SCEPTREPLUS

Final Report

Trial code:	SP 58
Title:	A review of control measures for leafhopper in outdoor and protected herbs
Crop	Outdoor and protected herbs
Target	Chrysanthemum or 'sage' leafhopper (*Eupteryx melissae*)
Lead researcher:	Jude Bennison
Organisation:	ADAS Boxworth, Battlegate Road, Boxworth, Cambridge, CB23 4NN
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Report authors:	Jude Bennison and Peter Seymour
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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.

2.12.2020
Date

J A Bennison Seymour

Summary

Introduction

Leafhoppers are a persistent problem for herb growers, affecting many species in both outdoor and protected crops including basil, mint, oregano, rosemary, sage and thyme. Feeding damage causes pale leaf flecks and bleaching. This can lead to reduced marketability or crop rejections of high value herb crops for both fresh culinary use or for processing or drying, due to stringent retail quality standards requiring produce with no or very little damage or pest presence.

Methods

A focused review was completed on key current knowledge on presently-used and potential future control measures for leafhoppers on herbs. The review included a literature search and discussions with selected growers, consultants, agronomists, biological control suppliers and plant protection product manufacturers.

Results

Growers of protected herbs are using biological control agents for other pests within Integrated Pest Management (IPM) programmes, so any control method for leafhoppers needs to be IPM-compatible. The main leafhopper species infesting herbs is the chrysanthemum or 'sage' leafhopper, *Eupteryx melissae* although other species can occur. A leafhopper egg parasitoid, *Anagrus atomus* can occur naturally in herbs but is no longer commercially available. Growers of perennial outdoor herbs rely on cultural and chemical control of leafhoppers but there are very few current options due to limited product approvals and EAMUs and to imminent further withdrawal of actives. In addition, the number of applications permitted for many of the available plant protection products is limited. Effective control with contact acting materials is difficult due to the mobility of adults and to most of the nymphs living on the leaf undersides. Growers need additional control methods to improve control and to reduce current losses. New potential control methods for leafhoppers were identified. Potential cultural control methods included evaluation of different coloured sticky traps for 'mass monitoring' of adults in protected herbs and use of suction techniques, flaming and refective mulches in field-grown herbs. Potential biological control agents include lacewing larvae, *Macrolophus pygmaeus, Orius* spp and the entomopathogenic nematode *Steinernema feltiae*. Potential botanical biopesticides were also identified, including azadirachtin and some other oil-based products. Three novel botanical biopesticides and two novel conventional plant protection products were selected for an efficacy trial on potted sage. The selected treatments are IPM-compatible and have a clear route to market if not already approved in the UK..

Conclusions

Contact with growers

- In protected herbs, growers used a combination of one cultural control method, four IPM compatible plant protection products and careful timing of three non IPM compatible plant protection products.
- In outdoor perennial herbs, growers used two cultural control methods but otherwise relied on the use of four non IPM compatible plant protection products.

Literature searching

- The literature search identified various addition potential approaches for leafhopper control (not necessarily *E. melissae*), including with five cultural control methods, five biological control agents, four biopesticides and six conventional plant protection products.

Take home message:

New potential control methods for leafhoppers on herbs were identified and some of these will be tested in an efficacy trial during 2020.

Methods

Objective: Review control measures for leafhopper in outdoor and protected herb crops

1. Discussions with key industry representatives

Growers of outdoor and protected herbs with a history of leafhopper problems and who were willing to take part in the review were g contacted and current control measures, problems and grower needs were discussed. Willing consultants, agronomists, biological control suppliers and plant protection manufacturers were contacted to gain additional information on leafhopper management. Plant protection manufacturers and biological control suppliers were also be asked if they had any novel products with a clear route to market that could be considered as candidate treatments for efficacy trials.

2. Complete a focused review of peer reviewed scientific and relevant 'grey' literature on control of leafhopper on herbs

A focused peer reviewed literature search was completed using Web of Science and Google Scholar. The search included 'grey' literature such as conference proceedings and research reports relating to control of leafhoppers on herbs using conventional plant protection products, biopesticides, biological and cultural control methods. Brief details of published information on the life cycle of 'sage' leafhopper was also included as this information is critical to planning effective control measures.

3. Summarise key relevant knowledge

Using information from 1.1 and 1.2, key knowledge on current and potential future control methods was summarised in a focused, concise report.

Results

Discussions with key industry representatives

Herb species affected and leafhopper species

Growers and agronomists confirmed that leafhoppers are a major problem on both outdoor and protected herbs, on a range of species including basil, lavender, mint, oregano, rosemary, sage and thyme. A photograph of the 'sage' leafhopper, *Eupteryx melissae* was sent to growers and other industry members contacted and this helped them to confirm this to be the main species damaging herbs. One sample of *E. melissae* was sent to us for confirmation of species.

