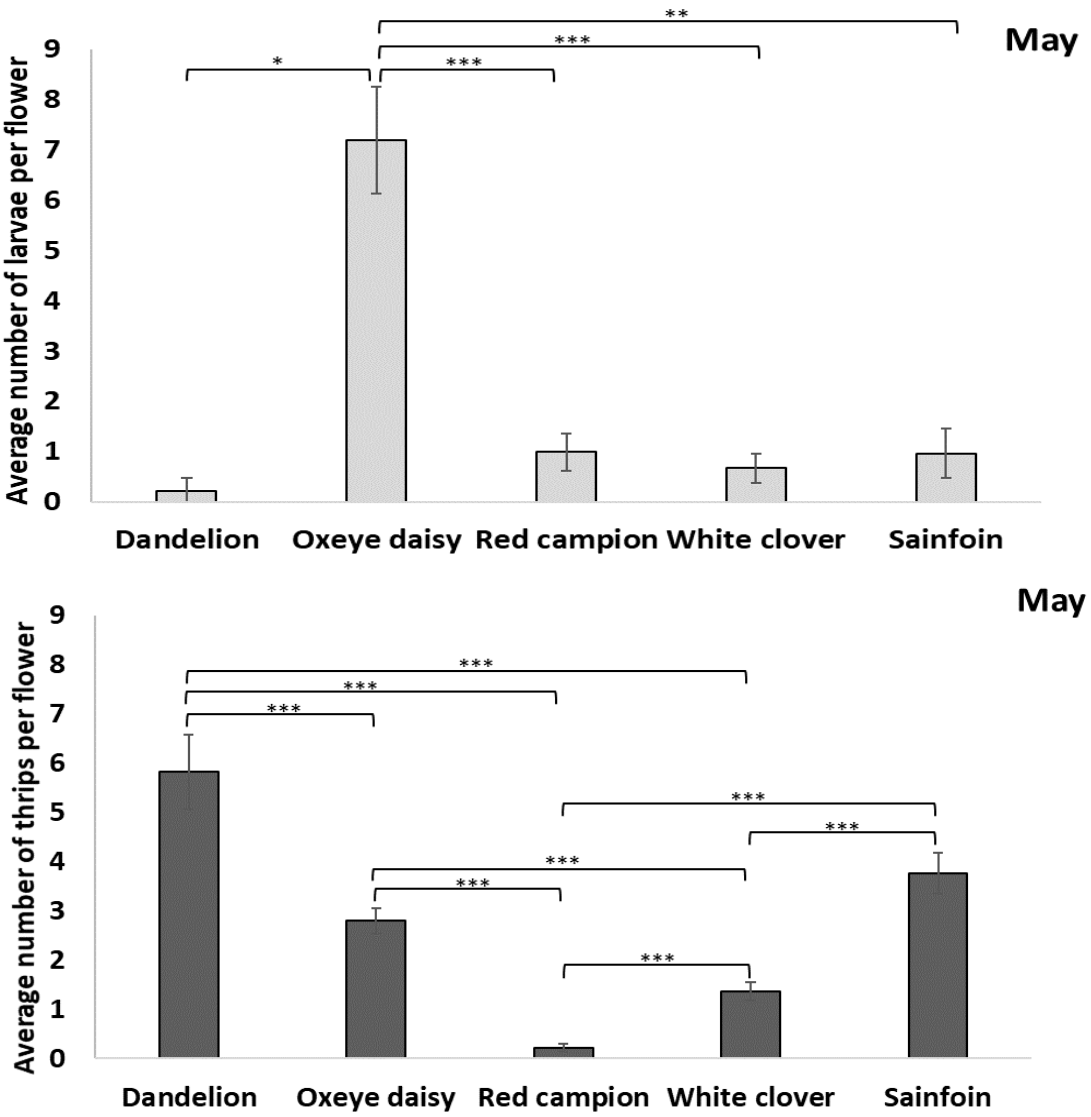


Figure 3.5.8. Mean (±SE) of larvae (top, light grey) and adult thrips (bottom, dark grey) per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in May at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

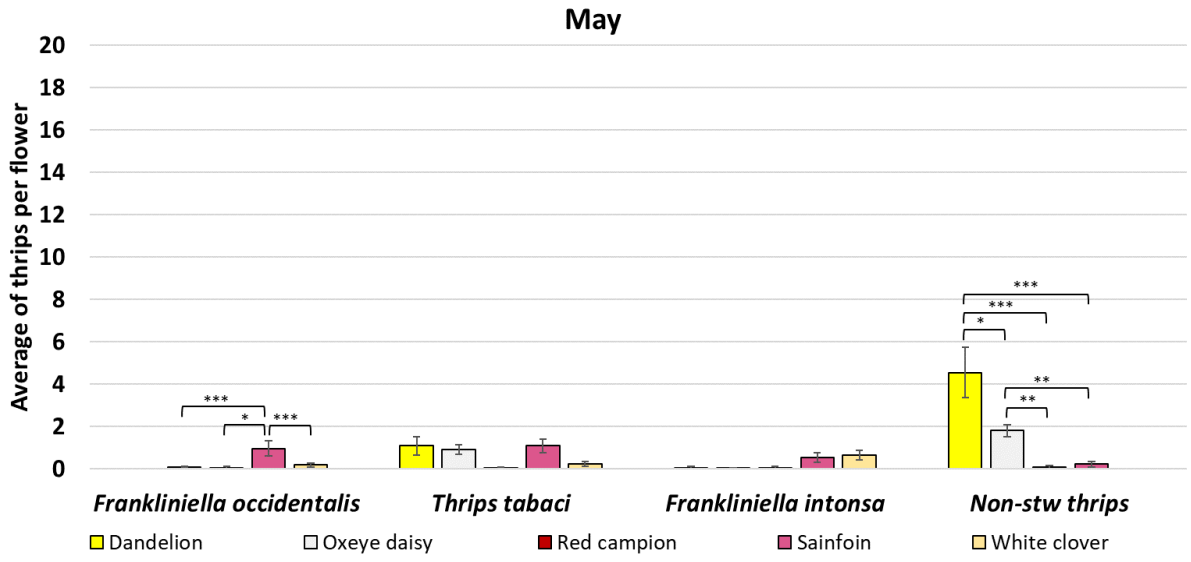


Figure 3.5.9. Mean (±SE) of thrip species per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in May at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

In June, more species of flower were available to thrips and the number of adult thrips increased when compared with May (Fig. 3.5.10). Plant species with higher numbers of adult thrips per flower, were bindweed (8.0 ±3.3) and hawkbit (13.8 ±3.9) found in unsown plots. Larvae numbers were lower than 2 larvae per flower for most plant species, except for sainfoin (3.2 ±0.6) and wild carrot (2.5 ±0.9). Sainfoin had significantly higher numbers of larvae than chicory ($p=0.013$) and yarrow ($p=0.004$). Hawkbit had significantly higher numbers of adult thrips when compared to chicory ($p=0.007$), oxeye daisy ($p<0.001$), red clover ($p=0.043$) and sainfoin ($p=0.002$). Yarrow also recorded significantly more adult thrips than oxeye daisy ($p=0.045$) (Fig. 3.5.10).

In June we recorded the same thrips species found in May: *F. occidentalis*, *T. tabaci*, *F. intonsa* along with 'other thrips' (Fig. 3.5.11). Average numbers of *F. occidentalis* were under 2 thrips per flower in all plant species sampled. Higher numbers of *T. tabaci* were found on yarrow (5.2 ±1.0) and wild carrot (6.7 ±2.3). These 2 species had significantly more *T. tabaci* when compared to oxeye daisy ($p_{yarrow}=0.004$; $p_{WildCarrot}=0.004$). On average, for *T. tabaci* under 2 thrips per flower was recorded for all other plant species. We found white clover had the highest average numbers of *F. intonsa* (5.1 ±4.1) when compared with the other plant species sampled in June but was only significantly different from oxeye daisy ($p=0.047$). All other plant species had 1.2 or fewer *F. intonsa* per flower. Plant species that recorded higher

than average numbers of ‘other thrips’ were hawkbit (10.9 ±9.2) and bindweed (3.9 ±3.8). ‘Other thrips’ in hawkbit were significantly higher when compared to oxeye daisy (p=0.042).

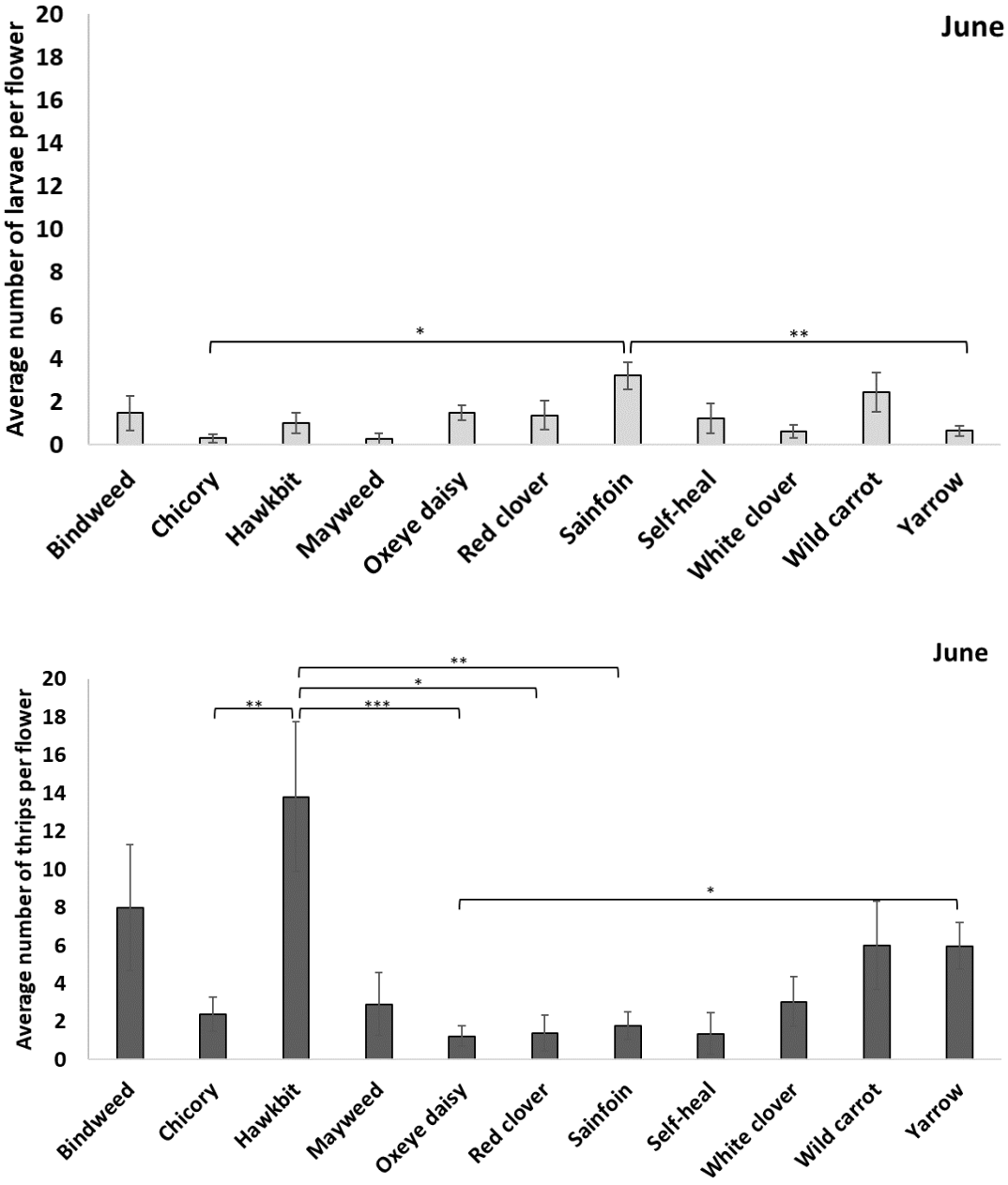


Figure 3.5.10. Mean (±SE) of larvae (top, light grey) and adult thrips (bottom, dark grey) per flower in each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in June at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

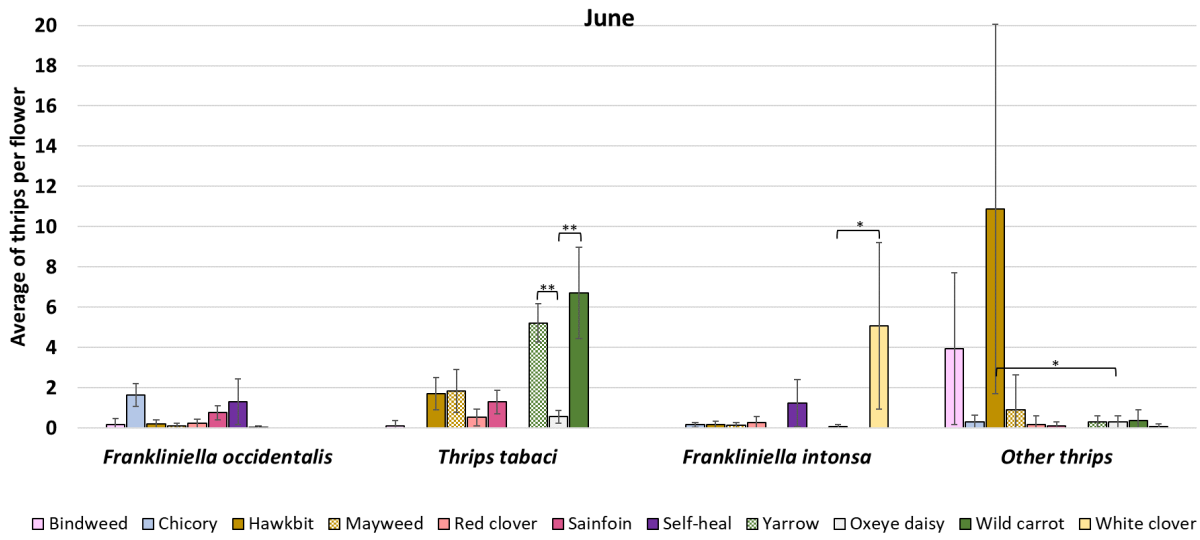


Figure 3.5.11. Mean (±SE) of thrips species per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in June at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

In July, flower richness and abundance decreased and sainfoin plots finished flowering. Thrips larvae were less than 2 per flower for all plant species and overall number of thrips decreased when compared with June (Fig. 3.5.12). Hawkbit (7.7 ±1.1) was the unsown species with the highest number of adult thrips per flower. In EM1 plots, the only 2 plant species flowering, common knapweed, and wild carrot, had similar numbers of adult thrips (respectively 4.7 ±1.0 and 4.4 ±1.6). Hawkbit had significantly more adult thrips when compared with chicory (p<.001) and yarrow (p<.001).

In July, *F. intonsa* was found in low numbers and was not statistically analysed. Average numbers of *F. occidentalis* were below 2 thrips per flower. Common knapweed had significantly more *F. occidentalis* when compared with yarrow (p=0.041). Wild carrot had significantly higher numbers of *T. tabaci* (4.4 ±1.4) when compared with yarrow (p=0.042), common knapweed (p=0.003), hawkbit (p<.001) and chicory (p=0.018). We also recorded significantly higher numbers of *T. tabaci* in yarrow when compared with hawkbit (p=0.010). Hawkbit had significantly higher numbers of other thrips when compared with chicory (p=0.001), common knapweed (p=0.005), yarrow (p<0.001) and mayweed (p=0.034). We also recorded significantly more 'other thrips' in common knapweed than in yarrow (p=0.005). Hawkbit (6.7 ±1.2) and common knapweed (2.2 ±0.6) had higher average numbers of other thrips per flower, while the other plant species sampled in July had fewer than 0.5 other thrips per flower.

In July we collected 3 samples of dog rose (*Rosa canina*) from 2 hedgrows at NIAB EMR. We recorded the presence of adults and larvae of *T. tabaci* (respectively, 0.7 and 1.9 individuals per flower head) but only adults of *T. fuscipennis* (0.5 individuals per flower head). An average of 1.8 "1st instar" individuals per flower was observed, but 1st instar identification to species was not possible.

