# A review of thrips species (other than western flower thrips) and their control on strawberry

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# Background

For a number of years, UK strawberry growers have faced the problem of western flower thrips feeding, breeding and damaging the flowers and fruits on strawberry crops, particularly ever-bearers. Despite many growers using integrated pest management IPM programmes to gain control, further damage has been apparent in recent times, which has been linked to other thrips species. This review was commissioned by AHDB to gather new and improved information about these species and how the industry might develop new control methods.

# Main findings for growers

- Western flower thrips (WFT) is successfully controlled by many growers in the UK using the predatory mite *Neoseiulus cucumeris*, along with the predatory bug *Orius laevigatus* and, on some farms, the ground-dwelling predatory mites *Stratiolaelaps* species
- However, in recent years, fruit bronzing similar to that caused by WFT has occurred where WFT has been satisfactorily controlled
- Other thrips species have been found in the flowers of such crops, including the rose thrips (*Thrips fuscipennis*), rubus thrips (*Thrips major*), onion thrips (*Thrips tabaci*) and flower thrips (*Frankliniella intonsa*)
- Where non-WFT thrips species occur, few larvae are found in flowers and it is thought that adults flying in are causing damage. However, *N. cucumeris* feeds only on young thrips larvae, and although *O. laevigatus* predates both thrips adults and larvae, temperatures are not always high enough for its successful establishment
- Spinosad (Tracer) is currently effective at controlling these other species, but, like WFT, they could develop resistance, so alternative control measures are required
- It is thought possible that immigrant adult thrips of species other than WFT are causing fruit damage before they start breeding in the crop
- Limited experience of *T. fuscipennis* in other countries has suggested that it is not well controlled by *N. cucumeris*, but this may be explained by a preponderance of adults and lack of larvae for the predatory mite to feed upon
- *T. tabaci*, *T. major* and *T. fuscipennis* larvae are all reported to drop to the ground to pupate, so if larvae do develop on the plants, the ground-dwelling predatory mite *Stratiolaelaps scimitus* may contribute to the control of their pupae
- The predatory flower bug *O. laevigatus* is likely to feed on all of the above thrips species and recent observations by ADAS indicated that it provided a similar level of control of *T. fuscipennis* as Tracer in an outdoor commercial strawberry crop. However, *O. laevigatus* only works well in warm summers (above 20$^{o}$C), is expensive to release and can be slow to establish. It is also susceptible to some plant protection products, including spinosad (Tracer)
- Research has shown that using the long-flowering annual plant alyssum as a ‘banker’ plant in ever-bearer strawberries can help to establish *O. laevigatus* and hasten its dispersal in the crop

and speed up control. However, some thrips species, including WFT, can also breed in alyssum and further research is needed in UK strawberry crops to test its potential benefits

- Some growers of glasshouse crops in Europe are using a commercially available pollen (Nutrimite$^{TM}$) to boost numbers of predatory mites and this might also help *Orius* establishment, but work is needed to test this
- Predatory *Aeolothrips* species (often known as banded thrips) feed on flower pollen and the larvae of other thrips species, although it is not yet known if they also feed on adult thrips. This predator should contribute to the control of thrips species that breed and produce larvae in strawberry flowers. It would be difficult to rear as a commercial predator, but it might be possible to boost its populations by the use of flowering 'banker' plants or supplementary pollen
- Entomopathogenic fungi (EPF), such as *Beauveria bassiana* (Naturalis-L and Botanigard WP) and *Lecanicillium muscarium* (Mycotal), are recommended for controlling whitefly, but also offer some control of thrips. Their efficacy is thought to be better against adult thrips than larvae and they work best in high relative humidities (60–80% depending on product)
- Entomopathogenic nematodes (EPN), such as *Steinernema feltiae* (e.g. Nemasys ®), have been shown to be effective against the ground-dwelling pupal stages of thrips and research in Canada showed that control on pot chrysanthemum was improved when combined with the EPF *Metarhizium anisopliae* (Met52) used as the granular formulation mixed with the compost. Further work is needed on the potential for EPN for thrips control on strawberry
- Research on the attractiveness of colour to WFT has led to some growers using blue sticky roller traps to reduce numbers of WFT in strawberry crops. An aggregation pheromone lure specific to WFT can be added to improve the attraction
- The few studies of the attractiveness of colour to the other thrips species have given mixed results but suggest that either yellow or blue traps are best, depending on species. However, the shade of colour used is known to make a major difference. The addition of LUREM-TR, a non-pheromone lure containing methyl isonicotinate (MI), to these traps can increase catches of 12 different species of thrips, including WFT, *T. major* and *T. tabaci.* There is potential to use LUREM-TR in push-pull or lure-and-kill strategies for thrips control on strawberry
- Insect netting may offer an alternative method of reducing thrips numbers in a strawberry crop. There has been observational evidence that thrips numbers in a commercial ever-bearer strawberry crop have been reduced where thrips-proof netting has been used on tunnel doors
- Some strawberry cultivars are known to suffer more from thrips fruit damage than others. However, very little work has been done on strawberry cultivar resistance to thrips or tolerance of fruit damage. It would be very useful to identify the plant traits that could allow plant breeders to select for host plant resistance or tolerance

# Introduction

Successful IPM programmes for management of western flower thrips (WFT), *Frankliniella occidentalis*, on UK strawberry crops have been developed using knowledge of its biology and behaviour (Bennison & Fitzgerald. 2008 in AHDB project SF 80; Harnden et al. in SF 120, HL01107; Raffle et al., 2015; Reitz et al., 2020). As WFT is now widely resistant to chemical plant protection products, these programmes are based on the use of biological control agents: the predatory mites *Neoseiulus cucumeris* against first-instar WFT larvae; the predatory bugs *Orius laevigatus* against WFT adults and larvae; and, on some farms, the ground-dwelling predatory mite *Stratiolaelaps scimitus*. against WFT larvae that drop to the ground to pupate.