Biological control and IPM in protected herbs

Biological control

Growers of protected herbs use biological control agents for other pests within Integrated Pest Management (IPM) programmes and need any control measures for leafhopper to be IPM-compatible. One grower had tried the parasitoid *Anagrus atomus* which is known to parasitise the eggs of 'sage' leafhopper' (Bennison, 2001a, b) but this biological control agent is no longer commercially available. The same grower uses lacewing larvae for control of aphids and has not noticed any benefit in control of leafhoppers.

Cultural control
Two growers use sticky traps for 'mass monitoring' of leafhopper adults and consider that red traps are more effective than blue or yellow traps.

Plant protection products
IPM-compatible plant protection products used for leafhopper control include:

- Fatty acids (Flipper: EAMU for use on outdoor and protected herbs for control of aphids, thrips and spider mites), reported by growers to be ineffective against leafhoppers. Flipper is contact in action.
- Maltodextrin (Majestik: Label recommendation for use on all protected and outdoor crops for control of spider mite and whitefly). Majestik is contact in action.
- SB Plant Invigorator, reported by growers to be effective if applied weekly. This product is not approved as a pesticide. It has a physical mode of action. Contact in action.
- Pyrethrins (Pyrethrum 5EC), reported by growers to give useful control. Label recommendation for use on all edible and non-edible plants for control of aphids, caterpillars and whiteflies. Contact in action.

Other, less IPM-compatible plant protection products used for leafhopper control include:

- Acetamiprid (Gazelle SG: EAMU for use against aphids on outdoor and protected herbs). Reported to be one of the more effective products, particularly against low numbers of leafhoppers, but limited to two applications per crop. Gazelle SG has systemic activity and should give quick knockdown.
- Thiacloprid (Calypso: EAMU for use against aphids on protected herbs). As for Gazelle SG, Calypso has systemic activity and is reported to be one of the more effective products but is limited to two applications per crop. Its 14-day harvest interval limits its use to early in the production cycle. The approval for thiacloprid will be withdrawn and growers have until 3 February 2021 to use up existing stocks.
- Spirotetramat (Movento: EAMU for use against aphids and whiteflies on outdoor and protected herbs). Movento has strong systemic activity but does not give a quick knockdown. It is reported by growers to be one of the more effective products but is limited to two applications per crop.

Control in outdoor perennial herbs

Cultural control
One grower reported use of flaming as a cultural control method for leafhoppers on mint following the first cut, after which the mint regenerates. Another grower who keeps outdoor sage stock plants aims to cut these back before going into winter and avoids propagating from any infested stock.

Plant protection products
Growers of outdoor perennial herbs reported use of Gazelle SG, Movento and also the pyrethroid products deltamethrin (Decis Protech) and lambda-cyhalothrin (Hallmark

Zeon), both of which have EAMUs for control of various pests other than leafhoppers on outdoor herbs. Pyrethroids should give quick knockdown but are contact in action; thus targeting any mobile adults and nymphs on leaf undersides will be difficult. Pyrethroids do not have a maximum number of applications per crop but are not compatible with IPM programmes.

Literature review

Leafhopper species, plant damage and biology

Species recognition and host plants

Eupteryx melissae: The main species infesting both outdoor and protected herbs is the chrysanthemum leafhopper (commonly known as the 'sage' leafhopper), *Eupteryx melissae*. The adults of this species are approximately 3 mm long, pale green with distinctive brown and black spots on the body and wings (Bennison, 2001a). The eggs are laid in leaf petioles and main veins but are not easily detected, even using a microscope, unless parasitized by *Anagrus atomus*, when they turn from pale green to dark brown. The young nymphs that hatch from the eggs are pale yellowish-green and the older nymphs develop dark bands across the body and the tips of the developing wing buds.

Eupteryx aurata: The potato leafhopper, *Eupteryx aurata* is common on nettle and bramble but has been recorded on spearmint (Bennison, 2001b). The adults of this species are similar in appearance to *E. melissae* but are larger (3.5-4.5mm) (British Bugs, N.D, a).

Hauptidia maroccana: Glasshouse leafhopper, *Hauptidia maroccana* is similar in size to *Eupteryx melissae* but the adult is pale green with two dark v-shaped marks on its back (British Bugs, N.D, b). The nymphs are pale and whitish. Glasshouse leafhopper has been recorded on mint but is more common on a wide range of other host plants including cucumber, tomato and many ornamental species (Hussey et al., 1969).

Empoasca decipiens: The green leafhopper, *Empoasca decipiens* is similar in size to *E. aurata* but is pale bright green with no spots or obvious markings (British Bugs, N.D, c). This species commonly infests protected sweet pepper and other host plants including cucumber, broad bean and French bean (Agboka et al., 2003) but it has not been recorded as a pest of herbs.

