Project title:	Development of novel control options for agapanthus gall midge
Project number:	HNS PO 199a
Project leader:	Hayley Jones, Royal Horticultural Society
Report:	Final report March 2020
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Key staff:	Hayley Jones, RHS entomologist Jude Bennison, Senior Research Entomologist, ADAS Kerry Maulden, Senior Research Manager, ADAS Alice Shrosbree, Senior Research Technician, ADAS Joe Perry, RHS Statistician
Location of project:	RHS Garden Wisley, Surrey
Industry Representative:	Patrick Fairweather, Fairweather's Nursery, Hill Top Nursery, Beaulieu, Hants SO42 7YR
Date project commenced:	03 December 2018
Date project completed (or expected completion date):	31 March 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.

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CONTENTS

GROWER SUMMARY

Headline

- A mulch of Strulch® reduced survival of agapanthus gall midge larvae by 20-25% in a laboratory pot test.
- Melcourt EcoBark® used as a pot topper did not reduce adult midge emergence but delayed it by three weeks.

Background

The agapanthus gall midge, *Enigmadiplosis agapanthi* poses a risk to both containerised plants and cut flowers. Midge infestation causes flower buds to be deformed and discoloured and often fail to open. Heavy infestations can lead to entire flower heads being aborted. It was first found in the UK in 2014 but has since spread, and has now been found in most counties in southern England and has successfully overwintered in Yorkshire

Due to the relative novelty and lack of information about the midge, there are no current recommendations available for control. Work carried out in HNS PO 199 did not identify any treatments other than cultural methods including removal of infested flower heads, destroying badly infested plants and avoiding growing highly susceptible cultivars such as Northern Star. None of the tested plant protection products had a significant effect when sprayed against larvae in the flowers. A test of drenches against the ground-dwelling stage of the larvae showed a significant effect of thiacloprid (Calypso), EAMU 2014/2153 (due to be withdrawn), but very high mortality in the water controls meant that drenches needed further study.

This project aims to address some crucial gaps in knowledge with the following objectives:

1. Review cultural control methods used for gall midge pests in a range of crops, identify knowledge gaps and produce a shortlist of candidate control treatments for objectives 3 and 4.
2. Evaluate the use of sticky traps and water traps for monitoring adult midge emergence.
3. Complete a field trial testing candidate novel spray treatments against first generation adults on a commercial cut flower farm.
4. Complete a laboratory pot test of candidate drenches of plant protection products, biological control agents and cultural control methods against the ground dwelling life stages.

Summary

Objective 1: Review of cultural control methods

The review highlights that there has been relatively little research into cultural control options against gall midges. Of the research that is available the most common effective strategies are:

- Use of resistant or less susceptible varieties of host plants
- Crop rotation or isolation
- Timing planting to avoid peak infestation
- Physical removal of infested material

Prior to this project there has been very little work done on barriers and other cultural techniques that target the ground-dwelling life cycle stages of these gall midges.

This literature review and knowledge of the project team indicated that timing was a crucial factor in control of gall midge species so for objective 3 (field trial of sprays targeting adults) the decision was taken to test a range of spray schedules rather than different products. For objective 4 (laboratory test of controls targeting larvae in the ground) cultural control in the form of mulches and barriers were prioritised due to a lack of data on effectiveness of these products against pests, the shortage of chemical control options and the increasing need to adopt IPM strategies. The biological, chemical and cultural control measures were selected based on literature review, grower opinions and using results from HNS PO 199. Selection of treatments was discussed with the host grower of the field trial (Greenyard Flowers UK Ltd) and with Patrick Fairweather (Fairweather's Nursery), to ensure they were appropriate and practical for industry needs.

Objective 2: Evaluate the use of sticky traps and water traps for monitoring

Work for objectives 2 and 3 was hosted by Greenyard Flowers UK Ltd at their site in Penzance, Cornwall. This is an outdoor cut flower grower with an ongoing problem with the midge. A suitable field trial area was selected, focusing on a large section of well-established plants of the earliest flowering varieties.

Three types of traps were tested for monitoring the midge; yellow and blue sticky traps and yellow water traps. Due to the impracticable methods required to identify the agapanthus gall midge to species level, all midges were counted that superficially resembled the agapanthus gall midge. Yellow water traps caught significantly more adult midges than either of the sticky traps. However despite relatively high number of midges seen in the water traps there was almost no midge damage in the field, possibly due to not all the midges in the traps being agapanthus gall midge. Use of water traps may not be practical for growers due to the high numbers of other insects caught; the complicated process to empty and refill traps; the requirement for a microscope to detect midges reliably and difficulties in identification.

For now, growers may need to rely on timing treatments with susceptible flower head development, and this strategy is initially supported by our data as the peak of midges recorded in water traps coincided with the flower spikes approaching canopy height.

Objective 3: Field trial of spray treatments

As with other gall midges, timing is likely to be a critical factor for control efficacy, so the trial tested a range of spray schedules rather than different products. For example, in AHDB-funded research, a single application of the pyrethroid, lambda-cyhalothrin (Hallmark with Zeon Technology) targeted at the first sign of first generation adult saddle gall midge was as effective as a programme of up to three applications and sprays targeted against larvae were ineffective. The synthetic pyrethroid 'Decis Forte' (deltamethrin) was the selected treatment, with a label recommendation for use on outdoor ornamentals for the control of various pests.

Eight different spray schedules were tested, corresponding to a period in which the developing flower heads would be becoming susceptible to the midge:

1. Timing A – when developing flower heads are expected to be susceptible to the midge – i.e. reaching the height of the foliage.
2. Timing B (with B being 7-10 days after A.)
3. Timing C (14-17 days after A)
4. Timing A and B.
5. Timing B and C.
6. Timing A and C
7. Timing A, B and C.
8. Untreated control

The Decis Forte was applied at the label rate of 17.5 ml per 100 litres of water in 400L/ha.The rate was selected after testing a range of rates using water sensitive paper attached to the flower spikes and upper and lower leaves to achieve a medium spray.

Extremely low levels of midge infestation were recorded throughout the trial. No midge infested heads were recorded until the final assessment when five plots each had only one infested flower head. These infestation levels were too low to allow the data to be analysed.

The field site had extremely high levels of infestation in the previous year so the almost zero levels in the study were unexpected. It may be that as with midges that attack cereal crops, the populations naturally fluctuate or cycle, but the presence of midges in the traps means it is likely to reoccur in this field in the future. Additionally, the areas of the field outside the study area were sprayed regularly with a pyrethroid insecticide and although an appropriate buffer was in place it may be that the field level population was supressed.

Objective 4: Laboratory test of control methods against the ground dwelling life stages.

In order to test controls for the ground-dwelling larval stage a laboratory test was done using pots of growing media (Figure 1). After larvae were added the pots were monitored weekly for adult emergence.

A preliminary experiment was carried out to optimise conditions for adult emergence, in order to solve the problem of very low numbers of adult midges emerging in the water controls in HNS PO 199, which was likely to have been caused by excess moisture in the pots. Melcourt Sylvagrow® (a peat-free compost) was used at the moisture level direct from a freshly opened bag.

Test of control methods

Through literature review, grower opinions and using results from HNS PO 199 control measures were selected and applied to ten replicate pots per treatment (Table 1). All treatments that were not applied in liquid form had 28 ml water added to the pots. Images demonstrating the depth of mulches and application technique for black polythene are shown in Figure 2.

Figure 1. Experimental set up for laboratory tests of control measures against agapanthus gall midge larvae. **a.** Pot test in controlled environment room. **b.** Pots filled with 280ml growing media and water/ treatment subsequently added. **c.** Adult midges caught and counted on yellow sticky trap inside pot lid.

Table 1. Control treatments tested against the agapanthus gall midge in a laboratory pot test.

No.	Treatment (justification for choice)	Rate
1	Containermulch by Klasmann (a pot topper with adhesive properties with some evidence of pest control)	2 cm depth added on top of 180ml growing media.
2	Melcourt Ecobark (Used as a pot topper and similar to bark mulches used for outdoor grown plants)	2 cm depth added on top of 180ml growing media.
3	Strulch (a mineralised straw mulch used for outdoor flowerbeds)	3 cm depth added on top of 130ml growing media.
4	Black polythene (agapanthus plants in the field often planted into this for weed suppression and gave significant control of blackberry leaf midge adults emerging in SF 102)	Circles of 8cm diameter cut from polythene sheet with small X cut through to simulate planting through. (Figure 5)
5	Nemasys (used on protected HNS for sciarid fly control)	*S. feltiae* - 1,000,000 nematodes/m^2 in 1 L/m^2 water (rate for curative drench for sciarid fly control).
6	Gnatrol (Bti) (label rec. for sciarid fly control as a drench in protected ornamentals)	Highest label rate:10 ml/ m^2
7	Pitcher – Garlic granules applied to compost surface (EAMU for vine weevil and leaf & bud nematode control but some evidence in SP 23 (Bennison & Brown, 2018) that garlic controls sciarid fly larvae)	24g/m^2 granules were sprinkled evenly over the surface. (EAMU 2018/3744).
8	Calypso (thiacloprid) (has EAMU for use as drench on protected ornamentals for control of vine weevil and sciarid fly. Included as a positive control despite pending withdrawal as it showed an effect on agapanthus gall midge in HNSPO199)	83 ml in 100 L per m^3 compost (per 1000L compost) (EAMU 2014/2153 drench for vine weevil and sciarid fly control).
9	Water-treated control	28 ml per pot

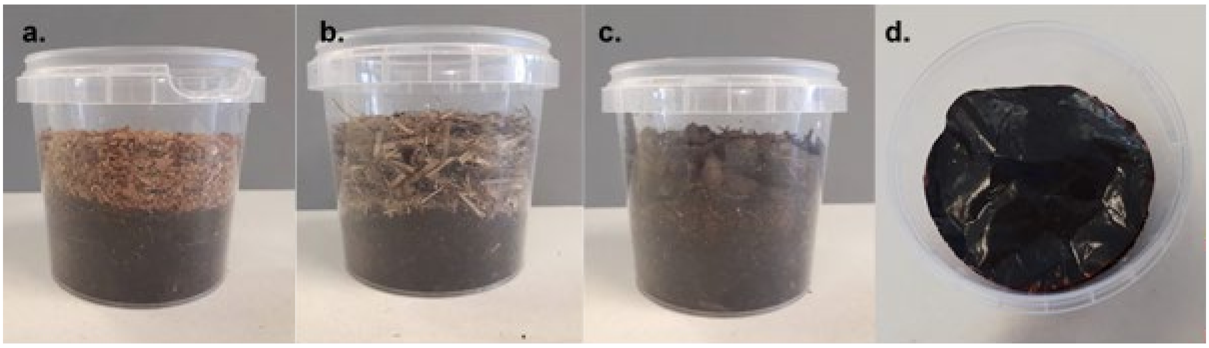

Figure 2. Barriers and mulches tested for control of agapanthus gall midge larvae.
a. Klasmann Containermulch **b.** Melcourt EcoBark **c.** Strulch and **d.** Black polythene.