However, in recent years, fruit bronzing similar to that caused by WFT has occurred in strawberry crops where IPM programmes have been giving good control of WFT, but other species of thrips have been confirmed in flowers. These species usually occur in a mix and include the rose thrips (*Thrips fuscipennis*), rubus thrips (*Thrips major*), onion thrips (*Thrips tabaci*) and flower thrips (*Frankliniella intonsa*) (Bennison & Hough, 2015; Brown & Bennison, 2017; AHDB project SF 156 annual report 2018; Gremo et al., 1997). The same species have also occurred in strawberry flowers where fruit damage was occurring in the Netherlands (Evenhuis and Huiting, personal communication, 2020). In some cases in both the UK and the Netherlands, *T. fuscipennis* was the only, or the predominant, species confirmed where fruit damage occurred (Bennison & Hough, 2015; Brown & Bennison, 2017; Roozemond, personal communication). *F. intonsa* has caused severe damage to strawberry in Denmark where it was the only species occurring in flowers (Stubsgaard, personal communication 2019 and Bennison, unpublished). It is noteworthy that several of these species were known as minor pests in British glasshouses in the pre-WFT era as far back as the 1950s (Morison, 1957). It is likely that now growers are using less broad-spectrum chemical control products on strawberry, some species previously being controlled incidentally by chemical products and regarded as minor pests are becoming more serious pests. Although *T. tabaci* is known and widely reported as a major worldwide pest, causing damage to a wide range of other crops (e.g. Diaz-Montano et al., 2011), very little is known about the potential of this, or any of the species, other than WFT, recorded in strawberry flowers as the cause of fruit damage. However, it is likely that all these species can cause damage to strawberry fruit (Bennison & Hough, 2015; Brown & Bennison, 2017; AHDB project SF 156 annual report, 2018).

UK growers have often used spinosad (Tracer) for control of these thrips species on strawberry and this is currently effective. However, there is concern that, like WFT, these other thrips species could develop resistance to Tracer and other products, and as growers wish to reduce their reliance on chemical plant protection products, they need an IPM solution. Where these thrips species occur, often very few larvae are found in flowers and it is thought that the adults are flying in and causing damage. *N. cucumeris* feeds only on young thrips larvae, and although *Orius* predates both thrips adults and larvae, temperatures are not always high enough for good establishment and this predator is very susceptible to products applied for control of other pests such as SWD. Therefore, *N. cucumeris* is ineffective against an influx of adult thrips and *Orius* may not always be sufficiently established to give effective control.

**Overall objective**: Complete a desk study review of research and development across the world on thrips species, other than WFT, and their control on strawberry and identify areas for further research.

**Aims**:

- Complete a focused literature review, to include published scientific papers and 'grey' literature such as conference proceedings and research reports
- Include relevant information on other crops or plant species, in addition to strawberry
- Contact selected scientists, biological control companies, agronomists, consultants, growers and other industry members in the UK and overseas
- Identify the most promising areas for further research

# Distribution, host range and biology of thrips species (other than WFT) on strawberry

### *Thrips fuscipennis* (rose thrips)

Rose thrips is native to the UK (Morison, 1957) but very little is known or published about its biology. The pest is known to be present in Europe and elsewhere, including North America and China (Nakahara, 1994). It has been reported from most counties of the UK (Mound et al., 1976) and appears to be more abundant in the east and south than in the west and north of the UK (Morison, 1957).

Rose thrips has a wide host range, including ornamentals such as rose, (Alford, 1991), fruit crops including blackberry and strawberry, and tree fruits, including apple (Morison, 1947–9; Alford, 1984; Badowska-Czubik & Olszak, 2006), which are all in the family Rosaceae. It is also known to breed on plants in other families, such as legumes and cucumber (Lewis, 1997). Rose thrips adults also occur in weeds such as bindweed and meadowsweet (Kirk, 1985b), clovers (Legutowska & Theunissen, 2003), rosebay willow herb and shepherd's purse (Brown & Bennison, 2017). The adults have been recorded from over 200 species of plant, although the range of plants in which they breed appears to be more restricted (Morison, 1947–9). Host plants suitable for larval development include *Althaea* spp. (e.g. marshmallow), *Chenopodium* spp. (e.g. fat hen), strawberry, ash, mint, *Prunus* spp., rose and *Rubus* spp. (e.g. blackberry and raspberry) (Morison, 1957). Previously, control of rose thrips on strawberry was considered unnecessary (Alford, 1984).

Rose thrips adults are recorded as overwintering on tree trunks and amongst 'herbage' (Morison, 1957), as fertile females in bark crevices on chestnut, hawthorn and rose, in wood crevices in glasshouses or among young leaves or flower petals (Orchard et al, 1938). The overwintering females are not dormant and they can move or even fly if conditions become unfavourable, e.g. if too wet (Orchard et al, 1938). It is possible that, like WFT, rose thrips may overwinter in strawberry fields, but this has not been recorded. Adult females (from unreported host plants) have been recorded from January to December and both males and larvae have been recorded from May to September (Mound et al., 1976). Adults can be abundant in flowers in summer, although they are often found without larvae (Ward, 1973), so it is not known which hosts are responsible for generating so many adults. Massive invasions of rose thrips adults to glasshouses have been reported in Europe, where they occasionally damage sweet pepper, aubergine and rose crops and are difficult to control biologically, with larvae rarely being seen under glass (Malais & Ravensberg, 2003). The source of influxes of adults to both outdoor and tunnel-grown strawberry crops is unclear. More knowledge of the hosts and distribution of the species is needed.

After adult rose thrips females have become active, they lay eggs from May onwards. Young apple shoots (Alford, 1984) and rose shoots (Orchard et al, 1938) have been recorded as egg-laying sites and the larvae feed on leaves, shoots and flowers until September (Alford, 1984). Adults have been recorded aggregating and mating in flowers of bindweed, which is not a host plant, and it is likely that the males produce an aggregation pheromone (Kirk, 1985a). Rose thrips is reported to have up to four generations a year (Alford, 1984). Larvae are recorded as pupating either in sheltered vegetation or in soil (Morison, 1957).