Plant damage and host plants

Leafhopper damage appears as white or pale yellow spots on leaves that later coalesce to form bleached areas leading to necrosis. Black faecal spots can also be visible on the bleached areas. Multiple retailers have almost a 'zero tolerance' for either pests or damage on fresh potted or cut culinary herbs, so presence of leafhoppers or damage can cause crop rejection. The 'sage' leafhopper has a wide host range including balm, basil, bergamot, French lavender, mints, marjorams, oregano, rosemary, sage and thymes (Bennison, 2001a and Bennison & Green, 2016)

Eupteryx melissae Biology and behavior

There is very little known about the biology and behaviour of the chrysanthemum ('sage') leafhopper, *Eupteryx melissae.* Adult *Eupteryx* species do not survive the winter (Stiling, 1980). Other species of *Eupteryx* e.g. the potato leafhopper, *E. aurata* overwinter as eggs in chamaephyte host plants (i.e. plants where some aerial parts survive the winter above the soil surface) such as stinging nettle (Stiling, 1980) so it is likely that *E. melissae* overwinters as eggs in any stems of perennial herbs that survive the winter. Adult *E. melissae* become active in spring and are very active, particularly on warm days and they hop from the plants when disturbed. *Eupteryx* species are reported to lay their eggs in the stems of host plants (Stiling, 1980), but *E. melissae* eggs parasitized by *Anagrus atomus* were found deep in leaf petioles or in main leaf veins in herb plants (Bennison, 2001b) so these must be common oviposition sites for the 'sage' leafhopper. The eggs take several weeks to hatch; in fluctuating glasshouse temperatures in May and June 2020, the first nymphs were seen on sage plants 25 days after adding adult *E. melissae* (Bennison, unpublished data). The nymphs are much less mobile than the adults and are usually found under the leaves next to a leaf vein. There are five nymphal stages. When each stage moults, the cast skins left behind on the leaf can be mistaken for live leafhoppers. The final nymphal stage develops into the adult. Most *Eupteryx* species are reported to produce only two generations per year outdoors although more generations may be produced in long, hot summers (Stewart, 1988). However, on short-term herb crops grown under protection, it is likely that there is insufficient time for the completion of a generation and that most of these short production crops are infested mainly with adult leafhoppers. The life stages present should be considered when planning control measures.

Cultural control

Sticky traps

Some UK growers currently use sticky traps for 'mass monitoring' of leafhopper adults in herb crops and two growers consider that red traps are more effective than blue or yellow traps. Red traps and roller traps are sold by Biobest for detection and monitoring of most leafhopper species and for use as a physical barrier (Biobest, n.d.). Pilot testing of red, blue and yellow traps for trapping the green leafhopper, *Empoasca decipiens* in sweet pepper has given variable results (Clare Sampson, Russell IPM, personal communication, 2020). Trap catch was affected by both trap colour and glue type. Yellow and red traps typically caught more leafhoppers than blue traps, and 'dry' glue traps caught more than 'wet' glue traps. Yellow traps caught a wider range of pest species (including leafhoppers, thrips and whiteflies), whilst red traps caught a narrower range of pest species, but also fewer natural enemies.

Although no published literature concerning trapping of leafhoppers in herbs was found, there are reports of trapping of other leafhopper species on other crops. Saona et al (2012) conducted a set of experiments in the USA investigating the effect of trap colour and height on catches of the sharp nosed leafhopper (*Scaphytopius magdalensis*) and blunt nosed leafhopper (*Limotettix vaccinii*) and various non-target insects in cranberry crops. They tested yellow, green, red, blue, white, and clear sticky traps, taking into account the associated colour characteristics (reflectance spectra, and red, green, and blue (RGB) values). The two species showed distinct colour preferences, adult blunt nosed leafhoppers were most attracted to green, followed by red and yellow. Sharp nosed adult leafhoppers were most attracted to yellow and then to green and red. They also placed red and yellow traps horizontally above a crop at

0.1m, 0.5m and 0.9m. More leafhoppers (and hoverflies) were caught on traps 0.1m above the crop compared to the other heights and more ladybirds were caught when the traps were at 0.5m above the crop. Hoverflies were most attracted to blue traps followed by white traps, and honey bees were most attracted to white traps. Green and red traps seemed to be either less attractive, or repellent, to both hoverflies and honey bees.

Demirel & Yildrum (2008) investigated the effect of colour on attraction of the potato leafhopper (*Empoasca decipiens*) in cotton crops in Turkey. They found that yellow sticky traps were significantly more attractive in four trials over two years, with orange traps being the next most attractive and they suggested these two colours for monitoring leafhopper adults in cotton crops. A field trial in India evaluated different coloured traps for attracting leafhoppers, aphids, thrips and whitefly on chilli pepper (Buragohain et al., 2017). Yellow traps were more attractive to the cotton jassid, *Amrasca biguttula biguttula* than violet, red, orange, green, blue or white traps and traps at plant canopy height were more effective than those placed 10 or 20 cm above the canopy.

