SCEPTREPLUS

Final Review Report

Trial code:	SP 48
Title:	Identifying chemical, biological, and cultural control methods for UK Blueberry gall midge management
Crop	Blueberry
Target	Blueberry gall midge *Dasineura oxycoccana*
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Organisation:	NIAB EMR
Period:	Start: January 2020 Duration: 13 months
Report date:	17 November 2020
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ORETO Number:	N/A

I the undersigned, hereby declare that the work was performed according to the procedures herein described and that this report is an accurate and faithful record of the results obtained

18/11/2020 Bethan Shaw
Date Authors signature

Review Summary

Introduction

Blueberry gall midge (BGM), *Dasineura oxycoccana* (Johnson 1899) infestation results in damage to growing shoots, uncontrolled branching of the crop and reduces yield in subsequent years. Currently populations are controlled with applications of thiacloprid but approval for this active expires in 2021. The aim of this review is to identify products and other control methods that can be used by UK blueberry growers to control BGM while not disrupting control of other blueberry pests. It includes those products already approved on blueberry, biological control options and information about approaches used overseas.

Summary

The key findings of this review are:

Cultural control

- Physical barriers to prevent pupation within the soil/substrate, such as nylon cloth, pot covers, or Perlite have been found to reduce subsequent BGM emergence but can be labour intensive to deploy.
- Crop hygiene and the physical removal of damaged plant growing tips could reduce the size of the following generations, but timing is key and would be highly labour intensive for very little benefit.

Pheromone trapping

- The use of pheromone traps has been found to be extremely valuable to time the application of plant protection products. Pheromone lures in combination with sticky roller traps could be used to reduce populations of midges for a season long approach.

Biological control

- Several predators have been identified which could contribute to the suppression of BGM, but there does not seem to be a specialist predator. It may be that several generalist predators together can reduce midge numbers, but this needs to be evaluated.
- Entomopathogenic nematodes and fungi appear to be very promising for the control of BGM and can also be used to control vine weevil *Otiorhyncus sulcatus.* Several species of both fungi and nematode are found to reduce the numbers of certain midge species but have yet to be tested on BGM.

Bioinsecticides

- Spinosad is used to control BGM in the USA and is approved for use in UK blueberry crops.
- Azadirachtin has been reported as having a variable impact on midge species but appears to be compatible with IPM for other pests.

Conventional insecticides

- Chlorantraniliprole and indoxacarb are approved for use in blueberry in the UK, but there is no evidence to show that they are effective against against BGM.
- Cyantraniliprole is also approved for use in UK blueberry crops and has been found to give good control of BGM in the USA.

Next Steps

Active ingredients/products that could be evaluated for control of pest midges in blueberry crops are shown in Table 1.

Table 1: Summary list of suggested active ingredients, products or biocontrol agents to test for IPM-compatible control of midge species in blueberry production.

Type	Active ingredient	Comments
Bioinsecticide	Spinosad	Good control of BGM in USA. Approved for use on blueberries in UK
Bioinsecticide	Azadirachtin	Effective against other midge species
Biological	*Metarhizium brunneum*	Effective against other midge species
Biological	*Steinernema feltiae*	Used to control vine weevil in blueberries
Biological	Hoverflies	No research to investigate control of BGM. Active at spring temperatures
Insecticide	Cyantraniliprole	Good control of BGM in USA. Approved for use on blueberries in UK
Insecticide	Chlorantraniliprole	Approved for use on blueberries but no record of testing against BGM
Insecticide	Indoxacarb	Approved for use on blueberries but no record of testing against BGM

- For **cultural control strategies**, the most promising approach appears to be covering the growing substrate to reduce the survival of pupae to adult emergence. This method prevents pupation occurring in the substrate and subjects larvae to predation and desiccation. Physically removing damaged plant growing tips containing larvae is a labour-intensive option but could be timed by monitoring adult populations in pheromone traps. The use of pheromone technology on a larger scale (mass trapping, attract and kill or mating disruption) should also be investigated.

- For **bioinsecticides**, **spinosad** is known to control BGM in the USA and is approved for use in the UK. **Azadirachtin** reduced blackberry leaf midge damage slightly on young raspberry growing shoots and is compatible with IPM strategies.

- **Insecticides** which the AHDB may also consider testing in the SCEPTREplus programme include **indoxacarb**, **chlorantraniliprole** and **cyantraniliprole**. All of these products are approved for UK blueberry crops.

- Trials with other IPM-compatible options such as attractants and repellents should be considered. However, because these compounds and application methods are still at the development stage, these approaches will require longer-term research outside of the SCEPTREplus programme.

Take home message(s)

- Use pheromone traps to monitor adult midge populations and apply insecticides once thresholds are reached (10 midges per trap per week). The most important generation to control is the first of the season. Adults are much easier to hit with sprays than the larval stages which are protected under bark or by leaf galls. Timing is key, and traps must be checked a minimum of twice per week, ideally Monday, Wednesday and Friday to achieve timely control applications.

