Grower Summary

TF 233

Improving integrated pest and disease management in tree fruit

Final Report

Project title:	**Improving integrated pest and disease management in tree fruit**
Project number:	TF223
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Date project commenced:	01/04/2015
Date project completed:	31/03/2020

DISCLAIMER

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

AUTHENTICATION

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

Michelle Fountain

Project leader, Deputy Head of Pest and Pathogen Ecology

NIAB EMR

Signature .... Date 16 June 2020.........................

Nigel Kitney

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Signature .... Date ....

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GROWER SUMMARY

Project TF 223 was a five-year project which commenced in April 2015 and was completed in March 2020. The project investigated solutions to the key tree fruit diseases and pests, namely: European apple canker, scab, powdery mildew, *Monilinia* species and bacterial canker affecting stone fruit, codling and tortrix moths including Blastobasis, pear sucker, apple fruit rhynchites weevil, apple sawfly, pear weevils and phytophagous mites. It also included surveillance or emerging insect pests and diseases including the brown marmorated stink bug. This Grower Summary includes information on the entirety of the five-year project. For ease of reading, it is split into sections for each of the diseases and pests worked on.

Objective 1. Surveillance

Headline

- During this project new and invasive pests have been reported and useful links and summaries can be found in the science section of the 2020 report.

Background and expected deliverables

This objective aimed to keep the industry briefed of ongoing pest and disease issues along with emerging pest and disease threats, which could ultimately lead to yield losses in tree fruit. The information gathered will also help to inform future research targets and priorities. Activities included the monitoring of scab virulence on indicator trees, undertaking apple rot surveys and horizon scanning for emerging and future pest and disease threats to the UK tree fruit industry.

Summary of the project and main conclusions

Scab virulence

- An indicator orchard was planted at NIAB EMR, containing 16 different *Malus* hosts which represent a range of apple scab resistance genes, as part of a large global project (VINQUEST) in which the same indicator cultivars were planted at over 30 sites in 24 different countries. These trees have been monitored for Scab lesions over the past 5 years.

- Resistant breaking strains of scab which have overcome *Rvi6* (formerly known as *Vf*, the most extensively used resistence gene for scab resistance in modern day varieties) have been observed at the UK site.
- Resistance breakdown in *M. floribunda* 821, the source of the *Rvi6* scab resistance gene, was again confirmed in 2019 as it had been in the previous three years.
- No breakdown was seen on the trees in a plot of the domesticated cultivar Priscilla which carries the *Rvi6* gene.
- Scab was also found on the indicator genotypes for the *Rvi3* and *Rvi8* genes; unlike *Rvi6* these genes cannot be found in any commercially available cultivars.

Apple rot survey

This task is a continuation of the apple rot survey which has been undertaken over the last century. The survey involves visiting packhouses during the months of January – March to determine the type and incidence of rot causing pathogens.

2018/2019

A total of 26 visits and 44 consignments of apples were examined. On average actual losses ranged from 0.01 to 5% with an overall mean of 1.2 %. The highest losses were recorded in Cox and Bramley which is as expected as these cultivars are stored at 3.5 – 4 °C, whereas the other cultivars are stored at around 1-2 °C. Neonectria rot was the most prevalent rot with an overall incidence of 24% and was the main rot in Braeburn (32.8%), Gala (29.7%) and Jazz (35.2%) reflecting the susceptibility of these cultivars to Neonectria. Brown rot (Monililnia) was the next most prevalent rot (19.3%) followed by *Neofabraea* (Gloeosporium, 16.2%), Botrytis (9.8%), Penicillium (8.8%) and Phytophthora (7.8%). Gloeosporium accounted for 58.8% of rots in Cox, most likely due to the extended storage of the samples assessed into April and the warm wet conditions pre-harvest. There was a higher incidence than previous years of Phytophthora rot in the late harvested cultivars Braeburn and Jazz, due to the high rainfall pre harvest. The data is summarised in Table GS1 together with the data from the previous four year's of apple rot surveys.

In summary

- The overall mean losses to fungal rot pathogens changed slightly between the sampled years, with 2.6% losses occurring in 2015/16, 1.5% in 2016/17, 1.6 % in 2017/18 and 1.2% in 2018/19.

- The pathogens causing the highest volume of rots in all sampled years were *Neonectria*, followed by *Monolinia* and *Neofabraea* (*Gloeosporium*).
- *Botrytis*, *Penicillium* and *Phytophthora* had similar incidence each year.
- A new apple rot pathogen, *Neofabraea kienholzii,* was reported for the first time in the UK.
- Different apple cultivars are more susceptible to certain pathogens. For instance, *Botrytis* tends to be more prevalent in Jazz, associated with missing stalks, whereas brown rot is more prevalent in Cox and Bramley.

Table GS1. Average loss (%) attributed to each rot pathogen during 2018/19 storage season. Data is compiled from 44 apple samples. Overall averages for 2017/18, 2016/17 and 2015/16 are included for comparison. [1]Core rots includes Fusarium and Phomopsis rots recorded separately.

Cultivar	Brown rot	Botrytis	Penicillium	Phytophthora	Neonectria	Gloeosporium	Fusarium	Mucor	Botryosphaeria	Phomopsis	Stalk	Eye	Cheek	[1]Core	No. samples	Loss (%)	Loss range %
Braeburn	11.9	18.6	13.9	13.6	32.8	7.6	0	0.4	0	0	0	0	1.1	0	10	0.23	<0.1-0.8
Bramley	34.5	2.0	8.2	0	8.1	2.2	5.2	0.4	0	32.5	0	0.3	2.2	14.3[1]	10	1.9	<0.1-3.6
Cox	12.3	5.3	4.8	2.7	14.4	58.8	0	0.3	1.0	0	0	0	0.4	0	5	2.3	0.5-3.0
Gala	36.4	5.1	6.1	0.8	29.7	10.6	0	0.6	0	0	0	0	0	0	9	0.5	0.01-0.7
Jazz	1.5	18.0	11.0	22.0	35.2	1.7	0	0.6	0	0	0	0	0	0	10	1.0	<0.1-5.0
Overall mean 2018/19	19.3	9.8	8.8	7.8	24.0	16.2	1.04	0.5	0.2	6.5	0	0.06	0.7	2.9	44	1.2	-
Overall mean 2017/2018	7.6	27.8	10.6	4.5	32.4	10.6	2.9	0	0	0.4	1.3	0.1	1.0	0.3	32	1.6	-
Overall mean 2016/17	19.3	9.7	11.2	1.6	31.3	12.4	0.4	4.2	0	0	2.0	0.6	1.5	5.6	52	1.5	-
Overall mean 2015/16	13.3	8.3	6.3	6.4	40.3	9.3	0.5	3.0	0	0	2.2	0	1.2	7.3	60	2.6	-

Invasive pests and diseases

A detailed summary for each pest and disease listed below is presented in the Science Section of this report with useful links.

- *Xylella fastidiosa* continues to be the biggest threat to UK horticulture including tree fruit crops but has not been detected in the UK to date.
- Another notifiable bacterial pathogen is *Xanthomonas arboricolae, pv. pruni.* which causes shot holing symptoms on leaves of plum and sweet cherry. Currently, it has only been reported on *Prunus laurocerasus* (cherry laurel) in the UK.
- *Drosophila suzukii* numbers (monitored only at NIAB EMR) rose slightly in 2019 compared to 2018.
- Summer fruit tortrix was detected for the first time in the West Midlands during the 2015 growing season and it is recommended that growers now monitor for this pest in the region using pheromone traps alongside codling moth and fruit tree tortrix monitoring traps.
- Brown marmarated stink bug (BMSB) was identified in the UK for the first time in Hampshire, in 2019.
- A new complex of shield/stink bugs have been found damaging apple and pear crops in recent years, including the forest bug (*Pentatoma rufipes*).
- A weevil found in pear orchards which has been damaging spring flower and leaf buds over the last two to three years, was identified as *Anthonomus spilotus* by the Natural History Museum and NIAB EMR in 2017. This pest is believed to be new to the UK. It has also recently been identified as an invasive pest in Belgium. Progress was made on the estimation of damage and the susceptibility to specific crop protection products. More details are included in the Science Section (Objective 9).
- The Royal Horticultural Society reported sightings of pear shoot sawfly (*Janus compressus*) in 2016. This has not been seen in commercial pear crops as far as we are aware.
- A new species of aphid, green citrus aphid (*Aphis spiraecola*) was reported in apple orchards the South East of England in 2018. This species is difficult to distinguish and is more resistant to aphicides than many other aphid species.