Suction methods

In HDC-funded project FV 241, an experimental machine that blew air through baby leaf salad crops at harvest could remove 60% of potential invertebrate contaminants without causing crop damage (Lole, 2002). Building on this work, an adapted 'paddock cleaner' designed for removing horse droppings from paddocks using suction, and modified and used by a commercial UK herb grower for removing pests from field-grown herbs, was evaluated in FV 330 for removal of leafhoppers and for reduction in leafhopper damage. Trials in commercial crops of thyme and mint showed that leafhopper populations in treated plots were reduced by up to 70% immediately after passage of the suction machine (Bennison & Lole, 2009). However, up to 85% of beneficial insects and non-target organisms (e.g. bees, parasitic wasps) were also removed. The suction machine had a 'flushing' effect on both leafhoppers and non-target invertebrates, rather than removing and destroying them. Suction treatment of plots of mint at weekly intervals for four weeks did not reduce the level of leafhopper damage compared to that in adjacent, untreated plots. Potential modifications to the design of the machine were suggested to improve its efficiency in not only flushing but also killing the target pests. Further evaluation of the modified machine would be needed.

Remote Sensing

Due to leafhopper damage reducing chlorophyll and water content in crops a study investigated the use of spectral imaging to monitor damage in cotton crops (Prabhakar et al, 2011) and found new indices able to detect leafhopper damage severity in cotton crops in India. Although this may not directly influence control, use of a similar technology could potentially allow for subtle detection of damage in the early stages of infestation.

UV absorbing plastics

Two studies were conducted by Weintraub et al (2008) to investigate the effects of covering tunnels with UV-absorbing plastic on the common brown leafhopper (*Orosius orientalis*), a vector of a phytoplasma disease in *Limonium* (statice, a cut flower crop) in Israel. They found that UV absorbing plastics ('Bionet') demonstrated an effect in both laboratory studies and in outdoor choice test chambers. In four trials, significantly more leafhopper adults (383) moved into chambers covered with regular plastic compared with the chamber covered in the UV-absorbing plastic (7). In field trials, significantly fewer *O. orientalis* were recorded in polytunnels covered with the UV-absorbing plastic, although numbers of another leafhopper species, *Circulifer* spp. were not significantly reduced.

Reflective mulch

A study investigating the application of reflective mulches for control of corn leafhopper, *Dalbulus maidis* in the US found evidence that reflective mulches were able to significantly reduce numbers of corn leafhopper in sweetcorn crops grown in the soil (Summers & Stapleton, 2002). They found that the mulches were more effective than applications of foliar insecticides (methomyl, 0.5 kg a.i./ha and permethrin, 0.28 kg a.i./ha) and a soil based insecticide (thiomethoxam, at 1.51 g a.i/100 m) but the protection was reduced as the crop canopy developed. Mulches were shown to have potential as an alternative cultural control method for repelling leafhoppers from crops.

Ozone Fumigation

A study investigating the use of ozone fumigation to control the ligurian leafhopper (*Eupteryx decemnotata*) in protected rosemary crops took place in Poland (Kopacki et al, 2017). The aim was to find an alternative method to insecticide applications for killing leafhoppers. The treatments varied by the number of seconds, the number of ozone doses and the ppm. Treatments of 120ppm for two minutes killed adults and nymphs by between 33.9% and 71.9%, and treatment by 595ppm for 10 minutes resulted in 70-91.7% control However, the higher dose led to phytoxicity of between 11.3 and 89.2%. Further work would be needed to adjust the effective dose and to reduce plant damage. If this method could be fine-tuned it is a potential alternative option to chemical control.

Biological control

Anagrus atomus

Anagrus atomus is a leafhopper egg parasitoid, first used for biological control of glasshouse leafhopper, *Hauptidia maroccana* on tomato within an IPM programme (Wardlow & Tobin, 1990; Cooper, 1993). *Anagrus atomus* was also shown to parasitise the green leafhopper, *Empoasca decipiens* on sweet pepper (Jervis & Kidd, 1995). Although it was thought that *A. atomus* would not parasitise the eggs of the 'sage' leafhopper, *Eupteryx melissae (*Cooper, 1993), *A, atomus* was confirmed to be naturally parasitising *E. melissae* eggs in herb plants from UK commercial nurseries, particularly from unsprayed organic rosemary (Bennison, 2001 a,b). *Anagrus atomus* is also known to parasitise other *Eupteryx* spp. eggs including *E. urticae* on stinging nettle (Stewart, 1988) and *E. decemnotata* on rosemary (Arno *et al*, 1987). Unlike glasshouse leafhopper eggs, which are laid in the leaf veins and turn from green to orange/red when parasitised and are thus easily seen, *E. melissae* eggs are laid deeper in the leaf main vein or petiole and turn brown when parasitised and are less easy to detect (Bennison, 2001 a,b; Bennison& Green, 2016). *Anagrus atomus* is no longer commercially available but is likely to occur naturally on herb nurseries and farms, particularly where the use of broad spectrum insecticides is limited and where IPM programmes are used.