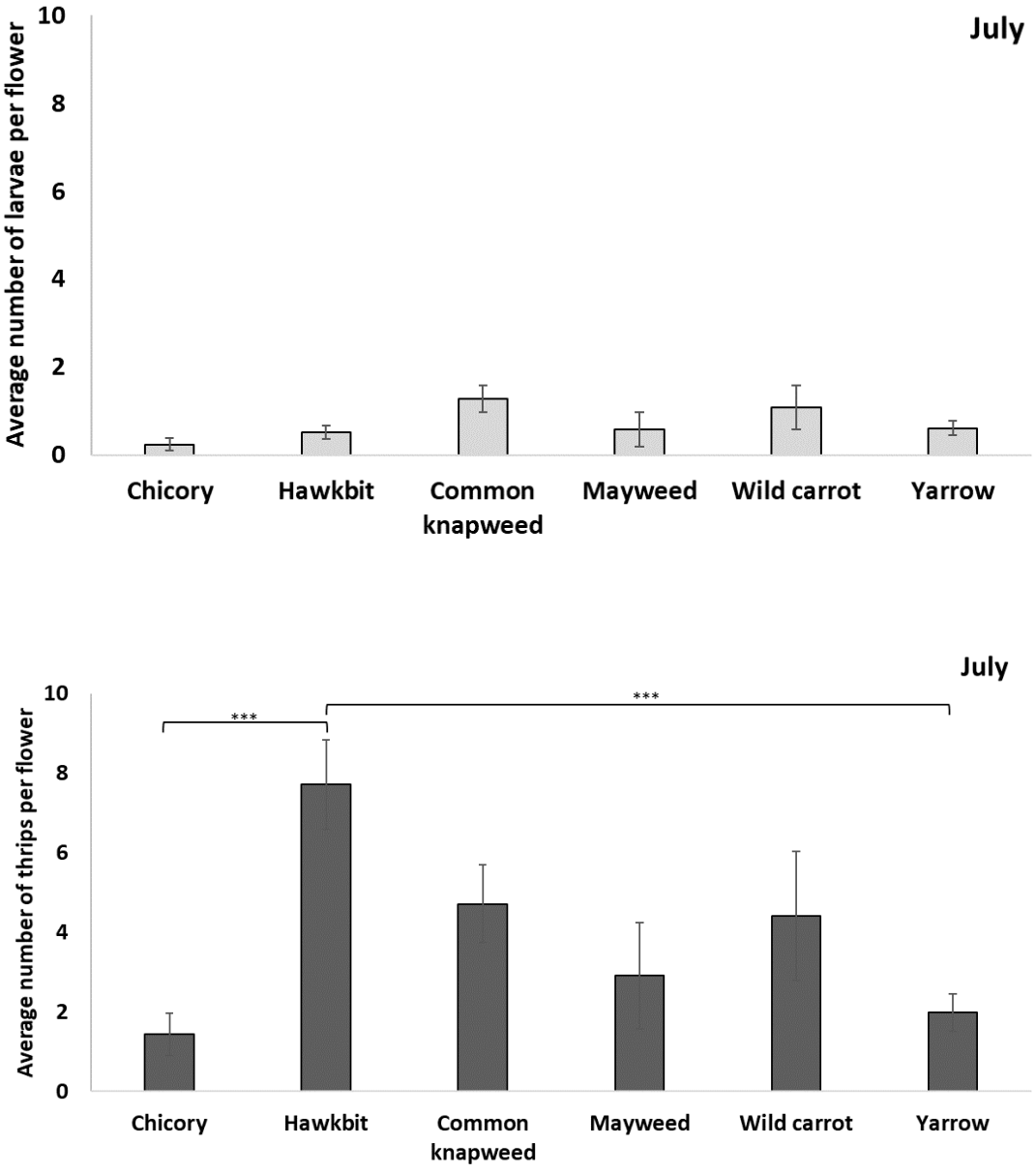


Figure 3.5.12. Mean (±SE) of larvae (top, light grey) and adult thrips (bottom, dark grey) per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in July at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

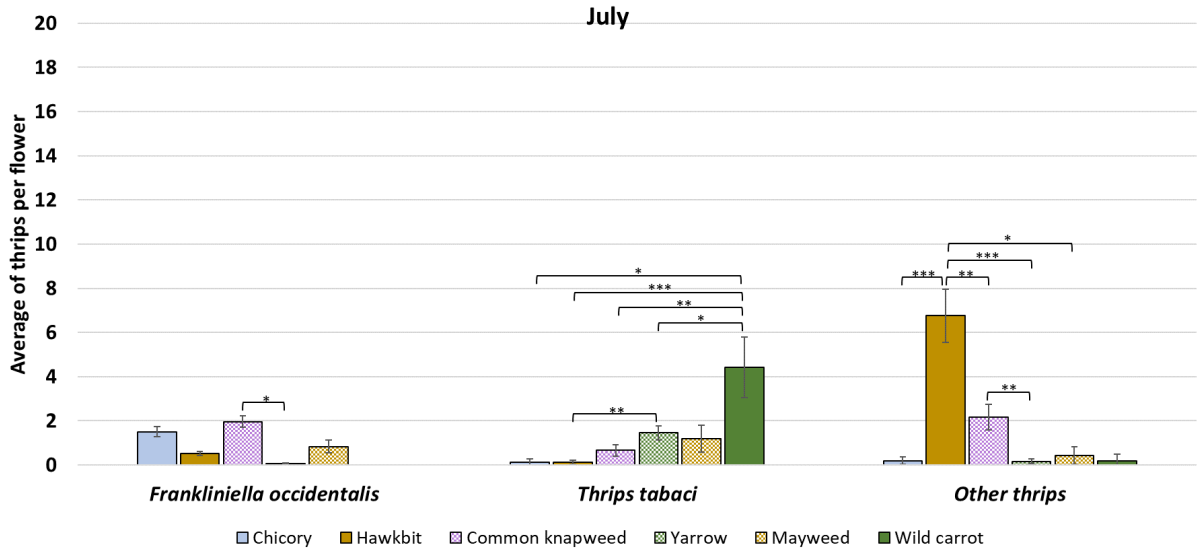


Figure 3.5.13. Mean (±SE) of thrip species per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in July at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

In August, only chicory and unsown plant species were flowering. Numbers of adult thrips declined even more when compared to July. Hawkbit (11.1 ±6.6) had high number of adult thrips and was significantly different when compared to chicory (p=0.001) and yarrow (p=0.004). Chicory and yarrow flowers had very few adult thrips and larvae (Fig. 3.5.14).

In August only *F. occidentalis* and 'other thrips' were found on the plant species sampled (Fig. 3.5.15). We recorded 2.0 (±1.9) *F. occidentalis* on yarrow and this was significantly higher when compared to hawkbit (0.032 ±0.032) (p=0.003). Most other thrips on hawkbit (13.6 ±6.2) and significantly higher when compared to chicory (p<0.001) and yarrow (p<0.001).

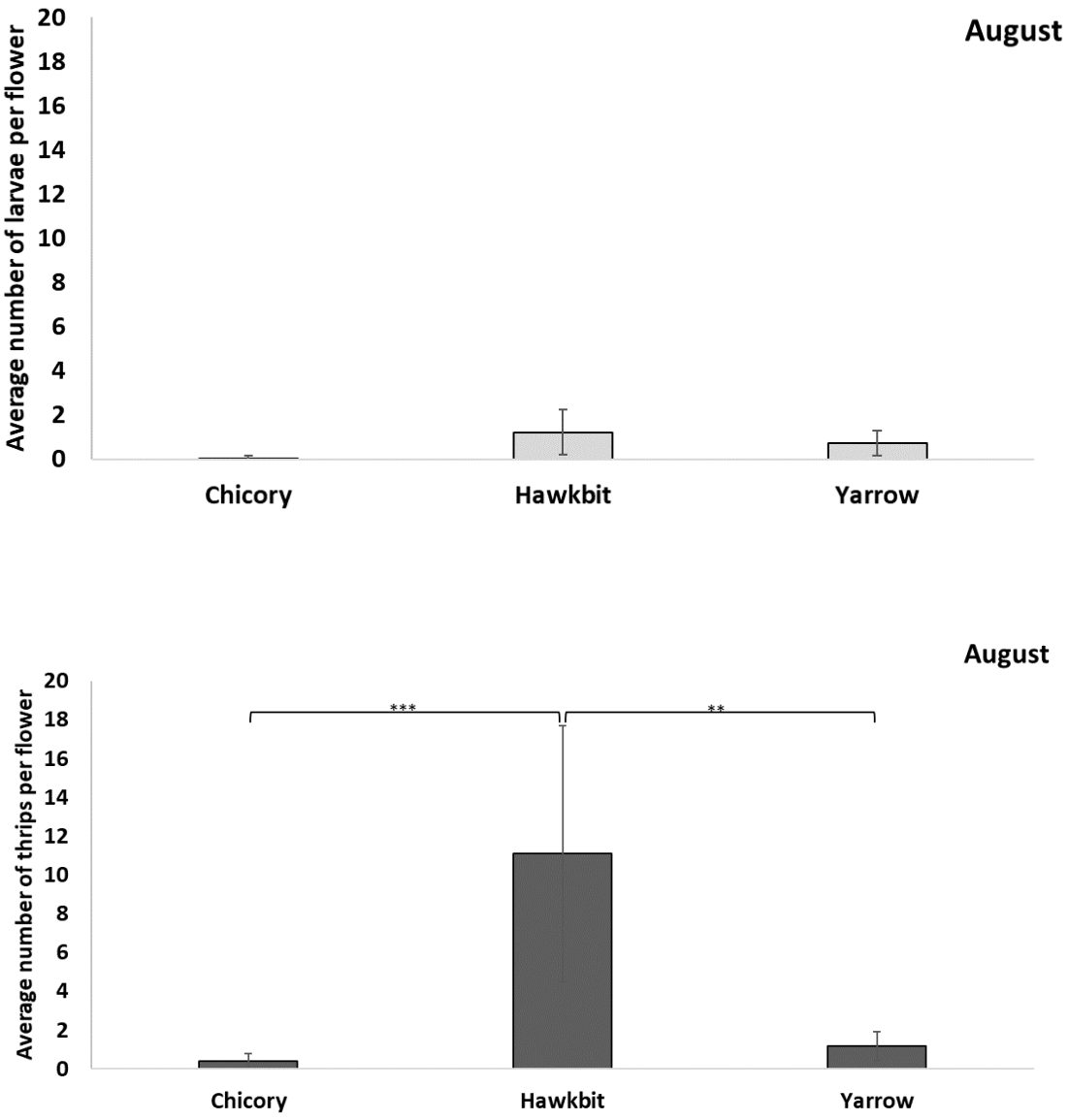


Figure 3.5.14. Mean (±SE) of larvae (top, light grey) and adult thrips (bottom, dark grey) per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed in August at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

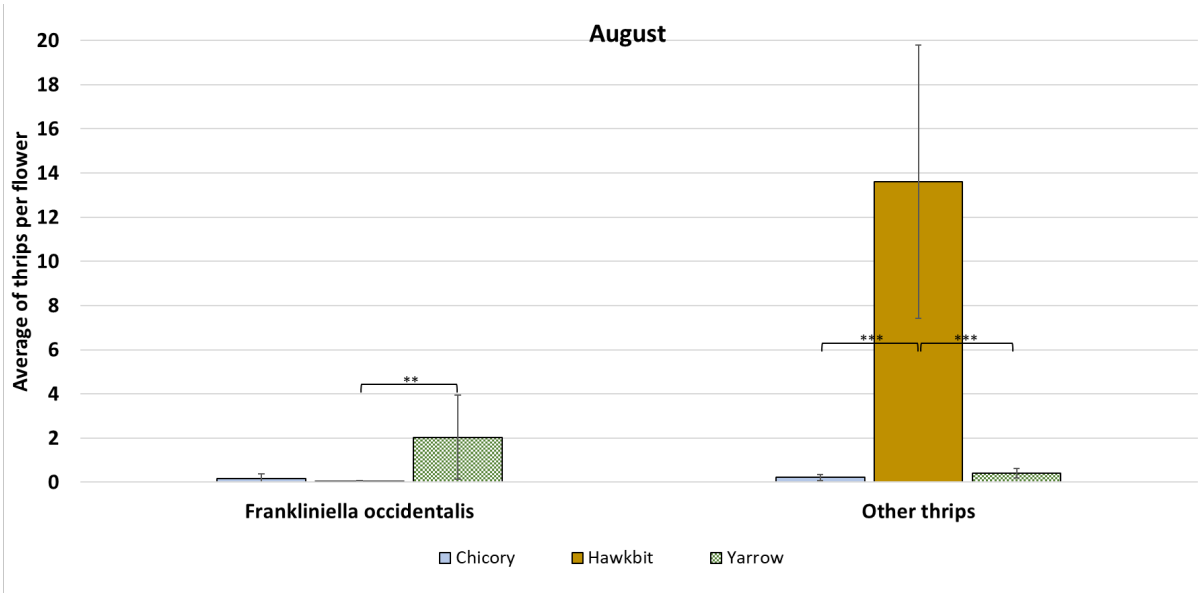


Figure 3.5.15. Mean (±SE) of thrip species per flower in each plant species sampled of unsown, meadow mix (EM1), chicory and sainfoin plots assessed in August at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Natural enemies in flower heads

While assessing for thrips species in the floral margins we also recorded relevant natural enemies found in plant species sampled (Fig. 3.5.16); thrips, carabid beetles, parasitoids and *Orius* (nymphs and adults). In May, numbers of parasitoids were too low to analyse. Predatory thrips (*Aeolothrips*) were found in red campion, sainfoin and white clover. Numbers of predatory thrips were significantly higher in sainfoin when compared to red campion and white clover. Carabid beetles were found on sainfoin and white clover, but no significant difference was observed.

In June, predatory thrips were found on red clover, sainfoin, self-heal and wild carrot. Parasitoids were observed on red clover, wild carrot, hawkbit, oxeye daisy and yarrow. *Orius* nymphs were recorded on chicory, sainfoin, wild carrot, oxeye daisy and yarrow. No significant differences were found.

In July, predatory thrips were found in chicory, yarrow, and common knapweed. Numbers of predatory thrips were significantly higher in common knapweed when compared to yarrow. *Orius* nymphs were found in chicory, wild carrot, hawkbit, yarrow, common knapweed and mayweed. Adults were only recorded on yarrow and common knapweed. No significant difference was observed between numbers of *Orius* found on plant species sampled.

In August flowering species decreased. Parasitoids and *Orius* adults were both recorded on hawkbit and yarrow, but no significant differences were found.

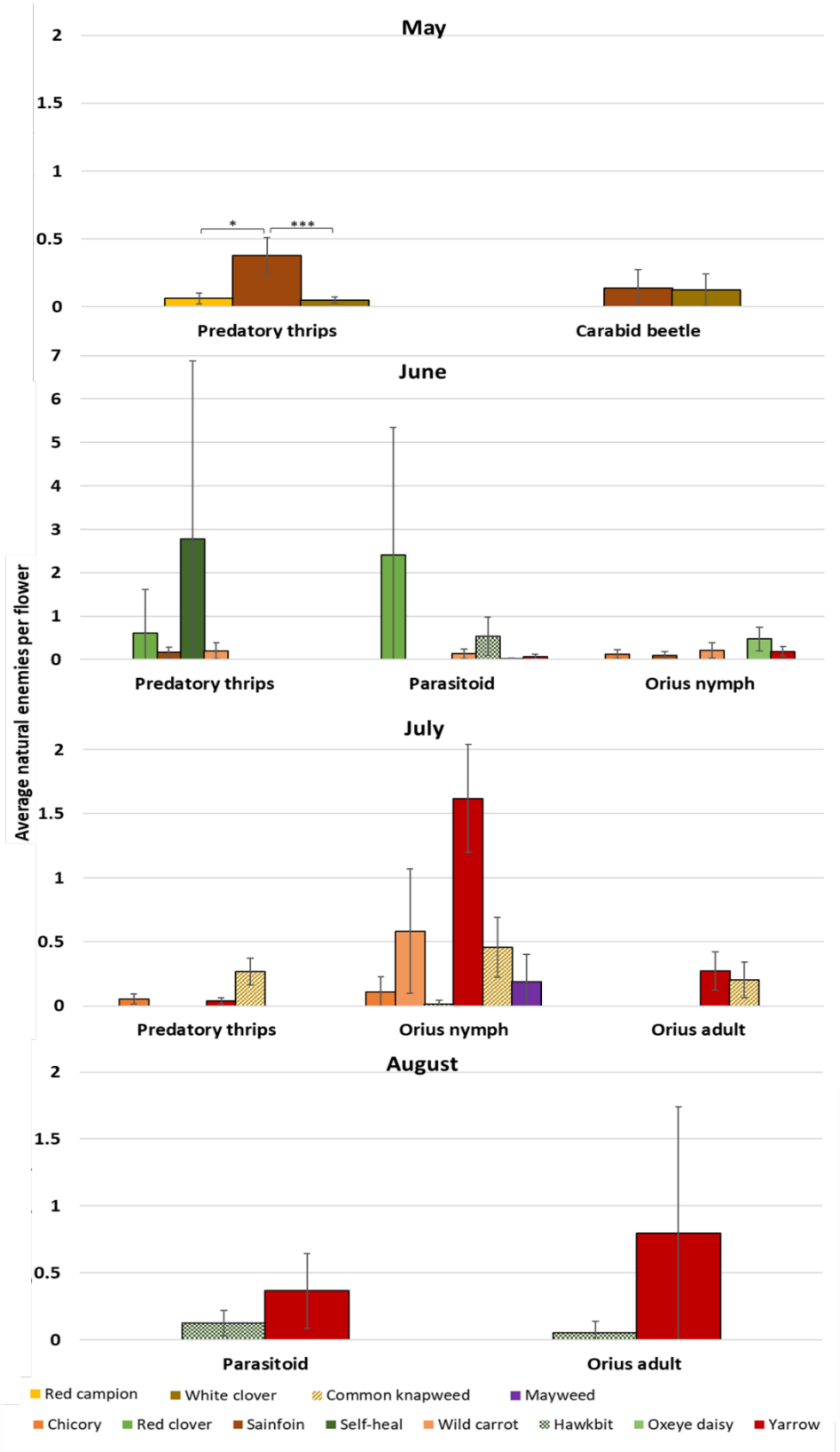


Figure 3.5.16. Mean (±SE) of natural enemies per flower of each plant species sampled in unsown, meadow mix (EM1), chicory and sainfoin plots assessed between May and August at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). Note: June chart in different Y axes scale.

Extraction device

MIK extraction device previously developed in SF 156 for use on strawberry flowers to extract thrips, was tested on the wildflower species (Fig. 3.5.17). The aim was to investigate if the device could be used on more complex flower structures.

The MIK extraction device successfully removed the majority (overall extraction percentage = 96%) of thrips adults from dandelion, meadow buttercup, oxeye daisy, sainfoin and white clover samples (Fig. 3.5.18). In mayweed, red campion, red clover, and wild carrot all thrips in the samples were recovered using the extraction device.

Larvae recovery was lower and variable between flower species (Fig. 3.5.19). Recovery of larvae ranged from 3 in 11 (21%) for red campion to 7 in 8 (88%) for meadow buttercup.

Figure 3.5.17. Extraction device with MIK dispenser used to extract thrips from sainfoin and red campion flowers in May at site 14.

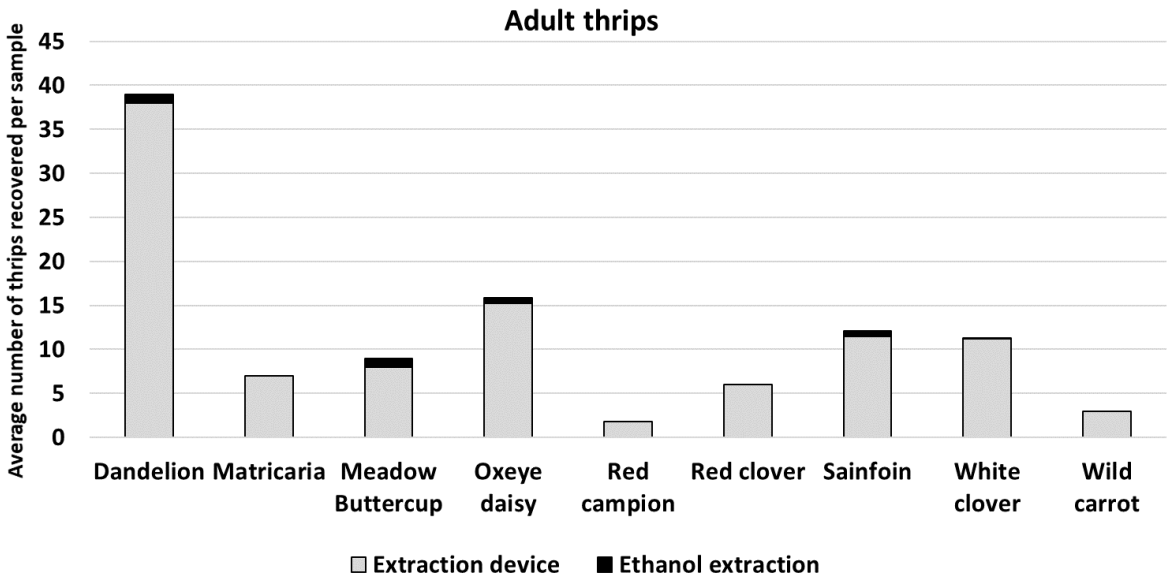


Figure 3.5.18. Mean number of adult thrips recovered from sampled flowers by the MIK extraction device (grey) and following ethanol extraction (black) in May at site 14.