Review

Introduction

Blueberry gall midge (*Dasineura oxycoccana* (Johnson 1899)) is a major, invasive pest on highbush blueberry in the UK and came originally from Canada and the USA (Collins et al., 2010). Its invasion and movement around the UK has been facilitated by the transport of infested material, generally from untreated nursery stock. While in the USA and Canada, blueberry gall midge (BGM) was historically known as cranberry tip worm. It is now apparent that there are two sub-species (one on cranberry and one on blueberry) which are attracted by different pheromones (as noted by AHDB SF 126 final year report (Cross, 2014)).

In the 8 years between 2010 and 2018 blueberry production in the UK increased 3-fold to 994 hectares of crop (Ridley et al., 2018). Due to the required acidity levels of the growing substrate, most production occurs within pots (76%), followed by soil grown (25%), and finally bags/troughs (1%). Ninety-six percent of blueberries grown were for the fresh market, 3% were grown as pick your own and 1% were grown for processing. In 2018, the highest percentage of insecticide applications to blueberries occurred in June and August (32% and 22% respectively). Insecticides targeting spotted wing drosophila (*Drosophila suzukii* Matsumura) accounted for 34% of all treatments applied, followed by 24% for aphids. The top 5 insecticide formulations (in descending order of use) included thiacloprid, lambda-cyhalothrin, spinosad, cyantraniliprole and chlorantraniliprole. Only four biological control agents were recorded as used; three entomopathogenic nematodes (*Heterorhabditis bacteriophora, Steinernema feltiae and S. kraussei*) to target vine weevil (*Otiorhyncus sulcatus*) and parasitic wasps for aphid control (species identity not provided).

The increasing production of blueberry over the past decade in the UK is likely to increase both the occurrence of BGM and frequency of damage. However, there has been very little research undertaken in the UK and IPM of this pest has not been investigated. With the upcoming loss of thiacloprid in 2021, blueberry growers will require strategies to suppress BGM damage while not disrupting IPM of other key pests. This report reviews the pest and potential control methods that could be employed in the UK.

Target description and life cycle

Adult midges are short-lived, and generally only survive a few days. Adult emergence and oviposition are temperature-dependent; the aspect/orientation of blueberry plantations may influence emergence and oviposition dates. Generally midges become a presence in the crop when temperatures exceed 15°C (Collins et al., 2010). A large percentage of blueberry is grown under protection in the UK (Ridley et al., 2018) and this accelerates the emergence of BGM, so that it occurs earlier in the season.

Female midges are between 2-3 mm in size and are larger than the males, which are generally 1.5-2.5 mm long (Figure 1). The females have long segmented antennae and long legs. The male midges have antennae which are almost equal in length to their body and feathered. The female is light orange and the male slightly lighter. They can be separated from other species by the venation of the wings. In pheromone monitoring traps, the male midges can usually be separated from other insects by the detachment of their wings and legs from the body as they try to free themselves from the glue. These are typically accompanied by small red /orange spots (Figure 2).

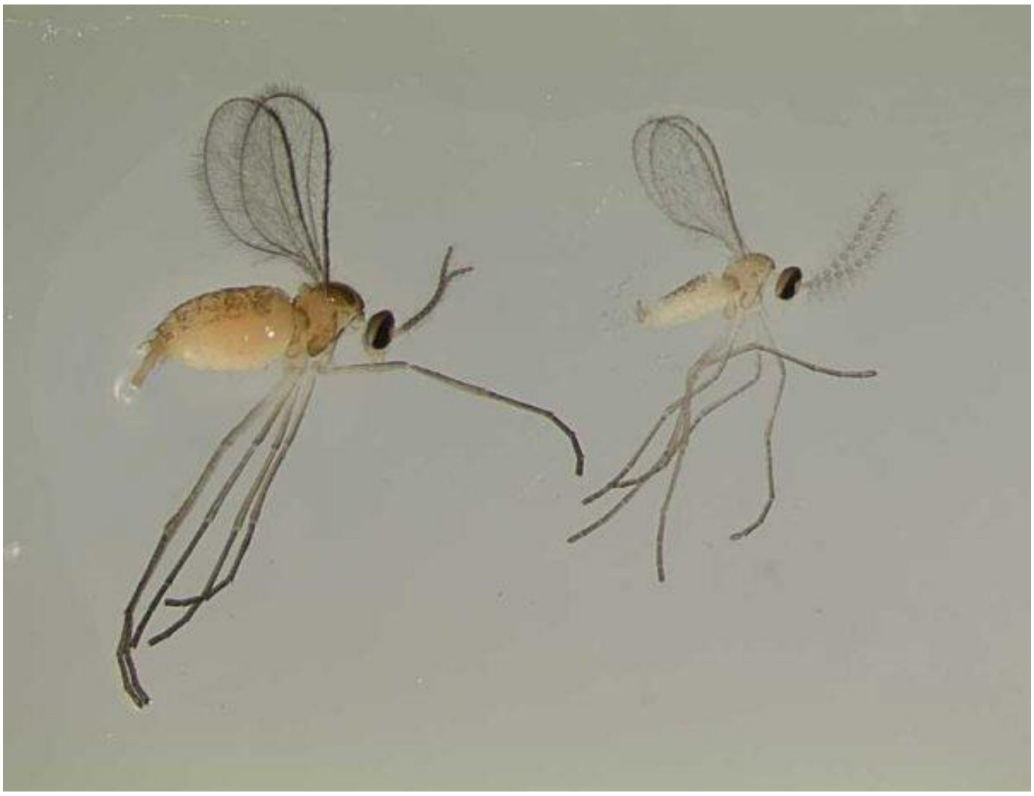

Figure 1: Female (left) and male (right) blueberry gall midge. Image credit: Florida Blueberry Growers Association.