Two treatments, Calypso and Strulch, significantly reduced adult emergence (by 20-25% compared to the other treatments) (Figure 3). Calypso currently has an EAMU for use as a drench on protected ornamentals for control of vine weevil and sciarid fly (2014/2153). However, thiacloprid is due to be withdrawn from the market in 2021 and many retailers ask growers not to apply neonicotinoids so use of Calypso is not a sustainable option for growers to control agapanthus gall midge.

Barriers and mulches are a more sustainable choice for control. Strulch significantly reduced midge emergence. This product is mostly used as a mulch for beds, and so may be a relatively practical option for growers of outdoor cut flower agapanthus. It may be appropriate as a pot mulch for containerised agapanthus, particularly if the surrounding surfaces are not suitable for the midge to burrow into to pupate.

Melcourt EcoBark did not reduce the number of adult midges emerging, but delayed their emergence by around three weeks. This may be useful if it can delay adult midge emergence to outside of the susceptible flowering period of the plants in the vicinity. However, its possible usefulness is limited by the long flowering time of many agapanthus cultivars and overlapping generations of the midge, so targeting the first generation would be a key strategy.
The other treatments (Klaasman Containermulch, black polythene, Nemasys, Gnatrol and Pitcher) did not have a significant effect on number of midges emerging, although the latter two may have delayed midge emergence by 2-4 days. If they were ineffective under these controlled conditions then they are very unlikely to be successful in field conditions.

A priority for future work would be to test the successful treatments in commercial conditions, both for containerised and field-grown agapanthus. Evaluation of other barrier and mulch solutions would also be justified.

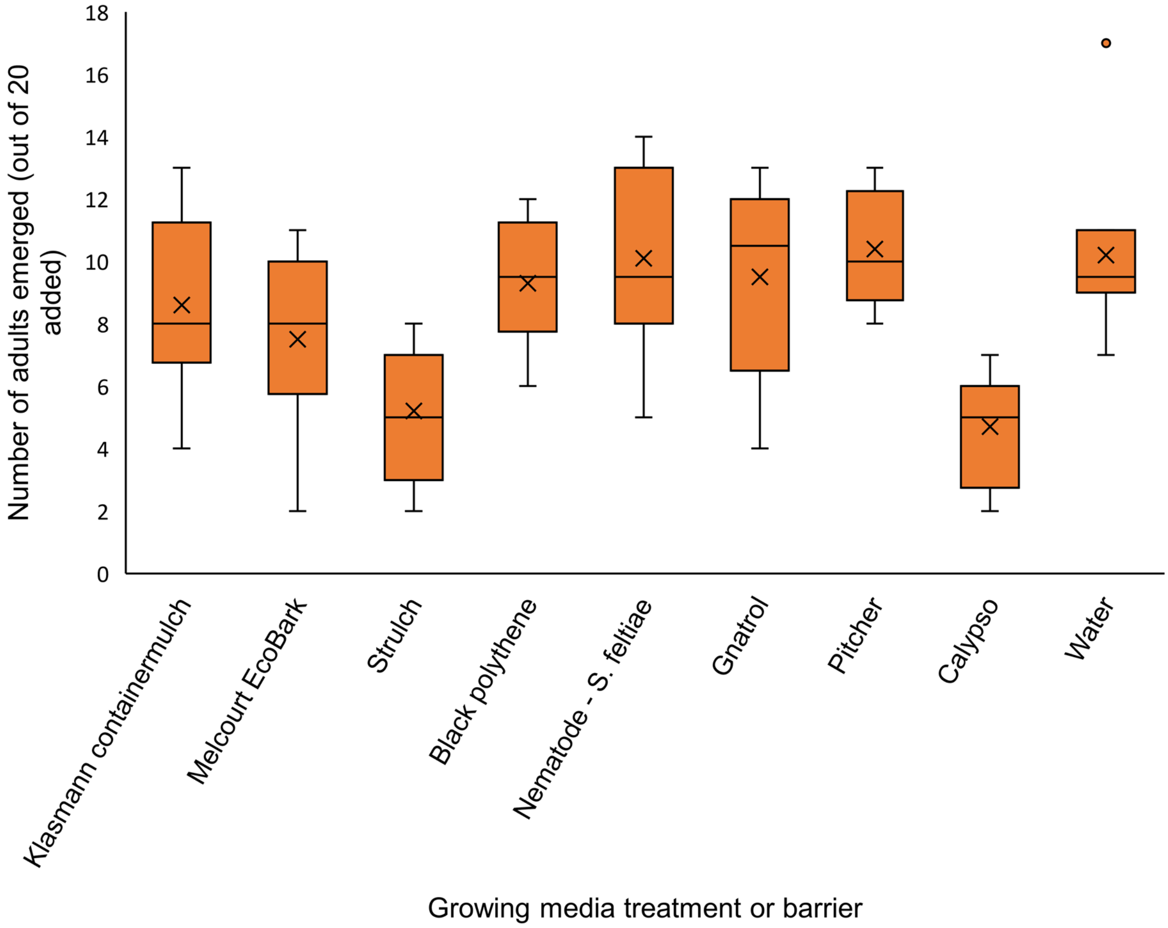

Figure 3. Box and whisker plot showing number of midges emerging from pots treated with cultural, biological or chemical controls. X shows mean, inner bar median and box spans the interquartile range.

Financial Benefits

A 25% reduction in damage could equate to a saving of £210,000 (based on an estimate of £3 production cost per pot and potential crop loss of 70% in an infested nursery costing approximately £840,000). In cut flowers a 25% reduction in damage could mean a saving of £75,000 (based on a cut flower grower estimate of midge infestation currently causing around 50% crop loss. A grower hoping to harvest 1.2 million stems would therefore suffer a loss of approximately £300,000).

Action Points

- Do not rely on insecticide sprays for control of the pest. Research has not yet demonstrated an effective method for controlling agapanthus gall midge with pesticides. In HNS PO 199, a pyrethroid spray targeting larvae in flowers was ineffective in a laboratory test. Research on control of other midge pests indicates that chemical control is most effective when targeted against first generation adults but this has not yet been demonstrated with agapanthus gall midge.

- Source agapanthus plants from uninfested nurseries
- Avoid highly susceptible cultivars such as Northern Star
- As plants may not yet be showing symptoms when brought onto the nursery, monitor closely for symptoms as soon as they start to flower
- Remove and destroy infested flower heads and destroy badly infested plants
- Consider water traps as a way to monitor for presence of the midge in fields, but be aware that other similar insects may be caught and that that numbers of midges in the trap may not reflect severity of infestation in the field.
- The results of this project indicated that a drench of Calypso (used according to EAMU 2014/2153 for control of vine weevil and sciarid larvae in protected ornamentals) may give some control of the larvae or pupae in the growing media after the larvae have dropped to the ground to pupate. However as thiacloprid is due to be withdrawn from the market this is not a future option for control.
- Consider using Strulch (a mineralised straw mulch) on field grown agapanthus and possibly as a pot topper for containerised plants. However, so far this has only been tested in a laboratory pot test and this result needs validating under commercial conditions. Growers may wish to test the product is suitable for their crops before widespread use.
- Melcourt EcoBark had a delaying effect on midge emergence which means that bark-based pot toppers may be useful to prevent egg laying at the susceptible flower stage, however further research is needed to test this further.

SCIENCE SECTION

Introduction

The agapanthus gall midge, *Enigmadiplosis agapanthi*, is a recently described pest affecting agapanthus (Harris *et al*., 2016). It poses a risk to both containerised plants and cut flowers, as midge infestation causes flower buds to be deformed and discoloured and often fail to open. Heavy infestations can lead to entire flower heads being aborted. A thorough background of the arrival, spread, symptoms and known biology of agapanthus gall midge can be found in the final report from HNS PO 199 (Jones, 2017).

The persistent presence of midge larvae throughout the growing season indicates there are several overlapping generations and control should most likely be focussed on the overwintering larvae and/or first generation adults at emergence in the spring (Jones, 2017). Larvae feed and develop inside the flowers and when fully grown emerge and drop into the soil or growing media. They bury themselves to pupate and took 10 – 14 days to emerge as adults when kept in an unheated laboratory during July - August. It is likely that agapanthus gall midge overwinter as larvae and pupate shortly before emergence in the spring as with other pest midge species e.g. blackberry leaf midge (Bennison, 2010) and saddle gall midge (Ellis, 2016), but this has not yet been confirmed.

Agapanthus gall midge is an invasive pest first found in the UK in 2014 in Surrey, but has since been found in most counties in southern England and has successfully overwintered in Yorkshire (Jones, unpublished data). The cost to an infested nursery, based on estimates of £3 production cost per pot and potential crop loss of 70% in an infested nursery, is approximately £840,000 (Fairweather & Carr, pers comms). A cut flower grower has estimated that midge infestation currently causes around 50% crop loss. A grower hoping to harvest 1.2 million stems would therefore suffer a loss of approximately £300,000. This could increase if the midge infestation becomes further established and a higher percentage of the crop was infested.