Previous HDC-funded research indicated that using broad beans infested with the green leafhopper as 'delivery plants' could be a cost-effective method for releasing *A. atomus* to sweet pepper crops (Jervis & Kidd, 1995). It is possible that such a 'delivery plant' or 'banker plant' method could be developed for use on herbs, using a natural population to initiate a culture, but this would require further research. Similarly, parasitism of grape leafhopper eggs, *Erythroneura elegantula* by the naturally-occurring egg parasitoid *Anagrus epos* was improved by planting prune trees infested with another leafhopper species in a Californian vineyard (Murphy et al., 1998). The prune trees acted as a source of *A. epos*, which parasitized both leafhopper species. *Anagrus epos* also parasitizes another leafhopper species on wild blackberry in California, which grows around the vineyards and provides naturally-occurring egg parasitoids for control of grape leafhopper (Doutt & Nakata, 1965; Kido et al., 1983).

Other parasitoids

Naturally-occurring parasitoids of *Eupteryx melissae* nymphs have been recorded (Jervis, 1980). These were identified as *Chalarus* sp. parasitic wasps, which lay their eggs in third, fourth and fifth instar nymphs. This species has never been commercially available.

Orius species

Orius species predatory bugs such as *O. laevigatus* are primarily used for thrips control but they have also been recorded as predators of leafhoppers, e.g. laboratory tests showed that *Orius insidiosus* (not native or available in the UK) fed on eggs, adults and larvae of the potato leafhopper, *Empoasca fabae* (Martinez & Pienkowski, 1982). The naturally-occurring anthocorid bug related to *Orius* spp., *Anthocoris nemorum* can be reared on various prey including the potato leafhopper, *Eupteryx aurata* and on *Eupteryx urticae* (Herard & Chen, 1985). High numbers of *A. nemorum* were found in association with infestations of the potato leafhopper on spearmint at a UK nursery in PC 178 (Bennison, 2001b).

Macrolophus pygmaeus

Macrolophus pygmaeus is primarily used for whitefly and caterpillar control on tomato. This predatory bug will feed on a range of prey. Although no published records could be found of *Macrolophus* feeding on leafhoppers, it is reported to have given control of the green leafhopper, *Empoasca decipens* on sweet pepper (Hubert, personal communication, 2020) although others reported that it gave no apparent control on other sweet pepper crops (Bull, personal communication, 2020 and Reid, personal communication, 2020).

Chrysoperla carnea

Lacewing larvae are generalist predators and feed on many species of soft-bodied invertebrates including aphids, leafhoppers, thrips, whiteflies, mites, mealybugs, moth eggs and caterpillars. In the absence of prey they will also be cannibalistic. The green lacewing, *Chrysoperla carnea* is primarily released for aphid control and was shown in initial laboratory tests to predate on *Eupteryx melissae* nymphs on sage (Bennison & Maher, unpublished, Bennison 2001b). However, a UK grower who uses *C. carnea* for aphid control reported no apparent benefit in leafhopper control on protected herbs. This might have been due to only adult leafhoppers being present, as on short-term herb crops there is very little time for nymphs to develop since the eggs can take 3-4 weeks to hatch in summer (Bennison, unpublished data). Releases of green lacewing eggs or larvae (*Chrysoperla* spp.) in California at 3-800 per acre led to up to 35% reductions in numbers of variegated grape leafhopper, *Erythroneura variabilis* (Daane *et al*, 1993). However, results were very variable and sometimes releases led to no reduction in numbers of leafhoppers compared with the controls. Lacewing releases were timed to match leafhopper egg hatch in each generation, to target the young nymphs. Lacewings were more effective at high leafhopper densities than at low densities, as when fewer prey were available they spent more time searching.

Entomopathogenic nematodes
The entomopathogenic nematode *Steinernema feltiae* is commonly used on protected herbs as a drench for control of sciarid flies and is used on some ornamental crops as a foliar spray for control of thrips. In laboratory tests to evaluate the potential control of 'sage' leafhopper nymphs by *S. feltiae*, significantly more (65%) of the leafhopper nymphs were dead two days after spraying infested leaves with nematodes, than the 5% dead on control leaves sprayed with water (Bennison, 2007). Most of the dead leafhopper nymphs contained nematodes when they were dissected. In the laboratory test, ideal temperatures and high humidities were provided for nematode survival and efficacy. However, in a subsequent small-scale glasshouse experiment with infested sage plants, the nematodes gave no control of leafhopper nymphs two days after treatment. This lack of control is likely to have been due to difficulties in targeting leafhopper nymphs on leaf undersides, and to the hot, dry conditions in the glasshouse causing the nematodes to desiccate shortly after application.