Figure 2: Male midge caught in sticky glue in monitoring trap. Note the detachment of the legs from the body and orange haemoglobin spots characteristic of midge species. Image credit: NIAB EMR

Oviposition by BGM coincides with the occurrence of new shoot growth on the blueberry bush in spring (Buckshaw and Henderson, 2008), with gravid females laying eggs in the tip of young growing shoots. The female lays several eggs per bud and these are roughly 0.25 mm long. The eggs hatch into larvae after approximately 3 days and pass through three larval instars, the first being almost transparent, the second white and the third orange in colour (Figure 3) (Collins and Drummond, 2017). The time from egg hatch to third instar larva is 10-14 days depending on temperature and during this time the larvae feed on leaf tissue, damaging the developing leaves. The third instar larva leaves the leaf, drops to the ground, and enters the soil to pupate. They pupate within the top 10 mm of the substrate. Pupation takes between 5-10 days and once the adult emerges it lives for only 1-2 days.

Figure 3: Blueberry gall midge larvae. The newly-hatched larvae are transparent in colour. They then turn white as a second instar larva (on right of image) before turning orange as a third and final instar larva (left of image). Image taken from AHDB.

The first generation of BGM adults are reported to emerge in April/May in the UK, with the precise timing being dependent on spring temperatures. In the UK, 3-4 generations occur each year. As the eggs and larvae are protected within the leaves of the shoots, the adult stage is the most vulnerable to plant protection products. The final generation overwinters as pupae in the soil/substrate prior to emerging in the following spring.

Symptoms

The damage inflicted on the plant is caused by the larvae feeding within the shoot tip. This results in characteristic blackening of the leaf tips and distortion and twisting of the growing shoot (Figure 4). Damage to the leaves can result in the abortion of buds, which can result in fewer buds developing, impacting the following year's growth. It can also promote shoot branching. For some varieties shoot branching can be a desirable trait as it can result in an increase in fruiting in the following season. However, branching caused by the midge is not systematic and is more likely to result in weaker crops.

Figure 4: Blackened tips caused by the feeding of the larvae (left) and the distortion of the leaves within shoots (right). Images from AHDB.

Cultural control and management

Physical barriers

Physical barriers may provide some control of BGM but this is dependent on the growing substrate. As BGM pupate in the ground (or sometimes in leaf/plant debris on the ground surface), preventing them from reaching the soil could prevent pupation. Applying fine mesh sheeting (such as MyPex® Don & Low Ltd.) over the surface of the growing area could prevent larvae pupating in the soil, leaving them exposed to desiccation, parasitism, and/or predation. In addition, the sheeting is an easier surface to brush to remove plant debris, improving crop hygiene. Sheeting should be of sufficient quality with a fine weave, allowing water to pass through, but not the larvae or emerging adults. Nylon cloth of 100 gsm has been used effectively. The cloth should cover the entire growing area and be placed and pegged down with overlapping sheets before the polytunnel supports are put into the ground. Gall midge larvae are able to vault (jump) several centimetres (Roubos, 2009), so covering the rows only and not the alleys is likely to be only partially effective. One issue associated with this method is an increase in water runoff at sites that are on hillsides and so it may not be appropriate for all sites.

Research carried out in Korea found that covering the surface of the substrate of potted blueberries with Perlite (an amorphous volcanic glass) significantly reduced the emergence of BGM adults which was attributed to preventing the larvae from reaching the soil to pupate (Kang et al., 2012). The implementation of this method could be laborious and time consuming for large areas of potted blueberry but may be more applicable in smaller plantations.

It is noteworthy that weeds are also problematic in blueberry and the use of substrate coverings could also help to suppress weeds and reduce herbicide applications.

Crop hygiene

BGM larvae damage the growing shoots of blueberry plants, often resulting in the abortion of infested growing shoots. As it unlikely that infested shoots will produce any viable plant material, agronomists may advise growers to pinch out the infested shoots to remove the BGM larvae. However, this is extremely labour-intensive, and timing is critical. As the larvae are within the growing shoots for up to 14 days, the infested shoots need to be removed as soon as distortion is detected. If growers wait until the blackening of shoot tips begins then it is likely that the larvae have already exited the leaf to pupate. In theory, this method could also be timed by monitoring adult trap catches but this has not yet been investigated.

Insect development models

Midge species have short adult lifespans (a few days) and oviposition is thought to occur within a few days post-emergence for each generation. Insect development models for midge species focus on prediction of the time of oviposition by the overwintered populations based on temperature. Prediction models forecast dates of oviposition of the first (overwintered) generation and can assist with improved timing of pheromone trap monitoring and spraying. Emergence of saddle gall midge, *Haplodiplosis marginata* von Roser, a pest attacking cereal crops, is, on average, predicted by models to within 4 days of the real-time event, but can be more accurately predicted by degree-days (DD) after rain events (rainfall followed by 512DD above

0°C) (Rowley et al., 2017). Raspberry cane midge, *Resseliella theobaldi* Barnes, oviposition can be predicted with a model incorporating soil temperature and crop orientation with egg laying predicted to occur 339DD >4°C from 1st March. If the area is on a slope, the model includes adjustments for the predicted date of oviposition based on the aspect of the slope. For south-facing slopes the predicted date is advanced by 5.2 days, and it is delayed by 6.3 days for north-facing slopes (Gordon et al., 1989).