Due to the relative novelty and lack of information about the midge, there have been few recommendations available for control. Work carried out in HNS PO 199 did not lead to any grower recommendations for treatments other than cultural methods including removal of infested flower heads, destroying badly infested plants and avoiding growing highly susceptible cultivars such as Northern Star. None of the tested plant protection products had a significant effect when sprayed against larvae in the flowers. A test of drenches against the ground-dwelling stage of the larvae showed a significant effect of thiacloprid (Calypso), EAMU 2014/2153, but very high mortality in the water controls means this needed further study before recommendations could be made for growers (Jones, 2017). In addition, many retailers are prohibiting the use of neonicotinoids in their supply chains, therefore many growers have stopped using them. Since this work was done, thiacloprid is due to be withdrawn from the market (current estimated dates are sale up to October 2021 and use-up date October 2022).

This project attempts to address some of the crucial gaps in our knowledge about the agapanthus gall midge with the following objectives:

Objectives

1. Review cultural control methods used for gall midge pests in a range of crops, identify knowledge gaps and produce a shortlist of candidate control treatments for objectives 3 and 4.
2. Evaluate the use of sticky traps and water traps for monitoring adult midge emergence.
3. Complete a field trial testing candidate novel spray treatments against first generation adults on a commercial cut flower farm.
4. Complete a laboratory pot test of candidate drenches of plant protection products, biological control agents and cultural control methods against the ground dwelling life stages.
5. Communicate the results and recommendations for control to the industry.

Materials and methods

Objective 1: Review cultural control methods used for gall midge pests in a range of crops, identify knowledge gaps and produce a shortlist of candidate control treatments for objectives 3 and 4

The candidate products to be tested in objectives 3 and 4 were selected following a review of cultural controls for a range of midge pests and from experience of the project team on biological and chemical control of other midge pests. A review of control of raspberry cane midge and blackberry leaf midge was done in Sceptreplus project SP 38 (Whitfield, 2019) but this was not available until after treatments had been selected for our project.

Selection of treatments was discussed with the host grower of the field trial (Greenyard Flowers UK Ltd) and with Patrick Fairweather (Fairweather's Nursery), to ensure they were appropriate and practical for industry needs.

A brief literature review was carried out for twelve arable and horticultural gall midge pests (see Table 2). The review was split between Hayley Jones, Jude Bennison, and Steve Ellis (ADAS) and aimed to summarise information on cultural control options, including mulches and barriers. Experience of the project team on biological and chemical control of midge pests was also considered when planning candidate treatments for work in Objectives 3 and 4, including relevant timing of potential control measures when targeting specific life stages.

Table 2: Gall midge pests covered by literature review for candidate control options for agapanthus gall midge.

Gall midge common name	Scientific name	Reviewer
Orange wheat blossom midge	*Sitodiplosis mossellana*	Steve Ellis
Yellow wheat blossom midge	*Contarinia tritici*	
Brassica pod midge	*Dasineura brassicae*	
Pea midge	*Contarinia pisi*	
Saddle gall midge	*Haplodiplosis marginata*	
Raspberry cane midge	*Resseliella theobaldi*	Jude Bennison
Blackberry leaf midge	*Dasineura plicatrix*	
Blueberry leaf midge	*Dasineura oxycoccana*	Hayley Jones
Blackcurrant leaf midge	*Dasineura tetensi*	
Pear midge	*Contarinia pyrivora*	
Apple leaf midge	*Dasineura mali*	
Swede midge	*Contarinia nasturtii*	

A brief, focussed peer reviewed literature search was completed focussing on cultural control methods. Relevant 'grey' literature (such as HDC/AHDB-funded project reports, conference proceedings and advisory outputs to growers and farmers) was also reviewed.

Objective 2: Evaluate the use of sticky traps and water traps for monitoring adult midge emergence

Field site

Work for objectives 2 and 3 was hosted by our collaborating grower Greenyard Flowers UK Ltd at their site in Penzance, Cornwall. This is an outdoor cut flower grower with an established problem with the midge. After initial field site visits one section within one field was selected to site both the trap tests and the spray trial (see Figure 4).

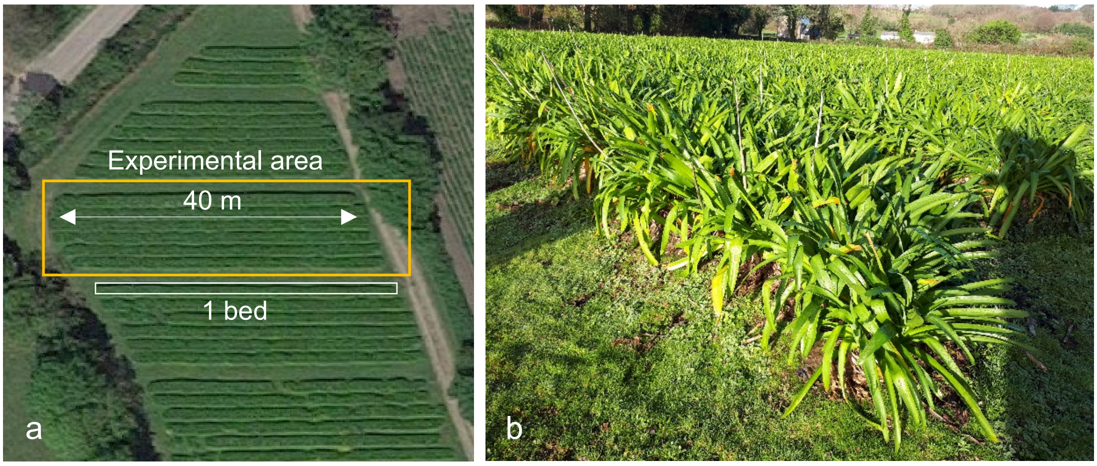

Figure 4. Agapanthus cut flower field site –'Tolver' at Greenyards Flowers UK Ltd, Penzance 50.134742, -5.505118. **a.** Plants arranged in beds of varying length. **b.** large established plants in beds two plants wide.

The whole field consists of approximately 0.5 acres of agapanthus of multiple varieties. The earliest flowering plants were selected as these historically have the worse symptoms, and when controlling any midge pest it is preferable to target the earliest emerging midges to reduce subsequent generations in the same season. The area selected contained plants known as 'Early Isles of Scilly' stock (unknown variety). Based on previous years the earliest anticipated harvest date for these plants was mid May to early June. These were planted circa 2004 (into black polythene mulch that is no longer apparent) and are raised up on their root masses due to long establishment (Fig. 4b). As shown in Figure 4a the plants are arranged in beds each of which is two plants wide measuring about 170 cm width including overhanging foliage. Narrow 70 cm paths run between each bed with a wider path every six beds. Length of bed is variable due to the shape of the field but most are around 40 m.

Monitoring traps

Three types of traps were tested for monitoring the midge; yellow and blue sticky traps and yellow water traps. From 26 April four replicates of each trap type were placed among the agapanthus plants in the trial area as per Figure 5. These were placed at least 5 metres from the edge of the crop or any hedges to minimise incidental catch of other flying insects. The traps were positioned on poles just below the upper level of the foliage.

Standard horticultural yellow and blue sticky traps were used. The water traps were 'Flora' brand water traps consisting of a yellow plastic bowl (approx. 30 cm diameter) on a fibre glass pole filled with water and a few drops of detergent (to break the surface tension and prevent trapped midges from escaping).

Figure 5. Layout of monitoring traps in agapanthus field

Traps were sent by the grower to RHS Wisley for assessment. Water traps were emptied by removing the bowl from the pole and sieving the contents through one piece of muslin per trap, which was placed in a screw lid tube. This along with sticky traps inside polythene bags were sent by first class post. At RHS Wisley, traps were emptied and midges counted weekly.

Midge identification

Consultation with cecidomyid expert Keith Harris indicated that it would be necessary to slide mount genitalia to identify to species level. This was not deemed practical with the time available for the project. It was decided to count all midges that superficially resembled the agapanthus gall midge – with orange coloured body, contrasting black eyes and long antennae with circumfilar loops (looped filaments on each segment) as illustrated in Harris *et al*. (2016) Midges from water traps were stored in ethanol, for subsequent identification if time and funding allows.

Statistical analysis

All analyses were carried out by the RHS statistician Joe Perry in Genstat (VSN International 2019). ANOVA was used to test whether any trap type caught higher numbers of midges.

Objective 3: Complete a field trial testing candidate novel spray treatments against first generation adults on a commercial cut flower farm

It was determined through the literature review and from knowledge of the project team that timing was a crucial factor in control of other gall midge species so the decision was taken to test a variety of spray schedules rather than a variety of products. For example, a single application of the pyrethroid, lambda- cyhalothrin (Hallmark with Zeon Technology) targeted at the first sign of first generation adult saddle gall midge was as effective as a programme of up to three applications (Ellis, 2016). The synthetic pyrethroid 'Decis Forte' (deltamethrin) was selected as the plant protection product to use in the trial, being a widely available pyrethroid with a label recommendation for use on outdoor ornamentals for the control of various pests.

As timing of treatments in the field trial was critical for the success of control of the target first generation adult midges, ideally an accurate method for monitoring midge emergence would have been used. However, no pheromone trap has yet been developed for agapanthus gall midge and the remit of the project did not include the use of semiochemicals. Models to predict midge emergence using soil and air day degree accumulations have been developed for some midge pests e.g. blackberry leaf midge (Bennison, 2010) and saddle gall midge (Ellis, 2016) but this, together with soil sampling to monitor midge larval pupation in the soil prior to adult emergence was beyond the funding scope of this project.

The earliest flowering varieties of agapanthus are usually severely affected so we anticipated that midge presence would precede flower susceptibility. Consultation with staff at Greenyards confirmed that infestation usually develops once flower heads grow above the foliage level, so the first spray timing was set to be as the first bulk flower heads became level with the foliage. This should protect the flowers that would be harvested first, excluding 'leaders' which are early isolated flowers.