- A table of additional pest and disease threats relevant to tree fruit growers is presented in the science section of this report with links to useful resources.

Overall conclusions from Objective 1 Surveillance in this project

- During this project new and invasive pest have been reported and useful links and summaries can be found in the science section of this report.
- These include, *Drosophila suzukii*, Summer fruit tortrix in the West Midlands, Brown Marmorated stink bug, Forest bug, Common Green Shieldbug, Mottled Shield Bug, *Anthonomus spilotus*, Pear Shoot sawfly, Apple maggot fly, Black and white citrus longhorn, False codling moth, Grapevine phylloxera, Ambrosia beetle on nursery stock, Gypsy moth, Magdalis beetle on pear, *Rhagoletis cingulate*, Green Citrus Aphid, American plum borer, European grapevine moth, Peach fruit moth, Oriental fruit fly, European Corn borer, Diaporthe causing apple leaf spots, *Neofabraea kienholzii* and *Xanthomonas arboricolae, pv. Pruni.*
- Resistance breaking strains of scab which have overcome *Rvi6* (formerly known as *Vf,* the major scab resistance gene used in modern varieties) have been observed at a UK site.
- *Neonectria* was the largest cause of storage rot in all years sampled, followed by *Monolinia* and *Neofabraea* (*Gloeosporium*).
- A new apple rot pathogen, *Neofabraea kienholzii,* has been reported for the first time in the UK.
- *Xylella fastidiosa* continues to be the biggest threat to UK horticulture but has not been detected the UK to date.

Financial benefits

Current, emerging and newly introduced pests and disease can have a devastating effect on yield and economic return to fruit businesses. Surveillance work ensures the ongoing monitoring of these threats, helping to inform future research priorities. For instance, before the spotted wing drosophila arrived in the UK, its spread to the USA and mainlaind Europe was identified and a UK SWD industry working group was set up (involving AHDB) to provide guidance to growers on how to identify and manage it when it arrived on our shores. This helped the industry to prepare for this existential threat and avoid serious financial losses.

Action points for growers

- Continue to use the rot risk assessment tool available in the AHDB/DEFRA apple best practice guide to limit loss of apples in store.
- Monitor for summer fruit tortrix moth in the west of England.
- Monitor for native and invasive stink bugs.
- Keep an eye on the trade press for important announcements from the animal and plant health agency (APHA) about invasive pests and disease which will affect your business such as *Xylella fastidiosa.* See https://www.jic.ac.uk/brigit/ for more information and partake in a survey of the insect vector at http://www.spittlebugsurvey.co.uk

Objective 2. Neonetria Canker of Apple

Headline

- A combined approach of careful rootstock selection, use of certain soil amendments at planting time and the application of wound protection treatments when pruning, can make a positive contribution to reducing incidence of Neonectria canker in newly planted orchards.

Background and expected deliverables

Neonectria canker caused by *Neonectria ditissima* is a devastating disease of apple which has been increasing in significance over the past 10-15 years as the industry has changed agronomic practices and cultivar choice. This project objective examined the effect of various factors such as development of an immunological based assay to detect *N. ditissima*, rootstock/interstock choice, the use of biological soil amendments, trunk injections to deliver active ingredients to trees and pruning wound protection treatments. Work from other projects including two BBSRC LINK projects which have AHDB and direct industry involvement and two AHDB funded PhD studentships, will contribute to the development of a systems approach for canker control from the nursery to the orchard.

Experiments were established on two sites to determine the effect of rootstock and biological soil amendments on canker incidence. The rootstock trials are evaluating a panel of industry standard rootstocks alongside several advanced selections from the NIAB EMR and Geneva rootstock breeding programmes. The amendment experiments evaluated the effect of arbuscular mycorrhizal fungi (AMF), plant growth promoting rhizobacteria (PGPR), Trichoderma and Biochar (at one of the sites) in newly planted orchards, as well as a stoolbed site to simulate a nursery scenario.

Summary of the project and main conclusions

A summary of results of all the work packages within this objective on Neonectria canker are provided below.

Development of an immunological based tool for Neonectria canker detection

- An Enzyme Linked Immunosorbant Assay (ELISA) protocol was optimized to detect *Neonectria ditissima* antigens in plant material.

- An antibody (1B10) was identified which gives good resolution in cross reactivity tests between *Neonectria ditissima* antigens and antigens from other fungi commonly found in UK apple orchards.
- With further refinement, this assay can be used to improve our understanding of the biology of *N. ditissima.*
- This diagnostic tool is being used in Project CP 161 with the intention of developing a sampling strategy to deploy its use in the nursery.

Rootstock/interstock

- Rootstock trials were established at two sites: at NIAB EMR, Kent (site 1) and at a commercial orchard in Gloucestershire (site 2). Conflicting results were recorded between sites.
- At site 1, the rootstocks MM106 and M116 had consistently lower levels of canker, while G.41 and G.11 had higher levels.
- At site 2, the rootstocks G.11 and G.41 had lower levels of canker, whilst MM106 and M116 had higher levels. The rootstocks were subsequently DNA fingerprinted and identities confirmed as correct.
- On further examination of the data for peripheral cankers from natural infection over three years at site 1, rootstock M9 (EMLA) showed significantly lower canker than the other rootstocks while G.41 had the highest canker number. There were no significant differences between the other 12 rootstocks at site 1.
- Combining three years of data (2017-2019) of peripheral cankers from natural infection at site 2, there was no significant difference in canker expression between the different rootstocks.
- Combining two years of data from artificial inoculation (2018-2019) from site 1 showed no significant difference in canker between rootstocks.
- Gala scions grafted to the NIAB EMR advanced selection EMR-001 had higher canker numbers at both sites.
- Factors such as site, scion cultivar selection and apple replant disease, are likely to be having some effect on canker incidence.
- Tree vigour does not appear to play a role in canker number.

Soil amendments

- *Trichoderma harzianum* (Trianum G) was the most promising amendment for reducing canker.

- A saving of >£1050.38 per 1,000 trees planted was calculated for Trichoderma amended trees at one of the trial sites.
- There was a significant effect of the amendment AMF+PGPR on fruit size at one of the trial sites, but no effect of any of the amendments on fruit number, fruit weight, or vigour (as measured by trunk girth).

Novel methods of treatment application to manage canker

- Trunk injections were found to effectively distribute some of the active compounds through trees.
- However, none of the chemistry tested to date has shown sufficient efficacy for the control of symptomatic cankers.

Future work could include a greater number of active ingredients representing a wider range of modes of action. Products could include those that affect plant hormones such as Bion, in addition to Trichoderma products which have shown promise in New Zealand trials, neither of which were tested in the current work due to current regulations not permitting their use.

Pruning wound protection treatments

- Application of wound protectant treatments using secateurs with a chemical dispenser to pruning cuts with Folicur (tebuconazole) with or without Blocade polymer, as well as the biological treatment T34 + Blocade polymer can significantly decrease the incidence of canker infection.
- T34 + Blocade polymer and both treatments that used Folicur ie. Folicur + Blocade and Folicur alone, had the lowest canker percentage compared to the other tested pruning wound treatments. T34 used on its own did not reduce canker.
- There was good callousing of host tissue at the cut site after application of Folicur.
- As of April 2020, Folicur can only be applied once in any given year, either before the first leaves are fully expanded or after the harvest of the final crop.
- The use of chemistry such as Folicur (tebuconazole) is increasingly being phased out in the UK with the current EAMU expiring on 28/02/2023.
- T34 was used under experimental approval and would need CRD approval for use on apple.