While some data have been collected about the relationship between BGM development and temperature (Roubos and Liburd, 2010), only pupation data have been obtained. For models or DD forecasts to be used for BGM, more work is needed to include adult emergence and oviposition and the environmental conditions associated with these behaviours. A model could provide a warning system for growers, enabling them to prepare for pest incidence during the season and reducing the unpredictability of the pest's appearance.

Monitoring and trapping

Pheromone trapping

The efficacy of a species-specific pheromone trap was investigated within AHDB project SF 126 and a blend of compounds was identified that is highly attractive to the male midge (Cross, 2014). Pheromone lures should be used in conjunction with red delta traps and deployed during early spring to ensure they are in place prior to first generation emergence. Traps should be in place prior to temperatures reaching 15°C when the pest is known to become active. Traps have been found to catch significantly more midges at a height of 0.5 m than traps at 1 or 2 m. As temperatures can vary between locations (i.e. on the edge of a covered tunnel verses at the centre of a row) traps should be deployed in different niches to take into account any possible differences in emergence between locations.

Sex pheromone monitoring traps can be deployed to provide growers with a means of monitoring pest population levels. Monitoring traps also give a good indication of midge phenology. The threshold for BGM is 10 midges per week and traps should be checked frequently (every 3 days is ideal) due to the short life span of the flying adults. Once action thresholds are reached, growers should apply plant protection products within 24 hours to control the adult midges, ideally before they have the chance to mate and oviposit. Many growers successfully use this technique to time their insecticide applications correctly, particularly for the first generation of the season. Adequate control of the first generation is paramount as it greatly reduces the pest pressure later in the season when sprays may damage biocontrol agents for other pests (e.g. Thrips). As adult emergence is temperature dependent and varies between locations, growers should deploy traps in each crop rather than rely on results from one monitoring trap to activate thresholds.

It should be noted that *Dasineura oxycoccana* infesting cranberry in the USA and Canada is attracted by different pheromones and so a UK-specific lure should be purchased.

Emergence trapping

Prior to identification of the pheromone, emergence trapping was used to time the emergence of the first generation of BGM from the soil/substrate. Extensive emergence trapping was conducted by C. Roubos who concluded that an inverted white bucket caught the highest number of BGM compared with other structures tested (Roubos, 2009). The bucket has the base removed and replaced with an adhesive sheet, which is permeable to light to attract the midges upwards. The lip of the bucket is slightly buried into the soil surface to prevent midges escaping or the bucket being knocked over. Buckets should be deployed <0.5 m from blueberries in early spring and the adhesive sheet checked twice a week to monitor adult emergence. There are limitations with the method, which are not a factor with pheromone trapping. For example, as pheromone traps attract the midge to a specific location, fewer traps are required; a degree of luck is required for the bucket trap location to be situated above substrate containing midges. For this reason, pheromone traps should be used rather than emergence trapping where possible.

Natural predators and biological substances

Currently there are few options for biological substances known to be capable of controlling midge pests in blueberry and many of the options below are taken from other soft-fruit crops, for other pests or from other countries. Products that are available are shown in Table 2, with effects on midges, if known.

Entomopathogenic fungi

In AHDB project SF 102, Naturalis-L (*Beauveria bassiana* (Balsamo)) was found to be ineffective at reducing the development of blackberry leaf midge pupae in the soil (laboratory experiment), and foliar applications of Naturalis-L onto the crop did not reduce the number of infested leaf tips (field experiment) (Bennison, 2011). As typically entomopathogenic fungi (EPFs) are slow to cause death of the target organism, they generally prove more effective against longer living pests. However, as the overwintering midge pupae that result in the first generation each year are present in the substrate for a few months prior to emergence, EPFs could be effective if applied to the soil or substrate at the end of the growing season. The performance of EPFs can be temperature- and humidity-dependent and so this timing of application may be inappropriate for some strains.

Metarhizium brunneum (Petch) is a biocontrol agent which has been found to infect a wide range of insect hosts. In laboratory-based trials dipping pear midge larvae, *Contarinia pyrivora* (Riley), in a solution of *M. brunneum* has recently been reported to result in mortality of the midge, as has applying a fungal solution to soil inoculated with midge pupae (Steinwender et al., 2020). A reduction in survival was shown, from 80% in the untreated control to 10% after 12 days when larvae were treated with *M. brunneum*, and 63% in the control to 24% in the treated soil after 35 days. *M. brunneum* has yet to be tested on midge species under field conditions but the use of *M. brunneum*, *M. anisopliae* and *B. bassiana* (Naturalis-L) are common for many other horticultural pests. In addition, there appear to be no negative effects on predators that come into contact with these EPFs through consumption of inoculated prey or general contact (Ríos-Moreno et al., 2018, Azevedo et al., 2017, Canassa et al., 2019). Some commercialised EPFs are only approved for use under permanent protection, including Naturalis-L. If advances are to be made in using these products, the scope of application needs to be increased and supporting evidence is needed.