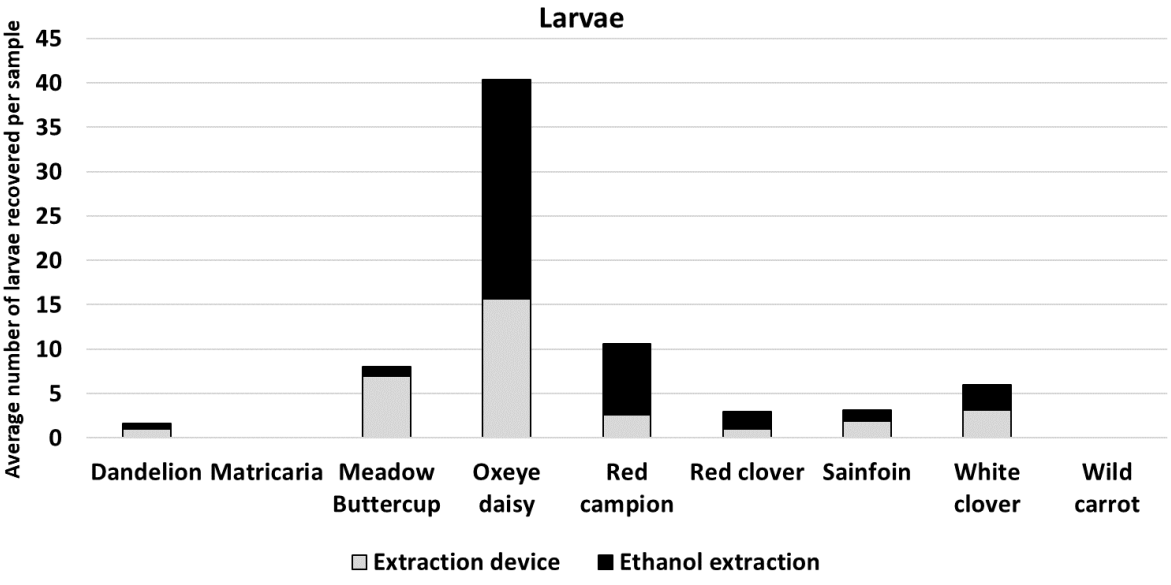


Figure 3.5.19. Mean number of larvae recovered from sampled flowers by the MIK extraction device (grey) and following ethanol extraction (black) in May at site 14.

Pollinators

Pollinator surveys were made in May and September. In May, sainfoin had significantly more visits from bumblebees ($p=0.032$), and honeybees ($p=0.041$) and significantly fewer from hoverflies ($p=0.044$), compared with unsown plots (Fig. 3.5.20). Significantly more beetles from *Oedomera* ($p<0.001$), and Diptera (p 0.002) visited EM1 plots. Ladybirds and butterflies were also recorded but numbers were too low to analyse.

In September, there was a low floral resource available. Only honeybees and hoverflies were found in sufficient numbers for analyses (Fig. 3.5.20). Unsown plots had more visits from honeybees when compared with all other treatments ($p_{chicory}=0.006$, $p_{EM1}=0.003$, $p_{sainfoin}=0.033$). Bumblebees and solitary bees were also recorded but were too low to analyse.

In both surveys, the main bumblebees visiting plots were wild bumblebee species not *Bombus terrestris* used in commercial hives. In May, high numbers of bumblebees were visiting sainfoin flowers. This may be linked to bumblebee species with long-tongues having been found to prefer flowers with longer corolla flowers, like sainfoin (Plowright et al. 1997).

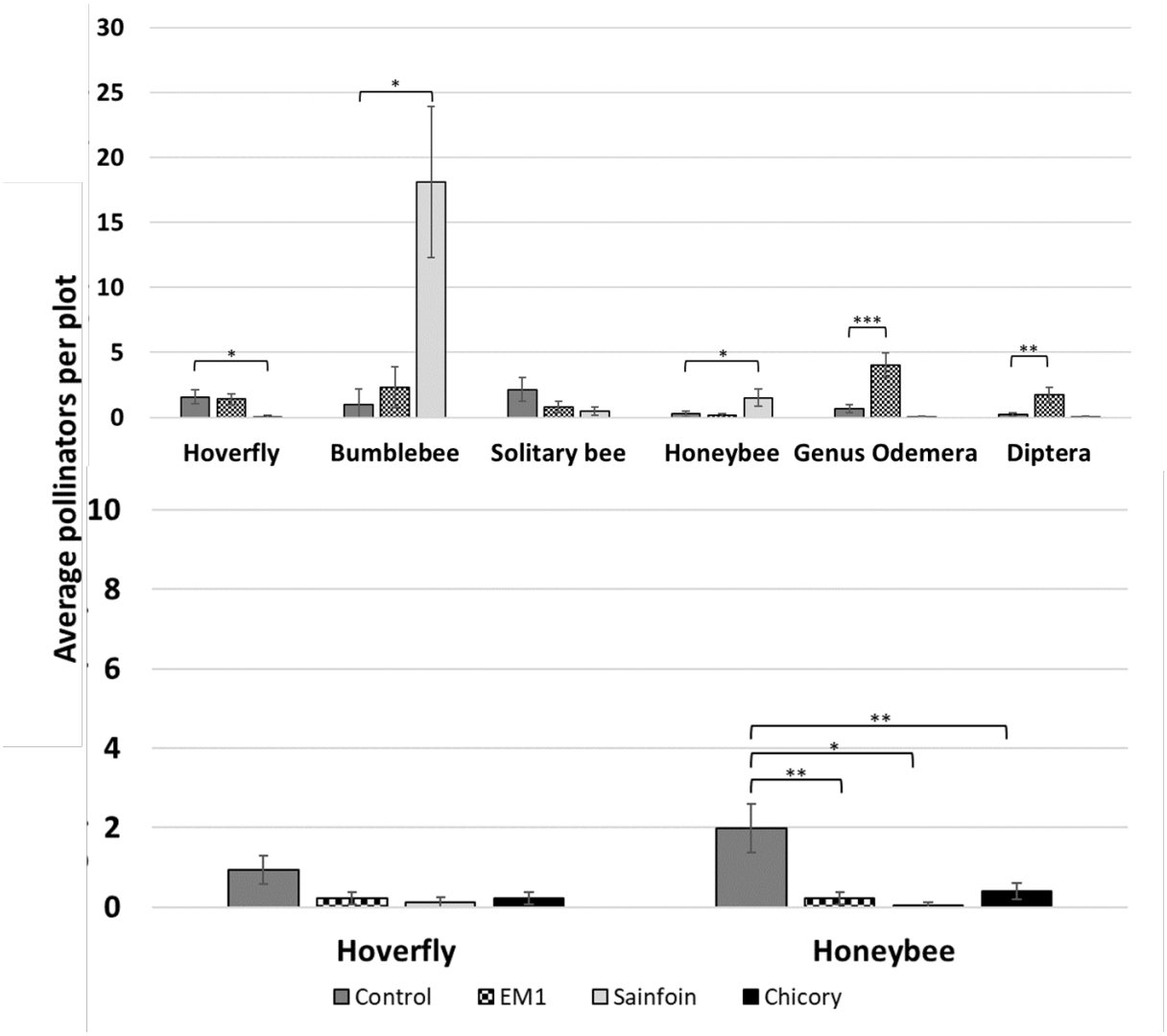


Figure 3.5.20. Mean number (±SE) of pollinators visiting flowers in unsown, meadow mix (EM1), chicory and sainfoin plots in May (top) and September (bottom) at site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). Note: September (bottom) chart in different Y axes scale.

Conclusions

- All sown plots established successfully. Single species plots had more than 90% coverage of the sown species, sainfoin and chicory. EM1 seed mix species 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.

- There was a higher abundance of beneficial arthropods in the margins of the strawberry crop in May and June. Floral resources were also adequate in July (Fig. 3.5.5), but some arthropod groups like beetles, ladybirds, and moths declined. This may be related to life cycle and/or dispersal into the crop.
- The meadow mixture (EM1) plots performed better 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 ground-bugs thought to be from genus *Nysius* (not a soft fruit pest).
- Most herbivores or potential soft fruit pests found during this trial were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in May and June and were particularly widespread in sainfoin plots.
- Capsid were thought to be breeding in sainfoin as higher numbers of nymphs were recorded in sainfoin in June. Most of the nymphs found were common green capsid. Numbers of herbivores declined greatly 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 found in high numbers in all treatments except in chicory. The meadow mix (EM1) was less attractive to capsids than the unsown treatment.
- Although the number of flowering species varied between sampling dates, thrips numbers and species in each flower type (species) appeared to be consistent.
- Unsown species like dandelion, bindweed, hawkbit, white clover, and yarrow had, on-average, numbers of thrips greater than 2 per flower head (Park et al. 2007). In June, yarrow contained 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 less than 2 thrips per flower or had thrips species not found on soft fruit.
- In sown plots chicory, sainfoin, oxeye daisy, common knapweed and wild carrot were the flowering species with more than 2 thrips per flower (Park et al. 2007) at least at one sampling occasion. Wild carrot had higher numbers of *Thrips tabaci* per flower head in June and July (respectively, on-average, 6.7 ±2.3 and 4.4 ±1.4). Common knapweed attracted on average 2.0 ±0.3 *Frankliniella occidentalis* (WFT) known to used strawberry crops and 2.2 ±0.6 ‘other thrips’ not found in soft fruit crops.

- Adult thrips present in dog rose (*Rosa canina*) were identified as *Thrips tabaci* (0.7 per flower) and *Thrips fuscipennis* (0.5 per flower). Only larvae of *Thrips tabaci* were found (1.9 per flower).
- Overall thrips numbers declined in August likely due to flower availability.
- Predatory thrips, parasitoids, carabid beetles and *Orius* nymphs and adults were found in the sampled flower heads. No significant numbers were recorded on any plant species.
- There was a more diverse and abundant community of pollinators in May than September, probably a reflection of floral resource.
- Bumblebees were frequent visitors to sainfoin flowers, the majority were observed to be wild bumblebees rather than commercial bumblebees from the strawberry crop, but this would need further confirmation. Some bumblebee species with long-tongues have been found to prefer flowers with longer corolla flowers (Plowright et al. 1997).
- The extraction device gave very good recovery of adult thrips (at least 90%) but was less efficient at extracting larval thrips (around 50%) from flower heads.

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 on the use of the predatory mites, *Neoseiulus cucumeris*, predatory bugs, *Orius laevigatus* and on some farms, 'mass monitoring' with blue roller traps, with or without the WFT aggregation pheromone lure which can increase numbers of WFT caught. (Sampson, 2014; Harnden et al. 2015; Raffle et al. 2015). Strategies for controlling WFT on strawberry are not effective against several other species of thrips which fly in as adults and can damage fruit (Brown & Bennison, 2017; Seymour et al. 2020). The potential options for 'mass monitoring' or 'push-pull' strategies for controlling adults of these other thrips species were reviewed (Seymour et al. 2020).

This study proposes to test a push-pull strategy 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. Magipal™ gave promising results in a preliminary trial on strawberry in a push-pull strategy together with blue roller traps and the WFT aggregation pheromone for WFT control within an IPM programme (Griffiths & Sampson, personal communication, 2020). 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, the rubus thrips (*Thrips major*) and the onion thrips (*Thrips tabaci),* (Teulon, 2017). However, there is no published evidence that LUREM-TR attracts the rose thrips, *Thrips fuscipennis* or the flower thrips, *Frankliniella intonsa*. However, it has been tested predominately in countries that lack these species.

Aims

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.

Materials and methods

During April and May 2020, two sites were selected for testing a push-pull strategy after checking thrips species from nine potential sites with histories of problems with thrips species other than WFT. *Thrips fuscipennis* (rose thrips) was the predominant or only species at both sites and both sites had a history of *T. fuscipennis* problems in previous years.

Locations

Site 1 (Surrey) – protected everbearer strawberry (Figure 4.1), Variety- Sweet Eve. Six tabletops per tunnel. Grass on ground beneath tabletops.

Site 2 (Worcestershire) – protected everbearer strawberry (Figure 4.2), Variety- Prize. Five tabletops per tunnel. Ground cover matting on ground beneath tabletops.

Figure 4.1: Site 1, protected strawberry

Figure 4.2: Site 2, protected strawberry

Treatments

There were four treatments including an untreated control (Grower IPM strategy). Treatments 2-4 (Table 4.1) were used in addition to the grower's IPM strategy. These treatments were replicated 10 times i.e. there were ten replicate tunnels, each with the four different treatments, laid out in a randomised block design. Each plot was five metres long and one tunnel wide. There was a 10 m buffer area between each plot along the length of the tunnels and a buffer tunnel between each treatment tunnel to reduce the risk of the semiochemicals drifting between the plots.

- Treatment 1 was the grower IPM programme. No sticky traps were placed in these plots.
- Treatment 2 (Push) had one Magipal™ sachet in the plot on a stake within the crop, so that the sachet was just above the level of the crop but below the height of the grower's tractor/spray boom. No sticky traps were placed in these plots.

- Treatment 3 (Pull) had 10 sticky traps mounted on stakes underneath each of the central two tabletops (one every 0.5 m, under two rows of tabletops, total of 20 traps per plot) and one LUREM-TR sachet.
- The LUREM-TR sachet in each Pull plot was stuck onto a sticky trap in the middle of one of the two rows of traps. The foil was peeled off the back of the LUREM-TR sachet to allow the lure to be released and the other side of the sachet was stuck to the trap so that the back of the sachet was free. The sticky traps were all orientated parallel to the tabletops and were the same height from the ground.
- Treatment 4 (Push & Pull) had both one Magipal™ sachet placed in the plot on a stake within the crop as in Treatment 2 and one LUREM-TR sachet in each push-pull plot on one of the traps in the two rows of 10 sticky traps underneath each of the two tabletops as in Treatment 3.

Once set up the Magipal™ and LUREM-TR sachets were not replaced during the trial.

The sticky traps used were 25x5 cm in size with a total sticky area of 210 cm^2.

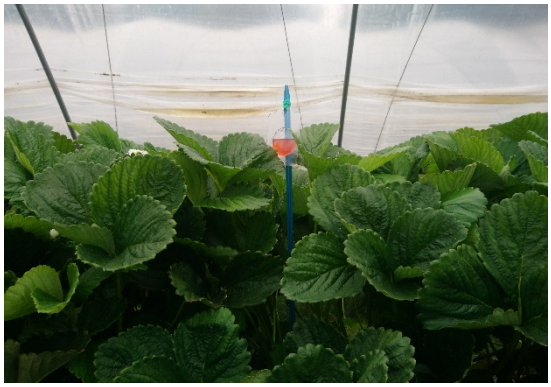


Figure 4.3: Magipal on cane above the crop

Figure 4.4: Traps with LUREM-TR sachet below tabletop

Table 4.1: Treatment list used at both sites.

Trt no.	Treatment	Sticky traps?	Collections (every 2 weeks)
1	Grower IPM programme	None	20 flowers per plot
2	Push (1 Magipal sachet / plot)	None	20 flowers per plot
3	Pull (1 LUREM-TR sachet / plot)	Yes- 20 per plot	20 flowers per plot & 2 sticky traps per plot
4	Push & Pull (1 Magipal and 1 LUREM-TR / plot)	Yes- 20 per plot	20 flowers per plot & 2 sticky traps per plot

Plot layout

Due to two different numbers of tabletops per tunnel at the two sites, the plot layouts were different at Site 1 and Site 2. Site 1 had six tabletops per tunnel and so the LUREM-TR and Magipal™ were centrally placed in row 3 and the flower collections were taken from the middle two rows (rows 3 and 4) of tabletops (Figure 4.5). Site 2 had five tabletops per tunnel and so a different plot layout was adopted. Here, the traps and, LUREM-TR were placed in rows 2 and 3 and the Magipal™ was placed in row 4 and flowers were collected from rows 4 and 5 (Figure 4.6).

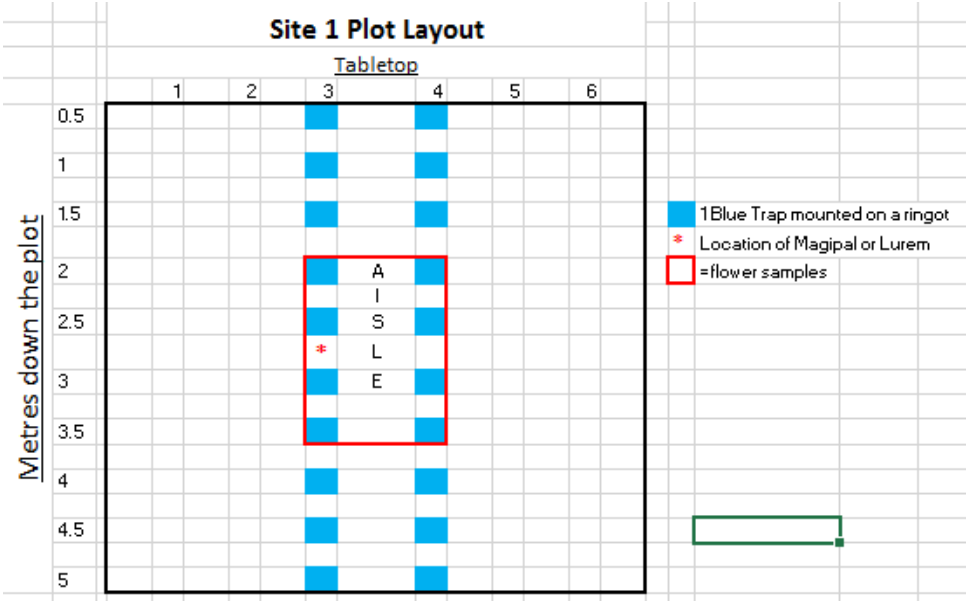


Figure 4.5: Plot layout at Site 1 showing a tunnel width.