Treatments tested

The following spray schedules were tested:

1. Insecticide spray at timing A – the first point at which developing flower heads are expected to be susceptible to the midge.
2. Insecticide spray at timing B only (with B being 7-10 days after A.)
3. Insecticide spray at timing C (14-17 days after A)
4. Insecticide spray at both timing A and B.
5. Insecticide spray at both timing B and C.
6. Insecticide spray at both timing A and C
7. Insecticide sprays at all three timings
8. Untreated control

These treatments were applied to six replicate blocks in the field site by ADAS. The plot design and layout was created in consultation with RHS statistician Joe Perry (Figure 6).

Figure 6. Layout of experiment testing seven spray schedules against agapanthus gall midge.

Each block consisted of a bed (two plants wide) divided into eight equal plots of five metres in length. Plants at the outer edge of the beds were excluded to keep the plots the same length and ensure no spraying within five metres of the field boundary (Decis Forte label recommendation to reduce effects on non-target insects). Growers find agapanthus gall midge more commonly near the edges of a field. Therefore, the treatments were randomised by the statistician to plots within each block using restricted randomization to ensure that no treatment occurred more than once in an edge plot at each of the eastern and western field edges.

The Decis Forte was applied at the label rate of 17.5 ml per 100 litres of water in 400L/ha. The volume per hectare was determined at the first spray timing by testing rates 200, 300, 400 and 500 L/ha using water sensitive paper attached to the flower spikes and upper and lower leaves. The water volume was selected that gave the best medium spray result - small discrete droplets that were evenly and closely spaced over the paper without joining up.

Assessment

Any symptoms of pesticide phytotoxicity was recorded two days after treatment application by the grower. Each plot was scored with a value of between 0 and 9 where 0 is no spray damage and 9 is severe damage compared with the untreated controls, taking a number of growth and appearance factors into account according to EPPO guideline PP1/135.

Assessment of midge infestation levels were carried out one week after each spray treatment. Within each plot the centre most 25 flower heads were assessed for midge. The flower heads were defined as midge present if the symptoms were severe enough so that the head was not considered marketable (according to visual inspection in conjunction with the host grower). HJ assessed each plot to record damaged and undamaged flower head numbers. Simultaneously a member of the grower team assessed flower development stage. This was recorded as number of flower heads in the following categories for each plot: closed flower head; sheath splitting; flower head expanded and flowering started. Developing flower heads were inspected and scored for infestation level and marketability using a visual assessment estimating proportion of buds with symptoms. Relative crop losses for each treatment were planned to be calculated with the help of the host grower.

Data analysis

Plans for data analysis by the RHS statistician were as follows:

- Analysis of the effect of the different treatments using a factorial ANOVA in Genstat.
- Analysis of differences in infestation severity and marketability between treatments using ANOVA
- Percentage control compared with the negative control using Abbotts formula.

Objective 4: Complete a laboratory pot test of candidate drenches of plant protection products, biological control agents and cultural control methods against the ground dwelling life stages.

Experimental units

In order to test controls for the ground-dwelling larval stage a laboratory test using pots of growing media was used as in HNS PO 199 (Figure 7). Each experimental unit consisted of a 365 ml plastic pot (8 cm diameter at compost surface level) with four ventilation holes near the top and one hole at the base (holes smaller than midge body size). These pots were filled with 280 ml growing media (or less where mulches were also to be used).

Mature midge larvae were added to the surface of the growing media in each pot, to mimic larvae dropping to the ground in order to pupate. Infested flower heads were dissected and mature larvae counted out into drops of water which were then transferred to the pots. The pots were sealed with snap-on lids, each of which had a yellow sticky trap secured on the underside. The pots were housed in a controlled environment room at the RHS Field Research Facility at 21°C and 65% relative humidity under a 16 hour day length.

The pots were monitored weekly for adult emergence and any adults on the sticky traps were counted and marked with a permanent marker. The surface of the growing media was also scanned, adults counted and removed or stuck to the sticky trap to avoid double counting.

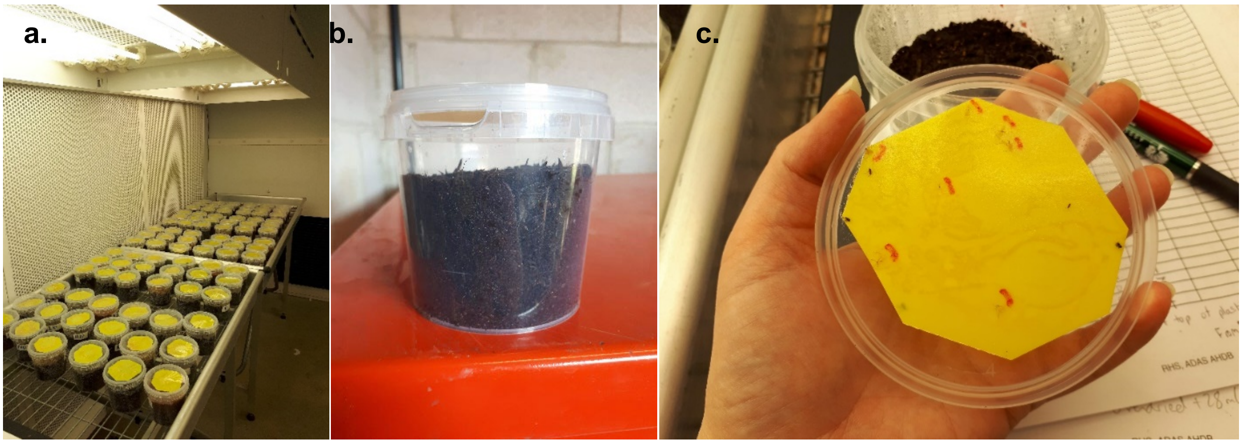

Figure 7. Experimental set up for laboratory tests of control measures against agapanthus gall midge larvae. **a.** blocks arranged in controlled environment room. **b.** Pots filled with 280ml growing media and water/ treatment subsequently added. **c.** Adult midges caught and counted on yellow sticky trap inside pot lid.

Preliminary experiment to optimise conditions

Due to very high mortality in the water controls in HNS PO 199 in 2017 a preliminary experiment was carried out to optimise the growing media and moisture levels for maximum midge adult emergence in the controls. Three growing media were tested:

1. Coir (rehydrated coconut husk bricks)
2. Peat-free (Melcourt Sylvagrow)
3. Peat-based (Levington's advanced M3)

In HNS PO 199 the growing media was moistened before being put into the pots then the treatments were applied in a volume of 28 ml of water i.e. 10% of growing media volume as this is usually the standard commercial practice for drench applications. It was concluded that this was too wet as the growing media was visibly wet and condensation formed on the inside of the lid of the pots. Therefore two lower moisture levels were tested in this preliminary experiment. For a low moisture level the growing media were dried for 24 hours at 75°C then added to the pots before being topped with 28ml of water and stirred. For medium moisture levels the growing media were used straight from the bag (or direct from rehydration in the case of coir) and added to the pots along with 28ml of water. Twenty midge larvae were added to the surface of the growing media in each pot and the lids replaced. The sticky traps and surface of the growing media were assessed at one, two and three weeks after this point and the number of emerged adults counted. A box and whisker plot (Tukey, 1977) was created to inspect the result of this experiment and select the best growing media and moisture level combination to use for the main experiment.

Test of control methods

Through literature review, grower opinions and using results from HNS PO 199 some biological, chemical and cultural control measures were selected (Table 3). Cultural control in the form of mulches and barriers were prioritised despite a lack of data on effectiveness against pests because many of the chemical controls are no longer accepted by grower customers. Nine different treatments including a water-treated control were tested with 10 replicates per treatment. The treatments were applied using the label or EAMU recommended rates for control of other pests as outlined in Table 3.

Images of the barriers, demonstrating the depth of mulches and application technique for black polythene are shown in Figure 8.

Larvae were added to the treated pots on 22nd and 23rd August 2019 and adults were counted weekly after this date. Unexpectedly protracted emergence meant counting continued fortnightly from October and ceased at the end of November.

ANOVA was carried out in Genstat to determine whether any of the treatments reduced the number of adults emerging.

Table 3. Control treatments tested against the agapanthus gall midge in a laboratory pot test.

No.	Treatment (justification for choice)	Rate
1	Containermulch by Klasmann (a pot topper with adhesive properties with some evidence against pests)	2 cm depth added on top of 180ml growing media. 28ml water added on top.
2	Melcourt Ecobark (Used as a pot topper but also similar to bark mulches used for outdoor grown plants)	2 cm depth added on top of 180ml growing media. 28ml water added on top.
3	Strulch (a mineralised straw mulch used for outdoor flowerbeds)	3 cm depth added on top of 130ml growing media. 28ml water added on top.
4	Black polythene (agapanthus plants in the field often planted into this for weed suppression and gave significant control of blackberry leaf midge adults emerging in SF 102)	Circles of 8cm diameter cut from polythene sheet with small X cut through to simulate planting through. (Figure 5) 28ml water added on top of compost and polythene placed over.
5	Nemasys (used on protected HNS for sciarid fly control)	*S. feltiae* - 1,000,000 nematodes/m^2 in 1 L/m^2 water- curative drench (rate for sciarid fly control). Calculated this for 8.5 cm diameter pot at growing media surface level = 5027 nematodes in 5.027ml. 5ml of nematode suspension added to each pot then 23 ml water added on top.