Nematodes

Several species of nematode are approved for use in blueberry crops. The nematode species *Heterorhabditis bacteriophora*, *Steinernema carpocapsoe* and *S. feltiae* are typically applied to manage vine weevil but have, to date, not been tested on BGM. Laboratory studies showed that drenching coir with *S. kraussei* (Nemasys® L) controlled blackberry leaf midge larvae, but when this species was tested in the field with a soil-grown raspberry crop, no effect on midge infestation was observed (Wenneker, 2008). Laboratory-based investigations could be pursued to determine the efficacy of these species on BGM. If effective, these nematodes could be applied via irrigation lines, resulting in a control option requiring a low level of labour input, as suggested for vine weevil control (SF 158). This method of delivery could also be used to apply EPFs, but the viability of the products would need to be confirmed.

Both EPFs and EPNs can be used to reduce vine weevil populations, however, growers have typically relied on thiacloprid to do so. With the loss of this active it is expected that more growers will make the transition to these products and so control of both BGM and vine weevil could be combined.

Parasitic wasps

Eulophid wasps are active in parasitizing BGM in the USA (Prodorutti et al., 2007, Sampson et al., 2002, Hahn, 2011), but to date there are no records of these species in the UK and they are not commercially available for release. Surveys of native UK parasitoids could be performed through the collection of infested shoot tips and identifying any emerging wasps. This would be beneficial as future commercialisation of the most common species could result in a higher rate of parasitism and pest control. The identification of parasitoid wasps requires expert taxonomic skills and a biocontrol company would be needed to develop the product. It is unlikely that parasitism would cease the damage to shoots by the first generation, but numbers could be suppressed over subsequent generations in combination with other Integrated Pest Management tools.

Predatory mites

Laboratory experiments executed as part of SF 102 showed that the predatory mites *Neoseiulus cucumeris* and *Amblyseius andersoni* would feed on the eggs and larvae of blackberry leaf midge. Field trials also indicated that *N. cucumeris* could reduce infestation by the midge but to date these predators have not been investigated in relation to BGM. Application of predatory mites would need to be as a preventive control option with established populations in the crop prior to the emergence of the first generation, due to the limited egg-pupa development time interval for BGM. In addition, some predatory mites require warm temperatures (above 20°C for *N. cucumeris*) to become active and, as BGM emerges in the spring, it may be too cool for them to become an effective biocontrol agent.

Orius sp.

Field observations and laboratory experiments showed that *Orius laevigatus* (Fieber) will feed on blackberry leaf midge larvae (SF 102). Subsequent field experiments assessing establishment of *O. laevigatus* and predation on midge larvae in the field could not confirm establishment and subsequent control. *Orius* may play a role in predation of BGM during the summer months when it is more active, but it is unlikely to make significant impact on midge populations. Simple laboratory trials could estimate predation rates for *Orius* on BGM eggs and larvae.

Hoverflies and Lacewings

Hoverflies are receiving more attention concerning the ecosystem services they deliver due to their voracious predation and pollination of commercial crops. There are currently no reports on the interaction of hoverflies with midge species but they could be an efficient spring predator, with larvae being active at 15°C (Dib et al., 2011). Although native hoverflies will be present in the field, populations in cultivated crops can be supplemented with commercially purchased hoverflies. The common green lacewing *Chrysoperla carnea* Stephens, is also known to be a common generalist predator of many pest insects but there is also no evidence for the control of midge species. It would be beneficial for growers to know if these predators will target BGM, as populations could be encouraged with floral resources or semiochemical attractants. As with *Orius*, laboratory-based bioassays could be used to investigate this.

Azadirachtin A

Azadirachtin A significantly reduces the number of raspberry cane midge larvae (67-82% reduction compared to an untreated control) in raspberry splits (Mohamedova, 2017) in field trials in Bulgaria. Azadirachtin also reduced blackberry leaf midge damage to young leaves after two applications within SP 38, but did not reduce larval counts. As blackberry leaf midge and BGM have similar oviposition habits (i.e. females laying eggs on shoot tips and the larvae being protected within the leaf), it is likely to have a similar effect on them.

Plant extracts

Plant extracts can have insecticidal or deterrent effects on pest insects, however registration of these products appears to limit commercialisation success (Isman, 2006). Annonaceas plant extracts have a natural abundance of ‘acetogenins’, a classification of natural insecticidal products, which can be extracted from various parts of the plant (Isman and Seffrin, 2014). Paw paw, *Asimina triloba* L., extracts have antimicrobial properties and were as effective as spinosad in causing BGM mortality in laboratory bioassays (Sampson et al., 2003). Acetogenin-based products are being used to target a range of pests but are toxic to some predatory mites including *Neoseiulus californicus* and *Phytoseiulus macropilis* (Miotto et al., 2020) which could disrupt biocontrol of other pests.