Key conclusions from Objective 2 Neonectria canker over the entire project

- Development of an immunological based tool for Neonectria canker detection was investigated.
- Rootstocks were identified with reduced canker, however there was conflict with the same rootstocks between the two tested sites.
- *Trichoderma harzianum* (Trianum G) was the most promising amendment for reducing the number of dead trees caused by canker in newly planted orchards with potential savings of >£1050.38 per 1,000 trees planted.
- Application of wound protectant treatments to pruning cuts with Folicur (tebuconazole) with or without a polymer, using secateurs with a chemical dispenser, can significantly decrease the incidence of canker infection.

Financial benefits

This work has established practical approaches growers can use to reduce losses to canker in their orchards including rootstock selection and the addition of biological soil amendments. Growers commonly remove trees with main stem cankers in the first five years of orchard establishment and canker is known to cause tree death of >10% of newly planted trees. This incurs the financial burden of replacing diseased trees and years of delayed fruit production. Employing a range of canker reducing methods is recommended, as using single methods in isolation may not have significant benefits.

Action points for growers

- It is still important to be vigilant with visual inspection, identifying trees which are showing canker symptoms and limiting abiotic stress as far as possible when planting out and establishing new orchards.
- Employing a range of canker reducing methods is recommended, as using a single method in isolation may not have significant benefits.

Objective 3. Apple Foliar Diseases

Headline

- Alternating conventional fungicides with biostimulant and physical acting products, can reduce reliance upon fungicides whilst maintaining acceptable mildew control and fruit quality.

Background and expected deliverables

Most UK apple cultivars are susceptible to powdery mildew, particularly Braeburn, Gala and Cox. The disease overwinters as mycelium in fruit or vegetative buds, which emerge as mildewed blossoms or shoot tips in spring (primary mildew). Spores from the primary mildew spread to developing shoots to initiate the secondary mildew epidemic. Mildew colonises fruit buds in June/July and vegetative buds at the end of shoot growth in late summer, where it remains dormant until the following spring. Under favourable humid conditions above 18°C, the fungus can infect leaves and produce sporing colonies in four to five days. Mildew inoculum level is the key factor in determining the seasonal epidemic. Therefore, control strategies depend on maintaining primary mildew at a low level. Season-long protection is essential, which can amount to 10 to 15 fungicide sprays.

With the continuing pressure to reduce reliance upon conventional fungicides, the industry needs to develop novel and alternative control measures for apple powdery mildew. A number of elicitors, biostimulants, biocontrol and physical control products are available to growers, but their success has shown great variation depending on seasonal weather conditions and disease pressure.

Work in this project aimed to find methods of reducing levels of over-wintering mildew and develop ways of improving the reliability and use of alternative control products.

Summary of the project and main conclusions

Reducing levels of overwintering mildew

Efforts were made to investigate the use of fungal and bacterial parasites, applied to apple trees in late summer as a means of antagonising the pathogen over the winter and reducing levels of overwintering inoculum. Trials to incorporate the mycoparasite *Ampelomyces quisqualis* (AQ10) in overwintering buds to reduce mildew inoculum were inconclusive. Plans to repeat the trials in 2018 applying both AQ10 and a novel bacterial parasite towards the end of shoot growth in late summer were hampered by early termination of growth due to the hot dry conditions. It is therefore planned to reassess this approach in a different project.

Improving reliability of alternative control products

Ways of improving tree health along with the tree's ability to withstand fungal infection were assessed using a range of substances within reduced fungicide control programmes and these were compared to traditional routine fungicide programmes. Various nutrients, substances reported to act as biostimulants that improve plant health and their ability to resist disease, and adjuvants that have a physical impact on mildew were included to assess their incidental effect on powdery mildew. Such substances can't be used for control of powdery mildew, but the knowledge of incidental effects on mildew may help inform a managed programme which could reduce fungicide use. Products based on potassium bicarbonate were not included in the trials as the efficacy of these products was already known.

Over the first three years of the project, the use of a range of substances to improve tree health were evaluated in small-plot replicated trials at NIAB EMR on Gala apples, with and without fungicides. From these trials promising incidental effects on mildew were seen for:

- Cultigrow (a potential biostimulant based on flavonoids)
- Trident (a silicon-based nutrient)
- Mantrac Pro (manganese nutrient)

Products which physically controlled mildew included SB Invigorator (a blend of surfactants) and the adjuvant Wetcit (a natural adjuvant based on alcohol ethoxylate) which can be used in combination with plant protection products.

In the final two years of the project the incidental effect of these substances were evaluated in season-long programmes with reduced fungicide use and compared for mildew control with a seven-day fungicide programme.

In 2019, three different programmes were evaluated in a large plot trial (six rows of 70 trees) in an orchard at NIAB EMR with alternating rows of Gala and Braeburn. The programmes were evaluated from early blossom and applied by a tractor-trailed orchard sprayer at 200 L/ha.

Two of the three were based on Cultigrow, applied monthly, with either Mantrac or Trident applied every two weeks. The other was based on Trident and Mantrac alternating every two weeks. SB Invigorator was applied as a separate spray (should not be mixed with other products) in all programmes and Cultigrow was used with the adjuvant Wetcit.

Fungicides were applied at 14-day intervals with the same product used as in the standard seven-day fungicide programme. Captan was included for scab control when necessary. Primary blossom mildew for both cultivars was low but there was a high incidence of primary vegetative mildew on Braeburn. Secondary mildew on extension shoots was assessed every week from petal fall.

The exact products used and the timing of applications in each of the four programmes (1-4) is laid out in the table below.

The incidence of primary mildew, particularly the primary vegetative mildew, in the trial orchard was higher than expected and appeared to be reduced by the early fungicide programme applied to the routine plots. Secondary mildew on Braeburn was higher than on Gala, indicating higher susceptibility to mildew. Initially the best control for both cultivars was achieved by the standard seven-day fungicide programme. However, by July all three trial programmes were performing as well as the standard programme with secondary mildew around 5-10% mildewed leaves. The standard seven-day fungicide programme was effective in controlling the early mildew resulting from the high primary mildew on the Braeburn. Starting all three trial programmes with a seven-day fungicide programme for the first few sprays would probably have resulted in comparable control throughout the season but with reduced fungicide input. There was no phytotoxicity noted in the trial from the programmes applied.

Programmes for powdery mildew control applied to apple cvs Braeburn and Gala in 2019.

Programme	Product / Timing													
	24 Apr	1 May	6 May	15 May	21 May	29 May	5 Jun	12 Jun	19 Jun	26 Jun	3 Jul	10 Jul	17 Jul	24 Jul
Growth stage	**Braeburn** **30% flower**	**Late flower**	**Petal fall**	**End flower**	**End flower**	**Petal fall +**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**End shoot growth**
	Gala **Early flower**	**Full flower**	**Full flower**	**Late flower**	**End flower**	**Petal fall +**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	
1 Fungicide 7 days	Flint	Sercadis + Captan	Flint	Sercadis	Topas + Captan	Talius	Cosine + Captan	Topas	Flint	Cosine	Sercadis	Topas	Flint	Talius
2 CBL/Mantrac	Mantrac + Flint	CBL+Captan	Mantrac + Flint	SBI	Topas + Captan + Mantrac	CBL+Wetcit	Cosine + Captan + Mantrac	SBI	Mantrac + Flint	CBL+ Wetcit	Sercadis + Mantrac	SBI	Mantrac + Flint	SBI
3 Mantrac/Trident	Mantrac + Flint	Trident + Captan	Mantrac + Flint	SBI	Topas + Captan + Mantrac	Trident	Cosine + Captan + Mantrac	SBI	Mantrac + Flint	Trident	Sercadis + Mantrac	SBI	Mantrac + Flint	SBI
4 CBL/Trident	Trident + Flint	CBL + Captan	Trident + Flint	SBI	Topas + Captan + Trident	CBL + Wetcit	Cosine + Captan + Trident	SBI	Trident + Flint	CBL Wetcit	+Sercadis + Trident	SBI	Trident + Flint	SBI

Main conclusions

- Plots treated with programmes 2, 3 and 4 which alternated between applications of conventional fungicides and biostimulants or physical control products received half the number of conventional fungicides compared to the routine treatment.
- The results show that by combining alternative products with fungicides it is possible to reduce fungicide inputs, while still maintaining mildew control and fruit quality.