### ***Thrips major*** **(rubus thrips)**

Rubus thrips is native to the UK (Morison, 1957) and has been reported from throughout Europe, although not in Northern Scotland (Mound et al., 1976). Rubus thrips, like rose thrips, is polyphagous and was recorded on 28 species of flowering plants in a nature reserve in Sussex (Ward, 1973). Rubus thrips adults can be found on many of the same plant species as rose thrips, particularly Rosaceae (Mound et al., 1976), e.g. *Prunus* spp., *Rubus* spp. and hawthorn (Morison, 1957), and the two species often occur together in the same flowers. Adult rose thrips have also been recorded on *Calystegia sepium* (hedge bindweed), (Kirk, 1985b), willowherbs (Morison, 1957), dandelion and buttercup (Brown & Bennison, 2017). It is reported to overwinter as an adult female under bark and in other dry places and to have two generations per year in southern England (Morison, 1957). If *T. major* emerges in spring before suitable flowers are available, large numbers can be found in the opening buds of various tree species (Mound, 1997).

*T. major* does not necessarily breed on all the plant species that adults can be found on, as larvae were only found on 10 of the 28 species where adults were recorded (Ward, 1973). In early summer, Ward reports finding larvae mainly on Rosaceae, especially *Rubus* spp. When these host plants finished flowering by August, larvae were mainly found on bedstraws and willowherbs. In autumn, adults were found on various flowering plants, including those not recorded as larval hosts. *T. major* larvae have been confirmed in strawberry flowers in AHDB project SF 156 (2019 annual report). *T. major* larvae are recorded as usually pupating in soil below the host plant (Morison, 1957).

*T. major* has been implicated in fruit losses in nectarine, peach and, together with *T. atratus* and *T. tabaci*, in strawberry (Lewis, 1997) and is reported to be the predominant species on apple, loquat and pear in Turkey (Atakan, 2008).

### ***Thrips tabaci*** **(onion thrips)**

*Thrips tabaci* is native to the UK, with adults recorded on over 355 species of flowering plants (Morison, 1957). In the UK, *T. tabaci* is the main thrips pest of leek and onion and, prior to western flower thrips arriving in 1986, it was also the main thrips pest of many protected crops, including ornamentals, cucumber and pepper. *T. tabaci* can also infest plum and apple (Badowska-Czubik & Olszak, 2005). It has often been recorded on strawberry, but although it has never been considered as a pest of strawberry in the UK, it has been recorded as damaging strawberry (Gremo et al., 1997; Lewis, 1997; Linder et al., 1998; Steiner & Goodwin, 2005; Bennison & Hough, 2015). *T. tabaci* and *Frankliniella intonsa* were the main species occurring on strawberry in Denmark (Nielsen, 2019). Weed hosts include *Asteraceae*, with *Achillea* and *Senecio* being noted as good hosts for larvae (Morison, 1947; Ward, 1973). Two generations of *T. tabaci* per year are recorded outdoors in north-east Scotland, 5–6 generations outdoors in central and southern France and 12 generations under glass (Morison, 1957). *T. tabaci* have been recorded overwintering as adults (Burnstone, 2009) in soil or creeping plant growth (Chambers & Sites, 1989).

The species includes several different strains, which are probably cryptic species. In Hungary, there are three distinct strains (Li et al., 2015; Fail, 2016). There has not been any systematic survey of *T. tabaci* populations in the UK to establish which strain or strains are present. The strains vary in their ability to transmit tospoviruses (Jenser et al., 2011). However, there are no current records of tospoviruses infecting strawberry. In the UK, *T. tabaci* adults are mainly females, with males being recorded only rarely (Morison, 1957), although males occur in some other countries. *T. tabaci* larvae drop to the ground to pupate (Binns et al., 1982). This knowledge led to the development of using a sticky polybutene glue with deltamethrin incorporated (Thripstick®) on the polythene floor beneath cucumber plants for control of the pest (Pickford, 1984). Current IPM programmes used in the UK on cucumber and many other protected crops include biological control agents for control of WFT and *T. tabaci* and mainly aim to control first-instar larvae with the predatory mite *N. cucumeris*. *T. tabaci* is known to breed in strawberry flowers. Larvae have been confirmed in flowers in AHDB-funded research, using a morphological diagnostic key (SF 156 annual report, 2019), and in Denmark, where both *T. tabaci* and *F. intonsa* were confirmed using a PCR molecular method (Nielsen, 2019).

## *Frankliniella intonsa* (flower thrips)

*Frankliniella intonsa* is native to the UK and has been reported from most European countries, along with Greenland, Siberia and Asia (Morison, 1957). Adults have been recorded from 81 species of flowering plants in Britain, with larval hosts including *Erica tetralix* (cross-leaved heath) and *Pedicularis sylvatica* (common lousewort) in marshy areas and *Ononis* (restharrow) and rose in drier areas (Morison, 1957). The species is recorded as being more numerous in eastern and southern Britain than in the west and north (Morison, 1957). Until recently, *F. intonsa* has been recorded only occasionally in UK strawberry flowers (Brown & Bennison, 2017), but in 2018 much larger numbers were recorded, possibly due to the very hot summer (SF 156, annual report 2018). Climate is thought to be an important factor for the geographical range of *F. intonsa*, with it possibly being more adapted to the more extreme climate of central Europe (Morison, 1957), so it is a species that may become more commonplace in the UK with climate change. In 2019, in one strawberry crop in the West Midlands, *F. intonsa* was recorded in high numbers in flowers and was the only species found (Hubert, personal communication, 2019). Both adults and larvae have been confirmed in strawberry flowers in both the UK and Denmark (SF 156, annual report, 2019; Nielsen, 2019). In boggy areas, *F. intonsa* is reported to pupate on host plants, like other species that can breed on bog plants with their roots covered by water (Morison, 1957). Pupae were recorded behind the calyx of strawberry fruit in Denmark (Stubsgaard, personal communication, 2018) and these were allowed to develop into adults and were confirmed as *F. intonsa* (Bennison, unpublished). However, it is possible that some *F. intonsa* larvae may have also dropped to the ground to pupate. High numbers of *F. intonsa* adults (over 20 per flower) were recorded in strawberry flowers cv. Murano in Denmark, when severe fruit damage was seen (Stubsgaard, personal communication, 2018). A summary of key knowledge of the biology of each of the above thrips species is given in Table 1.