Semiochemical based control

Semiochemicals

Attract-and-kill formulations have been developed for control of raspberry cane midge and blackberry leaf midge which combine sex pheromones, attractive plant volatiles and a pyrethriod killing agent (Jay and Cross, 2016). A commercial product was not developed for commercial reasons, including the cost associated with the pheromone lure. As the sex pheromone for BGM has been identified and commercialized, as discussed in the monitoring and trapping section above, there is scope to expand the use of semiochemical control for this pest. For BGM it is a female sex pheromone, attracting males into the trap. The efficacy of the lure could be improved by combining or including volatiles that are also attractive to females, which has been done for pests such as the European Tarnished Plant Bug *Lygus rugulipennis* Poppius (SF 156). This could include blueberry plant volatiles, but laboratory-based bioassays would be needed to identify promising compounds.

Russell IPM are developing an attract and kill system for use against midge species in soft-fruit tunnels. This consists of a very long and thin (>100 m x 0.2 m), sticky trap which can either be impregnated with the target midge species pheromone or individual lures can be attached. The sticky trap, known as a roller trap or Optiroll, is applied to the base of the tunnel structure in the leg rows and acts as a mass trap. The benefit of using individual pheromone lures is they can be replaced through the season to target numerous generations. This approach could be extremely time consuming, depending on the area of blueberry grown and area of sticky trap deployed. As with many midge species, targeting the first generation each year is a priority and so deploying the pheromone impregnated roller trap may be sufficient to suppress BGM. To ensure success this would need to be deployed early in the season.

Mating disruption could be investigated for BGM as the pheromone has already been identified. This is a system whereby mating is reduced by flooding an area with synthetic pheromone, which prevents males from being able to locate females and subsequent mating. This can either be via false trail following, whereby the male follows a trail to a pheromone dispenser, or through deploying high quantities of pheromone, which damage the male volatile receptors (McGhee et al., 2014). Mating disruption is used successfully in tree fruit to suppress codling moth *Cydia pomonella* Linnaeus, populations (see Knight et al. (2019) for more details). Devices impregnated with the sex pheromone can be deployed at high densities within a crop and the area becomes so saturated with pheromone that the males are unable to locate the females. Alternatively, aerosol 'puffers' can be programmed to release the pheromone at defined times, typically to coincide with the natural pheromone calling of the codling moth females which also disrupt the males locating the females. Neither approach have been investigated for any midge species so there is no evidence to support or dispel this suggestion.

<u>Predator-attracting and repellent semiochemicals</u>
Previous work (unpublished) carried out at NIAB EMR has shown that specific volatile organic compounds (VOCs) significantly reduce numbers of *Dasineura pyri* (pear leaf midge) when applied as prototype sprayable formulations. Although the cause of the reduction in midge numbers was not established, it is suspected that the VOCs are attracting and arresting predators such as hoverflies whose larvae are then feeding on the midge larvae, and/or acting as repellents to the adult midges reducing oviposition.

Attractants can also be used to encourage beneficial organisms into the crop. In laboratory studies, conducted by Verheggen et al. (2008), the presence of a synthetic aphid pheromone in cages containing prey, resulted in an increase in hoverfly foraging behaviour and an increase in oviposition by female hoverflies. In AHDB funded project TF 218 (2016), several volatiles and blends were successful in attracting hoverflies, and other beneficials, including common green lacewings, *Chrysoperla carnea* Stephens, into cropping areas. Methyl salicylate identified from a range of plants which are under attack by herbivores has been used to attract hoverflies and lacewings into apple orchards in TF 218 and was also found effective in attracting lacewings (James, 2003), ladybirds and Orius (James, 2005) into hop yards. Russell IPM's MagiPal lure, is commercially available to attract native predators into cropping areas, although the impact many of these beneficials have on BGM is currently unknown and requires verification.

Table 2: The list of currently available biological products for blueberry crops in the UK.

Products	Active substance	Max/recommended individual dose	Total doses	Crop	Method of application	Crop stage	Final Use Date	Known effects on midges
Dipel DF, Lepinox Plus	*Bacillus thuringiensis* var. kurstaki	0.75 kg/ha	8 applications	Blueberry protected and unprotected	Ground spray	Field application	31 October 2022	Minimal effect on other midge species
Naturalis-L, Botanigard WP	*Beauveria bassiana*	0.6 kg/ha	5	All edible crops under permanent protection	Spray application	Before leaves begin to discolour	31 October 2022	Ineffective on blackberry leaf midge
Met52 granular bioinsecticide	*Metarhizium anisopliae*	500 g/m³	1	Blueberry protected and unprotected	Substrate incorporation	Pre-planting	31 October 2023	Unknown but closely related *M. brunneum* is effective on pear midge
Entonem Koppert	*Steinernema feltiae*	500,000 nematodes/ m² (for thrips pupae)	UL	Blueberry protected and unprotected	Substrate drench or foliar spray	Field application	NA	Unknown
Thripex	*Neoseiulus cucumeris*	50 mites/ m²	UL	Blueberry protected and unprotected	Deployed on plants manually	Field application	NA	Predation of blackberry leaf midge in lab and field*

Orius-System, Biobest	*Orius leavigatue*	3-5 bugs/m^2 (for curative control of thrips	3 releases recommended	Protected blueberry	Deployed on plants manually	Field application	NA	Predation of blackberry leaf midge larvae in lab*

*Results from AHDB SF102-Biology and integrated control of blackberry leaf midge on blackberry and raspberry (Bennison, 2011).