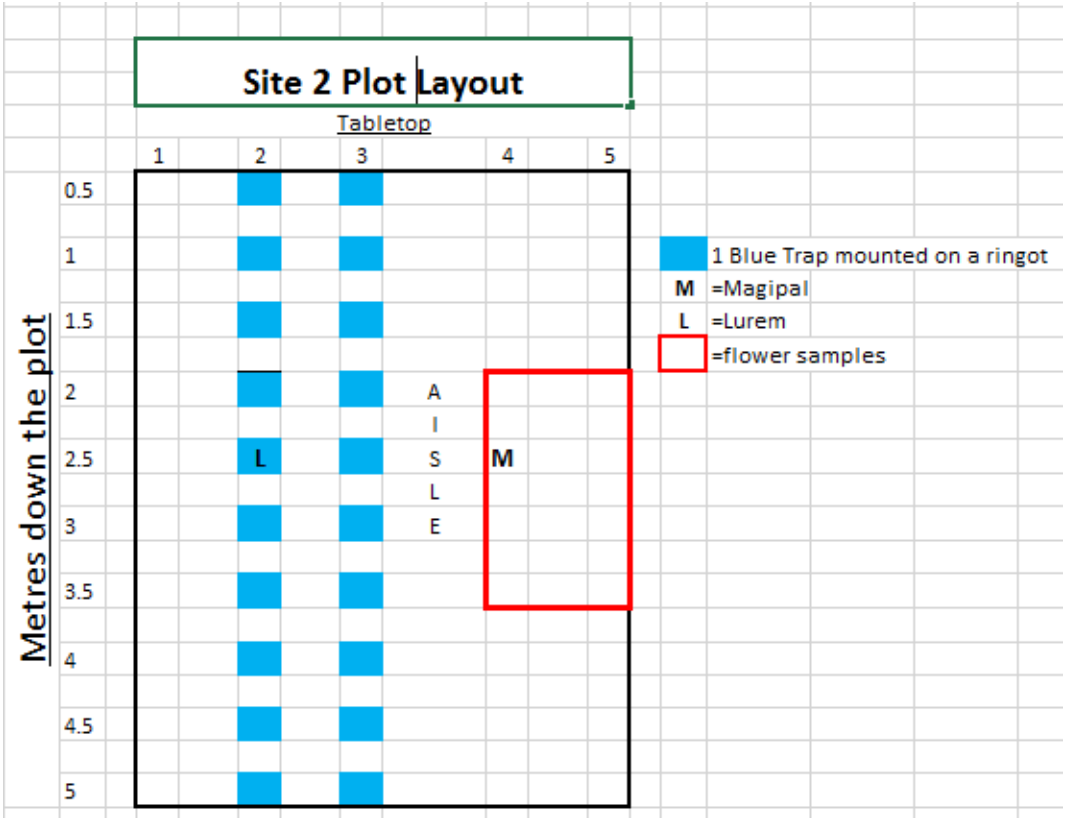


Figure 4.6: Plot layout at Site 2 showing a tunnel width.

Assessments

At each assessment (including setup date) 20 flowers per plot were collected from each plot (400 per site per assessment), once every two weeks from 3 June to 1 July at Site 1 and 10 from June to 8 July at Site 2. Additionally, in treatments 3 and 4, two sticky traps were collected per plot on the second and third assessment dates for laboratory processing using procedures outlined below.

Flower sampling: The 20 flowers per plot were taken from the central 2 m of the two sampling rows. Only upward facing mid-aged flowers (all petals present, anthers brown rather than yellow) at the top of each plant were sampled. All flowers were collected into lidded specimen tubes (one tube per plot) containing 70% alcohol and returned to the laboratory for thrips extraction and identification using the procedures detailed below (Extraction and Identification).

Flower counts: In one monitoring plot in each block, five plants were sampled in the field and the numbers of flowers on each plant recorded. This was carried out because often thrips damage to fruit is more severe when there are few flowers available, as thrips adults

congregate in the few available flowers, leading to more intensive feeding on the young developing fruit. When white fruit were available percentage fruit area with thrips bronzing damage was assessed in situ on 20 white fruit per plot on each sampling date.

Trap sampling: On each of the two assessment dates following the initial set-up date, two sticky traps from each plot in each of the 'Pull' and 'Push-Pull' plots were collected; one from each of the flower sampling rows. One trap adjacent to the central trap with the LUREM-TR sachet was collected and one in the same position in the other sampling row. On the assessment date, two weeks after set-up, the collected traps were replaced with fresh traps. On the final assessment date, the traps that were replaced on the previous assessment date were collected. The traps were placed into individual, labelled polythene bags after cutting the sides to allow easy placement on the lower side and covering with the upper side.

Extraction

In the laboratory, thrips and any beneficial invertebrates were extracted from the flowers from each of the 40 plots after using the following procedure:

1) A square piece of thrips proof mesh (120 microns) was secured over the top of a beaker using an embroidery hoop. A depression was made in the mesh to prevent spillage of alcohol and thrips.
2) The flowers and alcohol were gently agitated in the sampling tube.
3) The alcohol and flowers were emptied from the tube into the beaker through the thrips-proof mesh using a sieve (mesh of suitable size to retain the flowers) held over the mesh-covered beaker.
4) The flowers were removed from the sieve using forceps and placed back in the tube and alcohol added to the tube.
5) Steps 2-5 were repeated twice more (a total of three flower rinses).
6) The flowers were discarded. The alcohol in the beaker was kept for washing further flower samples.
7) The mesh was removed and placed on top of a laminated sheet of white paper and examined under a dissecting microscope.

Identification of thrips and beneficials in flowers

A minimum of one thrips adult per monitoring plot was identified, i.e. a minimum total of 40 thrips adults per site per sampling date. Identification was done after mounting adult thrips females in a clearing medium on glass slides, viewing them under a high-power microscope once the specimens had cleared sufficiently to see the diagnostic features and using

morphological keys (Mound et al. 1976 for adults; Vierbergen et al. 2010 for larvae). The following procedure was used:

a) Thrips adults were divided into two groups based on morphological features: those belonging to the genus *Frankliniella* and those belonging to the genus *Thrips.* Numbers of thrips adults were recorded (males and females recorded separately) and numbers of larvae. Cereal thrips were grouped together with the *Thrips* species.
b) Numbers of *Orius* sp. adults and nymphs were recorded, also numbers of other beneficial insects such as lacewings, hoverflies, and bumble bees.
c) Numbers of *Aeolothrips* adults were recorded.
d) A minimum of one adult female thrips per plot was identified (minimum of 40 per site per assessment date if available). Additional thrips adults were mounted on slides to ensure enough females could be identified (only females should be used when keying out the species) as some may lie in an awkward angle on the slide to enable species confirmation. Numbers of each species were recorded.
e) All remaining thrips adults and larvae on the mesh were kept by picking them off into a tube of 70% alcohol under a dissecting microscope using a fine paintbrush. These thrips 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 traps

In the laboratory, each trap was examined under a binocular microscope and the total number of thrips adults and beneficials on each side of the trap was recorded.

1. Numbers of *Thrips* spp., *Frankliniella* spp. and predatory thrips (*Aeolothrips*) were recorded on each trap. They were recorded as male or female. *Frankliniella* species were determined by looking for the long post ocular (eye) hair, the long complete rows of hairs on the wings or the extra (8th) antennal segment.
2. Thrips were circled with a black felt tip pen on the polythene covering the traps to make them easier to find later.
3. Numbers of beneficial insects were recorded. (*Orius*, other Anthocorid bugs, bees, hoverflies, lacewings, ladybirds etc. Any beneficials were circled with a red felt pen.
4. Numbers of capsids were recorded; these were then circled with a blue felt pen.
5. A small subsample of thrips was removed from traps at Site 2 using white spirit to determine whether if the species on the traps matched those seen in the flowers.

Data analysis

Mean thrips numbers in flowers from the three sampling dates at Sites 1 and 2 were compared using Analysis of Variance in GenStat 16. Mean thrips numbers on traps on the two collection dates were also analysed using 4 factor Analysis of Variance in GenStat 16 for each site. Sites were examined separately. All analysis was completed by Chris Dyer, the ADAS statistician.

Data loggers: temperature and humidity

At each site two data loggers were used to monitor temperature and humidity for the trial duration. These were attached underneath the tabletops using cable ties.

Results

Mean numbers of thrips adults per flower

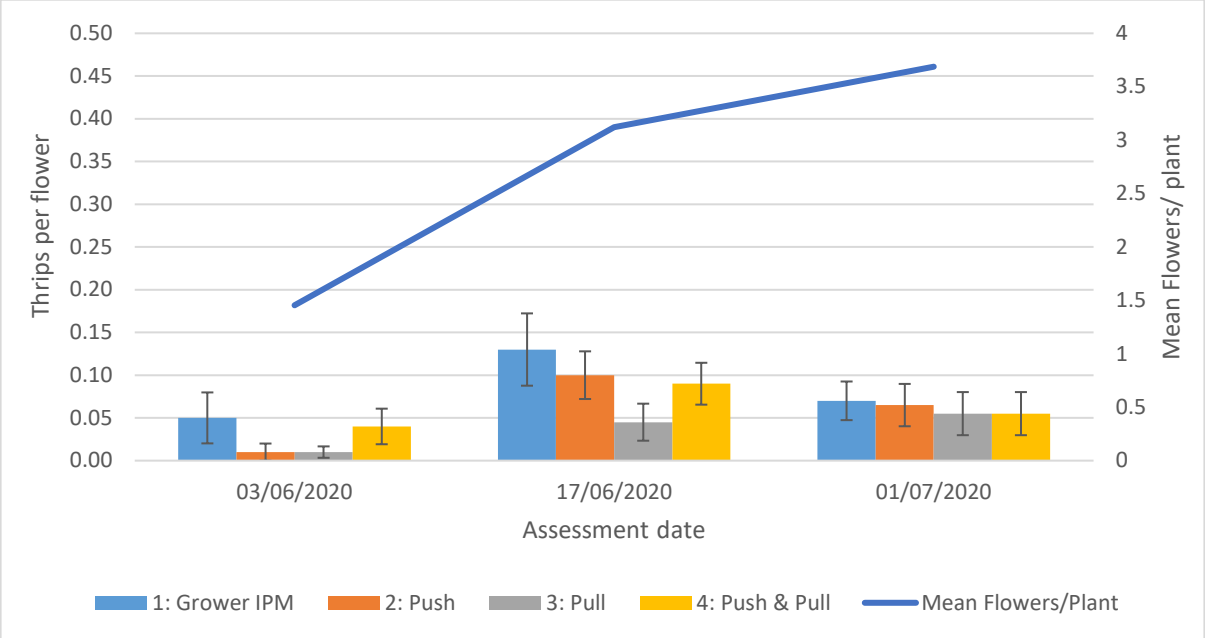


Figure 4.7: *Thrips* spp. adults per flower in the four treatments at Site 1. Average flowers per plant plotted on the Z axis.

Site 1 had low mean numbers of all thrips species adults per flower overall at the three assessment dates with mean numbers remaining well below one per flower at all assessment dates (Table 4.2, Figure 4.7). Numbers of all *Thrips* spp. per flower were lowest at the first assessment (3 June) when mean numbers of flowers per plant were 1.45 per plant. Numbers

of flowers per plant increased as the trial progressed, increasing to 3.12 per plant on 17 June to 3.68 on 1 July.

Mean numbers of *Thrips* spp. were slightly higher in untreated plots on all assessment dates but were not significantly different from the other two treatments on any date. At the second assessment (17 June) of there was a mean of 0.13 thrips per flower and at assessment 3 (1 July) there was a mean of 0.07 per flower.

Mean numbers of *Frankliniella* spp. were lower than those of *Thrips* spp. (Table 4.2) therefore no analysis on these was performed.

Table 4.2: Mean numbers of thrips adults per flower in the two species groupings; *Frankliniella* spp. and *Thrips* spp. at site 2 on the initial setup date and the two subsequent assessment dates (DAS = Days after setup). N/A = not analysed due to low numbers.

Date	**3/6/20**		**17/6/20**		**1.7.20**	
DAS	**0**		**14**		**28**	
Treatment	*Frankliniella* spp.	*Thrips* spp.	*Frankliniella* spp.	*Thrips* spp.	*Frankliniella* spp.	*Thrips* spp.
1: Grower IPM (untreated)	0	0.05	0	0.130	0.01	0.070
2: Push	0	0.01	0.01	0.100	0.005	0.065
3: Pull	0	0.01	0.005	0.045	0	0.055
4: Push & Pull	0	0.04	0.005	0.090	0	0.055
F value	N/a	1.62	N/a	2.53	N/a	0.15
P value	N/a	0.209	N/a	0.078	N/a	0.929
d.f.	N/a	27	N/a	27	N/a	27
s.e.d.	N/a	0.023	N/a	0.031	N/a	0.027
l.s.d.	N/a	0.047	N/a	0.064	N/a	0.056

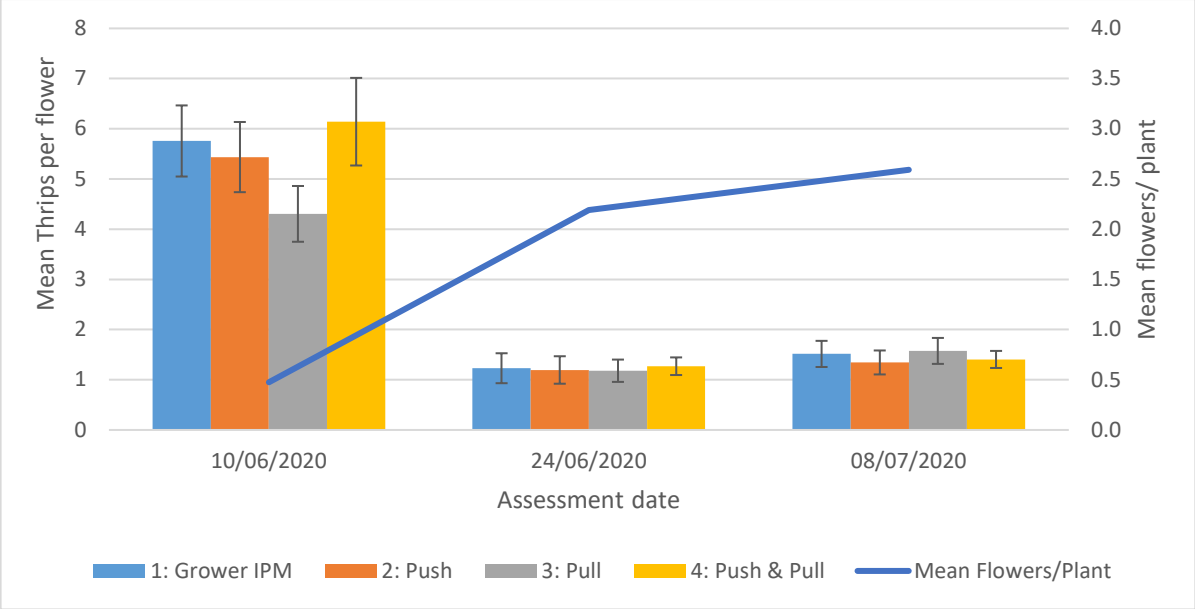


Figure 4.8: *Thrips* spp. adults per flower at the four treatments at Site 2. Average flowers per plant plotted on the Z axis. Note the different Y axis scale to Site 1.

Mean numbers of *Thrips* sp. adults per flower were higher at Site 2 than at site 1 but there were no significant differences between any of the treatments on any assessment date (Table 4.3, Figure 4.8). Mean flower numbers per plant were low initially with a mean of 0.47 at the setup date (10 June) then they increased to a mean of 2.19 per plant at assessment 2 (24 June) and 2.59 at assessment 3 (8 July). Mean numbers of *Thrips* spp. per flower were highest at the setup date, with the push-pull plots having the highest with a mean 6.14 per flower, although this was statistically similar to those in the other treatments. Mean numbers of *Thrips* sp. per flower were lower at the second and third assessments than on the setup date. On the second assessment mean numbers were highest in the push-pull treatment (mean of 1.27 per flower) and on the third assessment mean numbers were highest in the pull treatment (mean of 1.57 per flower) but these were statistically similar to the other treatments.

Table 4.3: Mean numbers of thrips spp. adults per flower in the two species groupings; *Frankliniella* spp. and *Thrips* spp. at site 2 on the initial setup date and the two subsequent assessment dates (DAS = Days after setup). N/A = not analysed due to low numbers.

Date	**10/6/20**		**24/6/20**		**8.7.20**	
DAS*	**0**		**14**		**28**	
Treatment	*Frankliniell a* spp.	*Thrips* spp.	*Frankliniella* spp.	*Thrips* spp.	*Frankliniell a* spp.	*Thrips* spp.
1: Grower IPM (untreated)	0.060	5.76	0.1	1.230	0.01	1.515
2: Push	0.097	5.44	0.2	1.195	0	1.345
3: Pull	0.130	4.30	0	1.180	0	1.575
4: Push & Pull	0.030	6.14	0.1	1.270	0	1.405
F value	0.51	1.80	N/a	0.09	N/a	0.48
P value	0.679	0.171	N/a	0.966	N/a	0.698
d.f.	27	27	N/a	27	N/a	27
s.e.d.	0.086	0.834	N/a	0.191	N/a	0.212
l.s.d.	0.177	1.711	N/a	0.392	N/a	0.435

Species of thrips adults in flowers

At both sites, high proportions of all the thrips species identified were *T. fuscipennis* with smaller numbers of *T. major, T. tabaci and Limothrips cerealium* (Table 4.4 & Table 4.5). No *Frankliniella occidentalis* (WFT) were found but small numbers of *F. intonsa* were seen at both sites.

At Site 1, 141 thrips adults were identified from flowers across the three sample dates (Table 4.4) and on each sample date the proportion of *T. fuscipennis* was over 50%. *Thrips major* was the next most abundant species with between 20 and 43% of the total thrips. *Thrips tabaci* and *L. cerealium* proportions were lower and did not occur on all dates, with *T. tabaci*

(3%) only confirmed on the second assessment date and *L. cerealium* only confirmed on two of the three sample dates with between 6% and 11% of the total number of thrips identified.

Seven *Frankliniella* sp. adults were identified at Site 1, all were *F. intonsa.*

Table 4.4: Summary of numbers and proportions of identified thrips species adults in the flowers at the three assessment dates at Site 1.

	T. fuscipennis		*T. major*		*T. tabaci*		*L. cerealium*		Total thrips spp. adults identified
Date	Number identified	% of total	Number identified	% of total	Number identified	% of total	Number identified	% of total	
3.6.20	11	58%	6	32%	0	-	2	10%	19
17.6.20	57	77%	15	20%	2	3%	0	-	73
1.7.20	25	51%	21	43%	0	-	3	6%	49

At Site 2, 748 thrips adults were identified across the three sample dates (Table 4.5) and on each sample date the proportion of *T. fuscipennis* was over 89%. *Thrips major* was the next most abundant species with between 2% and 9% of the total number of thrips. The proportion of *T. tabaci* was under 2% of the total thrips identified on the first two assessment dates and was not identified on the third date. *Limothrips cerealium* was not identified at this site at all. Fifteen *Frankliniella* species adults were identified at Site 2, all were *F. intonsa.*

Table 4.5: Summary of numbers and proportions of identified thrips species adults in the flowers at the three assessment dates at Site 2.

	T. fuscipennis		*T. major*		*T. tabaci*		*L. cerealium*		Total Thrips spp. adults identified
Date	Number identified	% of total	Number identified	% of total	Number identified	% of total	Number identified	% of total	
10.6.20	290	89%	30	9%	5	2%	0	0%	325
24.6.20	248	93%	16	6%	2	1%	0	0%	266
8.7.20	154	98%	3	2%	0	0%	0	0%	157

Mean numbers of thrips larvae in flowers

Low numbers of thrips larvae were recorded in flowers at both sites at all the assessments (Table 4.6). However, at Site 1 on the setup date on 3 June, mean numbers of thrips larvae per flower were higher (0.13) than mean numbers of thrips adults per flower (0.03). No thrips larvae were recorded at Site 1 on the second assessment (17 June) and very low mean numbers per flower (0.001) were recorded on the final assessment (1 July). Mean numbers of larvae per flower were higher (0.49) at Site 2 on the setup date on 10 June when mean numbers of thrips adults were also higher but mean numbers were lower (0.06) on the second assessment date (24 June) and were not recorded on the third assessment (8 July).