**Table 1. Key knowledge on the biology of thrips species on strawberry in the UK**

| Species | Confirmed strawberry fruit damage | Strawberry as larval host | Pupation site* | Overwintering site (relevant to strawberry production) |
|---|---|---|---|---|
| WFT | Yes | Yes | On ground, sometimes on plant | Strawberry plantations: plants/weeds/debris/substrate (Sampson et al., 2019) |
| *Frankliniella intonsa* (Flower thrips) | Yes | Yes | On host plant (Morison, 1957), behind calyx on strawberry fruit (Stubsgaard & Bennison, unpublished) | Adult females on vegetation (Morison, 1957) |
| *Thrips fuscipennis* (Rose thrips) | Yes (Brown & Bennison, 2018) | Yes (Morison, 1957, but so far unconfirmed in SF 156) | In shelter on vegetation or in soil (Morison, 1957) | Adult females on tree trunks and amongst herbage (Morison, 1957) |
| *Thrips major* (Rubus thrips) | Yes (SF 156 2018 report) | Yes (SF 156, 2019 report) | Usually in soil below host plant (Morison, 1957) | Adults under bark or in dry places (Morison, 1957) |
| *Thrips tabaci* (Onion thrips) | Yes | Yes (SF 156, 2019 report, Nielsen, | In soil, less often on plants (Morison, 1957) | Adults in soil or creeping plant growth (Chambers & Sites, 1989) |

| | | | | |
|---|---|---|---|---|
| | | pers. comm. 2019) | | |

*Known recorded pupation sites. However, pupation sites for thrips species, other than WFT, are poorly studied and recorded and all species could potentially pupate both on the host plant and on the ground.

### ***Thrips setosus*** **(Japanese flower thrips)**

*Thrips setosus* (Japanese flower thrips) is not native to the UK and was first detected here in 2016 (Defra, 2020) and so far has mainly been found on cyclamen crops on the South Coast of England, where it has damaged leaves and transmitted *Tomato spotted wilt virus* (Helyer, personal communication, 2019). The pest has also been confirmed on UK protected herbs. *T. setosus* is currently not a notifiable quarantine pest in the UK. The species is widespread in Japan (Murai, 2001) and has also been confirmed in Korea, Indonesia and some Northern European countries. Recorded host plants include beans, lettuce, cucumber, pepper, strawberry, tomato, dahlia, hydrangea and chrysanthemum (Defra, 2020). The pest is reported to feed on leaves rather than on pollen in flowers. So far, *T. setosus* has not been confirmed on UK strawberry crops but has been confirmed on an increasing number of strawberry crops in the Netherlands during the past two years, where it has occurred both in flowers and on leaves (Roozemond, personal communication, 2019). *T. setosus* was first confirmed in the Netherlands in 2018 on protected hydrangea, where it was causing leaf damage (Vierbergen & Loomans, 2016). *T. setosus* has proved difficult to control on cyclamen with *N. cucumeris* (Helyer, personal communication) but is currently being controlled on hydrangea in the Netherlands with *Transeius (Amblyseius) montdorensis* (Roozemond, personal communication) (see 'Predatory mites' in the Biological control section below). It is possible that *T. setosus* could infest UK strawberry crops in the future, but it is not yet known whether it can damage the fruit.

# Biological control

### Predatory mites

Most UK biological control programmes for thrips, including on strawberry, are based on control of first-instar larvae using the native predatory mite *N. cucumeris*, which is also used for control of tarsonemid mites (Irving et al., 2012). In fully enclosed glasshouses, other, non-indigenous species can be released, including *Amblyseius swirskii*, *Transeius (Amblyseius) montdorensis* and *Amblydromalus (Amblyseius) limonicus*. These three species have an advantage over *N. cucumeris* in that they can feed on both first- and second-instar thrips larvae, but currently they are not permitted to be released to UK polytunnels. All these predatory mites will only contribute to control of thrips species that breed on the host plant, i.e. that produce larvae that the mites can predate.

*N. cucumeris* can now be used successfully within an IPM programme for control of WFT on most UK strawberry crops (Raffle et al., 2015). However, it does not always control thrips of other species, particularly when large numbers of adults are found in flowers and when fruit damage is seen at the same time or shortly afterwards. It is possible that immigrant adult thrips of other species are causing fruit damage before they start breeding in the crop and, in the case of *T. fuscipennis,* although strawberry has been recorded as a host crop (Morison, 1947–9), so far no larvae have been found in strawberry flowers in SF 156 (annual report 2019). Larvae of *T. major, T. tabaci* and *F. intonsa* have been confirmed in strawberry flowers in SF 156, although in much lower numbers than adults, unlike where WFT is the predominant species, when large numbers of larvae can occur in strawberry flowers.

Before WFT became a common pest species in protected crops in Europe, *T. tabaci* was the most common thrips species. The first IPM programmes to include *N. cucumeris* for control of *T. tabaci* were developed in sweet pepper in the Netherlands (Ramakers, 1987; Ravensberg & Altena, 1987; Altena & Ravensberg, 1990). However, although these programmes were successful for control of *T. tabaci*, problems with *T. fuscipennis* sometimes occurred (Ramakers, 1987; Ravensberg & Altena, 1987). The authors do not explain why *T. fuscipennis* was not controlled by *N. cucumeris,* but large invasions of rose thrips adults to glasshouses have been reported in Europe, where they have occasionally damaged sweet pepper, aubergine and rose crops and are difficult to control biologically, with larvae rarely being seen under glass (Malais & Ravensberg, 2003).