UL- unlimited

Conventional Insecticides

A number of conventional insecticides are registered for use in protected and outdoor blueberry production in the UK (listed in Table 3), some of which have been trialled against BGM. The predominant insecticide used to control midge species in the UK is thiacloprid. However, in the EU, approval for thiacloprid expired on 30/04/2020. The date for expiry of approval for these substances is longer in the UK (see Table 3 for details), but there is an obvious need to find alternative control measures in the short to medium term. Lambda-cyhalothrin has been found to vary in efficacy depending on the blueberry variety, which may relate to the phenology of both crop and midge. For example on 'Ozark Blue' treated with lambda-cyhalothrin, there was a reduction in both larval counts and damage to shoot tips up to 14 days after application, but for 'Spartan' only larval counts were reduced (project SF 126; (Cross, 2014).

Movento (spirotetramat) is widely used in The Netherlands to control midges in raspberry and provided good control of blackberry leaf midge in SCEPTREplus project SP 38 in 2020. It has approval until 2024 in the EU and there is a current EAMU for Movento to control blackcurrant midge (*Dasineura tetensi*) and aphid in blueberry, along with gooseberry, black-, red- and white-currant. However, this has a 365-day harvest interval. Currently Batavia, also spirotetramat, isapproved for use on blueberry and other soft fruit in the UK, and has a lower active ingredient concentration than Movento (100g/L verses 150g/L). There are concerns about the application of spirotetramat in relation to flowering time, as it should not be applied prior to petal fall, and the long-term impact it has on pollinators is unknown. In addition, there has been some evidence to show it reduces adult longevity in solitary bees (Sgolastra et al., 2015).

In SP 38, FLiPPER (fatty-acid) showed a 1.5 fold reduction in blackberry leaf midge damage to young leaves but this was not a statistically significant reduction compared with the untreated control. Both cyantraniliprole and spinosad have been found to reduce BGM damage in the USA (Collins and Drummond, 2016, Collins and Drummond, 2018). As BGM targets the growing shoots, it occurs in the crop earlier than the soft-fruit pest, Spotted Wing Drosophila (SWD), which targets the developing fruit. Blueberry growers in the UK stated that in 2016, 44% of insecticide applications were applied to target SWD. As cyantraniliprole and spinosad are the two more effective products against SWD, growers may be reluctant to use their limited applications to target BGM, and risk a lack of products later in the season. Both products should still be considered for trialling against BGM as blueberry growers do have other options available (such as netting) to control SWD.

Chlorantraniliprole and indoxacarb are approved for use in outdoor blueberry in the UK, but there is no evidence to show their effectiveness against BGM. After a discussion with a blueberry agronomist there seems to be no reason why these products should not be tested for efficacy against BGM.

Table 3: List of insecticide products available for blueberry crops in the UK.

Active Substance	Max individual dose	Total dose/Max application	Registration expiry in UK	Products	Comments	Known effects on midge spp.
Chlorantraniliprole	150 ml/ha	2 per year	26/10/2021	Coragen	Outdoor	Unknown
Cyantraniliprole	900 ml/ha	2 per year	30/11/2020	Exirel 10 SE	Protected and outdoor	Ineffective against blackberry leaf midge** but reduced BGM damage in USA
Fatty acids C7-C20	10 L/ha	8 per year	28/02/2023	FLiPPER	Protected and outdoor	Minimal reduction in blackberry leaf midge larvae**
Indoxacarb	250 g/ha 12.5 g/100L 170 g/ha	3 per year 6 per year 1 per year	30/04/2023	Steward Steward Explicit	Outdoor Protected Protected and outdoor	Unknown
Lambda-cyhalothrin	100 ml/ha 200 ml/ha	2 per year 400 ml/ha/year	09/09/2099	Hallmark with Zeon Technology Markate 50	Outdoor Outdoor	Reduction in BGM damage and larvae***
Pyrethrin	6 L/ha	2 per year	28/02/2023	Spruzit	Outdoor	Reduction in BGM larvae***
Spinosad	200 ml/ha	2 per year	31/10/2023	Tracer	Protected and outdoor	Used to control BGM in the USA
Spirotetramat	750 ml/ha 500 ml/ha	2 per year 1 per year	31/10/2026	Batavia Movento	Outdoor Outdoor. Currently 1 year harvest interval on EAMU	Good control of leaf midge spp.*** Good control given of blackberry leaf midge**

Thiacloprid	250 ml/ha	750 ml/ha/year	03/02/2021	Agrovista Reggae/Calypso	Protected and outdoor	Used to target BGM and other midge species effectively**,***

**Results from SP38 - Control of raspberry cane midge and blackberry leaf midge (efficacy trials)
*** Results from AHDB SF 126 - Blueberry gall midge: sex pheromone monitoring and control with insecticides

Current overseas control practices and opportunities for their application in the UK

Products used outside of the UK that may be suitable PPPs are shown in Table 4.