Table 4.6: Mean thrips larvae and adults per flower (all species) at the two sites.

Site 1			Site 2		
Date	**Mean larvae per flower**	**Thrips spp. adults per flower**	**Date**	**Mean larvae per flower**	**Thrips spp. adults per flower**
03/06/2020	0.13	0.03	10/06/2020	0.49	5.49
17/06/2020	0	0.10	24/06/2020	0.06	1.22
01/07/2020	0.001	0.07	08/07/2020	0	1.46

Species of thrips larvae in flowers

Table 4.7: Summary of numbers and proportions of identified thrips species larvae in the flowers at the three assessment dates at Site 1.

	F. intonsa		*T. major*		*T. tabaci*		L1 Thrips larvae		Total thrips spp. identified
Date	Number identified	% of total	Number identified	% of total	Number identified	% of total	Number	% of total	
17/6/20	2	11%	11	61%	1	6%	4	22%	21
01/7/20	0	-	0	-	0	-	0	-	0

At Site 1, 18 thrips larvae were identified from one sample date (3 June, Table 4.7). One larva was found in the flowers on 1 July but could not be identified to species because the diagnostic features were not visible. *Thrips major* was the most abundant species of larvae found with 61% of total thrips larvae identified. *Frankliniella intonsa* was the next most abundant species with 11% of the total larvae identified. The proportion of *T. tabaci* was the lowest at 6% of the total thrips identified. Of the thrips larvae mounted for identification, 22% were stage one (L1) which cannot be identified with the taxonomic key. No larvae of *T. fuscipennis* were found in the flowers at site 1.

Table 4.8: Summary of numbers and proportions of identified thrips species larvae in the flowers at the three assessment dates at Site 2.

	F. intonsa		*T. major*		*T. tabaci*		L1 Thrips larvae		Total thrips spp. identified
Date	Number identified	% of total	Number identified	% of total	Number identified	% of total	Number	% of total	
10/6/20	0	0%	9	53%	1	6%	7	41%	17
24/6/20	0	-	0	-	0	-	0	-	0

At Site 2, 10 thrips larvae were identified from one sample date (10 June, Table 4.7). Low numbers of larvae were found in the flowers on 24 June but could not be identified to species because the diagnostic features were not visible. *Thrips major* was the most abundant species of larvae found on 10 June, with 53% of the total thrips larvae identified. No *Frankliniella intonsa* larvae were recorded. The proportion of *T. tabaci* was the lowest at 6% of the total thrips identified. Of the thrips larvae mounted for identification, 41% were stage one (L1) which cannot be identified with the taxonomic key. No larvae of *T. fuscipennis* were found in the flowers at site 1.

Fruit Bronzing

Overall mean percentage white fruit area with bronzing at both sites was low with less than 1% fruit area bronzed on all assessment dates (Table 4.9). Site 1 had lower levels of bronzing than Site 2. More fruit bronzing was recorded at Site 2 on 10 June than on subsequent dates and this coincided with higher mean numbers of thrips adults per flower than on later assessment dates (Table 4.2, Figure 4.8).

Table 4.9: Mean % white fruit area bronzed at the two sites on the three assessment dates.

Site 1		**Site 2**	
Date	**Mean % area white fruit with bronzing**	**Date**	**Mean % area white fruit with bronzing**
03/06/2020	0.15	10/06/2020	0.51
17/06/2020	0.16	24/06/2020	0.27
01/07/2020	0.09	09/07/2020	0.09

Mean numbers of thrips and beneficials on sticky traps

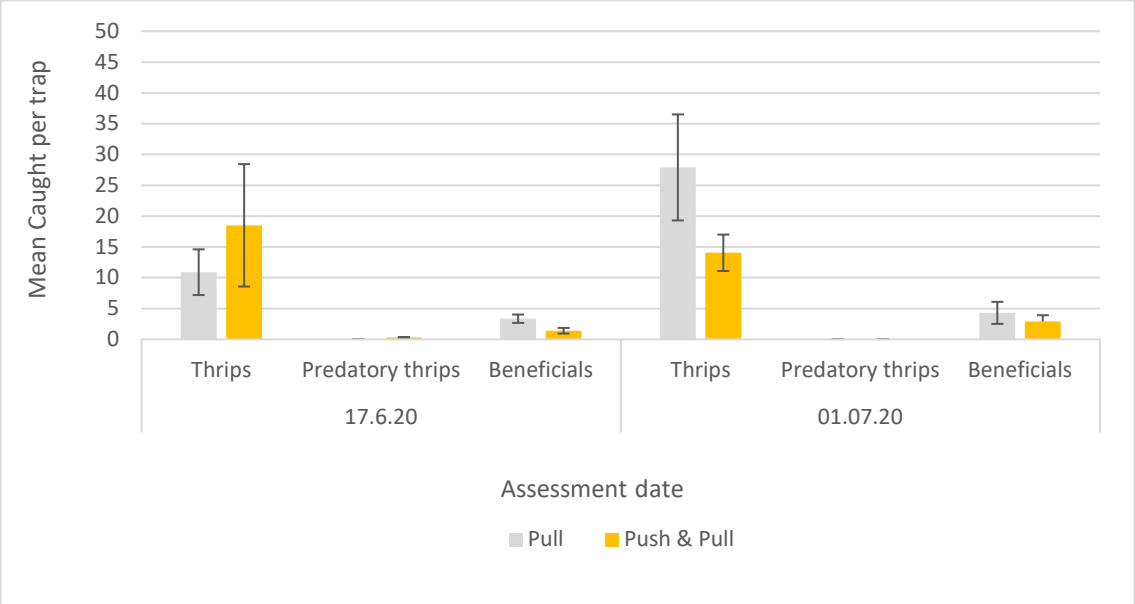


Figure 4.9: Mean numbers of thrips (of all species), predatory thrips and beneficials (grouped) per trap in 'Push' and 'Push-Pull' treatments three on the two post-setup assessment dates at Site 1.

Mean numbers of thrips caught on traps at site 1 was variable between treatments (Figure 4.9), on 17 June higher numbers were caught in the push-pull plots (mean 18.15 per trap) than in the pull plots (mean 10.9 per trap). On 1 July higher mean numbers of thrips were caught on traps in the pull plots (mean 27.9 trap) than in the push-pull plots (mean 14.05 per trap). However, there was no significant difference between treatments on either date (Table 4.10).

Small numbers of predatory thrips (*Aeolothrips* sp.) were caught on 17 June with a mean of 0.3 per trap but none were caught on 1 July.

Low numbers of other beneficial insects were caught overall on the traps. On 17 June, a mean of 2.3 beneficials were caught per trap in the pull treatment, the push-pull had lower numbers with a mean of one per trap. Higher numbers of beneficials per trap were caught on 1 July with means of 4.3 in the pull plots and 2.9 in the push-pull plots. Most of the beneficials caught on both dates were hoverflies and bees (Figure 4.10).

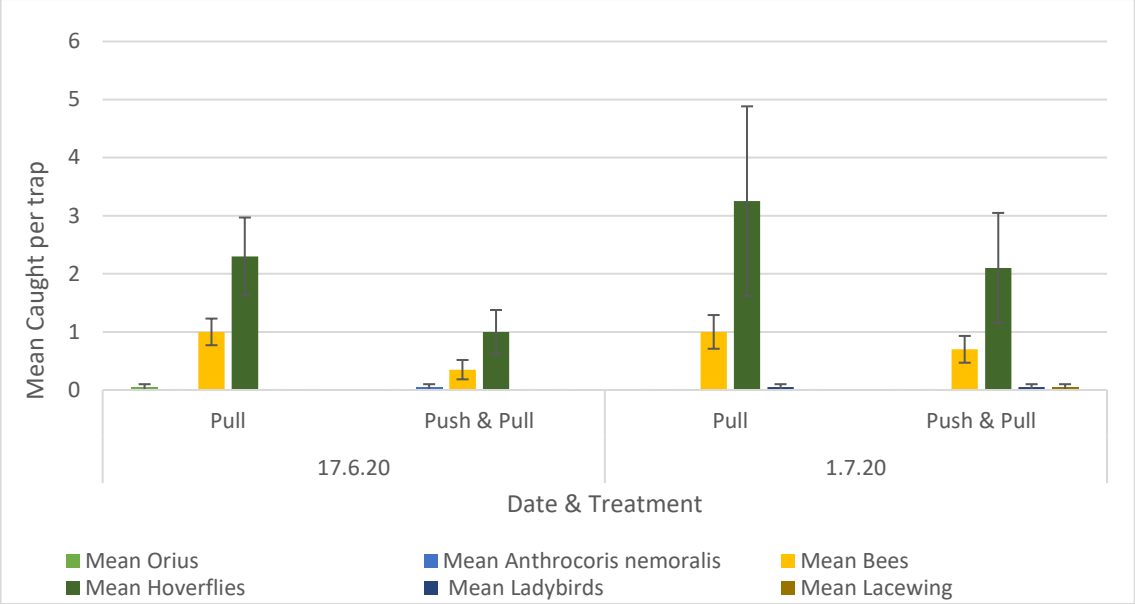


Figure 4.10: Mean numbers of beneficials caught per trap at Site 1 on the two assessment dates.

As a result of storms and high winds some traps were lost. The number lost per plot was recorded at each of the assessments (Figure 4.11). Similar numbers of traps were lost in each treatment by 17 June, with the pull plots having a mean of 14.8 of the 20 remaining and the push-pull plots having a mean of 15.8 of the 20 remaining. As the loss of traps was unexpected, the lost traps at Site 1 were not replaced on the second assessment date. By the third assessment on 1 July, a few more traps had been lost with means of 12.8 and 14.5 remaining in the pull and push-pull plots, respectively. However, mean numbers of thrips per trap were not significantly different on either date (Table 4.10).

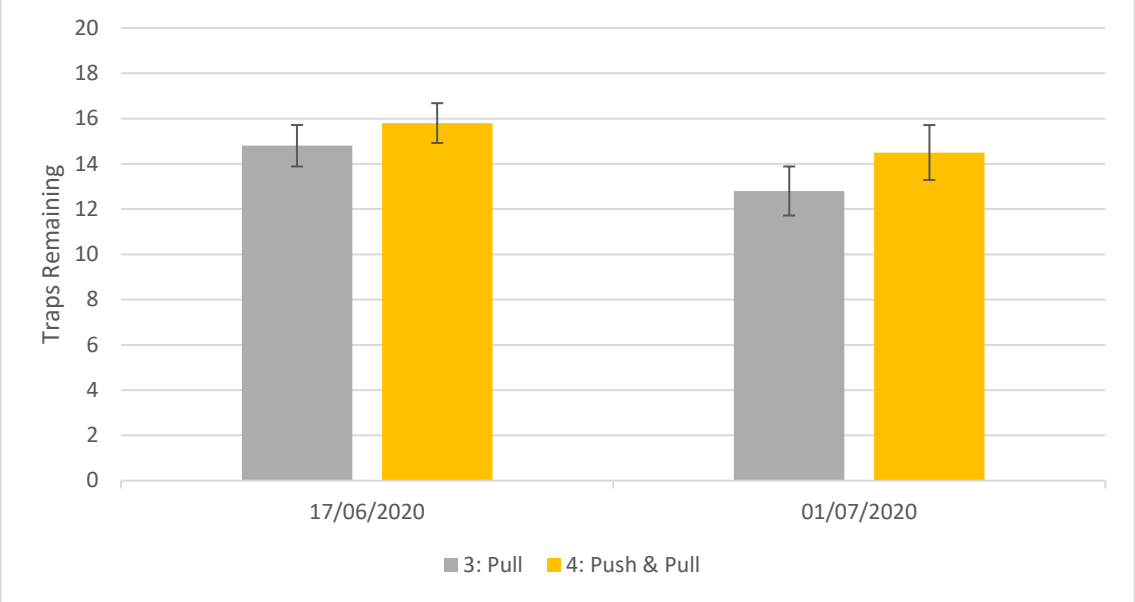


Figure 4.11: Mean numbers of traps remaining out of the 20 original traps per plot in the Push and Push-Pull plots at each assessment date at Site 1.

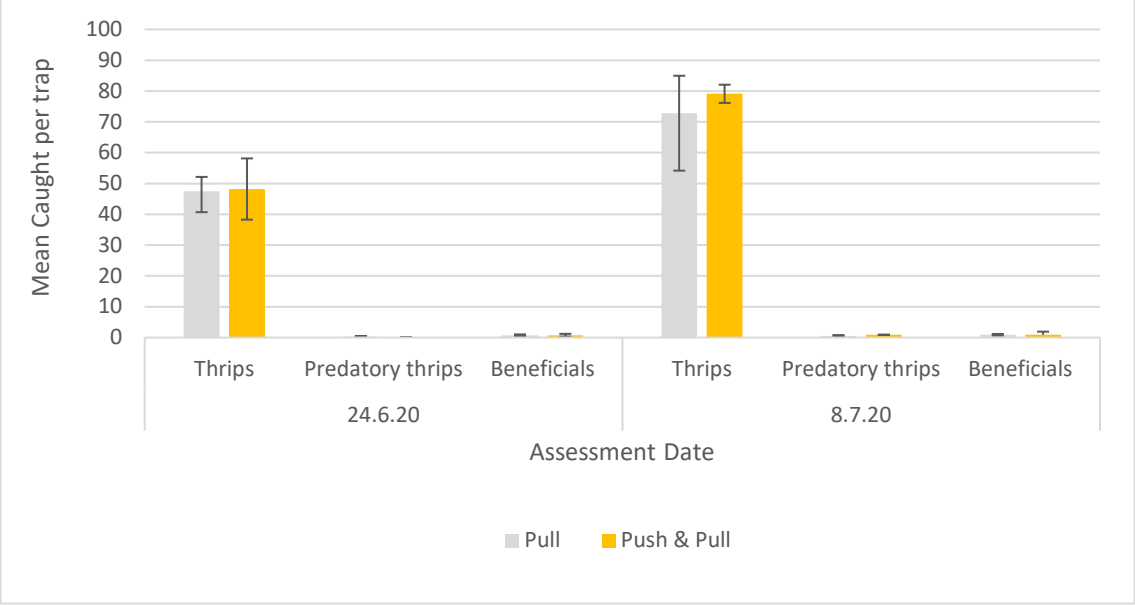


Figure 4.12: Mean thrips (of all species), predatory thrips and beneficials (grouped) caught per trap in the Pull and Push-Pull plots on the two assessment dates at site 2. Note the different Y axis scale to Site 1.

Higher numbers of thrips were caught on the traps at Site 2 than at Site 1 (Figure 4.12). More thrips were caught on the traps on 8 July (means of 72.8 and 79.1 per trap in Push and Push-Pull plots respectively) than on 24 June (means of 47.4 and 48.2 per trap in Push and Push-

Pull plots respectively). There was no significant difference between the two treatments on either assessment date (Table 4.10).

As at Site 1 only low numbers of predatory thrips were caught on the traps (less than a mean of one per trap on both dates, (Figure 4.13).

Lower numbers of other beneficial insects were caught on traps at Site 2 than at Site 1, (less than one per trap for either trap on either date). Whereas most of the beneficial insects caught at Site 1 were hoverflies and bees, at Site 2 similarly low numbers of all the beneficials were recorded (Figure 4.13).

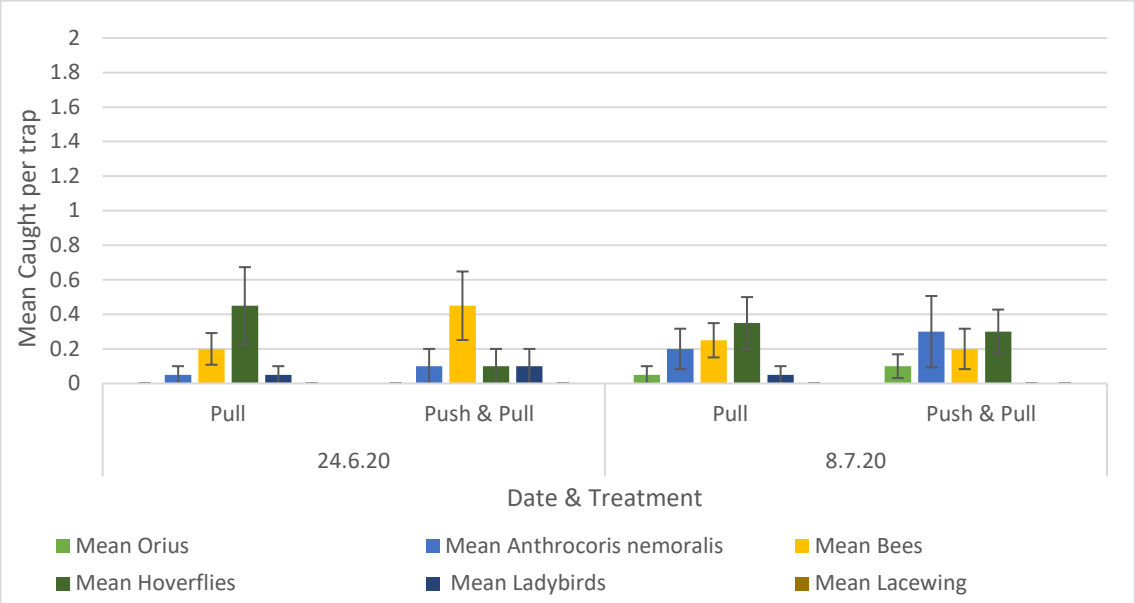


Figure 4.13: Mean numbers of beneficials caught per trap at Site 2 on the two assessment dates. Note the different Y axis scale to Site 1.

As at Site 1, high wind levels during the trial period led to some traps being lost. The number lost in each plot were recorded at each of the assessments (Figure 4.14). On the second assessment date on 24 June, more traps were lost in the Pull (mean 11.7 remaining) than in the Push-pull plots (mean 15.8 remaining out of the original 20). As Site 2 was visited on later dates than Site 1, extra traps were taken on the second assessment date to replace any that were lost. However, on the third and final assessment date on 8 July, similar numbers of traps were missing as on the second assessment, with a mean of 11.9 and 15.2 traps per plot remaining in the Pull and Push-Pull plots, respectively.