The results from these trials show that there is potential for reducing fungicide inputs by improving the health of the tree and its ability to resist powdery mildew infection through the use of substances with biostimulant and physical properties. As the biostimulant products boost plant resistance to disease, they act slowly and require frequent applications from an early stage of growth to be most effective. The products that increase the tree's physical ability to resist infection, act more directly and could be used to intervene if mildew incidence was increasing. In a commercial situation, the key to effective mildew control is regular monitoring of mildew incidence on shoots during crop inspections so appropriate decisions on product use can be made. Full details of all of the records collected between the treatments and post harvest are laid out in the Science Section of this report.

Financial benefits

A high incidence of powdery mildew in apple orchards significantly reduces yield and fruit quality. Generally, 10-15 conventional fungicide sprays are required to control powdery mildew and to ensure buds are free from overwintering mildew. There are now decreasing numbers of effective conventional products available to control mildew. The use of effective alternative products will help growers to reduce their reliance upon conventional products and ensure that mildew can continue to be controlled, preventing economically damaging disease thresholds being reached.

Action points for growers

- Alternative products should be used in programmes combined with mildew monitoring.
- The key to effective mildew control is regular monitoring of mildew incidence on shoots during crop inspections. Decisions on product use can then be adjusted to the identified mildew risk.
- Growers and agronomists should consult the AHDB Apple Best Practice Guide online on how best to do this.

- Alternative products can reduce mildew and boost plant health, although they act slowly and require frequent applications from an early stage of growth to be most effective.

Objective 4 - Stone Fruit Diseases

Headline

- Progress has been made in identifying new control measures for brown rot and bacterial canker of cherry.

Background and expected deliverables

Brown rot of cherry

Brown rot (caused by Monolinia species) is one of the principal diseases causing yield loss in plum and cherry crops in the UK. Total losses are difficult to quantify as infection can occur throughout the season from blossom time through to harvest and during the storage period. Post-harvest development of brown rot limits the storage potential of plums and cherries. To gain control, growers currently rely heavily on the use of conventional fungicides such as Signum (boscalid + pyraclostrobin) and Switch (cyprodinil + fludioxonil) applied both during blossom and close to harvest.

This project aimed to evaluate newly available control products including plant health promotors, biological control agents and fungicides, which in combination, could provide a more effective programme for brown rot control.

Bacterial canker of cherry

Pseudomonas syringae pathovars; *syringae* (Pss), *morspronorum* race 1 (Psm1) and *morspronorum* race 2 (Psm2) cause a destructive disease called bacterial canker on prunus species. The disease reduces yields due to cankers girdling branches and trunks causing wilting and tree death. Until now growers have relied on copper treatments at leaf fall to reduce bacterial populations and control this disease. However copper is no longer permitted for use as a plant protection product. In this project, investigations have focussed on both bacteriophages and cultural control as alternatives to copper use.

Bacteriophages, often simply referred to as phages, are natural antimicrobial agents with very specific modes of action. They can control individual bacterial populations/strains and have therefore minimal unintended consequences in terms of inhibiting beneficial organisms. Moreover, phages are considered safe for human consumption. This objective focused on i) finding and characterising native UK phages against prunus canker pathogen and ii) testing their efficacy on plants to provide proof of concept for their use in disease management.

Anecdotal evidence has suggested that the cultural control measure of leaving the cover of tunnelled cherries on for longer after harvest may result in reduced canker development, when compared to the standard practice of removing the covers immediately after harvest. This current practice opens up the tunnel allowing light to reach leaves, which may positively affect potential yield in the following year. Observations on one grower site in Scotland where the covers were left on until later seemed to suggest that there was less canker and a better yield the following year. An observation trial was instigated on two grower sites where we assessed the effects of altering the timing of covering cherry tunnels on disease incidence.

Summary of the project and main conclusions

Brown rot of cherry

A range of control products were tested including a biostimulant, an elicitor, the biofungicide Serenade, standard fungicides (Signum and Switch) and an untreated control. The coded product HDC F266 was effective in reducing brown rot and Botrytis rot on cherries. However, this is not currently approved for use on cherry and further work is required to secure an approval before growers can benefit from it.

Good orchard hygiene is also important for brown rot control. The work that most growers now undertake to remove all damaged, diseased and mummified fruit, both from trees and the orchard floor, to reduce damage from spotted wing drosophila has had a major impact on reducing brown rot infection and spread. Such fruit removal has the benefit of reducing sources of inoculum of *Monolinia* spp. and *Botrytis.*

Bacterial canker of cherry

Initial bacteriophage work identified more than 70 different phages which were effective against bacterial canker. In a subsequent cherry tree trial, a mix of four phage isolates were applied prior to leaf fall and their efficacy was observed. On the cultivars Van and Roundel, phage treatments decreased bacterial population by approximately 10-fold (90%) in comparison to a water control, which is comparable to current chemical and biocontrol products.

CRD/HSE approval was obtained for field trials of UK phages against *Pseudomonas syringae.* The permit is valid until June 2022. The 2019 experiments provided evidence for phage biocontrol and should be followed up in collaboration with a suitable biocontrol producer to deliver phage treatment against bacterial canker.

In the cultural control trial, tunnel skins were retained post-harvest in tunnels and were compared to those where tunnel skins were removed after harvest. Leaving tunnels covered until leaf fall was found to reduce canker progression in trees that already have canker. Covering cherry trees prior to blossom, as well as after harvest appeared to have the largest impact on the canker progression. Leaving the crop covered until leaf fall may also help to suppress weed seedling germination during late summer and early autumn.

Main conclusions

- The coded product HDC F266 was effective for reducing brown rot and Botrytis rot of cherry.
- A large collection of more than 70 bacteriophages isolated from UK orchards has been established and characterized.
- Using the data obtained in this project in 2018 and early 2019 we have successfully obtained CRD/HSE approval for field trials of UK phages against the cherry canker pathogen *Pseudomonas syringae*. The permit is valid until June 2022 and should enable further trials.
- 2019 experiments provide solid proof-of-principle for phage biocontrol and should be followed up in collaboration with a suitable biocontrol producer to deliver phage treatment against prunus canker to the growers as soon as possible.
- Extending the period cherry trees are covered for during the season can result in a reduction of new canker infections in orchards with existing infections.

Financial benefits

The use of effective products such as the coded HDC F266 is an effective method for reducing brown rot and Botrytis rot of cherry and will make significant reductions in crop loss caused by these diseases.

The phages tested in this project were found to be specific, efficient and robust enough to be considered as a future canker control which could help to reduce financial losses caused by this disease. The investment in more trials and collaboration with a plant protection producing company is required to expedite product development.

The tunnel covering trial assessed a simple cultural control that can reduce the spread of canker with no significant increase in cost to growers. This will lead to decreased losses to yield and increased profit.

Action points for growers

- The coded product HDC F266 was found to be an effective method for reducing brown rot and Botrytis rot of cherry. Approval will need to be granted before legal use of this product can be made.
- No commercial phage product is available yet for canker control but if growers have a serious outbreak of bacterial canker on prunus or other host, they should inform NIAB EMR who are seeking trial sites for future work.
- The period that cherry trees are covered during the season should be extended to reduce the spread of canker at critical times during rain events.

Objective 5 – Optimise spray coverage for key pest and disease targets

At the outset of this project, it was decided that the work on this objective would be dependent on progress in a TSB (former name of Innovate UK) funded project which was developing equipment to determine the optimum coverage of spray deposits for foliar pest and disease control. Due to the progress made in that project, it was ultimately decided in consultation with the TF223 programme management group, not to proceed with this work objective, however this did enable additional work to be conducted (Obj. 9 and 10) which focused on emerging issues.

Objective 6 – Codling, Tortrix, and Blastobasis Moths

Headline

- The RAK3&4 mating disruption system appeared to be very effective at disrupting male moth pheromone detection, but complete ‘trap shut-down’ (no moths captured) was not achieved for codling moth.