6	Gnatrol (Bti) (label rec. for sciarid fly control as a drench in protected ornamentals)	Highest label rate:10 ml/ m^2
7	Pitcher – Garlic granules applied to surface of growing media (EAMU for vine weevil and leaf & bud nematode control but some evidence in SP 23 (Bennison & Brown, 2018) that garlic controls sciarid fly larvae)	28ml water added on top of compost before 24g/m^2 granules were sprinkled evenly over the surface. (EAMU 2018/3744).
8	Calypso (thiacloprid) (has EAMU for use as drench on protected ornamentals for control of vine weevil and sciarid fly and showed an effect in HNSPO199)	83 ml in 100 L per m^3 compost (per 1000L compost) (EAMU 2014/2153 drench for vine weevil and sciarid fly control). Equivalent to 0.83 ml in 1 L. 28 ml of this rate added per pot.
9	Water-treated control	28 ml per pot

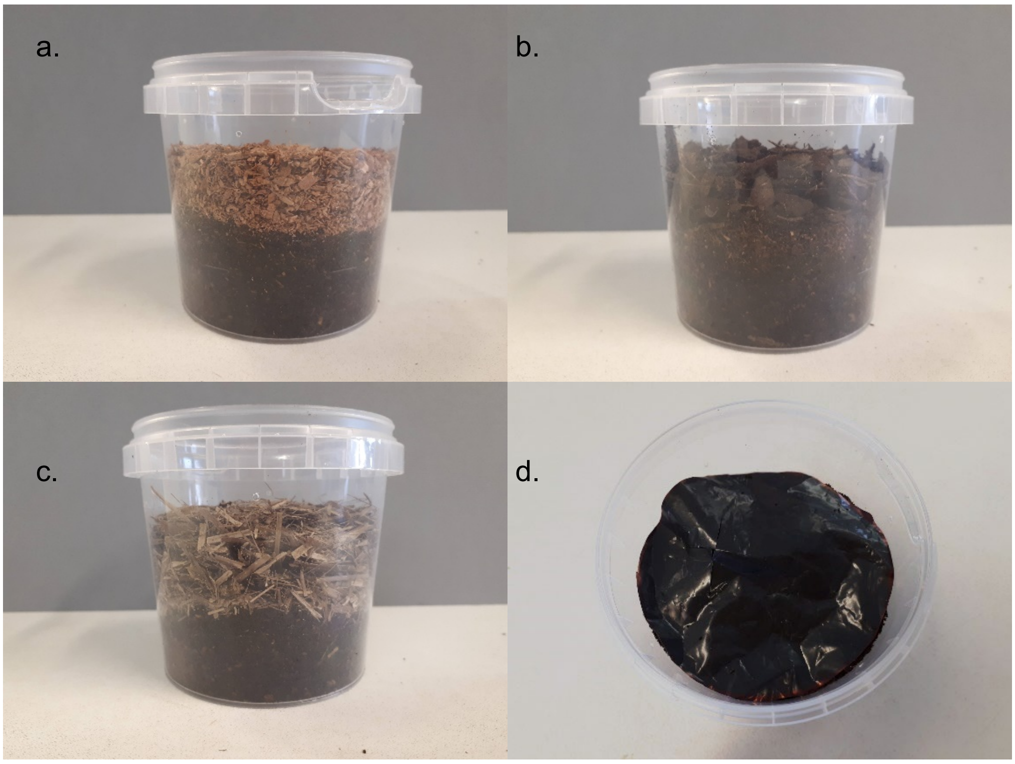

Figure 8. Barriers and mulches tested for control of agapanthus gall midge larvae.

a. Klasmann Containermulch **b.** Melcourt EcoBark **c.** Strulch and **d.** Black polythene.

Objective 5: Communicate the results and recommendations for control to the industry

Knowledge exchange activities include:

- Submission of this final report to AHDB Horticulture, to be made available on their website.
- 4 July 2019 – Presentation at Herbaceous Perennial Technical Discussion Group, Syngenta, Jealotts Hill

Results and discussion

Objective 1: Review cultural control methods used for gall midge pests in a range of crops, identify knowledge gaps and produce a shortlist of candidate control treatments for objectives 3 and 4

Orange wheat blossom midge

Orange wheat blossom midge (OWBM) is a sporadic pest of wheat. The larvae feed on the wheat grain affecting crop quality. Oakley (1994) provides a review of the 1993 outbreak of orange wheat blossom midge. Unless otherwise indicated the information in this section is taken from that source.

- Growing resistant varieties is a very effective way of minimising risk from orange wheat blossom midge. These varieties prevent the pest from completing its life cycle. AHDB Cereals and oilseeds recommended lists provide information on those varieties that show midge resistance (AHDB, 2019). Currently 16 out of 25 varieties on the winter wheat recommended list show resistance to OWBM. It might be expected that as the proportion of OWBM- resistant varieties in the UK wheat area increases so the proportion of midges returning to the soil will decrease.
- Sowing crops early or late may be one way of avoiding flights of OWBM and ensuring that the susceptible stage of the crop and OWBM migration do not coincide. However, this is not a very practical approach as the timing of midge emergence will vary from season to season depending on weather conditions. Selecting varieties or husbandry methods to ensure that ear emergence is completed over a short period of time would also potentially reduce OWBM risk. Again this is an impractical suggestion as it is unlikely that all the farms crops could be fine-tuned to emerge together.
- Crop rotation is also recommended as a way to reduce incidence of OWBM (Ellis *et al.,* 2014b).

Yellow wheat blossom midge

As with orange wheat blossom midge, yellow wheat blossom midge (YWBM) is also a sporadic pest of wheat in the UK. It is less common than orange wheat blossom midge but will attack the crop earlier and potentially reduce yield. Much of the information on yellow wheat blossom midge that follows is taken from Oakley (1994).

- Unlike OWBM there are currently no varieties with resistance to YWBM.

Brassica pod midge

Brassica pod midge (*Dasineura brassicae*) is a pest of oilseed rape. The adult midges lay their eggs in holes in the pods e.g. those made by cabbage seed weevil. Feeding by midge larvae can cause the pods to split and all the seed to be lost. Both winter and spring oilseed rape can be affected. Information is taken from Farmers Weekly guide (Anon not dated) or Gratwick (1992) unless otherwise specified.

- Not all seeding crops are equally attractive to the pod midge (McKinlay, 1992). Lesser numbers of eggs are laid on black mustard (*Brassica nigra*) leaf mustard (*B. juncea*) and Abyssinian mustard (*B. carinata*), which are also less suitable for larval development than turnip rape (*B campestris*) and swede rape (*B. napus*). Also female midges land less and stay for shorter periods on the less favoured species. Similar numbers of eggs were laid on low and high glucosinolate cultivars of swede rape but breakdown products of the glucosinolates which were present in greater quantities in the 'resistant' than 'susceptible' plants were toxic to pod midge larvae.
- Pod midge is a weak flier and isolation of crops from the sites of previous years' oilseed rape should reduce the level of infestation, although this might not always be practical.

Pea midge

Pea midge is a relatively localised pest in the UK with large populations occurring in Humberside, Lincolnshire, north Cambridgeshire and parts of Norfolk (Gratwick, 1992). The leading shoots and flower buds of peas are deformed or killed by the feeding of the larvae. This ultimately can have an impact on crop yield. In intensive areas of production, particularly in vining peas which are more determinate than combining peas, pea midge may cause significant yield loss.

- Crop isolation -Ideally sowing peas in land adjoining previously infested land should be avoided.
- For dry-harvested peas, early drilling, so that the earliest of the pods are set before the period midge attack helps to minimise losses.

- Selecting early varieties can help to avoid the main period of midge migration but this will also be dependent upon drilling date (Ellis *et al.,* 2014b)
- Deep ploughing may help to bury the overwintering larvae.

Saddle gall midge

Saddle gall midge is a sporadic pest of cereals which usually persists at low population levels. In 2010 and 2011 local epidemics were reported in central England, particularly in continuous cereal cropping or tight rotations (Ellis *et al.,* 2014a). Both Rowley *et al.* (2016) and Dewar (2012) have provided good reviews of the biology of saddle gall midge and unless otherwise specified the information in this section has been taken from these sources.

There is limited data on the economic impact of saddle gall midge in the UK but in the most severe case, there was an estimated 70% decrease in yield as reported by an agronomist in Buckinghamshire (Ellis *et al.,* 2014a).

- Growing cereal crops continuously increases the risk of saddle gall midge attack. Break crops are an effective means of reducing infestation by depleting larval soil populations. A break from wheat or barley by substituting a non-cereal crop for one, or preferably two years will allow populations of the pest to decline. Oats can also be grown as a break crop but to achieve maximum benefit should be sown early as numerous eggs have occasionally been laid on young late sown oats (Gratwick, 1992). The introduction of the EU crop diversification requirement as part of the 2013 CAP reform aims to encourage farmers to grow a greater variety of crops by specifying a minimum number of crops and a maximum land cover amount for the two main crops (Regulation (EU) 1307/2013, 2013). This may result in a reduction in saddle gall midge outbreaks if continuous wheat systems are disrupted by widespread use of rotations and break crops.
- Yield loss can be reduced by early sowing and by husbandry designed to ensure quick germination and vigorous early growth.
- Couch grass can maintain high populations of saddle gall midge so a high standard of weed control is necessary to take full advantage of crop rotation.

Raspberry cane midge

Raspberry cane midge is a serious pest of raspberry and some Rubus hybrids such as loganberry. The adults lay eggs beneath the rind of primocanes, usually in natural splits but also where mechanical damage has caused splitting. Damaged canes are weakened and susceptible to secondary infection with various fungal diseases including those that cause cane blight, leading to a combined problem known as ‘midge blight’ (Allen *et al*., 2012).

- In the SCEPTREplus review referred to below under blackberry leaf midge, it was reported that covering the tunnel floor with ground-cover matting should reduce numbers of both raspberry cane midge and blackberry leaf midge (Whitfield, 2019).
- In the same review it was recommended that growers should select raspberry varieties that are less prone to stem rind splitting, as the splits allow egg laying by adult midges (Allen *et al*, 2012). Growers can also remove the primocane using a herbicide in order to reduce infestation.

Blackberry leaf midge

Blackberry leaf midge is a serious pest of both blackberry and raspberry, particularly those grown under protection. The larvae feed on the leaf tips, causing leaf twisting and distortion, cane stunting and branching and reduced yield in the following year's crop.