WFT second-instar larvae dropped from cucumber and pot chrysanthemum plants to the ground to pupate when relative humidities were below 81% (Holmes et al., 2012), although at higher humidities they can pupate on host plants (Steiner et al., 2011). This behaviour offers the opportunity to use ground-based control measures against WFT. In addition to using *N. cucumeris* for control of WFT larvae on the plants, some growers of various protected crops are also using *Stratiolaelaps scimitus* (formerly known as *Hypoaspis miles*) applied to the substrate. This is a ground-dwelling predatory mite which feeds on WFT larvae and pupae after the larvae drop to the ground to pupate and can contribute to WFT control in IPM programmes (Bennison et al., 2002a). Where *S. scimitus* has been used together with *N. cucumeris* and *Orius* in IPM programmes on strawberry, improved control of WFT is considered to have been given (Raffle et al., 2015). *T. tabaci*, *T. major* and *T. fuscipennis* are all reported to drop to the ground to pupate (Table 1), therefore *S. scimitus* is likely to contribute to control of their ground-dwelling life stages. However, *F. intonsa* is thought to pupate on host plants and pupae have been observed behind the calyx of strawberry fruit and, therefore, if no larvae drop to the ground to pupate, larvae and pupae would not be controlled by ground-dwelling predatory mites. However, there has been very little research on pupation sites of different thrips species and the factors that determine whether they pupate on or off the plant. Much of the information appears to be based on a few observations. Further knowledge of pupation sites could be important for understanding the effects of various control measures.

## *Orius* spp.

*Orius* spp. are commonly occurring predatory anthocorid flower bugs feeding on thrips, aphids, mites and other small invertebrates. Both the adults and nymphs have the advantage, unlike *N. cucumeris*, of feeding on both thrips adults and larvae and the adults can actively fly to find food. There are six native species in the UK (Bantock & Botting, 2012), including the two commercially available species, *Orius laevigatus* and *Orius majusculus*. *O. laevigatus* is commonly released to flowering crops for control of WFT, e.g. sweet pepper and strawberry, as it is more of a flower-dweller than *O. majusculus* and can establish on pollen in the absence of prey. *O. laevigatus* also occurs on many other flowering plants and weeds, e.g. clover (Loomans et al., 1995). Population growth and establishment of *O. laevigatus* in a crop is mainly dependent on temperature and food supply. Typically, *O. laevigatus* establishes well in strawberry crops in warm summers and when there are plenty of flowers to provide pollen and potentially thrips as food. Egg laying occurs mainly between 20 and 30°C, with very few being laid below 15°C, and time from egg to adult is 27 days at 20°C and 12 days at 30°C (Malais & Ravensberg, 2003). Therefore, releases should only be made when temperatures are suitable for establishment, i.e. from May/June onwards in UK polytunnels, depending on the season (Raffle et al., 2015). *O. laevigatus* is known to predate *T. tabaci*, as well as WFT (Loomans et al., 1995). ADAS work in AHDB Project CP 89 indicated that *O. laevigatus* provided similar reduction in numbers of thrips per flower to spinosad (Tracer) on an outdoor commercial strawberry crop in 2014 where *T. fuscipennis* was the only species confirmed (Bennison & Hough, 2015). *O. laevigatus* established in two outdoor strawberry crops in Essex and Buckinghamshire during July and August 2018 and is considered to have contributed to keeping a mix of thrips species, including *T. fuscipennis*, *T. major, T. tabaci* and *F. intonsa*, below damaging levels (SF 156 2018 annual report). Thus it is likely that *O. laevigatus* predates all these thrips species. *O. laevigatus* is susceptible to some chemical plant protection products used on strawberry crops for control of spotted wing drosophila (SWD), e.g. Tracer, which is harmful for 1–2 weeks after application. However, *O. laevigatus* was still found in strawberry flowers following applications of cyantraniliprole (Benevia) for SWD control in 2018 (SF 156, 2018 annual report) and this plant protection product is reported to be safe to this predator (Koppert, n.d.).

*O. laevigatus* is expensive to release and populations can be slow to establish on strawberry, particularly when flowers are scarce. Research has been done on boosting numbers of the predator using flowering ‘banker’ plants to provide an additional host plant and source of pollen. *Lobularia maritima* (alyssum) has been recorded as a natural early-flowering host plant for *O. laevigatus* in Spain (Alomar et al., 2006). In a pilot experiment in a UK research glasshouse, *O. laevigatus* established well on flowering alyssum, quickly dispersed to and established on flowering ever-bearer strawberry plants and rapidly reduced numbers of WFT (Bennison et al., 2011; and HortLINK report for project HL01107). Alyssum has a long flowering period and has the potential for use as a combined ‘trap’ plant for WFT and ‘banker’ plant to support *O. laevigatus* populations in ever-bearer strawberry for improved biological control within an IPM programme. In Florida and Canada, researchers and growers have also planted alyssum around strawberry crops to increase numbers of *Orius* spp. for improved control of *Frankliniella bispinosa* and WFT respectively (Renkema, personal communication, 2019). Results also indicated that alyssum could have the added benefit of providing a trap crop for capsids and a repellent for SWD.

As an alternative to using flowering plants as ‘banker’ plants for pollen-feeding natural enemies, growers of glasshouse crops in Europe are using a commercially available *Typha* (bulrush) pollen (Nutrimite™) to boost numbers of some species of predatory mites. For example, *Amblyseius swirskii* and *Iphiseius degenerans* have been provided with Nutrimite™ for improved establishment of the predators, and thus better control of thrips, spider mites and whiteflies, in strawberry, rose, poinsettia, sweet pepper and cucumber (Nguyen et al., 2015; Pijnakker et al., 2017; Jacob and Pijnakker 2017). WFT can also feed on *Typha* pollen (Hulshof & Vanninen, 2002), but, despite this, the pollen benefits these predatory mite species and WFT control. Nutrimite™ is also being used in glasshouse strawberry in Europe to allow *Amblyseius swirskii* to establish better in advance of thrips infestation for improved biological control (Collen, 2018).

The effect of Nutrimite™ on *Orius* establishment is not known. However, research has been done on providing *O. laevigatus* with other pollens in order to improve biological control of WFT. In laboratory tests, providing *O. laevigatus* third-instar nymphs or adults with pine pollen on cucumber leaves increased predation rates on WFT larvae compared with on cucumber leaves alone (Hulshof & Linnamaki, 2002). Adding pine pollen allowed *O. laevigatus* females to lay eggs in the absence of thrips prey but did not increase predation of WFT adults.

*O. laevigatus* lay eggs in strawberry flowers and on green, white and ripe fruit and petioles and egg hatch is higher on flowers than on leaves (Coll et al., 2005). Work would be justified on testing whether *O. laevigatus* feed and lay eggs on strawberry plants when fed with Nutrimite™ when flowers are scarce and determining the effects of providing a pollen food source on predation of adult thrips species, e.g. *T. fuscipennis*. Adding pollen from oilseed rape boosted the oviposition rate of *T. fuscipennis* compared with that on other floral tissues in the laboratory (Kirk, 1985b).