Management with plant protection products

Conventional chemical plant protection products

- Acetamiprid: use of acetamiprid against the green leafhopper (*Empoasca spinosa*) in fenugreek led to a significant reduction (1.4 per three leaves) compared with the untreated control (2.7 per three leaves) three days after two applications at 10-day intervals (Prajapati et al, 2017). Acetamiprid (Gazelle SG) is used by UK growers of protected and outdoor herbs and is reported to be one of the most effective products, however it is not fully compatible with all biological control agents used in IPM.
- Spirotetramat: In a laboratory test, spraying grapevine canes infested with overwintering eggs of the American grapevine leafhopper, *Scaphoideus titanus* reduced numbers of nymphs hatching from the eggs by 99% (Goetsch et al., 2020). Spirotetramat (Movento) currently has an EAMU for use on outdoor and protected herbs in the UK and is reported to be one of the more effective products against 'sage' leafhopper but is limited to two applications per crop. The knowledge that Movento could potentially prevent egg hatch could help growers time applications to perennial herbs as the 'sage' leafhopper also overwinters as eggs in stems of the host plant (Stewart, 1986).
- Buprofezin: Early season use of the insect growth regulator buprofezin (Applaud) on tomato controlled glasshouse leafhopper (*Hauptidia maroccana)* for over three months (Jacobson et al, 1996). UK tomato growers used Applaud for control of leafhoppers within IPM programmes until 2008 when the product was withdrawn from the market. Applaud is now available again in the UK but is currently only approved for use against whiteflies on protected ornamentals, so may not be used on herb crops.
- Indoxacarb: A single high volume spray of indoxacarb (Steward) on sweet pepper reduced numbers of green leafhopper (*Empoasca decipiens)* by over 90% compared with those in untreated controls after six, 18 and 28 days (Jacobson, 2009). A second application seven days after the first gave no additional benefit in control. Indoxacarb is compatible with most biological

control agents and was subsequently adopted by UK growers of sweet pepper for leafhopper control within IPM programmes. Indoxacarb (Steward, Explicit and Rumo) has current EAMUs for use on protected herbs for caterpillar control, so could have potential for control of leafhoppers. However, indoxacarb approval is due for withdrawal in 2021 with a use-up date of 30 April 2023, so it is not a long-term option for control.

- Flonicamid was used in a study on the cotton leafhopper (*Amrasca devastans*) on cotton. Seven days after sprays were applied, flonicamid at 75g and 100g a.i./ha gave mean reductions of 72.6% and 76.3% respectively in numbers of leafhoppers (1.83 and 1.58 per three leaves) compared with the untreated control (mean of 7.4 per three leaves), (Lakshmi *et al*, 2018). Flonicamid (Mainman) currently has an EAMU for use in outdoor herbs for aphid control so could potentially be used for control of leafhoppers, although its 21-day harvest interval would limit application timing.
- Neonicotinoid seed treatments of thiamethoxam and imidacloprid were applied to the seed of snap bean for the control of the (American) potato leafhopper (*Empoasca fabae*) (Nault et al, 2004). Thiamethoxam gave persistent control of leafhoppers for 31 to 38 days after planting and prevented leaf damage but imidacloprid only gave control in one of four plantings. Both of these neonicotinoid insecticides are no longer approved in the UK and continental Europe. However, if other seed treatments could be effective this method could have potential for leafhopper control, thus reducing the need for foliar sprays during early growth stages.

Botanical biopesticides

- Azadirachtin: azadirachtin has insect antifeedant and moulting inhibiting properties and is extracted from the neem tree, *Azadirachta indica* and also the chinaberry, *Melia azedarach* (Alessandro, 1993). Currently only one azadirachtin product is approved in the UK, Azatin, which is recommended only on protected ornamentals for thrips control and thus cannot currently be used on herbs. Extracts of chinaberry fruits and seeds were applied to field-grown sage and evaluated for the control of 'sage' leafhoppers, *Euperyx* and *Empoasca* spp. The higher concentrations of the extracts led to significant reductions in numbers of leafhopper nymphs per leaf compared with untreated controls eight days after application (Alessandro, 1993).

  Bhonde et al (2017) evaluated azadirachtin alone or in combination with yellow sticky traps in okra against the cotton jassid leafhopper, *Amrasca biguttula*. Azadirachtin in combination with sticky traps 15cm above the crop canopy led to significantly fewer leafhoppers per leaf (3.3 and 4.4 per leaf respectively seven and 14 days after treatment) compared with untreated controls (10.2 and 11.7 per leaf respectively).

  Goetsch et al (2020) also tested azadrachtin amongst other products and reported that compared with water controls, it led to 72% reduction of egg hatch of the American grapevine leafhopper, *Scaphoideus titanus*, which overwinters under the bark of grapevine canes. In the same study, spirotetramat led to 99% reduction in egg hatch.

  Another study compared the use of neem oil and NSKE (Neem Seed Kernel Extract) with the conventional insecticides thiamethoxam and acetamiprid and the entomopathogenic fungal (EPF) biopesticides *Metarhizium anisopliae,* *Verticillium lecanii* and *Beauveria bassiana* for the control of the cotton jassid, *Amrasca biguttula* on okra (Madhuri & Thakur, 2019). Thiamethoxam and acetamiprid) were the most effective treatments (mean 1.4 per three leaves) compared with the untreated control (3.1 per three leaves). Although not as effective as the insecticide options, neem oil and NSKE were as effective (2.2 and 2.5 per three leaves) as the EPF *M. anisopliae* (2.6 per three leaves)*, V. lecanii* (2.5 per three leaves) and *B. bassiana* (2.4 per three leaves).