Background and expected deliverables

Codling moth is the most important pest of apples and is also an important pest of pears in the UK. Most spray control products employed on these crops are targeted towards these moths. Control is usually good, but populations are not reduced to such low levels that spraying is reduced in subsequent years, so growers find it difficult to reduce dependence on spray control. A number of novel approaches to the management and control of codling, tortrix and blastobasis moths in apple orchards were investigated in this objective. Sex pheromone mating disruption technology is one approach that offers a sustainable way of reducing damage and reducing local codling moth populations in the long term. Sex pheromones can also be deployed in monitoring traps to improve our knowledge of pest appearance and population development within an orchard. Predatory nematodes may also offer an alternative form of control.

Sex pheromone mating disruption

The original aim of this work was to demonstrate the efficacy of sex pheromone mating disruption, alone versus in combination with granulosis viruses or nematodes, including effects on other pests and natural enemy populations. The effects were examined over two growing seasons as treatment with mating disruption pheromones is targeted at long-term control on a landscape scale.

Nematodes

A series of laboratory and field microcosm tests were done to test the efficacy of nematode sprays to target diapausing codling moth larvae in July and August in apple orchards. This work was kindly funded by BASF.

Blastobasis pheromone

Larvae of the moth *Blastobasis lacticolella*, Rebel, 1940 (Synonym: *decolorella*) (Lepidoptera: Blastobasidae) (Figure 10.1) feed on the surface of apple and pear fruits in mid- and late-summer, often where clusters are touching, causing large open, scallop-shaped wounds in the flesh, and making affected fruit unmarketable. Very severe damage can result if the pest is allowed to increase over a number of years unchecked, especially on short stalked varieties such as Bramley and Egremont Russet which are very susceptible.

Growers currently have no means of identifying whether they have a problem other than the occurrence of damage the previous year, which is often confused with damage caused by other apple moth pests. It is also difficult to time sprays accurately against blastobasis. Sprays are likely to be most effective when they are applied against hatching eggs.

During the life of this five-year project, it was noticed that the less frequent use of conventional spray control products to reduce the occurrence or residues in harvested fruit, coupled with increased use of pheromone mating disruption and granulovirus for control of codling and tortrix moths, led to increased incidence of blastobasis moth and the subsequent occurrence of occasional but severe outbreaks of blastobasis damage. The resulting need to employ control sprays for blastobasis negates the benefits conferred by using RAK3+4 for mating disruption of codling moth and tortrix moths.

Pheromone traps are the easiest way of monitoring the flight activity and egg laying period of moth pests. There is a clear commercial need to develop a pheromone monitoring trap for blastobasis so that growers can determine whether they have a problem and determine the optimum time to apply control products.

Summary of the project and main conclusions

Sex pheromone mating disruption

Two farms, one in the South East and one in the West Midlands of England, offered to demonstrate the RAK3+4 mating disruption system. However, in the second year of work, the West Midlands farm was over sprayed with chlorantraniliprole (Coragen) so this was not used for monitoring, and an additional farm in the South East that had been treated with the RAK3+4 mating disruption (MD) system for three years was monitored instead. Each farm was divided into two halves. One half was treated wth RAK3+4 (supplied in kind by BASF) mating disruption (MD) system for control of codling moth (*Cydia pomonella* - CM) /tortrix moths (*Adoxophyes orana* - summer fruit tortrix - SFT and *Archips podana* - fruit tree tortrix - FTT). The other half received the growers conventional spray programme. Over six hectares on each farm was treated with RAK3+4. The trial data could not be analysed statistically as there were only two replicates.

In both years at each farm, assessments were made of the numbers of pests and natural enemies on three occasions; spring (pre-treatment); July (first generation codling damage) and harvest (second generation codling damage). All three pest moth species (codling, summer fruit tortrix and fruit tree tortrix) were monitored weekly in each orchard using sex pheromone traps. For codling moth and tortrix assessments, both fruit that had dropped to the ground and those attached to trees were assessed. Other notable pest damage was also recorded.

Although few moths were captured in the pheromone monitoring traps on the MD side of the farms, the RAK3+4 did not cause complete trap shut-down (no moths in traps), indicating that some males may have been able to locate and mate with female moths. Some minor damage was observed in RAK3+4 treated orchards, but was comparable, with orchards receiving a conventional spray programme. Some orchards on the mating disruption sides of the farm received an additional chlorantraniliprole (Coragen) spray when trap moth catches of four or more were recorded per week, or where early ripening cultivars which are more vulnerable to codling moth were present.

There was some concern over tortrix caterpillars in the young shoots in the spring at Site 1. These were reared through and found to be summer fruit tortrix (SFT). However over 50% of the caterpillars were parasitized by wasps. Two sprays of granulovirus (Capex), 10 days apart, killed the majority of remaining caterpillars in the affected orchards.

There were few observable differences in natural enemies between the RAK3+4 deployment and conventional spray programme over the trial period including earwig numbers. However, as earwigs have a single generation each year, the study may not have been long enough to identify differences.

In both years of the study there was more first-generation codling moth damage in the early ripening cultivars Early Windsor and Bramley.

There was notable damage from two pests in the second year on the MD side of the farms. Blastobasis caused damage to fruit at harvest and woolly aphid was abundant in some orchards on the MD side of farms in orchards that had lower numbers of earwigs. These pests would normally be controlled with conventional spray applications targeted at CM and tortrix and, in previous years, a spring spray of chlorpyrifos, respectively.

At harvest the damage to fruit caused by CM was fairly similar between the MD and conventional sides of the farms. Tortrix caterpillar damage to the fruits was noticeably higher on the MD side of one farm compared to the conventional side.

In conclusion, the mating disruption was effective at low population densities, but at higher densities, some additional sprays were required when monitoring trap catch thresholds were exceeded.

Nematodes

Using the orchards in the MD trials (above) we used sentinel cages of codling moth larvae attached to the trunks of apple trees with the grower's spray equipment. These were targeted with a mixture of *Steinernema carpocapsa* (Nemasys C) and *Steinernema feltiae* (750 million of each sp. per ha) at high water volumes to the cages. Because we did not get good infection of the larvae, believed to be because the cage mesh prevented droplets containing the nematodes reaching the larvae, we used a series of laboratory tests to give a 'best' chance for nematodes to locate and infect codling moth larvae and pupae.

Using a Birchmeier B245 motorised mist blower it was possible to infect codling moth larvae/pupae with nematodes, even when they were hidden within sentinel cages. Codling moth pupae were less susceptible to nematode infection than larvae. In the cages sprayed with 50 % and full dose nematodes, 62.5 % and 100 % died as a result of infection, respectively. These experiments show there may be some efficacy of the nematode sprays against codling moth larvae in the field and the tests should now be repeated in the field with larvae in cardboard rolls without the mesh cages.

Dissected codling moth larvae infested with nematodes

Blastobasis pheromone

Field trapping experiments with three potential pheromone blends based on previous work were carried out in Northern Ireland, Hereford and Kent. A number of moths were caught, but analysis of sample moths by DNA barcoding of COI gene locus and comparison with the NCBI database indicated that probably none were *Blastobasis lacticollela*. The majority identified were *Rhigognostis incarnatella* and six out of eight were from traps baited with a two-way blend (1:10; Z11-16:Ac : Z11-16:Ald). This species is related to the diamondback moth, *Plutella xylostella*, the pheromone of which is a 1:1 blend of Z11-16:Ac and Z11-16:Ald. These results confirmed that the lures were working as intended and would have trapped *B. lacticolella* if the pheromone blend was correct and this species was present.

Field trapping was repeated in 2018 and once again blends of (Z)-11-hexadecenal and (Z)-11-hexadecenyl acetate failed to attract *Blastobasis lacticolella* moths in field trapping tests, even though this species was clearly present as indicated by catches in light traps. Rearing *B. lacticolella* adult moths from larvae collected in the field proved a real challenge, but some were reared through to adult. Extracts of the pheromone glands of female moths were made from both moths collected in the field which were probably mated and from virgin female moths reared from larvae in the laboratory. In analyses of extracts by GC-MS, potential pheromone components including (Z)-11-hexadecenal, (Z)-11-hexadecenyl acetate, (Z)-5-decenyl acetate and (Z)-5-decenol could not be detected. However, (Z,Z,Z)-3,6,9-Nonadecatriene was identified as a potential component of the female sex pheromone but was subsequently shown to be present in extracts from both female and male moths and did not attract male *B. lacticolella* moths in the field.