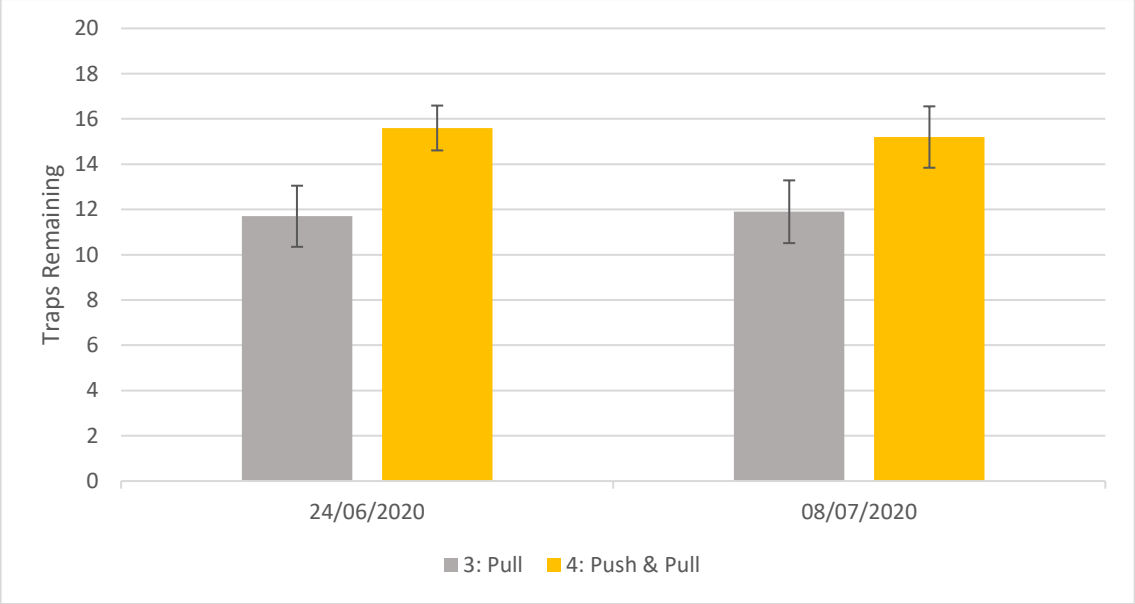


Figure 4.14: Mean numbers of traps remaining out of the 20 original traps per plot in the Push and Push-Pull plots at each assessment date at Site 2. Additional traps were added to replace missing ones on 24 June.

Table 4.10: Mean numbers of thrips adults per trap at Sites 1 and 2 (data from Sites 1 and 2 combined for analysis).

	Site 1		Site 2	
Date	**17/6/20**	**1/7/20**	**24/6/20**	**8/7/20**
3: Pull	27.9	10.9	47.4	72.8
4: Push & Pull	14.1	18.5	48.2	79.1
F value		0.00		
P value		>0.05		
d.f.		36		
s.e.d.		8.48		
l.s.d.		17.20		

Thrips species on traps

Table 4.11: Thrips species confirmed on traps at Site 2.

	T. fuscipennis		*T. major*		*T. tabaci*		Total thrips spp. identified
Date	Number identified	% of total	Number identified	% of total	Number identified	% of total	
24.6.20	4	33%	0	-	8	67%	12
8.7.20	5	38%	5	38%	3	24%	13

Due to the time needed to remove thrips from the traps, dissolve the glue sufficiently to mount the thrips on slides to identify them to species, only small numbers of thrips were confirmed to species, from Site 2 only (Table 4.9). However, the thrips removed from the traps at Site 2 were the same species that were confirmed in the flowers (Table 5), with no additional species being recorded. The proportions of *T. major* and *T. tabaci* were higher and those of *T. fuscipennis* were lower on the traps than in the flowers at Site 2. However, it was noted that the darker coloured thrips were more difficult to remove from the traps whilst keeping them intact as easily as some of the lighter coloured thrips (which were mostly *T. tabaci*) causing diagnostic features to be missing. It was noted that a further five thrips that were removed (three on 24 June and two on 8 July) were highly likely to be *T. fuscipennis* but were lacking some of the diagnostic features for confirmation.

Growers crop protection programme and tunnel temperature and humidity are in Appendix 4.0.

Discussion

Thrips species in flowers

Adults

A mix of thrips species were confirmed in flowers at both sites with higher proportions of the rose thrips, *T. fuscipennis* and the rubus thrips, *T. major* than other species. *Thrips fuscipennis* was the predominant species at both sites especially at Site 2 (89% or more of all thrips identified on all assessment dates). Other species recorded in lower numbers were the onion thrips, *T. tabaci* at both sites and the grain thrips, *Limothrips cerealium* at Site 1 only. This species mix is similar to those confirmed at other sites in the previous SF 156 project.

Frankliniella occidentalis (WFT) was not recorded at all at either site. Both sites were using IPM programmes that included *Neoseiulus cucumeris* and it is likely that this contributed to the absence of this species, although *N. cucumeris* usually does not eradicate WFT but maintains it in very low numbers. Site 1 introduced *N. cucumeris* earlier than Site 2 (from 16 March compared to 11 May). However, Site 1 had continued its strawberry plants through from a previous year which could have led to a higher potential pressure from WFT. This would have needed an earlier introduction than at Site 2 which was using new plants.

The only *Frankliniella* species confirmed in low numbers in the flowers at both sites was *F. intonsa.* This species is often found as a small proportion of the thrips species mixes in UK strawberry flowers; however it has occurred in much higher numbers at some other sites in recent years (Brown & Bennison, 2017). *Frankliniella intonsa* is thought to be more adapted to the climate of central Europe than that of the UK (Morison, 1957) but might become more common in UK summers due to climate change. However, only low numbers were recorded at these two sites in the hot summer temperatures during 2020 in this project and during the hot summer of 2019 at four different sites in SF 156. Other local factors are likely to contribute to the incidence of *F. intonsa* as high numbers were recorded in strawberry flowers (cv. Favori and Malling Centenary) at a West Midlands site in June 2019 where this was the only thrips species present (Hubert, personal communication, 2019).

Larvae

At Site 1, thrips larvae were found in flowers on only one date, 24 June. Although the predominant species of adults found in flowers on all assessment dates was *T. fuscipennis*, no larvae of this species were found. Most of the second instar larvae were confirmed as *T. major* together with smaller numbers of *F. intonsa* and *T. tabaci*. First instar larvae were also present, but these cannot be identified with the diagnostic key. Similar results were given at

Site 2, with the majority of the second instar larvae confirmed as *T. major* with low numbers of *T. tabaci.* No larvae of *F. intonsa* were seen at Site 2.

This result is consistent with those in 2019 in SF 156, when the main species of thrips adults in strawberry flowers at two different sites was *T. fuscipennis* but no larvae of this species were found, only those of *T. major*, *T. tabaci* and *F. intonsa*. Strawberry has been reported to be a suitable host plant for the development of *T. fuscipennis* larvae (Morison, 1957) but it is still uncertain whether this species breeds in strawberry flowers. Adult *T. fuscipennis* have been reported to be abundant in the flowers of many wild plant species in summer without any larvae present (Ward, 1973). Massive invasions of *T. fuscipennis* adults to glasshouse crops have also been reported in Europe where they occasionally damage sweet pepper, aubergine and rose crops and are difficult to control biologically, with larvae rarely being seen under glass (Malais & Ravensberg, 2003).

Thrips numbers in flowers

Adults

Mean numbers of thrips adults per flower remained well below a mean of one per flower at Site 1 throughout the monitoring period between 3 June and 1 July. It is possible that the application of thiacloprid (Calypso) at Site 1 on 15 and 24 May for control of strawberry blossom weevil reduced numbers of thrips present at that time and at the first assessment on 3 June, as thrips species other than WFT are not resistant to neonicotinoids. However, it is unlikely that this insecticide would have persisted until the second and third assessments on 17 June and 1 July. At Site 2, although mean numbers of adults per flower were around five per flower when the trial was set up on 10 June, mean numbers then fell to around one and 1.5 per flower on 24 June and 8 July. The higher numbers at this site on 10 June than on later dates could have been partly due to there being fewer mean numbers of flowers per plant on this date than on later dates, as this leads to thrips adults congregating in the few available flowers. Previous work in SF 156 showed that numbers of *Thrips fuscipennis* in flowers often peak in mid to late June and then only low numbers are seen later in the summer, so as *T. fuscipennis* was the predominant species at both Sites 1 and 2, the higher numbers on 10 June at Site 2 could reflect the natural activity pattern of this species. The higher numbers of thrips in flowers at Site 2 than Site 1 could have been due to several factors, including the flowering weeds present under the tabletops at Site 2 which were absent at Site 1. The three *Thrips* species and *F. intonsa* recorded at both sites are known to occur in a wide range of flowering plants including some weeds (Seymour *et al*., 2020).

Larvae

Mean numbers of thrips larvae per flower remained well below one per flower at both sites and were not recorded at all on one date at each site. This result was similar to those in SF 156, where high numbers of larvae were only recorded at sites where WFT was the predominant species. At both sites in this project, mean numbers of larvae per flower were highest on the set-up dates on 3 June and 10 June respectively for Sites 1 and 2, and on this date at Site 1, numbers were higher than those of thrips adults. These larvae must have been produced by adults active prior to the trials being set up. Although the trials were set up in early June prior to the anticipated peak in thrips activity, it is possible that peak activity was earlier in 2020 due to the very warm spring.

Thrips numbers and species on traps

Mean numbers of thrips adults per sticky trap at both sites were higher than expected considering the low mean numbers of thrips per flower. As with thrips in flowers, there were no significant differences in mean numbers of thrips adults per trap in the 'pull' and 'push-pull' plots. Higher numbers of thrips were recorded on traps at Site 2 which was consistent with those recorded in flowers. At Site 2, although mean numbers of thrips adults per flower were highest on the setup date on 3 June than on later assessment dates, mean numbers of thrips per trap were highest on the final assessment date on 8 July, at 72.9 and 79.1 per trap in 'pull' and 'push-pull' plots, respectively. Trapping this number of thrips did not lead to significantly fewer thrips adults in flowers in the 'push' or 'push-pull' plots, therefore it is likely that higher numbers of thrips would need to be trapped to significantly impact numbers in flowers. Some traps were lost at both sites during the assessment period due to strong winds and storms, but if all 20 traps had remained in position, a mean of 79 thrips per trap on this date would have trapped 1,580 thrips per plot over a 2-week period. This represents a mean of 39.5 thrips trapped per m^2 per 2-week period. Individual sticky traps were used in these trials rather than roller traps, as the trial was set up during COVID-19 restrictions on ADAS staff working in proximity, and this would have been necessary to set up the roller traps. Roller traps are likely to trap higher numbers of thrips per m tunnel length than individual traps, as if used in both leg rows, they would provide around three times the sticky surface area. Roller traps will be used in the 2021 push-pull trials planned in this project to maximise the trapping potential and give the treatments the best chance of success.

Beneficials in flowers and on traps

Site 1 introduced *Orius* twice in early June whereas Site 2 did not release this predator at all. *Orius* were not recorded in any of the flower samples from either site on any assessment date, so the low numbers of thrips at both sites cannot be attributed to predation by *Orius*, which feeds on both thrips adults and larvae. The absence of *Orius* in flower samples from Site 1 was unexpected, especially as the introductions were made before the second assessment. Low numbers of *Orius* adults (mean of less than 0.1 per trap) were recorded on the sticky traps at both sites, confirming that some were present in both crops. At Site 1, these must have been naturally-occurring as they had not been released. It is possible that when sampling the flowers at Site 2 the *Orius* were disturbed and left the flowers before they were placed in the sampling tubes. Staff will be extra vigilant in the second year for detecting *Orius* in the flowers.

One concern growers have about using sticky traps for 'mass monitoring' is the potential trapping of beneficial insects. At both sites, mean numbers of *Orius* sp. caught on traps were negligible and mean numbers of predatory thrips (*Aeolothrips* sp.) were below one per trap on all assessment dates. At Site 2, mean numbers of all other beneficials (lacewings and ladybirds) were also below one per trap. However, at Site 1, mean numbers of bees and hoverflies were up to one and three per trap respectively on the two assessment dates, with no significant difference between numbers trapped in 'push' and 'pull' plots. If all 20 traps per plot had remained in place, this would represent up to 20 and 60 bees and hoverflies per 5 m length of tunnel respectively (0.4 and 1.2 per m^2 respectively) over a 2-week period in June. However, growers using roller traps have not experienced pollination or aphid problems in the past (Clare Sampson pers. comms., 2020) monitoring of beneficials both in flowers and on traps will continue in any future work.

Fruit bronzing

White fruit was assessed for thrips damage (bronzing) in these trials as damage shows up better than on white fruit and in addition, on some dates, insufficient ripe fruit would have been available for assessment due to it already have been picked. Mean percentage fruit area bronzed was below 1% on all dates at both sites, which was well below a mean of 10% fruit area damaged which is usually considered as the 'threshold' above which fruit is downgraded. At Site 1, the low level of fruit bronzing was consistent with the very low mean numbers of thrips adults per flower on all assessment dates (maximum of 0.1). At Site 2, the most fruit bronzing was recorded on the setup date on 10 June (0.5% fruit area) when mean numbers of thrips adults per flower (5.5) were also higher than on subsequent dates and 89%

of those thrips were *T. fuscipennis*. These results indicate that higher numbers of thrips adults of the species recorded at both sites would be needed to lead to commercial losses due to fruit damage on the everbearer varieties Sweet Eve (Site 1) and Prize (Site 2). Everbearer varieties are known to vary in their susceptibility to thrips damage. However, this result was consistent with results in SF 156 when in 2019, peak numbers of thrips adults (all species combined) did not exceed a mean of four per flower at any site and that on the everbearer varieties monitored (Favori, Finesse, Katrina, and Murano), mean numbers of thrips adults per flower would need to be higher than this to cause severe fruit damage.

Summary

- Despite best-efforts on site selection, thrips numbers per flower were low overall in the untreated and treated plots at both sites on the three assessment dates and there were no significant differences between treatments.
- At Site 1 there was less than a mean of one adult per flower on all three dates. At Site 2 there was a mean of around five adults per flower/flower on the set-up date but a mean of only one and 1.5 per flower on the second and third dates.
- Thrips adults were predominantly *T. fuscipennis* at both sites but particularly at Site 2.
- *Thrips major* was the second most common species, especially at Site 1.
- No WFT were seen at both sites and only small numbers of *F. intonsa*.
- Low numbers of larvae were recorded in flowers. *Thrips major* was the main species of thrips larvae confirmed at both sites. *Thrips tabaci* was also confirmed at both sites and *F. intonsa* at Site 1 only. No *T. fuscipennis* larvae were found in flowers at either site despite this being the predominant species of thrips adults at both sites.
- Some fruit bronzing was seen early on when setting up the trials, but little bronzing seen overall at both sites.
- There were no significant differences between treatments in mean numbers of thrips on traps in ‘pull’ or ‘push-pull’ plots.
- Thrips species on the traps were confirmed at Site 2 and were the same as those in the flowers.
- Low numbers of beneficial insects were caught on the traps.

Task 4.2. Culture of thrips species other than WFT for future biological and control studies

Materials and methods

Western flower thrips

A standard laboratory method for rearing thrips on French bean pods (e.g. Loomans & Murai, 1997) was initially tested using western flower thrips in order to establish a successful protocol for rearing other thrips species. The method was adapted to provide high humidity for improved WFT survival during the pupation stage (Kirk, personal communication, 2020). Screw top Perspex jars, 12cm deep and 11cm diameter were used as rearing containers (Figure 4.15). The jars were washed with soapy water, rinsed with tap water and allowed to dry before use. A hole, 8cm in diameter was cut in the lid to provide ventilation. Before securing the lid onto each jar, a double layer of 'blue roll' (similar to kitchen paper) was placed over the mouth of the jar for ventilation. Paper, rather than insect-proof mesh, was used in order to maintain a high humidity inside the jars to allow successful WFT pupation whilst also avoiding condensation inside the jar (to prevent thrips drowning).

'Oviposition jars' were first set up to allow the WFT to lay eggs into French bean pods. Several overlapping filter papers were placed in the bottom of the jars. French bean pods obtained from a supermarket were washed in soapy water, rinsed in tap water and allowed to dry on kitchen paper. Six dry bean pods were placed on top of the filter papers. Commercial bee pollen (Picklecoombe House Premium Bee Pollen, Holland and Barrett, UK) was added to each jar in a small specimen tube lid (2cm diameter, 1cm deep) as a food source for the adult thrips. Western flower thrips (WFT) adults (mixed females and males) from a laboratory culture at Keele University were added to the jars. The jars were placed onto wet capillary matting in the base of a Perspex insect rearing cage, 50x50x50cm with the fans turned off to maintain a high humidity. The rearing cage was placed in a laboratory at ambient temperature. The jars were left for three days to allow the WFT females to lay eggs into the bean pods. The beans were then transferred to fresh jars that were then used for larval and pupal development. Fresh bean pods were added to the 'oviposition' jars to initiate another generation of thrips. In the larval development jars, instead of filter papers on the base, ten layers of dry blue roll, 3cm by 3cm square were placed in the bottom of the jars to provide thrips pupation sites.

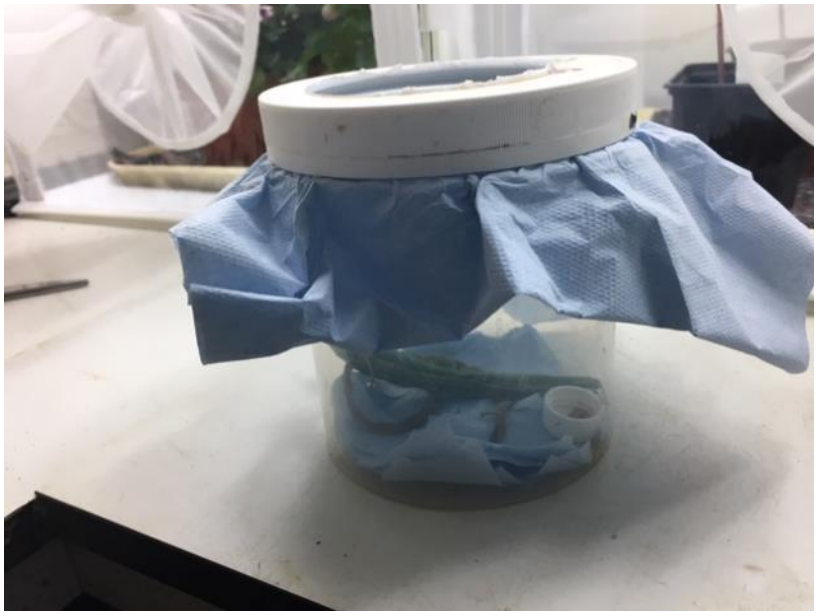


Figure 4.15: Rearing jar with French bean pods

In addition to adding WFT adults to jars of French bean pods, WFT adults were also maintained on both flowering pot chrysanthemum plants (obtained from a supermarket) and French bean plants (grown from seed) in a 'Bugdorm' thrips-proof cage. The cage was placed in the same rearing laboratory as the Perspex cage containing the jars of French bean pods. The potted host plants were stood on a small square of capillary matting on a plastic tray and watered sparingly when necessary.