### ***Aeolothrips* spp.**

*Aeolothrips* spp. are naturally occurring predatory thrips, feeding on other thrips species and other small invertebrates, including some mite species such as two-spotted spider mite, whiteflies and aphids (Trdan et al., 2005). They also feed on pollen of many flowering plants, and whereas they can complete their development on pollen, they cannot complete their development on WFT alone (Bournier et al., 1979; Trdan et al., 2005). *Aeolothrips* spp. are commonly known as banded thrips due to the dark, broad stripes on their wings. There are over 20 species of *Aeolothrips* in Europe, with *Aeolothrips intermedius* being the most common. *A. intermedius* is recorded as a predator of more than 44 thrips species (Riudavets, 1995), including *T. tabaci* (Bournier et al.,1978; Lacasa et al., 1982; Trdan et al., 2005) and WFT (Elimem & Chermiti, 2012). Large populations of *Aeolothrips* are reported to have been responsible for reducing *T. tabaci* populations more than pesticide applications in field vegetable crops in Ethiopia (Zereabruk et al., 2018). In Italy, *A. intermedius* is also recorded as frequently occurring in flowers together with *F. intonsa*, e.g. on alfalfa and clovers in Italy (Conti, 2009). In Italy, *A. intermedius* is thought to have 3–4 generations a year, with adults being active from early April to late September. *A. intermedius* is often seen in strawberry flowers in the UK, for example in AHDB project SF 156, it was recorded in strawberry flowers in 2018 together with a mix of thrips species, including *T. fuscipennis, T. major, T. tabaci* and *F. intonsa* between June and August. Both the adults and larvae of *Aeolothrips* spp. predate thrips larvae, but there are no published records of them predating thrips adults. Therefore, *Aeolothrips* spp. are likely to contribute to control of thrips species that breed and produce larvae in strawberry flowers. So far in SF 156, larvae of WFT, *T. major* and *F. intonsa* have been confirmed in strawberry flowers but only adults of *T. fuscipennis* have been found, although strawberry is recorded as a larval host plant for *T. fuscipennis* (Morison, 1957).

Several other natural enemies will predate *Aeolothrips* spp., including *Orius* spp. *A. intermedius* survived well together with *Orius niger* on potato in Iran with high populations of *T. tabaci* but not with low thrips populations, when more intraguild predation occurred (Fathi et al., 2008). In SF 156, *O. laevigatus* occurred in strawberry flowers together with *A. intermedius* during July and August.

*A. intermedius* would be difficult to rear as a commercial predator as the larvae are cannibalistic when reared in the laboratory (Loomans et al., 1995), although this has not been observed in the field. It might be possible to boost populations of *Aeolothrips* spp. by planting flowering plants around or among strawberry crops to provide pollen when strawberry flowers are scarce, which is when thrips adults congregate in the few available flowers and potentially lead to fruit damage.

## Entomopathogenic fungi (EPF)

Several entomopathogenic fungi (EPF) are approved for use as bioprotectants in the UK. Two *Beauveria bassiana* products are approved for use on protected strawberry: Naturalis-L is recommended on any protected edible crop and BotaniGard WP may currently be used on strawberry in fully enclosed glasshouses, but not in polytunnels. Mycotal (*Lecanicillium muscarium*) is also approved for use on protected strawberry. All these products are recommended for use as high-volume sprays for control of whitefly, although they will also give some control of thrips. The products applied as sprays are more effective in high relative humidities (60–80% depending on product) (Bennison et al., 2015) in order to allow the spores to germinate, grow and infect the host insect.

*Metarhizium anisopliae* (Met52 Granular Bioinsecticide) is also approved for use on both outdoor and protected strawberry for control of vine weevil, when incorporated into soil or substrate. This EPF is also known to give some control of WFT ground-dwelling life stages, i.e. second-instar larvae and pupae after the larvae drop to the ground to pupate (Ansari et al., 2008). However, as most UK strawberry crops are grown in coir substrate that is imported as solid blocks in grow bags that are then wetted up before planting, incorporation of Met52 Granular Bioinsecticide is not practical. A liquid formulation of this EPF, Met52 EC, is approved in Canada and the US on various crops, including strawberry, for use either as a foliar spray or as a drench, for control of thrips, whitefly, mites and weevils. This product is not yet approved for use in the UK.

Most research investigating the efficacy of EPF against thrips has been done on WFT (e.g. Jacobson et al., 2001; Gouli et al., 2009; Niassy et al., 2012), but some studies have also included *T. tabaci* (Gillespie, 1986; Vestergaard et al., 1995). Efficacy is reported to be greater against adult WFT than against larvae (Vestergaard et al., 1995; Maniania et al., 2001), possibly due to larvae removing the spores from their bodies during moulting. EPF can be adversely affected by fungicides applied for disease control and can also potentially infect non-target beneficial species (Thungrabeab & Tongma, 2006), so these factors should be considered when planning an IPM programme. However, Horticultural Development Council (HDC) funded research on cucumber crops (PC 129 report; Jacobson et al., 2001) showed that sprays of Naturalis-L and BotaniGard WP gave 65–85% control of WFT adults and larvae on a cucumber crop and there was no evidence that the activity of *N. cucumeris* was impaired by EPF application. *B. bassiana* is also reported to be compatible with *Orius sauteri* for biological control of WFT (Gao et al., 2012). *Lecanicillium muscarium* is reported to be safe to both *N. cucumeris* and *O. laevigatus* (Koppert, n.d.).

Some research has been done with EPF against WFT on strawberry. Sprays of BotaniGard WP and Met52 onto strawberry plants in polytunnel/cage experiments did not reduce numbers of WFT adults and larvae in HortLINK project HH01107: HDC SF 120 (Cross et al., 2014). The reasons for this are not clear but may have included the thrips in the flowers not receiving a lethal dose of fungal spores. Although no published records could be found of testing EPF against *T. major* or *F. intonsa*, EPF are known to give some control of other thrips pests, such as legume flower thrips, *Megalurothrips sjostedti* (Ekesi et al., 2009; Mfuti et al., 2017) and chilli thrips (Arthurs et al., 2013), so it is likely that they will infect most thrips species. *Metarhizium* spp. have also been shown to have potential for use, together with the thrips attractant LUREM-TR, in a lure-and-infect strategy for control of *M. sjostedti* using an autoinoculation device (Mfuti et al., 2017).