- Research in SF 102 included testing ground-cover materials as a cultural control method, to reduce numbers of adults emerging from pupae developing from larvae that drop to the ground to pupate (Bennison, 2011). In a laboratory pot test where mature midge larvae were added to pots of both black polythene and woven ground-cover matting (Mypex ®) significantly reduced numbers of adult midges emerging compared with those in the untreated control. It was considered that if the whole tunnel floor was covered in matting or polythene, and if this could be kept intact and free from plant debris, it might prevent adults successfully emerging from overwintered cocoons in the soil or plant debris, or prevent first generation midge larvae successfully pupating and emerging as second generation adults. However, it was recommended that further work would be needed to validate this potential cultural control method in a commercial protected blackberry crop.
- Although no further research on the above approach was done, a SCEPTREplus review of control measures for raspberry cane midge and blackberry leaf midge reported anecdotal evidence that use of ground-cover matting had proved effective against midge pests in raspberry (Whitfield, 2019). One grower reported that use of both ground-cover matting and netting to exclude adults from tunnels had almost eradicated midge pests. The entire tunnel floor had been covered with overlapping sheets of Mypex®).
- In the same SCEPTREplus review, it was reported that another cultural control strategy might be pinching out shoots infested with blackberry leaf midge to remove blackberry leaf midge larvae (Whitfield, 2019). However, this might not be effective as by the time the characteristic leaf distortion is visible, some or all of the larvae may already have dropped to the ground to pupate (Bennison, 2010).

Blueberry leaf midge

The blueberry leaf midge, *Dasineura oxycoccana*, causes galls in the developing leaf and flower buds of a range of cultivated *Vaccinium.* It is native to North America and introduced in Europe (Topičová & Kapitola, 2016).

- Varietal resistance to the midge has been explored but has not yielded any species or varieties with stable resistance (Sampson *et al.,* 2002) but levels of resistance are reported among different varieties for the flower buds (Lyrene & Payne, 1996).
- It has been suggested that shallow tillage under blueberry plants may affect diapausing larvae, and that spreading sand under bushes can inhibit adult emergence (Steck *et al*., 2000).

Blackcurrant leaf midge

The blackcurrant leaf midge, *Dasineura tetensi,* creates galls on the terminal leaves of blackcurrant shoots and can thereby disrupt growth. It is a common pest in UK blackcurrant plantations, particularly since the withdrawal of some pesticides that were previously used routinely against blackcurrant gall mite (Saunders, 2018). Established crops can often tolerate infestation but it is more important to control it in newly planted crops and ones that are re-growing or establishing (Cross *et al.,* 2015).

- Some varieties are resistant to infestation by the midge, including 'Ben Connan', 'Ben Nevis' and 'Ben Sarek' (Buczacki & Harris 2014). This resistance is likely to operate by reducing larval size rather than discouraging egg-laying (Crook *et al.,* 2001).
- Abiotic conditions affect growth and survival of the midge, they are disadvantaged at low humidity (Hellqvist 2001).

Apple leaf curling midge

Apple leaf curling midge (ALCM), *Dasineura mali*, is a very widespread but usually minor pest of apples. All information is from the AHDB 'Apple Best Practice Guide' unless otherwise referenced. Biological control with the naturally occurring parasitoid *Platygaster demades* is the most important method of control of ALCM in orchards. This means the use of IPM strategies that avoid broad spectrum insecticides, especially during the egg laying period of ALCM. Chemical control with pyrethroid insecticides may be more necessary on nursery trees.

- All varieties are susceptible but trees with vigorously growing shoots are worst affected. Summer pruning of excess growth and watershoots where high numbers of eggs and larvae have been seen can help, but may affect subsequent years' growth.

- Natural predators can be encouraged by providing habitats between trees for ground beetles. Cultivation of the soil under trees could affect the ground dwelling stage, but this has not been demonstrated and may have adverse effects on natural predators.

Pear midge

Information in this section is from Buczacki & Harris (2014) unless otherwise referenced. The pear midge *Contarinia pyrivora* forms galls inside pear fruitlets, which initially grow faster than uninfested fruitlets but then halt and become blackened and distorted. Another pear midge, *Dasineura pyri*, causes leaf-rolling but is considered less damaging than the fruitlet midge.

- Recommended control for *C. pyrivora* is to remove and destroy infested fruitlets where practical.
- Little scientific research has been published on the control of these midges, except for some tests of insecticides.

Swede midge

All information from the HDC factsheets ‘Swede midge control in brassicas’ and ‘Minor pests of brassicas’ unless otherwise referenced (Lole 2005; Collier 2012). Swede midge, *Contarinia nasturtii,* is a sporadic pest of plants in the Cruciferae family in the UK, but has become a more prominent problem in North America (Olfert *et al.,* 2006). The midge causes swollen, distorted or corky growth and allows secondary rots to enter. The majority of recommended control measures against this pest are cultural.

- As this insect’s dispersal ability is limited, crop rotation should be practiced, with as much distance as possible from the previous two years’ infestations. Early planting of crops can mean they are more advanced in size, and therefore less damaged by the midge when it emerges. Additionally, remaining plants should be removed or destroyed after harvest as the midge can continue to develop in side shoots (Hodgdon *et al.,* 2017). Cruciferous weeds in the area should be controlled to minimise local populations (e.g. Chen *et al.,* 2009). Cultivar selection can also play a role, with susceptibility varying across *Brassica oleracea* (Hodgdon *et al.,* 2017).
- Intercropping may have some utility; occurrence of the midge was reduced by intercropping with Pot Marigold and French Marigold (Jankowska *et al.,* 2009) but not with clover (Theunissen *et al.,* 1992).
- Vertical barriers may provide opportunities to exclude this midge. Wyss & Daniel (2004) used insect mesh fences (1.35mm gauge, 1.4 m height with 0.25m overhang) and saw a statistically significant reduction in the severity of midge symptoms.
- Abiotic conditions may also be exploited, as midge survival is lower if particularly dry or wet soils (Chen & Shelton 2007). Midges pupate at ~1 cm depth, and emergence

can be reduced by the addition of more than 5cm depth of soil (Chen & Shelton 2007), but tillage does not seem to have an effect (Chen *et al.,* 2011).

Conclusions

This review highlights that there has been relatively little research into cultural control options against gall midges. Of the research that is available the most common effective strategies are:

- Use of resistant or less susceptible varieties of host plants
- Crop rotation or isolation
- Timing planting to avoid peak infestation
- Physical removal of infested material

Additionally, pheromones have been well studied for cecidomyiid midges (Hall et al. 2012) and have the potential to be used as another form of non-chemical control (e.g. Samietz *et al*., 2012). However the use of pheromones for midge control rather than for monitoring has not been well studied yet and is outside the remit of this project.

Prior to this project there has been very little work done on barriers and other cultural techniques that target the ground-dwelling life cycle stages of these gall midges.

This literature review and knowledge of the project team indicated that timing was a crucial factor in control of gall midge species so for objective 3 (field trial of sprays targeting adults) the decision was taken to test a range of spray schedules rather than different products. For objective 4 (laboratory test of controls targeting larvae in the ground) cultural control in the form of mulches and barriers were prioritised despite a lack of data on effectiveness against pests because of the shortage of chemical control options and the increasing need to adopt IPM strategies. The biological, chemical and cultural control measures were selected based on literature review, grower opinions and using results from HNS PO 199.

Objective 2: Evaluate the use of sticky traps and water traps for monitoring adult midge emergence

The average catch for each type of trap over the dates of the experiment are shown in Figure 9.

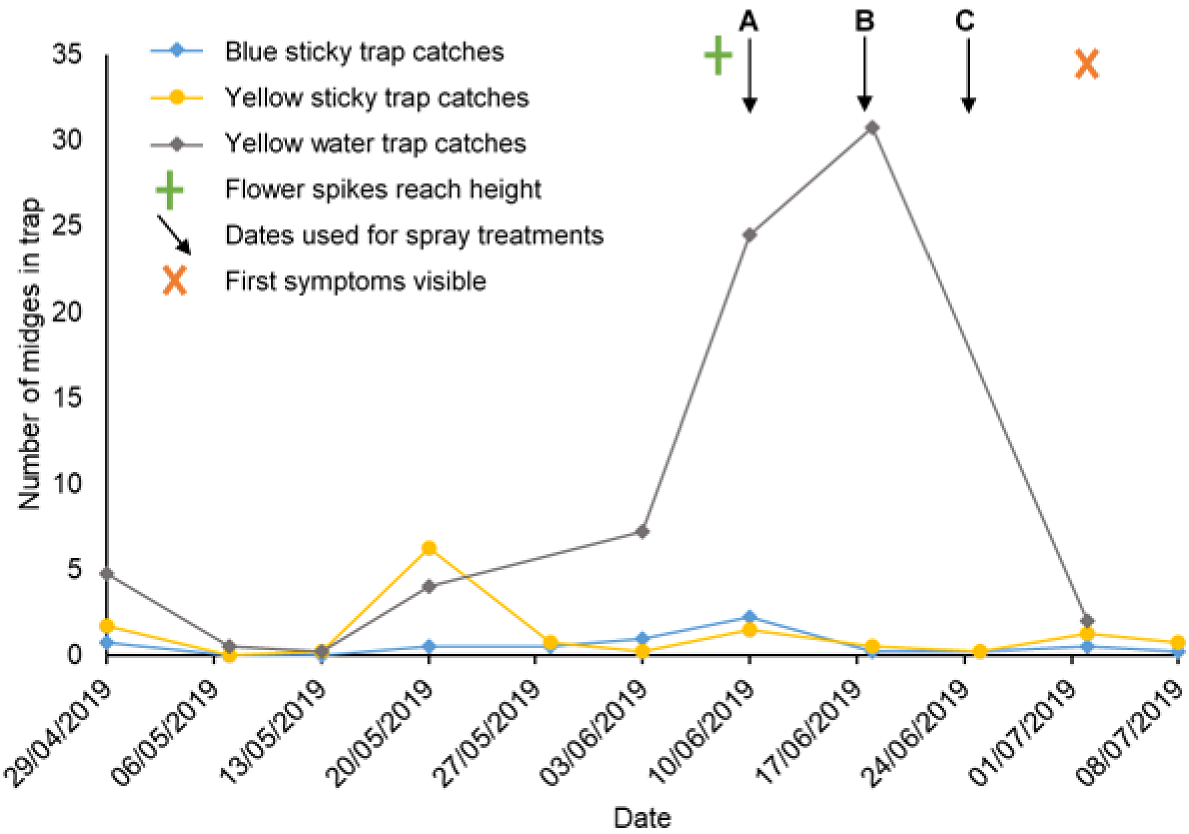

Figure 9. Average number of agapanthus gall midges caught in three different trap types throughout field experiment. 'Flower spikes reach height' means reached level with the top of the canopy (the designated time to start spray treatments). Spray dates A (10 June), B (17 June) and C (25 June) were used on different combinations of plots as outlined in objective 3).