Main conclusions from this objective

- The RAK3&4 mating disruption system appeared to be very effective at disrupting male moth pheromone detection, but complete 'trap shut-down' (no moths captured) was not achieved for codling moth.
- In laboratory studies codling moth larvae were vulnerable to commercially available pathogenic nematodes.
- A putative blastobasis moth pheromone was tested but did not attract blastobasis males.

Financial benefits

Codling moth control programmes typically cost growers >£200/ha/annum. Even a low level of fruit damage (<0.3% fruits damaged) is economically unacceptable. Improving control and/or reducing use of conventional control products will be of financial benefit to growers, may enhance natural predators in the crop and benefit the wider environment. The estimated cost comparison of RAK3+4 mating disruption system compared to a conventional spray programme for codling moth and tortrix moth are presented in the table below.

Estimated cost comparison of RAK3+4 mating disruption system compared to conventional spray for codling moth and tortrix moth.

Cost/ha (£)	RAK 3+4	Conventional
Cost	£240-300	-
Person hours	2	1 (as part of fungicide round)
Cost of labour	Minimum, £8.20/hour (inc. NI&AL) **£16.40**	£20-25
Monitoring	same	same
Coragen	-	£71-85 (per spray) x2
Runner	-	£44-75 (per spray)
TOTAL	**£256.40-£316.40**	**£206-270 (chemicals only)**

Action points for growers

- Mating disruption technologies can offer a similar level of control of codling and tortrix moths to conventional spray pgorammes, but where pest pressure is medium to high, It may be advantageous to apply an additional Coragen to early ripening or vulnerable apple and pear cultivars.
- Growers should closely monitor for other pests which may occur because of the limited use of Lepidopteran control products. In particular sporadic tortrix species and blastobasis caterpillars.
- Even if growers have not had previous experience of blastobasis in orchards it would be wise to continue to monitor as populations may build up locally over years.
- Growers and agronomists should consult the AHDB Apple Best Practice Guide online on how best to do this.

Objective 7.1 Improving the reliability of natural predation of pests

Headline

- The use of wildflower mixes, earwig refuges and hoverfly attractants have hastened the influx of natural enemies and reduced pest damage in newly established orchards.

Background and expected deliverables

Establishing new crops requires substantial investment (~£35k/ha for apple) and growers need confidence that their orchards will crop reliably, and that fruit will find a profitable market. Ecological succession is the observed process of change in the species structure of an ecological community over time. The community begins with relatively few pioneering plants and animals and develops through increasing complexity until it becomes stable or self-perpetuating, as a climax community.

Newly planted orchards have an un-established ecosystem. The recently tilled ground in newly planted orchards often has minimal, simplified or absent vegetation cover with a low diversity of annual plant species resulting in low pollen and nectar provision and low refugia and structure. The tree bark and canopy are simple compared to older established trees affording little availability for predatory arthropods to gain refuge. Hence, local, populations of natural predators and pollinators have not built up and established in new orchards leading to random, sporadic, attacks from a number of pest species which can then be difficult to control.

The aim of this work was to apply interventions to newly planted orchards to hasten the establishment of beneficial ecology.

Summary of the project and main conclusions

Six replicate commercial apple orchards were chosen in 2017 and secured for experimental purposes through help from Caroline Ashdown at Worldwide Fruit Ltd. In each orchard, 0.25 ha was treated with ecological enhancement interventions.

In each treated area, interventions included the sowing of alleyway seed mixes (including yarrow, ox-eye daisy, bird's foot trefoil, self-heal, red campion and red clover), and the provision of earwig refuges (Wignests) and hoverfly attractants. Each treated area was assessed and compared to an untreated area of the same orchard throughout 2018 and 2019.

- Seeded floral alleyways were successful in most orchards and percentage coverage from the seed mix seemed generally increased from 2018 to 2019.

- Not all species in the seed mix established. Red clover and yarrow were the most common in 2018. Red clover was also one of the most common in 2019 along with common knapweed.
- Sward height in treated plots was higher than in untreated alleyways in both years but only significantly in 2018.
- In both years fewer aphids were observed in the treated plots in spring but not in summer.
- More predatory spiders were found than earwigs in Wignests deployed in treated plots in spring 2018 and 2019. In 2019 anthocorids were also found in refuges. Most predatory spiders found in the refuges in 2019 belonged to the family Araneidae.
- Predatory spiders were the most common arthropod recorded in apple trees in all seasons in both years. In 2019 most belonged to the Araneidae and Philodromidae families. Some species of the Philodromidae, like *Tibellus macellus*, primarily feed on aphids, accounting for over half the total prey they ingest when available (Huseynov 2008).
- Linyphiidae was the only family with significantly higher numbers of individuals in the treated plots compared to untreated. A subfamily of Linyphiidae, Erigoninae (also known as Micryphantids), are reported preying on soft-bodied pests, like aphids (Nyffeler & Benz 1988; Mansour & Heimbach 1993).
- In 2018, no apple leaf curling midge damage occurred in treated plots compared to untreated (insert percentage damage?). Apple leaf curling midge was not assessed in 2019.
- In 2018, fewer predatory mites and fruit tree red spider mites were found in treated plots compared to untreated. However, the opposite was observed for rust mites and spider mites. In 2019 only predatory mites were found, with higher numbers recorded in treated plots.
- In 2018, significantly fewer codling moth deep entry damage was recorded on treated plots in summer and significantly fewer codling moth stings were recorded on treated plots in the dropped apple assessment. In 2019, codling moth stings were significantly less frequent in the treated plots in autumn.
- There were significantly more hoverfly adults in the treated plots in autumn 2018. It is not known if this is the consequence of the attractant sachet and/or the floral alleyways. This effect was not observed in summer 2019.Statistical analysis on all data have to be interpreted with caution since numbers of arthropods were low in the orchards.

Main conclusions

- Positive benefits have been shown over two seasons following sowing wildflowers in alleyways in newly planted orchards.
- Orchards were also amended with earwig refuges in each tree and hoverfly pheromone attractant.
- Positive effects recorded included reduced numbers of pests including damage by codling moth, and higher numbers of natural enemies including hoverflies, spiders, and lacewings.
- Perennial wildflower mixes in orchard alleyways also have the potential to outcompete undesirable weed species.

Financial benefits

The costs of implementing this system of management incorporating wildflower mixes, earwig refuges and hoverfly attractants are laid out in the table below.

The estimated costs associated with implementing floral resource alleyways and natural enemy attractant	Per unit	Per ha	Time (hours)
Seed Mix for 1 ha; every other row	-	~£152-310	-
Sowing/Drilling and Rolling over large area (Minimal ground prep because new orchard)	Large areas	New orchard £28	8 hours for 10 ha
Hoverfly attractant (7x7 m spacing)	£2.70/device 196/ha	£529.20 (£265 – half rate)	-
Cost of Labour (2019) Inc. NA + PEN	£8.77/hr	-	1
Deploying hoverfly attractant	-	£35.08	4
Reduced cost due to less mowing through labour and fuel		£ ?	Faster moving sprayer
OPTIONAL: Wignests, marketed by AgroVista		~50/pack @ £43.87/50 for 1-19 packs or £40.62/50 for 20+ packs	
Total		~£480-902	

Action points for growers

- New orchards, and even existing orchards, should be provisioned with pollen, nectar and structural resources to provide pollinators and natural enemies with habitat and food to increase their numbers.
- Selection of perennial wildflower seed mix should be largely driven by soil type.
- It is recommended to use a perennial mix which should be regularly cut to 10 cm in the first year to encourage establishment. The plants will flower from year 2.
- In preparation for sowing, soil should be weed free and have a fine tilth. Once the wildflower seeds are broadcast (not drilled) they should be rolled to help seeds make contact with the soil. Following this, a period of rain or irrigation is desirable to encourage germination.
- Sowing can be done in the autumn or spring.
- Seed mixes should contain a range of native open, legume, and complex flower types with non-competitive grass species making up a high percentage of the mix.
- From year 2, in general, one cut before fruit harvest is recommended or maybe an additional midsummer higher cut – depending on weather conditions.