Thrips species other than WFT

The same method used for rearing WFT on bean pods was used for rearing thrips species other than WFT. Thrips adults were collected from strawberry flowers at Site 1, from a tunnel next to one of the trial tunnels, next to the adjacent hedgerow. In addition, thrips adults from other strawberry crops and hedgerow plants including wild rose, where *Thrips fuscipennis* had been confirmed were collected. Individual adults were placed in oviposition jars with French bean pods and then transferred to larval rearing jars, as described above for WFT. In addition to adding thrips adults to jars of French bean pods, some adults were also added to a thrips-proof 'Bugdorm' cage containing pots of French bean plants and jars of cut flowering mint, which is recorded as a host plant suitable for Thrips fuscipennis larval development (Morison, 1957).

Results

Western flower thrips

Western flower thrips were successfully reared from adults to next generation adults using the bean pod technique. For example, larvae were seen on bean pods one week after setting up adults set on 19 May and the next generation adults were seen during the week after larvae were recorded. The mean temperatures in the rearing laboratory fluctuated between 20°C and 25°C during this period. Western flower thrips were also successfully maintained on both pot chrysanthemum and French bean plants in the 'Bugdorm'.

Thrips species other than WFT

Only low numbers of thrips adults of species other than WFT were collected on most dates. Yellow second stage larvae were recorded on the bean pods in only one rearing jar, on 2 July, after adding 15 adult thrips, collected from site 1 on 17 June. No next generation adults were subsequently recorded in the jars and the original adults died. No thrips larvae were seen developing on the French bean or mint plants in the 'Bugdorm'.

Discussion

Western flower thrips were successfully reared from adults to next generation adults on both French bean pods in jars and on both pot chrysanthemum and French bean plants in the 'Bugdorm'. Western flower thrips have been maintained on pot chrysanthemum plants at ADAS Boxworth for many years. However, in 2019, the culture crashed at a similar time to WFT culture problems being experienced at Keele University (William Kirk, personal communication, 2019). It is possible that the WFT larvae in both the ADAS and Keele University cultures crashed due to predation by predatory mites brought in on the pot chrysanthemum plants. Keeping watering to a minimum and reducing the size and wetness of the capillary matting the plants were stood on during this project may have reduced the size of the predatory mite populations. High humidity is known to be needed for *Neoseiulus cucumeris* egg laying. The development times recorded for WFT larvae on the bean pods in jars at the temperatures in the rearing laboratory (20-25°C) are consistent with those recorded on French bean (Loomans & Murai, 1997; Lublinkhof & Foster, 1977).

Thrips species other than WFT were successfully reared on bean pods from adults collected at site 1 in only one jar, but only to the larval stage. Larvae were not recorded until 15 days after adding adults, whereas WFT larvae were recorded one week after adding adults. This indicates that the development rate of the thrips species collected from site 1 was slower than

that of WFT. The thrips adults were collected from site 1 on 17 June, and on this date, identification of thrips adults collected in flowers in all the trial plots were confirmed that 72% were *T. fuscipennis*, 25% were *T. major* and 3% were *T. tabaci*. Thus, the larvae reared on bean pods from adults collected from this site could have been one or a mix of these species. However, as the larvae were yellow, they were unlikely to be *T. tabaci* as second instar larvae of this species are usually greenish in colour (Bennison, 2009). As no new adults developed from these larvae, it is likely that mortality occurred during the pupal stage. Layers of paper towel were provided in the jars as pupation sites as these allow successful pupation of WFT. Very little is known about the biology of *T. fuscipennis* or *T. major,* but larvae of both species are recorded as pupating in either sheltered vegetation or in soil below the host plant (Morison, 1957). The aim of this work was to establish a culture of a thrips species other than WFT that is a damaging pest of strawberry. This was to allow further work to fill in key gaps in knowledge on biology such as confirming fruit damage, potential further testing of colour attraction and testing predation of adults by predators including *Orius* and the predatory thrips *Aeolothrips*. Larger numbers of either *T. fuscipennis* or *T. major* would need to be collected to try to establish a successful culture on bean pods and any problems with providing suitable pupation sites to allow successful emergence of new adults would need to be overcome.

Summary

- Western flower thrips were successfully reared from adults to next generation of adults on French bean pods in the laboratory.
- When the same rearing system was used for *Thrips* species adults collected from strawberry flowers at Site 1, larvae were successfully reared on bean pods but these 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, the proportions of thrips species adults in the strawberry flowers in trial plots were 72% *T. fuscipennis*, 25% *T. major* and 3% *T. tabaci*.
- Further work would be needed to establish a successful laboratory rearing system for a thrips species such as *T. fuscipennis*.

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

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Appendix 2.1.1.

Grower spray record for the crop where the capsid repellent trial took place, summer 2020

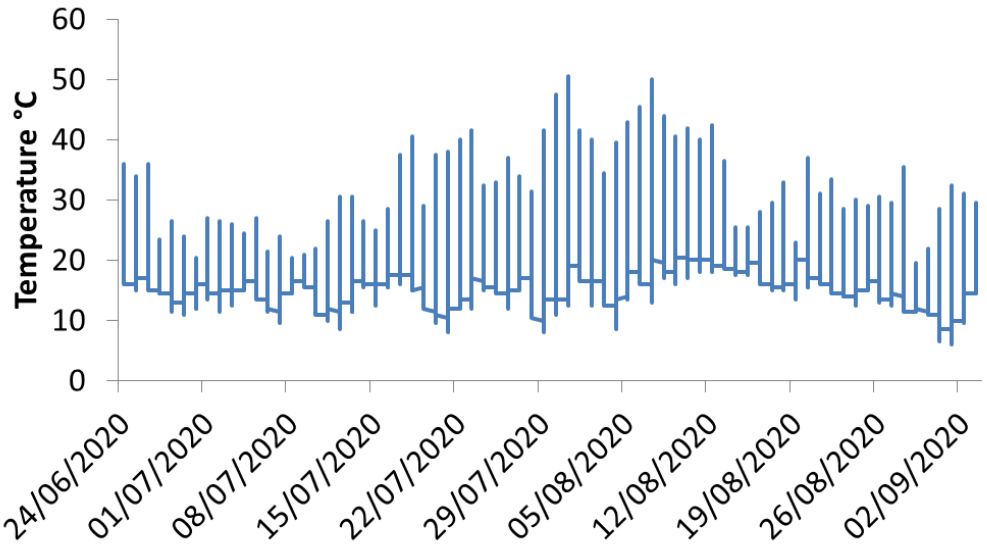
Activity Date / Timing	Operation	Product	HI	Rate	Reason	Water	Area	Operator	Machine
24/03/2020	Spraying #155	Folicur (16731) Tebuconazole (250 g/l) EAMU: 2648/16		0.350 lts/ha	Cane Blight	1,000.00 lts/ha	3.60 ha		DUO PROP
20/04/2020	Spraying #164	Hallmark With Zeon Technology (12629) Lambda-cyhalothrin (100 g/l) EAMU: 0728/06	28 days	0.075 lts/ha	SWD	1,000.00 lts/ha	3.60 ha		DUO PROP
		Codacide (ADJ0284) Rapeseed Oil Or Soya Oil (95 % w/w)		2.000 lts/ha	Adjuvant				
06/05/2020	Spraying #168	Switch (15129) Cyprodinil (37.5 % w/w); Fludioxonil (25 % w/w)	14 days	1.000 kgs/ha	Botrytis	1,000.00 lts/ha	3.60 ha		DUO PROP
06/05/2020	Spraying #172	Calypso (11257) Thiacloprid (480 g/l) EAMU: 2139/14	3 days	0.250 lts/ha	Caterpillars	1,000.00 lts/ha	3.60 ha		DUO PROP
		Omex SW7 (MBS119) Silicate		0.400 lts/ha	Adjuvant				
11/05/2020	Spraying #180	Switch (15129) Cyprodinil (37.5 % w/w); Fludioxonil (25 % w/w)	14 days	1.000 kgs/ha	Botrytis	1,000.00 lts/ha	3.60 ha		DUO PROP
03/07/2020	Spraying #189	Flipper (19154) Fatty acids C7-C20 (479.8 g/l) EAMU: 3418/19		10.000 lts/ha	Spider Mites	1,000.00 lts/ha	3.60 ha		DUO PROP
30/07/2020	Spraying #208	Signum (11450) Pyraclostrobin (6.7 % w/w); Boscalid (26.7 % w/w) EAMU: 2102/10	3 days	1.250 kgs/ha	Botrytis	1,000.00 lts/ha	3.60 ha		DUO PROP
07/08/2020	Spraying #196	Calypso (11257) Thiacloprid (480 g/l) EAMU: 2139/14	3 days	0.250 lts/ha	Leaf Curling Midge	1,000.00 lts/ha	3.60 ha		DUO PROP
		Omex SW7 (MBS119) Silicate		0.400 lts/ha	Adjuvant				
11/08/2020	Spraying #200	Tracer (12438) Spinosad (480 g/l) EAMU: 1207/18	1 days	0.200 lts/ha	SWD	1,000.00 lts/ha	3.60 ha		DUO PROP
09/09/2020	Spraying #211	Teldor (11229) Fenhexamid (50 % w/w)	1 days	1.000 kgs/ha	Botrytis	1,000.00 lts/ha	3.60 ha		DUO PROP

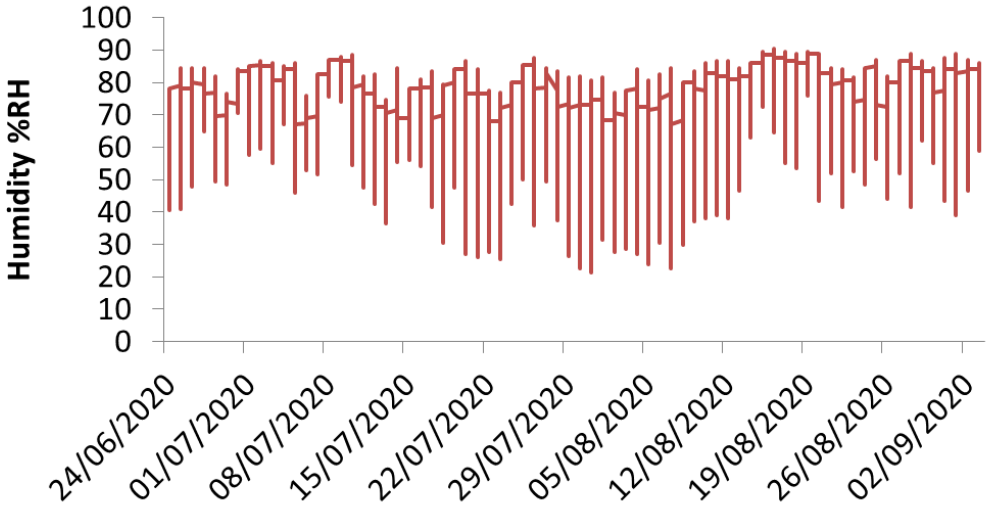
Appendix 2.1.2.

Temperature and Humidity data capsid repellent trial 2020. For temperature graphs, daily peaks are highest temperatures during daylight hours, troughs are lowest temperatures during the night. For humidity graphs, daily peaks are highest %RH during the night, troughs are lowest %RH during daylight hours.