Analysis (using ANOVA) of the trap catch data indicated that yellow water traps caught the most adult midges ($F^{2,81}$ = 4.46, P=<0.001). This means they are the most useful monitoring device of the three tested. However the number of midges seen in the traps was not reflected in symptoms seen in the field, which were almost zero even in the unsprayed plots. This may be because it was not possible to identify the midges in the traps to species level, so incidental catch of similar species may have inflated the numbers recorded, or it may be because threshold levels for economic damage are quite high.

This trapping method may not be widely practicable by growers due to:

- High levels of incidental catch of other insects (including pollinators)
- Fairly complicated process to empty and refill traps
- Requires microscope to detect midges reliably
- Identification was difficult, even with specialist knowledge, at the non-specific level used

For now, growers may need to rely on timing treatments with susceptible flower head development, and this strategy is initially supported by our data as the peak of midges recorded in water traps coincided with the flower spikes approaching canopy height.

Objective 3: Complete a field trial testing candidate novel spray treatments against first generation adults on a commercial cut flower farm

Pesticide application

The water volume per for application of the pesticide was tested at rates 200, 300, 400 and 500 L/ha using water sensitive paper. The rate of 400l/ha was selected as it gave the most even and closely spaced droplets (Figure 10).

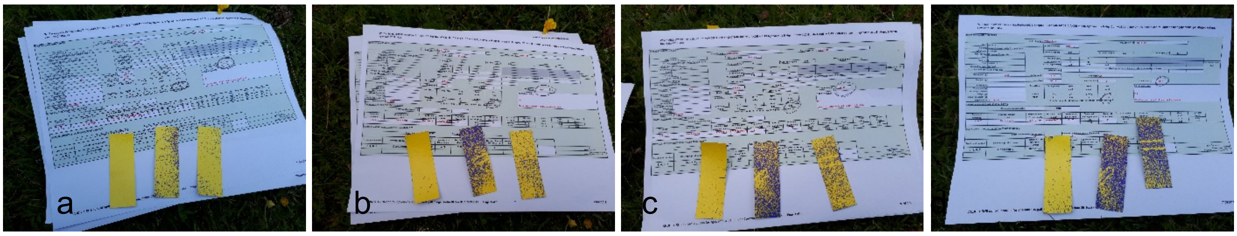

Figure 10. Water sensitive paper results for application volumes a. 200, b. 300, c. 400 and d. 500 L/ha. Paper attached to plants from left to right on flower spike, upper foliage and lower foliage.

None of the spray volumes gave good coverage to the flower spikes, but this is to be expected as they are narrow vertical structures. This might be a relevant difficulty for control methods that target ovipositing midge adults and also confirms the impracticality of targeting larvae inside flower heads, particularly with plant protection products that are purely contact in action. However, orange wheat blossom midge adults rest in wheat foliage during the day and fly up to the ears to lay eggs in the evening (Oakley, 1994) and it is possible that agapanthus gall midge adults have a similar behaviour. Very little is known about the biology of agapanthus gall midge, but if adults rest in the foliage during the day this would make them an easier target for both contact and residual activity of contact-acting plant protection products such as pyrethroids.

Phytotoxicity assessment

Negligible levels of potential spray damage were recorded across all plots.

Assessment of effectiveness

Extremely low levels of midge infestation were recorded throughout the duration of this trial. No midge infested heads were recorded until the final assessment date where five plots each had only one infested flower head. These infestation levels were too low to allow meaningful statistical analysis.

The field site had extremely high levels of infestation in the previous year so the almost zero levels in the study were unexpected. It may be that the populations are naturally fluctuating or cycling, and the presence of midges in the traps means it is likely to reoccur in this field in the future. Agapanthus gall midges may be able to diapause in the soiling dwelling stage for multiple years, as with the orange wheat blossom midge (Oakley, 1994) Additionally, the areas of the field outside the study area were sprayed on 22 May, 5 June, 22 June, 15 July and 13 September with either Decis Forte or Hallmark with Zeon Technology (EAMU 2008/2944 for use on outdoor ornamentals). Although although an appropriate buffer was in place, it may be that the field level population of midges was suppressed. However other growers have sprayed and not seen such low levels as a result.

Objective 4: Complete a laboratory pot test of candidate drenches of plant protection products, biological control agents and cultural control methods against the ground dwelling life stages.

Preliminary experiment to optimise conditions

The number of adults emerging from the different growing media and moisture levels can be seen in Figure 11. Data analysis (using ANOVA) showed that there were significant differences between growing media types ($F^{2, 25}$ = 24.75, P<0.001), moisture levels ($F^{1, 25}$ = 235.32, P<0.001) and an interaction between the two ($F^{2, 25}$ = 15.03, P<0.001).

Both Coir and Melcourt Sylvagrow at medium moisture levels gave significantly higher adult emergence than other conditions, and the latter was selected to be used in the experiment testing treatments.

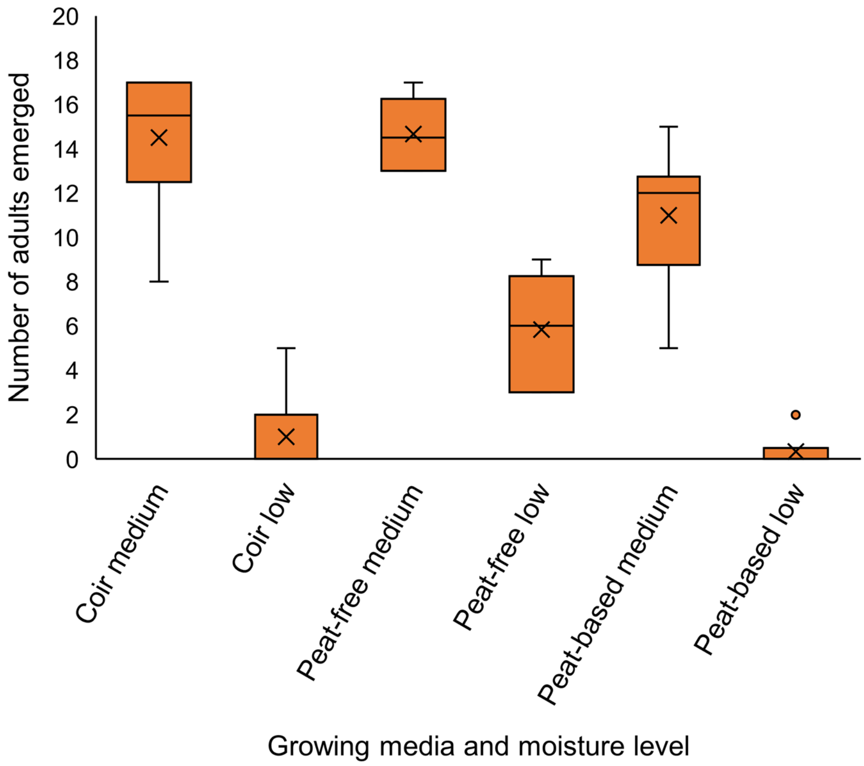

Figure 11. Box and whisker plot showing number of midges emerging from pots with combinations of growing media and moisture levels. X shows mean, inner bar median and box spans the interquartile range.

Test of control methods

The numbers of adults that emerged from the different treatments can be seen in Figure 12.

Data analysis (using ANOVA) showed a significant effect of treatment ($F^{8, 639} = 4.6$, $P<0.001$) with Calypso and Strulch significantly reducing emergence, by 20-25% compared to the other treatments. The other treatments were all similar to one another (their means were all covered by two standard errors of difference, which was 0.0306).

There was also a significant effect of date ($F^{7, 639} = 43.46$, $P<0.001$) and an interaction between date and treatment ($F^{56, 639} = 3.94$, $P<0.001$). This interaction was clearly caused by some treatments delaying the emergence of the midges, this phenomenon is illustrated in Figure 13. The mean date to emergence for each treatment is shown in Table 4, which shows that the most notable delay was caused by Melcourt EcoBark with a delay of 21 days compared to the water treated pots. Delaying emergence could be a useful strategy for avoiding egg laying at the susceptible flowering stage.

Data reanalysed without the Melcourt EcoBark treatment still gave a significant interaction between date and treatment ($F^{49, 567} = 2.20$, $P<0.001$), albeit a weaker one, so some of the other treatments also caused a significant delay, but with a smaller effect size (only a few days).