- Other natural oils: in addition to neem oil, other natural oils have biopesticidal properties and some have been evaluated against leafhoppers. There is a general lack of natural oil products on the market due to the difficulty in obtaining patents for their production (William Kirk, personal communication, 2020). A laboratory and semi field study (Aziz et al, 2018) investigated the use of menthol oil (from mint), camphor oil (from camphor laurel) and their combination against the green leafhopper, *Empoasca decipiens* in Egypt. The most effective treatment was the mixture of the two oils (71-90% corrected mortality compared to the untreated in the laboratory test and 50% mortality in the semi-field experiment on cowpea).

  Another study conducted laboratory bioassays of 124 essential oils against the citrus flatid planthopper, *Metcalfa pruinosa* (Kim et al, 2013). The bioassay consisted of a dip test using nymphs. Oils that gave 99% mortality in the dip test were then selected for a spraying test against adults. Depending on concentration, 19 of the oils led to 100% mortality of nymphs. Twelve formulations were then tested as sprays against adults and cinnamon and pennyroyal were the most effective. Further research is needed on essential oil formulation, modes of action and human safety before commercial products could be developed.

Entomopathogenic fungi

Various entomopathogenic fungi (EPF) have been tested as microbial biopesticides against leafhoppers.

- The efficacy of five fungal isolates were tested against nymphs of the green leafhopper, *Empoasca decipiens* under laboratory conditions (Kodjo *et al*., 2011). The five isolates were *Beauveria bassiana*, *Metarhizium anisopliae* (Ma43 & Ma57), *Paecilomyces fumosoroseus* and *Verticillium lecaniicillium*. All of these isolates had high levels of virulence when tested under laboratory conditions (high humidity and moderate temperature) and have potential for the control of leafhopper nymphs. Dose rates and insect development stage were significant factors affecting mortality. It was considered that the fungal inoculum was shed following moulting in the younger instars, which would significantly affect mortality, especially if the time interval between moults is short. *Paecilomyces fumosoroseus* isolate Pfr12, *M. anisopliae* isolate Ma43 and *B. bassiana* isolate a113 were the most effective isolates tested in the study, leading to 89%, 95% and 87% mortality respectively, and median survival times (MST) of 4.3, 4.6 and 5.3 days respectively, compared with untreated controls at 3% mortality and over 8 days MST. It should be noted that this study was under optimum conditions for the EPF and conditions in a crop may not lead to the same level of control.

- Field trials on false-eye leafhopper, *Empoasca vitis* in tea in southern China showed that applications of *Beauveria bassiana* were more effective (mean 69.3% control) when combined with a conventional insecticide (imidacloprid) than when used alone at a high rate (mean 42% control), (Feng et al, 2004).

- Twelve fungal isolates were tested in the laboratory against the cotton jassid leafhopper, *Amrasca biguttula biguttula* in Thailand. *Metarhizium anisopliae* CKM-048 was the most virulent. This EPF strain was then tested in field trials on aubergine and gave good efficacy (mean 73% control), statistically similar to that given by the conventional insecticide lambda-cyhalothrin 2.5% EC, and both were significantly different from the control (Maketon et al, 2008). Average temperatures and relative humidities during the trials were 26-36°C and 70-80% respectively.

- Trials on the cotton jassid (*Amrasca biguttula biguttula*) tested *Beauveria bassiana* (1500g/ha) and *Lecanicillium lecanii* (5000g/ha) compared with the conventional insecticides diafenthiuron 50WP 200-600 g ai/ha, imidacloprid 20g ai/ha and thiamethoxam 25g ai/ha. Overall *B. bassiana* was more effective (1.5 leafhoppers per leaf) than *L. lecanii* (1.74 per leaf) and the untreated control (3.08 per leaf) but not as effective as diafenthiuron 50WP (600g a.i/ha), (0.42 per leaf) or imidacloprid (0.78 per leaf) (Naveeda et al, 2016).

- There has been recent research on the endophytic action of various EPF, where the fungus is applied as a spray and is taken up by the plant, giving persistent control of a range of pests. *Beauveria bassiana* was applied to grapevine and was detected as an endophyte in mature plants for up to five weeks after application, with significant reduction in numbers of mealybugs and the grape leafhopper, *Empoasca vitis* (Rondot & Reineke, 2018). This mechanism of EPF justifies further research.