Objective 7.2 Determining pear sucker/predator thresholds for spraying

Headline

- Sprays targeted against pear sucker can be avoided where the numbers of pear sucker eggs do not exceed 1,000 and the numbers of natural enemies were greater than 10 per 30 branch beat samples.

Background and expected deliverables

Pear sucker, *Cacopsylla pyri*, is still a major pest on pear with sporadic population growth in response to warm dry weather and in those orchards where populations of earwigs and anthocorids are not sustained at levels necessary to provide natural control. Emerging evidence from other AHDB and Innovate UK projects is showing that earwigs are important control agents for aphids and pear sucker. Additional research in the USA also demonstrates predation of codling moth eggs. Earwigs, hoverfly larvae, lacewing larvae, spiders and ladybirds are able to penetrate the leaf rolls (galls) caused by the various apple aphid species.

There are large differences in earwig populations between orchards, and Project TF 196 has demonstrated that use of conventional spray products and their timing may be, at least partly responsible for lower than optimum populations. However, anecdotal evidence is showing that earwigs can be distributed unevenly within an individual orchard.

The aim of this study was for the entomology team at NIAB EMR to collaborate with commercial pear growers and their staff and train them to record pear sucker pest and predator numbers. This will help them to make more informed decisions on whether and when to apply control measures and contribute to data for a potential model for predator/prey thresholds.

Summary of the project and main conclusions

Six farms were involved in the study in 2016, 2017 and 2018. All participants were trained in the monitoring technique at the start of the growing season. Each grower selected three orchards (high, medium and low pear sucker populations) on each farm, and allowed time for a worker to systematically assess the chosen orchards each week. The results were collated at least fortnightly by NIAB EMR and then shared with all participants.

Records of pear sucker eggs, nymphs and adults, along with ladybirds, earwigs and anthocorids in the perceived low, medium, and high pear sucker pressure orchards were completed from March to September. It was found that in general, sprays could be avoided where there were <1,000 pear sucker eggs per 30 shoots per week and >10 natural enemies per 30 shoots per week. More work is needed to determine the threshold of nymphs. In addition, we ascertained that a mix of natural enemies (earwigs, anthocorids and ladybirds) provide resilience to pear sucker control.

Financial benefits

Close monitoring of pear sucker and natural enemies can prevent the application of unnecessary sprays and conserve natural enemies which control pear sucker. This will reduce the need for applications of products needed to control 'honey dew' on trees. The reduction of pear sucker in the crop reduces crop loss through the maintenance of fruit quality and prevents damage to overwintering bud and tree health.

Action points for growers

- Sprays targeted against pear sucker can be avoided where the numbers of pear sucker eggs do not exceed 1,000 and the numbers of natural enemies were greater than 10 per 30 branch beat samples.
- Monitor pear sucker life stages in the crop to improve the timing of spirodiclofen (Envidor) applications and prevent use of unnecessary sprays.
- A recently published study has also shown that spirotetramat (Batavia) can offer good control of early and late stage nymphs of *C. pyri*, both on the shoot tips and on cluster leaves in the central part of the tree. Spirotetramat is also reported to be safe to anthocorids.
- Use the monitoring of natural enemies such as earwigs, anthocorids and ladybirds alongside pear sucker monitoring to inform likely future control options that avoid damaging these predators.
- Consider releases of commercially produced anthocorids early on if numbers of natural enemies are low, but think about the surrounding habitat to encourage long term resilience in anthocorid populations (hazel, willow, hawthorn and nettle are good alternative hosts).
- Be considered with the choice, numbers and timing of spray applications. Think about spray frequency and impact on natural enemies.

Objective 8.1 - Apple fruit rhynchites

Headline

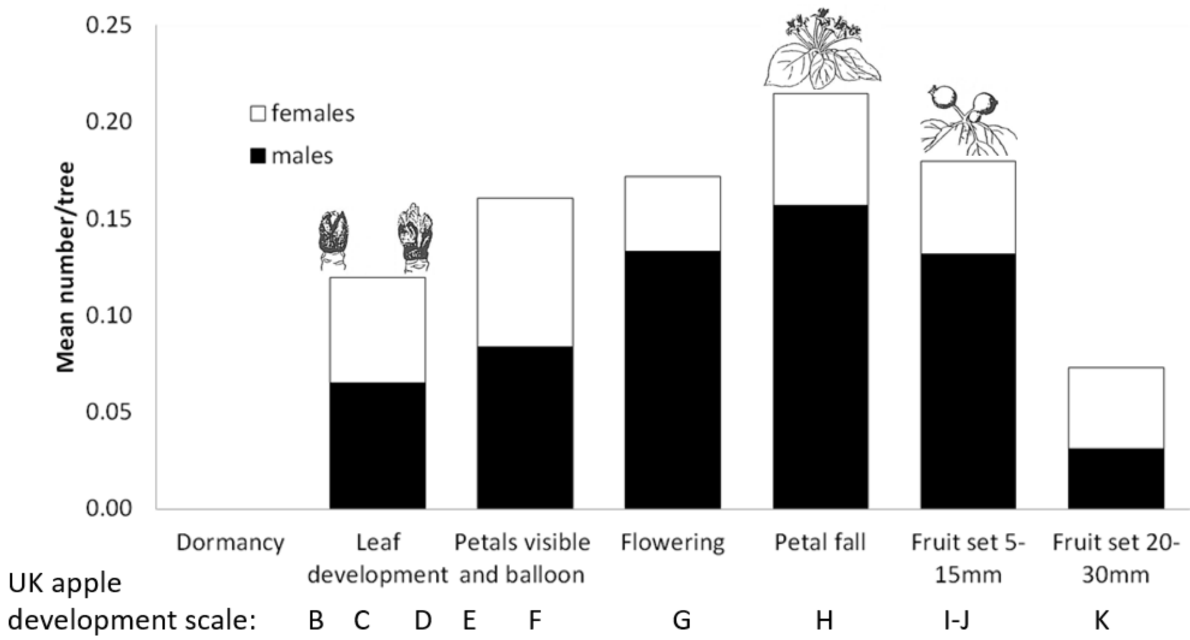
- There may be a window of opportunity to target weevils with control options both pre bloom and at petal fall – when females are likely to be laying eggs.

Background and expected deliverables

Damage by apple fruit rhynchites weevil, *Rhynchites aequatus*, has been increasing in UK apple orchards and sometimes pear orchards in recent years, probably due to changing use of crop protection products. Losses of 1% of fruit are common and losses >5% are not unusual. The development of a sensitive, specific, semiochemical-based monitoring trap for apple fruit rhynchites would enable growers to minimise losses due to the pest, and target sprays against it only when they are needed. The aim of this study was to investigate the presence of semiochemicals attractive to apple fruit rhynchites weevil, but as a consequence we also undertook more detailed phenological studies of the pests' occurrence in orchards.

Summary of the project and main conclusions

In the first year's work, volatile collections were made from field-collected male and female weevils and analyzed. Significant quantities of any compounds associated with either sex of the weevils could not be reliably detected and no attraction was demonstrated using weevils as bait in orchards. However, it was shown that weevils entered the orchard in all cultivars once bud scales were first visible and antennal responses were found in reaction to a flower bud compound. There was a window of opportunity to target weevils with control options both pre-bloom and at petal fall – when females are likely to be laying eggs.



Mean numbers of male and female Rhynchites in apple orchards according to tree development stage.

Financial benefits

Damage by apple fruit rhynchites weevil, *Rhynchites aequatus*, has been increasing in UK apple orchards and sometimes pear orchards in recent years, probably due to changing use of crop protecton products. Losses of 1% of fruit are common and losses >5% are not unusual. Although the research work done in this study has not successfully identified semiochemcals produced by this weevil, new information on the influx of the weevil to apple orchards has been gathered and this will allow growers to improve the timing of application of control products, thereby improving the effectiveness of control.

Action points for growers

- Target control options for apple fruit Rhynchites just pre or post blossom.