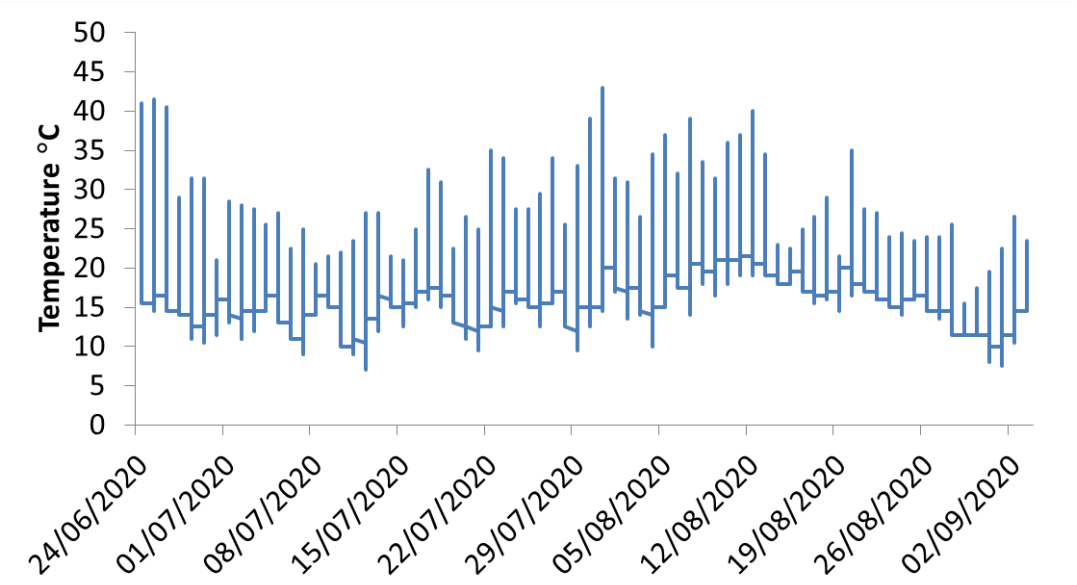
Block 1 Data logger damaged

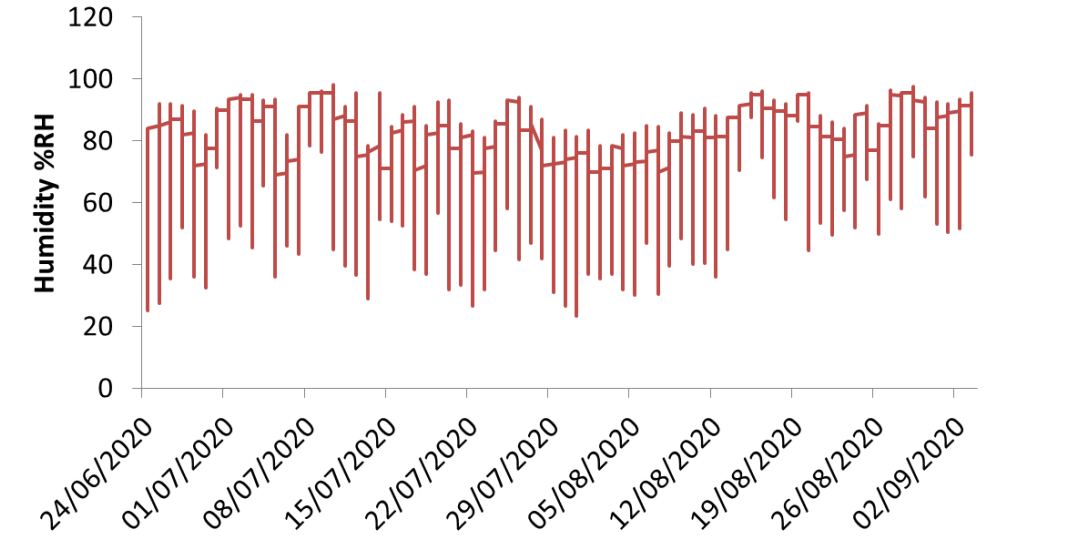
Block 2



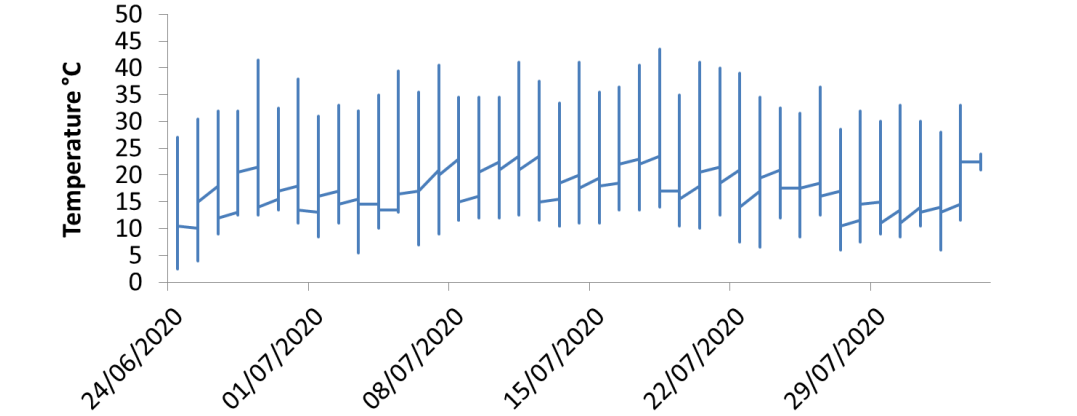


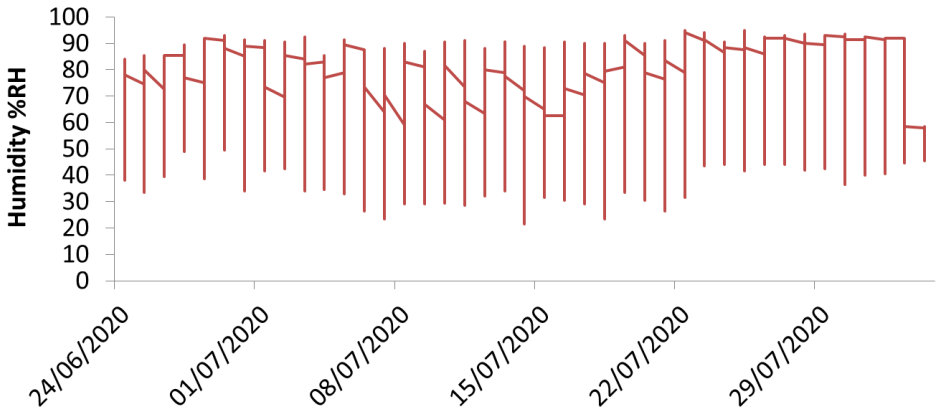
Block 3



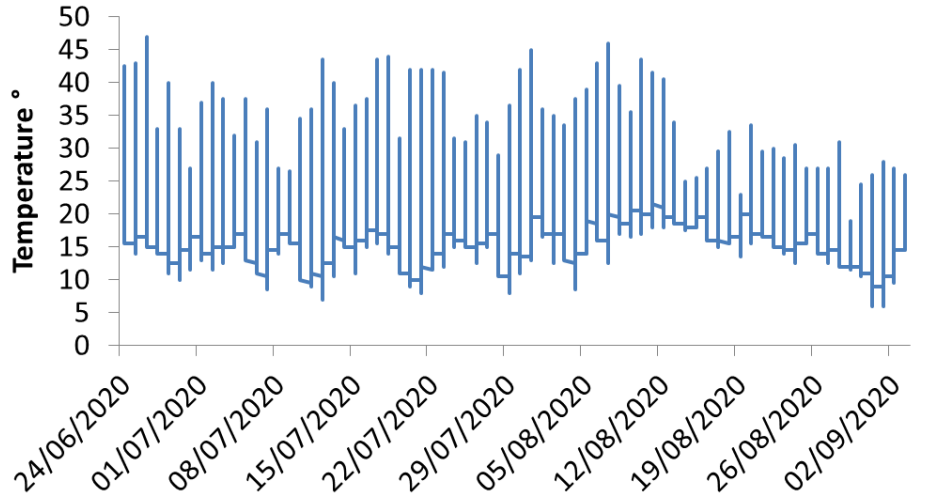


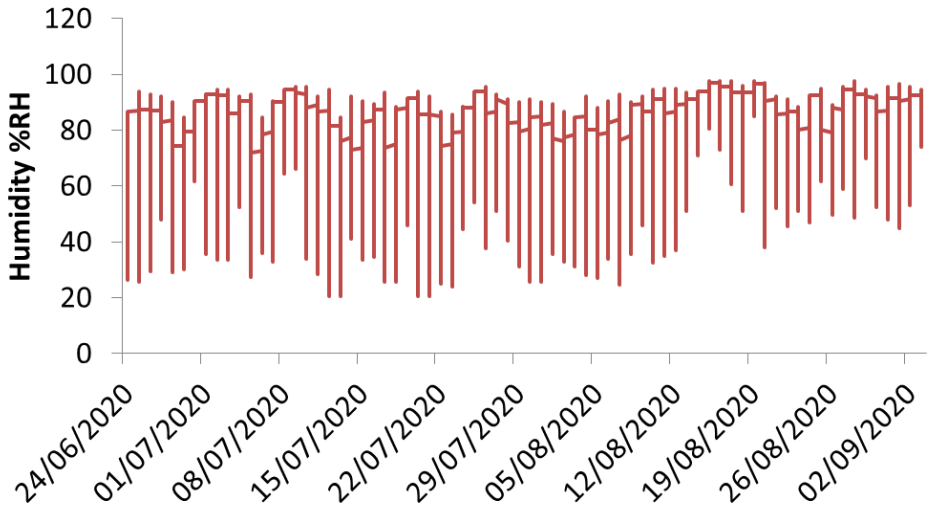
Block 4





Block 5





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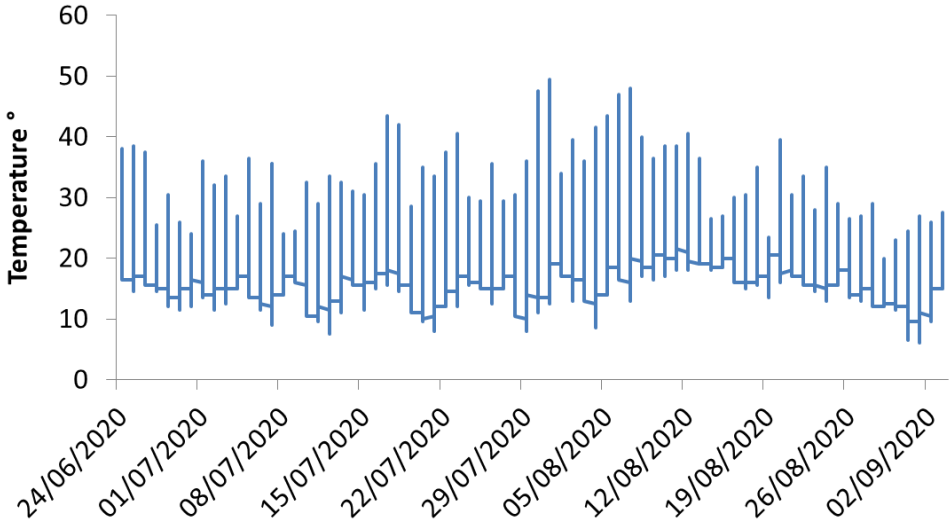

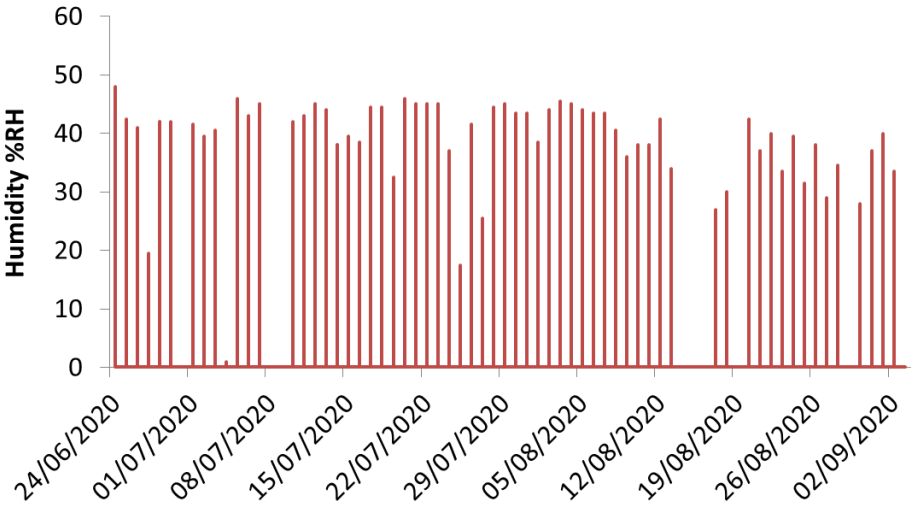

Appendix 2.1.3.

Leaf phytotoxicity key.

- Discolouration of the whole leaf lamina:
- chlorosis
- whitening
- other abnormal coloration

Local leaf discolouration or abnormal coloration of:

- veins
- areas between veins
- edges of leaves
- tip of leaves
- along the veins
- the whole leaf lamina
- stunting, dwarfing, curling, etc.
- deformation of the leaf lamina (wilt, swelling, curling, etc.)
- modification of venation (position and form of veins)
- sticking together of organs (petioles, peduncles, leaf lamina)

Appendix 4.0

Temperature & Humidity

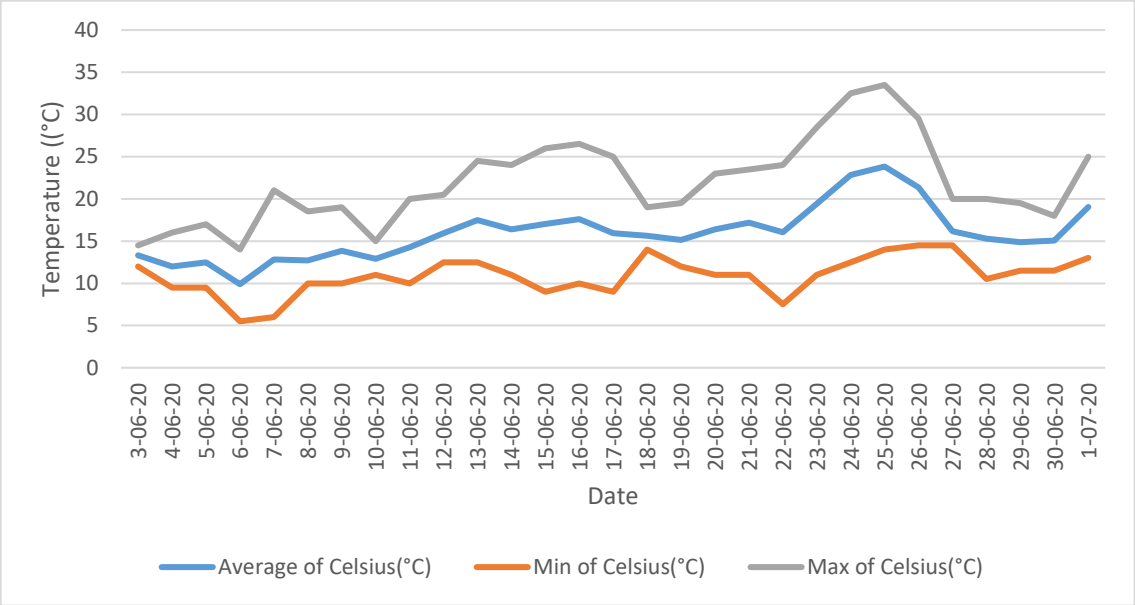

Figure 16: Mean daily temperatures from data logger under the tabletops at site 1.

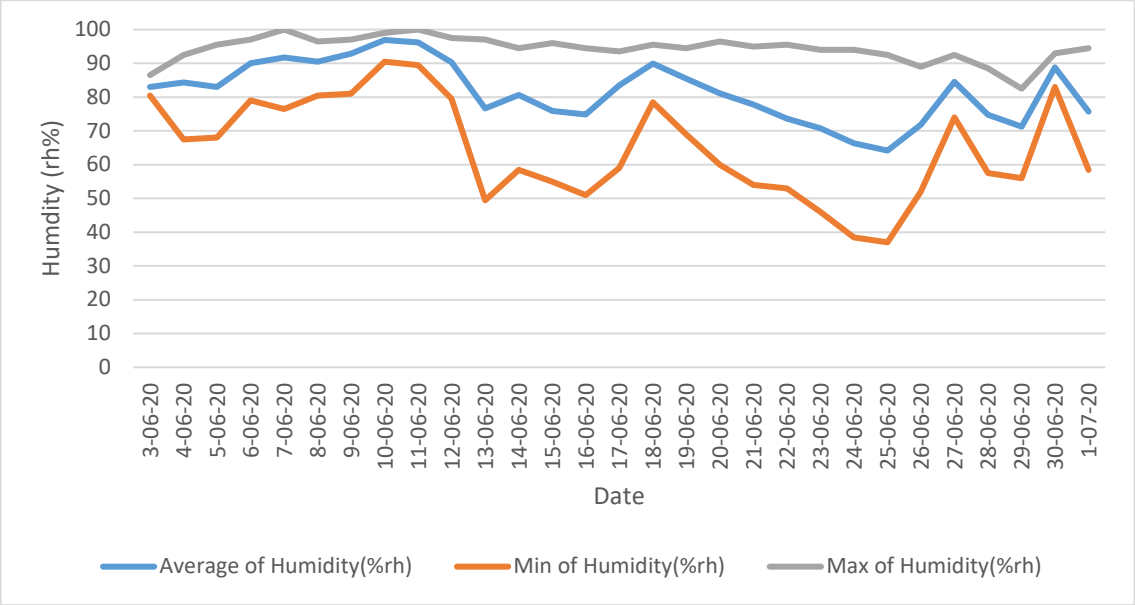

Figure 4.17: Mean daily humidity from data logger under the tabletops at site 1.

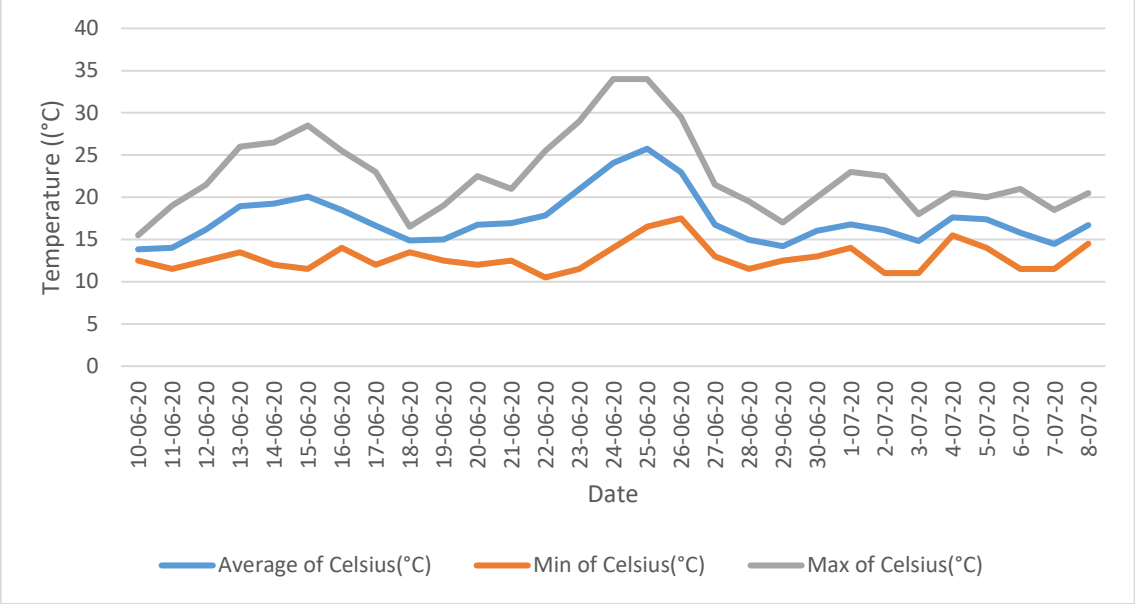

Figure 4.18: Mean daily temperatures from data logger under the tabletops at site 2.

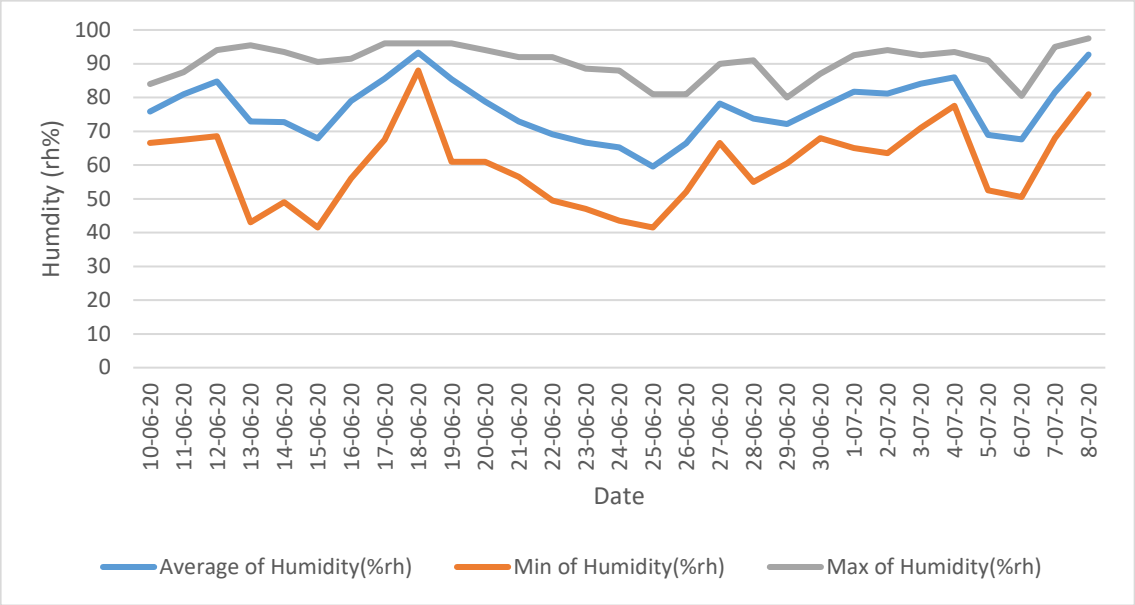

Figure 4.19: Mean daily humidity from data logger under the tabletops at site 2**.**

Grower IPM programmes

Table 4.12: Grower spray inputs at Site 1 from the beginning of the season until the end of the trial.

Date	Chemical	Rate
17/03/2020	Apollo 50 SC (17187)	0.4 L/ha
	Omex SW7 (MBS119)	0.05 L/100L
25/03/2020	Sluxx HP (16571)	7 Kg/ha
	Centurion Max (17911)	2.0 L/ha
02/04/2020	C Tech Prilled Urea (MBS431)	0.4 kg/100L
	Maxicrop Triple (MBS003)	0.2 L/ha
06/04/2020	Topas (16765)	0.5 L/ha
	Prolectus (16607)	1.2 Kg/ha
09/04/2020	C Tech Prilled Urea (MBS431)	0.4 kg/100L
	Maxicrop Triple (MBS003)	0.2 L/ha
11/04/2020	Amistar (18039)	1.0 L/ha
17/04/2020	Systhane 20 EW (19160)	0.3 L/ha
24/04/2020	Takumi SC (16000)	0.15 lts/ha
01/05/2020	Stroby WG (17316)	0.3 Kg/ha
	Teldor (11229)	1.5 Kg/ha
06/05/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
09/05/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
15/05/2020	Topas (16765)	0.50 L/ha
	Calypso (11257)	0.250 L/ha
20/05/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
24/05/2020	Justice (12835)	0.190 L/ha
	Calypso (11257)	0.250 L/ha
29/05/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
05/06/2020	Amistar (18039)	1.0 L/ha
10/06/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
16/06/2020	Systhane 20 EW (19160)	0.3 L/ha
22/06/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
26/06/2020	Charm (18396)	0.6 L/ha
02/07/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
06/07/2020	Takumi SC (16000)	0.150 L/ha
13/07/2020	Potassium Bicarbonate (MBS166)	0.75 kg/ 100L
18/07/2020	Stroby WG (17316)	0.3 Kg/ha

Table 4.13: Grower biological control inputs at Site 1 from the beginning of the season until the end of the trial.

Week beginning	Biological control	Rate
March 16, 2020	N. cucumeris	1 sachet per 2 m^2
March 23, 2020	Phytoseiulus	10 per m^2
	Hypoaspis	50 per m^2
	B. terrestris (Pollinator)	0.2 per m^2
April 6, 2020	N. cucumeris	1 sachet per 4.8 m^2
	B. terrestris (Pollinator)	0.2 per m^2
April 13, 2020	Phytoseiulus	10 per m^2
April 20, 2020	N. cucumeris	1 sachet per 2 m^2
May 11, 2020	N. cucumeris	1 sachet per 4.8 m^2
	B. terrestris (Pollinator)	0.2 per m^2
June 1, 2020	N. cucumeris	1 sachet per 2 m^2
	Orius	2 per m^2
June 8, 2020	Orius	2 per m^2
June 15, 2020	N. cucumeris	1 sachet per 4.8 m^2
July 6, 2020	N. cucumeris	1 sachet per 4.8 m^2
July 27, 2020	N. cucumeris	1 sachet per 4.8 m^2

Table 4.14: Grower spray and biological control inputs at Site 2 from the beginning of the season until the end of the trial.

Date	Chemical	Rate
03/04/2021	Decis	500 ml/ha
	Omex SW7	0.05 L/100L
06/05/2020	Amistar Top	1.0 L/ha
	Omex SW7	0.05 L/100L
11/05/2020	Neoseiulus cucumeris	50/plant
17/05/2020	Systhane	0.450 L/ha
	Teldor	1.5 kg/ha
	Omex SW7	0.05 L/100L
25/05/2020	Neoseiulus cucumeris	25/plant
29/05/2020	Signum	1.5 kg/ha
	Omex SW7	0.05 L/100L
09/06/2020	Systhane	0.3 L/ha
	Omex SW7	0.05 L/100L
11/06/2020	Neoseiulus cucumeris	25/plant
14/06/2020	Pot. Bicarb	5 g/L
	Omex SW7	0.05 L/100L
22/06/2020	Amistar Top	1.0 L/ha
	Scala	2.0 L/ha
	Omex SW7	0.05 L/100L
25/06/2020	Pot. Bicarb	5 g/L
	Omex SW7	0.05 L/100L
	Neoseiulus cucumeris	25/plant
01/07/2020	Switch	1.0 Kg/ha
	Takumi	0.150 L/ha
	Omex SW7	0.05 L/100L
04/07/2020	Pot. Bicarb	5 g/L
	Omex SW7	0.05 L/100L
09/07/2020	Neoseiulus cucumeris	25/plant
10/07/2020	Phytoseiulus Application	3/plant