In the USA, blueberry production suffers greatly from BGM, which is also known as blueberry tip-midge or -worm. It should not be confused with cranberry tipworm. Whilst listed as the same species, it has become apparent over the past few years that these are two different organisms (one infesting cranberry, the other blueberry) which respond to different species-specific pheromones (Fitzpatrick et al., 2013, Fitzpatrick et al., 2018). These two species, whilst still both listed as *Dasineura oxycoccana* do not interbreed but it is assumed they respond to PPP's in a similar manner due to their identical life cycles and phenology.

Flupyradifurone (Class: Butenolides- Bayer CropScience´s own chemical sub-group) has been trialled against BGM in the USA. Flupyradifurone should kill a range of midge larvae and has performed well in some trials. However, in other trials, initial results for BGM do not look promising and further details will be released in 2021 (C. Roubos, pers. comm.). Flupyradifurone is not yet registered for use in the UK, and only has limited approval in the EU (for use on hops and lettuce in eight countries) indicating that approval in the UK is unlikely.

In the USA, OMRI (Organic Materials Review Institute) certified blueberry production appears to rely on spinosad (Entrust/ Success) for control of BGM (C. Roubos, pers. comm.). Reductions in damage were found up to 19 days post application (Collins and Drummond, 2018). However, as in the UK, spinosad is extremely effective against SWD and so may be reserved for application later in the season. Organic blueberry production in the USA also relies on various rates of azadirachtin (neem), pyrethrins, and products based on garlic juice. Azadirachtin has been trialled against blackberry leaf curling midge on raspberry in SP 38, resulting in a reduction of damage to younger leaves but not significantly reducing the number of larvae. In trials by Mohamedova (2017) on raspberry cane midge, azadirachtin reduced larval numbers in splits up to 12 days post application compared to a control. This active is currently approved in the UK for use in some permanent protected vegetables for the control of whitefly.

Spinetoram is known to be effective against adult midges but does not have any residual effect and so timing of application is critical to its efficacy (Liburd and Phillips, 2019). When combined with the pheromone trap action thresholds, this should not be an issue.

The most IPM compatible product currently used in the USA is novaluron. It is an insect growth regulator and considered to have low risk to the environment and non-targets as it only affects larval stages and has no effect on adults. It reduces numbers of BGM up to 1 week post-application before efficacy declines (Collins and Drummond, 2016). However, whilst the product was previously registered for use in four EU countries, the manufacturer withdrew its application for approval in 2012 and it is no longer available within the EU.

Acetamiprid (in several formulations) reduced damage to blueberry shoots for up to 18 days post-spray in lowbush blueberry (Collins and Drummond, 2018, Collins and Drummond, 2016). It is not currently approved for use in blueberry within the UK. Gazelle (an acetamiprid formulation) is approved for use in some UK soft fruit but with a 12-month harvest interval and crop destruct on treated fruit, indicating it is not appropriate for BGM in the UK.

Phosmet was ineffective against BGM in US studies (Collins and Drummond, 2013, Collins and Drummond, 2014) and cyantraniliprole gave control up to 8 days post application, but efficacy had diminished after 21 days (Collins and Drummond, 2016). Zeta-cypermethrin gave good control of BGM in US trials, reducing damage up to 25 days post-application (Collins and Drummond, 2018). Cypermethrin products are broad spectrum and not IPM compatible.

Table 4: Alternative products used outside of UK to target blueberry gall midge on blueberry and other soft fruit. Note that maximum doses vary between states.

Products	Active Substance	Max individual dose (a.i.)	Total dose per year	Restrictions	Target pest	Country	Comments
Assail 30 SG	acetamiprid	0.095 kg/ha	0.56 kg/ha	PHI = 1	Various including *D. oxycoccana*	USA	Effective against *D. oxycoccana*[1,2]
Exirel SE	cyantraniliprole	0.15 kg/ha	0.44 kg/ha	PHI= 3	Various including *D. oxycoccana*	USA	Reduced BGM damage up to 8 days post application[2,3]
Delegate WG, Radiant SC	spinetoram	0.05 kg/ha	3 applications	PHI = 1	*Choristoneura rosaceana* (oblique banded leaf roller)	USA	Effective against *D. oxycoccana*[2]
Rimon 0.83EC	novaluron	880 ml/ha product	2.6 l/ha product		Various including *D. oxycoccan*	USA	Insect growth regulator. Considered low risk to environment and non-targets. IPM compatible[3]

Sivanto Prime	flupyradifurone	100 g/m high canopy	2 applications	PHI = 3	Sucking pests	EU/USA	Possible reports of phytotoxicity in raspberry (not confirmed). Limited efficacy on BGM. Further trials being conducted in USA
MUSTANG® MAXX	zeta-cypermethrin	0.03 kg/ha	6 applications	PHI = 1	Various	USA	Effective against *D. oxycoccana*[1]

[1](Collins and Drummond, 2018)
[2](Liburd and Phillips, 2019)
[3](Collins and Drummond, 2016)
PHI = post-harvest interval

Acknowledgements

Many thanks to C. Roubos for the correspondence regarding BGM control in the USA, G. Moore for the insight into UK blueberry production, Glen Powell for manuscript review. Thank you also to the AHDB for funding and supporting this project and for the financial and in-kind contributions from the crop protection manufacturers and distributors involved with the SCEPTREplus programme.

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