## Entomopathogenic nematodes (EPN)

Most of the research on using EPNs for control of WFT has been done with *Steinernema feltiae (*e.g. 'Nemasys'®). *S. feltiae* was shown to be effective against WFT on pot chrysanthemum in Defra-funded project HH 3102TPC (Bennison, 2006). This research showed that *S. feltiae* was effective when applied to the ground only, or to both the plants and ground, but not when applied to the plants only. This result indicated that the nematodes were more effective against the ground-dwelling life stages of WFT than those on the plants. Research in Canada confirmed this result, when experiments in the laboratory and on pot chrysanthemum showed that *S. feltiae* was more effective on WFT prepupae and pupae than on larvae and was ineffective against adults (Buitenhuis & Shipp, 2005). Drenches of *S. feltiae* are now widely used in Canadian ornamental crops for control of WFT (Brownbridge et al., 2014).

Research in Canada has also demonstrated that when a combination of *S. feltiae* (applied as a high-volume spray to both plants and compost) and Met52 (used as the granular formulation mixed with the compost) were applied to pot chrysanthemums, both treatments reduced numbers of WFT, but the combination of the nematode and EPF treatments gave better control than either of the individual treatments (Brownbridge et al., 2014*).* Entomopathogenic nematodes are currently not used for control of thrips on strawberry but are widely used in the UK through dripline irrigation for vine weevil control. Some UK growers of strawberry and blueberry are successfully using a 'little and often' approach to using nematodes for vine weevil control, applied through the irrigation (Bennison et al., 2018). Recent research has shown that this method is also effective against vine weevil when applied through overhead irrigation on hardy nursery stock (Bennison et al., 2017). Research would be justified on testing whether the nematode species used for vine weevil control (*Steinernema kraussei* and *Heterorhabditis bacteriophora*) also control thrips and whether a 'little and often' approach to using them through dripline irrigation on strawberry could give control of both target pests. Nematodes, when used either alone or in combination with Met52 (if a liquid formulation becomes available in the UK), might give effective control of thrips species other than WFT on strawberry that drop to the ground to pupate.

For example, *T. tabaci* larvae drop to the ground to pupate and both *S. feltiae* and *Steinernema carpocapsae* have been shown to be effective against ground-dwelling *T. tabaci* prepupae and pupae (Khajehali & Poorjavad, 2014).

# Cultural control

### Mass monitoring for WFT

As thrips adults can actively fly and be carried on the wind, their attraction to both colour and scent can potentially be used in monitoring, mass trapping, push-pull or lure-and-kill management strategies. WFT is known to be attracted preferentially to a certain shade of blue (Brødsgaard, 1989; Sampson et al., 2012; Sampson, 2014; Vernon & Gillespie, 1990). Both males and females are attracted to an aggregation pheromone (neryl (*S*)-2-methylbutanoate) produced by male WFT (Hamilton et al., 2005) that is now commercially available either as individual lures or incorporated in the glue on sticky traps. The WFT aggregation pheromone is specific to WFT and does not attract other species of thrips, such as onion thrips, *T. tabaci* (Broughton & Harrison, 2012). The WFT aggregation pheromone can increase numbers of WFT on sticky traps (Sampson et al., 2012; Broughton et al., 2015), but this effect is reduced on traps that are not visually attractive to thrips, indicating that attraction to colour and scent are linked. The pheromone is considered to increase the amount of time WFT adults spend actively flying or walking rather than feeding (Kirk, 2017).

Several UK growers currently use 'mass monitoring' of WFT in strawberry, using blue roller traps in the leg rows or under tabletops, with or without the commercially available aggregation pheromone lure specific to WFT. The roller traps are used as part of an IPM programme, together with releases of predatory mites and often additional releases of *O. laevigatus*. This is a result of research in a Defra HortLINK project which showed that the traps could significantly reduce WFT numbers in the crop and reduce thrips damage to fruit, although results from different trials were variable (Sampson, 2014; Harnden et al., 2015; Raffle et al., 2015). Of the 11 roller trap trials carried out in ever-bearer crops around the country, thrips density was low in some and two were terminated early. Of the seven remaining trials, roller traps significantly reduced numbers of adult thrips per flower in six trials, and of these, the traps significantly reduced fruit damage in three trials. The addition of the WFT aggregation pheromone to the roller traps significantly improved WFT control in some trials but only by a small margin. For example, in one season, the traps without the pheromone reduced WFT numbers in flowers by 61% and fruit damage by 55%, but with the pheromone they reduced WFT numbers by 73% and fruit damage by 68% (Sampson et al., 2012; Raffle et al., 2015). The traps could not be relied on as the sole method of control, being more effective when used together with the predatory mite, *N. cucumeris*. The traps were most useful at sites with a history of poor WFT control and in higher-risk crops, e.g. those grown for a second year and thus with overwintered WFT populations from the previous crop. However, the traps also caught thrips even at low densities and thus it is likely that they helped to reduce population increase. The traps were more effective between July and September, when WFT fly more frequently, than between April and June when it is cooler.

There is some concern among growers and agronomists that roller traps can also attract and/or trap flying beneficial invertebrates, including thrips predators and pollinators such as bumble bees. White sticky traps have been reported to catch more bees than blue traps (Clare et al., 2000). *Orius* spp. have been recorded on blue, yellow and white sticky traps (Boone, 1999; Atakan & Bayram, 2011). However, it is considered that *Orius* may accidentally fly into traps rather than being attracted to them as only low numbers were recorded on blue, yellow, clear or black traps in a sweet pepper crop where they were well established in the crop (Sampson et al., 2012). The predatory thrips *Aeolothrips* spp. were also recorded on sticky traps in the same sweet pepper crop, with more caught on yellow than blue (Sampson et al., 2012). However, numbers of *Aeolothrips* in the sweet pepper crop itself were not recorded and further work would be needed to estimate the potential impact of traps on their populations. UK growers who routinely use blue roller traps as part of their IPM strategies for thrips control in strawberry have not observed any negative effects on pollination or on numbers of *Orius* in the flowers (Creed, Sampson, personal communication).