Results from the literature review indicate that EPF have potential for giving some control of leafhoppers as part of an IPM programme. However, no published work was found on EPF control of the 'sage' leafhopper and as with fungal control of other pests, it is likely that environmental conditions will affect efficacy. Currently, four EPF products have approval or EAMUs for use against other pests on herbs in the UK. Naturalis-L (*Beauveria bassiana*) is approved for foliar application to all protected edible and ornamental crops for the control of whitefly and reduction in numbers of thrips. Mycotal (*Lecanicillium lecanii*) has an EAMU for foliar application to protected herbs for the control of whitefly and thrips. Botanigard WP (*B. bassiana*) has an EAMU for foliar application to protected herbs with full enclosure for the control of whitefly, spider mite, thrips and aphids. Met52 granular bioinsecticide (*Metarhizium anisopliae*) has EAMUs for both soil incorporation and use as a mulch before and after planting herbs respectively, for control of ground-dwelling pests including thrips pupae and sciarid flies. This use would not give control of foliar-dwelling leafhoppers unless there was any endophytic action, and as yet there is no published evidence of this.

Conclusions on current and potential future control methods for leafhoppers on outdoor and protected herbs

Currently used control methods:

- Cultural control methods include weed control, cutting back infested stock plants and avoiding propagating from infested stock plants, flaming outdoor mint after final cut and 'mass monitoring' of adults using sticky traps in protected herbs.

- Biological control agents are widely used for controlling other pests in IPM programmes in protected herbs, but since the leafhopper egg parasitoid *Anagrus atomus* has no longer been available, there is no specific biological control agent available for leafhopper control. Some herb growers use predators including lacewing larvae for control of other pests such as aphids but no reductions in leafhopper numbers have been reported.
- Currently-used plant protection products include fatty acids (Flipper), maltodextrin (Majestik), SB Plant Invigorator, pyrethrins (Pyrethrum 5 EC), acetamiprid (Gazelle SG), spirotetramat (Movento) and thiacloprid (Calypso). The approval for thiacloprid will be withdrawn and growers have until 3 February 2021 to use up existing stocks. The pyrethroid products deltamethrin (Decis Protech) and lambda-cyhalothrin (Hallmark Zeon) are also used on outdoor herbs but not on protected herbs, as they are not compatible with IPM programmes.

Currently available alternative plant protection product options:

- Indoxacarb has efficacy against leafhoppers and currently there are EAMUs for three products (Steward, Explicit and Rumo) for use on protected herbs, but approval is due for withdrawal in 2021 with a use-up date of 30 April 2023, so it is not a long-term option for control.
- Flonicamid (Mainman) also has efficacy against leafhoppers and currently has an EAMU for use in outdoor herbs for aphid control so could potentially be used for control of leafhoppers. However, its 21-day harvest interval would limit application timing.
- Entomopathogenic fungi (EPF) have potential for giving some control of leafhoppers as part of an IPM programme although there is no published evidence of EPF control of the 'sage' leafhopper. Currently, four EPF products have approval or EAMUs for use against other pests on herbs in the UK. Naturalis-L (*Beauveria bassiana*) is approved for foliar application to all protected edible and ornamental crops for the control of whitefly and reduction in numbers of thrips. Mycotal (*Lecanicillium lecanii*) has an EAMU for foliar application to protected herbs for the control of whitefly and thrips. Botanigard WP (*B. bassiana*) has an EAMU for foliar application to protected herbs with full enclosure for the control of whitefly, spider mite, thrips and aphids. None of these EPF products were selected for the efficacy trial following the review in this project, as AHDB asked us to focus on novel products. However, evaluation of these products against 'sage' leafhopper in protected herbs justifies consideration.

Potential future control methods:

- Research is warranted on the comparative efficacy of different coloured sticky traps for 'mass monitoring' in protected herbs, as currently only anecdotal evidence is available for adult 'sage' leafhoppers. Data on trapping non-target flying beneficial species of parasitoids and predators would also be needed.
- Further evaluation of cultural control methods in field-grown herbs should be considered, including suction methods, flaming and use of reflective mulches.
- If the egg parasitoid *Anagrus atomus* is made commercially available in the future, research is warranted on practical methods for herb growers to use

it in IPM programmes as it is a naturally occurring egg parasitoid of 'sage' leafhopper eggs.

- Potential predators for use in IPM programmes include lacewing larvae, *Macrolophus pygmaeus* and *Orius* spp. Research would be needed to evaluate efficacy against 'sage' leafhopper adults, eggs and nymphs and on practical methods for use.
- The entomopathogenic nematode *Steinernema feltiae* has been shown to be effective against 'sage' leafhopper nymphs and this nematode species is commonly used on protected herbs as a drench for control of sciarid flies. Further research would be needed on evaluating efficacy against leafhoppers in commercial glasshouse conditions.
- The botanical biopesticide azadirachtin which acts as an insect growth regulator has been shown to give some control of the nymphs of other leafhopper species and to reduce egg hatch. If any azadirachtin products gain approval for use on herbs in the UK they would warrant testing against 'sage' leafhopper.
- Other oil-based botanical biopesticides would also warrant testing if they have a clear route to market in the UK.

Efficacy trial

Candidate novel IPM-compatible treatments were selected for an efficacy trial on potted sage following this review. Selected treatments were put forward by the manufacturers as having potential against leafhoppers and a clear route to market in the UK. The selected products included both conventional chemical plant protection products and microbial and botanical biopesticides.

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