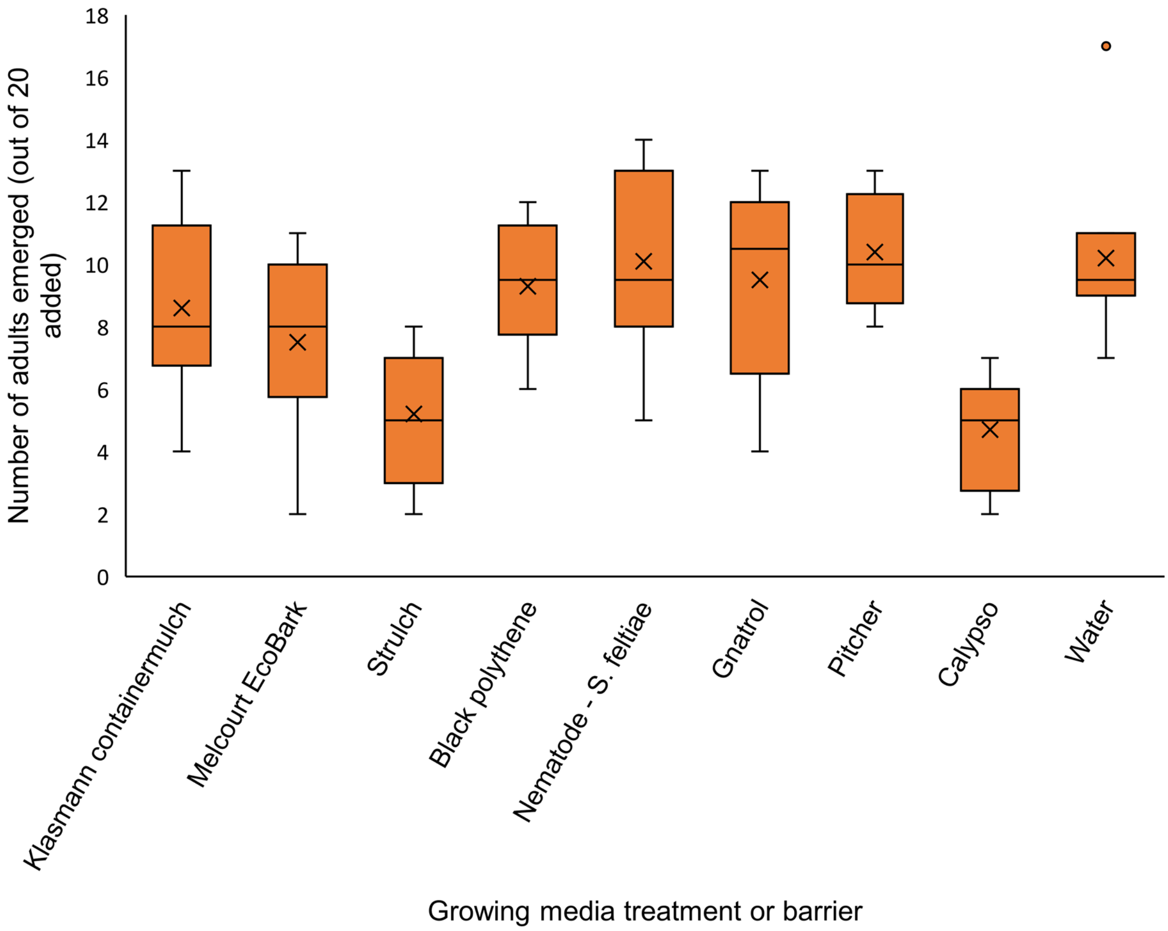

Figure 12. Box and whisker plot showing number of midges emerging from pots treated with cultural, biological or chemical controls. X shows mean, inner bar median and box spans the interquartile range.

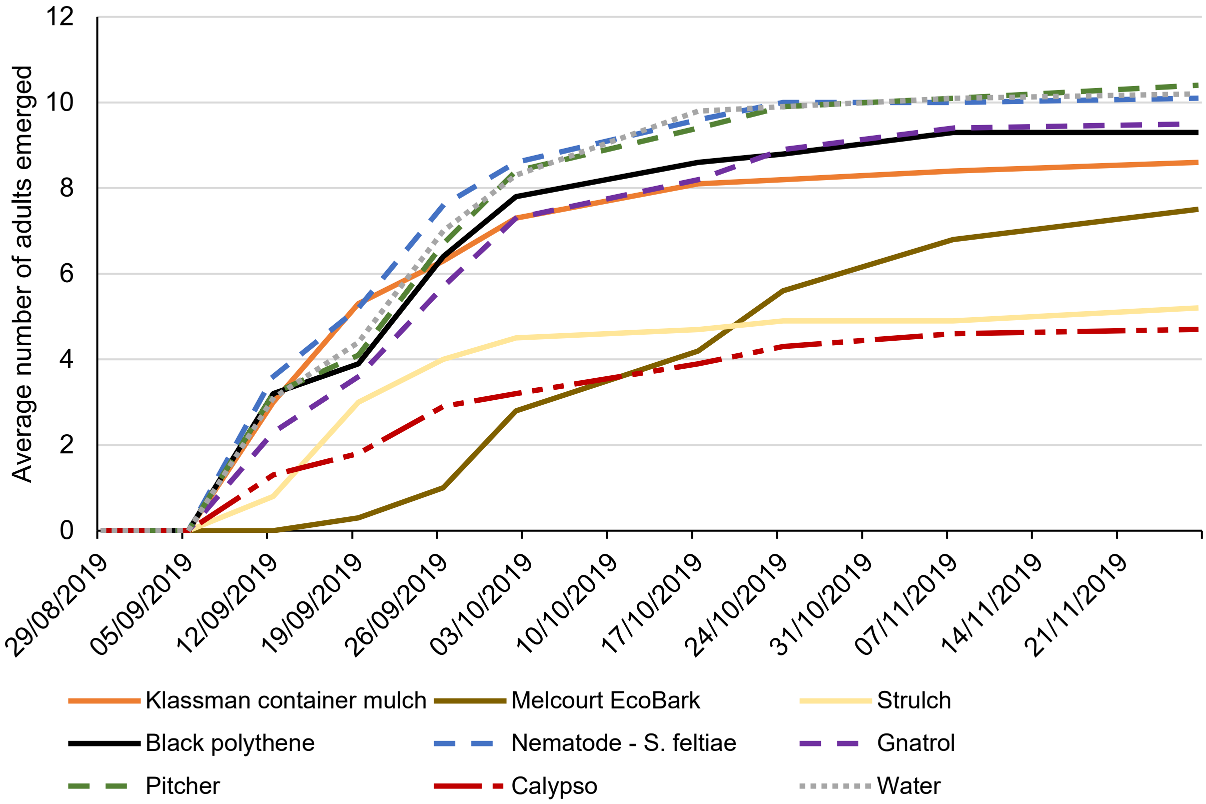

Figure 13. Cumulation curves for the average number of agapanthus gall midge adults emerged under nine different control treatments.

Table 4. Mean days to agapanthus gall midge adult emergence under nine different treatments.

Treatment	**Mean days to emergence**
Nematode - S. feltiae	34.2
Klassman container mulch	35.4
Water	36.3
Strulch	36.6
Black polythene	36.9
Pitcher	38.2
Gnatrol	40.4
Calypso	40.7
Melcourt EcoBark	57.7

The Calypso drench was the only treatment which showed effectiveness in HNS PO 199 in 2016, so it is encouraging that this treatment was effective again in this study under optimum conditions for adult midge emergence. Calypso currently has an EAMU for use as a drench on protected ornamentals for control of vine weevil and sciarid fly (2014/2153). However, thiacloprid is due to be withdrawn from the market (current estimated dates are sale up to October 2021 and use-up date October 2022). In addition, retailers do not wish growers to use neonicotinoids so use of Calypso will not be a sustainable option for growers to control agapanthus gall midge.

Barriers and mulches are preferable in many ways because they are not at risk of withdrawal and there are no consumer objections to them. It is therefore encouraging that Strulch significantly reduced midge emergence. This product is mostly used as a mulch for beds, and so may be a relatively practical option for growers of outdoor cut flower agapanthus. It may also be useful as a pot mulch for containerised agapanthus, particularly if the surrounding surfaces are not suitable for the midge to burrow into to pupate.

Melcourt EcoBark, a wood bark based pot topper, did not significantly reduce the number of midges emerging by the end of the experiment, but it did delay their emergence by around three weeks. This may be useful if it can delay adult midge emergence to outside of the susceptible flowering period of the plants in the vicinity. However, its possible usefulness is limited by the long flowering time of many agapanthus cultivars and overlapping generations of the midge, so targeting the first generation would be a key strategy. If it is useful it may also be applicable to outdoor agapanthus in the ground, as similar bark-based mulches. The effectiveness of these mulches may be due to creating drier conditions for pupation, or by adding extra depth for the larvae to reach the growing media. This aligns with a study by Chen & Shelton (2007) on Swede midge which found reduced midge survival in dry soils and if covered by addition soil.

The other treatments (Klaasman Containermulch, black polythene, Nemasys, Gnatrol and Pitcher) did not have a significant effect on number of midges emerging, although the latter two may have delayed midge emergence by 2-4 days. If they were ineffective under these controlled conditions then they are very unlikely to be successful in field conditions.

Black polythene did not provide any control, which was disappointing as it gave significant control of blackberry leaf midge in SF 102 (Bennison, 2011) and ground-cover matting has been reported to be useful against blackberry leaf midge and raspberry cane midge in poly tunnels (Whitfield, 2019). In this experiment the ineffectiveness may be because the midges were able to move to the edges of the disk of polythene or go through the small X cut to simulate planting through. These holes in the polythene barrier represent field realistic conditions however, as fully intact polythene sheeting would be very hard to maintain in the field.

In this experiment larvae were added to pots that had already been treated with cultural, biological, chemical controls. In the field larvae would be dropping down to the soil over a long period so some would fall onto areas that were already mulched or treated, but seasonal timing might mean that some were already in the soil when treatments were applied. This might change the effectiveness of different treatments depending on whether mortality in the midges was higher on entry to the soil or emergence. It may be worth further experimental work to investigate this.

A priority for future work would be to test the successful treatments in commercial conditions, both for containerised and field-grown agapanthus. Exploration of other barrier and mulch solutions would also be a productive avenue of enquiry.

Conclusions

Traps for monitoring

- While yellow water traps caught significantly more midges than blue or yellow sticky traps the catches did not correspond to symptoms seen in the field so may not be a helpful tool for growers.
- There was some indication however that the peak of midges in the water traps matched the time when flower heads were approaching canopy height. This supports the strategy of targeting possible spray treatments to flower development stages rather than midge presence.
- Further work is needed to determine a threshold trap catch that indicates damaging levels of midge adults in the crop. It will be important to refine specificity and usability of trapping techniques, for example by developing a specific pheromone trap that would reduce the confounding factors of incidental catch of other species.

Field trial of control measures

- Due to the very low incidence of midge symptoms in the study area, no conclusions can be drawn from the test of pesticide application timing. A further field trial is justified if funding could be made available as sprays targeting the first generation adult midges are likely to be one of the most effective control options.

Laboratory trial of cultural, biological and chemical controls.

- Two of the eight treatments tested showed significant control of adult midge emergence. Calypso (thiacloprid) and Strulch (a mineralised straw mulch) reduced the number of midges emerging by 20-25%.
- One treatment, Melcourt EcoBark (a wood bark based pot topper) did not significantly reduce the number of midges emerging by the end of the experiment, but it did delay their emergence by around three weeks.

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