Objective 8.2 Apple sawfly

Headline

- Attempts to identify the sex pheromone of the apple sawfly for use in monitoring and mating disruption studes were unsuccessful.

Background and expected deliverables

Apple sawfly is a locally common and problem pest, particularly in organic orchards where products for effective control are not available. However, timing of application relies on knowing when the first flight is occurring and when females are laying eggs. The aim of this project was to identify the sex pheromone of the apple sawfly for use in future monitoring and mating disruption studies.

Summary of the project and main conclusions

Apples containing apple sawfly larvae were collected in spring 2015, 2016, 2017, 2018 and 2019 from an unsprayed orchard at NIAB EMR. The apples were placed onto compost in mesh covered bins. Larvae were allowed to crawl out from the fruits and enter the compost. As apple sawfly has only one generation per year these were maintained outside until spring 2016 and spring 2017. However, no apple sawfly adults emerged and pupae were found to be infected with either bacteria or fungus, even when in 2017, bins were maintained with lids to prevent over wetting from rain. The previous winter had been very wet and it was speculated that the soil may have become too wet outside.

In spring 2017 and 2018, apple sawfly infected apples were collected again and kept in Bugdorm cages under cover. As the larvae emerged from the apples and began to 'wander' they were transferred into smaller plant pots of compost. Six were kept at ambient conditions in an outside area under cover and two were stored at 6°C for 2 months in 2017 and 5 months in 2018 to attempt to simulate a cold period. Again, no adults emerged.

Larvae collected in 2019 were kept in terracotta pots outdoor to mimic more realistic conditions. However, when the compost was removed in the spring, at the time of writing, it was once again very wet and to date no adults have emerged. Future work should deploy emergence cages, dig up orchard soil for flotation, and/or catch live adults in orchards in spring.

Financial benefits

- No financial benefits have arisen from this study.

Action points for growers

- No action points have arisen from this work.

Objective 9. *Anthonomus spilotus* in pear

Headline

- A damaging weevil pest of pear blossom has been identified as *Anthonomus spilotus* and is new to the UK.

Background and expected deliverables

A new pest of pear was identified in the first years of this project by NIAB EMR and the Natural History Museum. The weevil is from the *Anthonomus* family of weevils known to feed and develop in buds and fruits of plants. Unlike *Anthonomus piri*, *A. spilotus* feeds and lays eggs in spring blossom and, later, leaf buds. In order to control the weevil it is likely to be necessary to target sprays in the spring, before the flower clusters open. Work in this objective aimed to establish the activity period, lifecycle and toxicity of commonly used control products. More research is needed to establish damage thresholds and to improve precision of spray timing.

Summary of the project and main conclusions

Extensive field surveys and damage assessments were done on four affected orchards in Kent. *Anthonomus spilotus* adult activity, eggs in buds and adult feeding damage were recorded from 8 March until 6 June in 2018. Weevils fed on, and laid eggs in, flower and leaf buds depending on availability. The percentage of flower buds damaged by adult feeding was 22.6% and the percentage of flower buds damaged by larvae 0.7%. The percentage of leaf buds damaged by adult feeding was 42.3% and the percentage of leaf buds damaged by larvae was 0.7%. Hence most bud damage was result of adult feeding.

Fewer than 10% of the flowers in a truss were damaged by adult feeding and fewer than 16% were damaged by larvae. Greater flower and leaf damage was observed when eggs/larvae were present. Hence the damage to flowers at 1 weevil per 40 taps is not the main consideration as only 1 of the 6 flowers in a cluster is normally destroyed and only 3-4 pear fruits can set to harvest on a single truss. The main consideration is the damage to leaves and photosynthetic ability for future years.

Even at very low levels of weevils (~1 per 40 tree taps) ~60% of new leaves were damaged later in the season. We have not been able to set a damage threshold for this because the resultant health to the tree cannot be estimated in this project. The majority of buds usually had 1 to 3 damage holes although buds with more punctures could be found.

There were indications that population activity may be sensitive to significant temperature changes, but more data is needed to reach a more accurate conclusion.

In laboratory tests in 2016, acetamiprid (Gazelle) only gave 50% control, but thiacloprid (Calypso) at full and half field rate gave 80-90% mortality. Thiacloprid, lambda-cyhalothrin (Hallmark), and pyrethrins (Spruzit) were the most effective products against *A. spilotus* in the laboratory. High mortality and rapid negative behavioural effects were observed in these treatments. However it should be noted that, in this experiment, weevils received a direct application of the control product. In a pear crop this scenario is less likely and weevils may be more likely to come into contact with dried residues.

In 2018 we determined whether product efficacy can be improved through stimulating ingestion of the control agents, spinosad (Tracer) and indoxacarb (Steward). Calypso was the most effective product against *A. spilotus* in the laboratory trial where shoots had been sprayed with products and then weevils allowed to feed. 100% mortality in 9 days after ingestion was observed compared to the control group (40%).

In 2019 we examined the best timing of control measures in growers' orchards. A fully replicated randomised design was established in four Kent orchards known to have moderate populations of *A. spilotus*. The spray applications were supported by the growers and Avalon Produce staff. All planned applications were made, but numbers of weevils in spring 2019 were too low to establish meaningful results and there was no difference in damage to flowers or leaf shoots with either pre or post blossom applications of Calypso or Steward.

Main conclusions

- In this 2019 field trial a spray application of Calypso or Steward before or after blossom had no effect on feeding damage or numbers of *A. spilotus*.
- The population of weevils may have been too low to show benefits from the product application.
- Calypso has been effective against *A. spilotus* in laboratory tests in previous years.
- More extensive studies are needed to confirm the effectiveness and best timing of application of these products in the field to control *A. spilotus* and other spring damaging weevils.
- The loss of Calypso approval will mean that growers will only be left with broadspectrum prodcts to control weevils. This I not desirable as these are harmful to natual enemies. However Gazelle gave 50% mortality in laboratory tests and could be used to keep populations in check.

Financial benefits

Larvae in flower buds feed on flowers, but then also feed on emerging leaf shoots. This could affect yield but also the health of trees over the long term. It is essential to calculate thresholds for spraying and spray timing. It is estimated that a female weevil in the *Anthonomus* family can lay around 25 eggs in her lifetime. Although the levels of damage to flowers, fruits and leaf tissue appear to vary, failure to monitor for the pest and employ control measures where necessary could lead to financial losses where significant damage occurs.

Action points for growers

- Monitor pear orchards weekly from February by inspecting for feeding holes in unopened flower buds and then later in leaf buds.
- Continue to monitor until May.
- Make a careful decision over the need to use control measures and the choice of product so that natural enemies are not adversely affected.
- Continue to monitor for the pest after control methods have been used.

Objective 10 – Brown Marmarated Stink Bug

Headline

- Adults of brown marmorated stink bug (BMSB) were reported and confirmed in Hampshire in 2018 and 2019, although no breeding populations have yet been detected.

Background and expected deliverables

The surveillance objective of this project (Objective 1) provides the opportunity for ongoing activities to continue and be reported. Such activities include the monitoring for the invasive pest BMSB. This objective aims to keep the industry up to date with the pest and disease threats which ultimately lead to yield losses and provides information for the industry to inform future research targets and priorities.

Summary of the project and main conclusions

Monitoring BMSB using sentinel pheromone traps in the South East, the East of England and South Wales did not detect any incursions of the pest. However, internet searches revealed reports of adults of this invasive pest free in the environment at two sites in Hampshire, and the species identification was confirmed. No establishment (detection of breeding populations inferred by the presence of nymphs or egg masses) has yet been reported.

Financial benefits

Current, emerging and newly introduced pests and disease can have a devastating effect on yield and economic return to your business. This objective enables the ongoing monitoring of these threats helping to inform future research priorities. BMSB alone represents a huge potential threat to multiple crops, and has caused extensive losses to tree fruit (including pear and apple) in North America and continental Europe.

Action points for growers

- Look out for news in the trade press or important announcements from the animal and plant health agency (APHA) about invasive pests and disease which will affect your business, such as BMSB and *Xylella fastidiosa.*
- Commercially produced traps to monitor BMSB are also available.