### Potential for mass monitoring for other thrips species in strawberry

The responses to colour of the thrips species, other than WFT, that are commonly found in UK strawberry crops have been less studied than those of WFT. Higher numbers of *T. major* and *T. tabaci* were recorded in blue, yellow and white without UV water traps than in green, red, black or white with UV traps in a grass field in the UK (Kirk, 1984). Higher numbers of *F. intonsa* were recorded on blue sticky traps in a greenhouse crop of strawberries in Korea than on yellow or white, and more were found on traps 50 cm above the ground than on those at 10 cm above or on the ground (Seo et al., 2006). However, more *F. intonsa* were reported in yellow water traps in a wheat field in Serbia than in blue, white or red traps (Andjus et al., 2002). It is possible that different shades of blue and other colours were used in the different studies, which could explain the variable results. Many published studies compare only one particular colour of yellow and one of blue without measuring the diffuse reflectance spectra, but the shade of the colour can make a big difference to thrips response (Brødsgaard, 1989), so such studies are of limited value in determining the best colour for trapping.

Little information is available on the attraction of *T. fuscipennis* to colour. Significantly more *T. fuscipennis* and *T. tabaci* were recorded on blue traps than on yellow or white traps in pea fields in two consecutive years in Poland and trap light reflectance measurements were made (Pobozniak et al., 2020). In the same study, similar numbers of *F. intonsa* were recorded on both blue and yellow traps in one year, but significantly more on yellow in the second year. In both years, white traps were significantly less attractive to the three thrips species. Numbers of thrips adults trapped were lower in rainy and cooler periods. The thrips adults were usually detected on traps a few days earlier or at the same time as on the plants, but the majority were found on blue traps when the crop was flowering. Numbers of *A. intermedius* recorded on yellow traps were higher than on blue or white traps in pea crops in both years, but only by 24–65%. These results indicate that blue traps could be used for early detection of immigrant adults of the three pest thrips species and also for potential ‘mass monitoring’. In AHDB project SF 156, preliminary data indicated that more *T. fuscipennis* were recorded in blue water traps on a tabletop strawberry crop than in yellow or green and the absolute irradiance spectra were measured in this experiment (SF 156 final report, 2020). Several studies have suggested that white traps (without UV) can catch more *T. tabaci* than blue or yellow (Kirk, 1984; Fernandez & Lucerna, 1990; Atakan & Pehlivan, 2015). However, it is worth noting that all shades of blue are not the same and some attract many more thrips than others (Brødsgaard, 1989).

The aggregation pheromone has been identified for *F. intonsa.* It has the same components as the aggregation pheromone of *Frankliniella occidentalis* (WFT), but a particular ratio of two compounds worked best in laboratory olfactometer experiments in China (Zhang et al., 2011; Li et al., 2019).

The most widely internationally studied non-pheromone semiochemical as a thrips attractant is methyl isonicotinate (MI), now commercially available as a thrips lure (LUREM-TR). This lure is reported to increase numbers of at least 12 thrips species on traps, including WFT, *T. major* and *T. tabaci* (Teulon et al., 2017). For example, in a sweet pepper glasshouse, sticky traps with a prototype MI lure caught 12–60 times more *T.major* than traps without the lure, and in an outdoor leek crop, traps with LUREM-TR lures caught 2–13 times as many *T. major* as traps without the lure (Teulon, 2008). There is no evidence yet that MI attracts *T. fuscipennis* or *F. intonsa* (Teulon, personal communication). However, as MI is very similar to compounds found in the flowers of many thrips host plants, it is likely to be used by flower-dwelling thrips in finding host plants (Teulon et al., 2017) and thus it is possible that both these species are attracted to MI.

LUREM-TR was shown to be useful together with blue sticky traps for monitoring the flower-dwelling thrips *M. sjostedti*, *Frankliniella schultzei* and WFT in French beans in Kenya (Muvea et al., 2014). In the same study, more natural thrips predators, *Orius* spp. and the thrips parasitoid *Ceranisus menes* were recorded on yellow than blue traps, but use of LUREM-TR did not increase catches of these natural enemies. However, Davidson et al. (2015) reported that both *O. laevigatus* and *Orius albidipennis* respond to MI, which may lead to opportunities for optimising predation. LUREM-TR was also shown to have potential in a lure-and-infect strategy for controlling *M. sjostedti* together with entomopathogenic fungi in an autoinoculation device (Mfuti et al., 2017).

There are many anecdotal reports from around the world that mass trapping is effective in reducing thrips damage in various crops. However, there is little rigorous scientific evidence of its efficacy. Further research is needed, using the necessary replicated large plots monitored over several months. Current knowledge on the potential for mass monitoring of a mixture of thrips species in UK strawberry as part of an IPM strategy indicates that use of blue roller traps together with LUREM-TR would be a promising avenue for future research.

### Push-pull

A push-pull strategy could be developed for thrips pests, whereby the target pest is 'pushed' from the crop using a repellent and 'pulled' with a lure to either traps or plants where the thrips can be controlled using 'mass monitoring' or with biological control agents. In Defra-funded projects HH1838SPC and HH3102TPC, research was done using pot chrysanthemum as a model crop to develop a push-pull strategy for WFT. The research aimed to lure WFT adults to attractive 'trap' pot chrysanthemum cultivars, where predators including *O. laevigatus* could be released or attracted for improved, cost-effective control (Bennison, 2002a; Bennison et al., 2002b; Bennison, 2006). Pot chrysanthemum cv. 'Swingtime' opening buds and flowers were highly attractive to WFT and lured WFT from a crop of pot chrysanthemum cv. Charm. Olfactometer studies showed that one of the volatiles collected from 'Swingtime' buds, *(E)*-ß-farnesene (EBF), attracted WFT. In a glasshouse experiment, EBF lures enhanced thrips attraction to 'Swingtime' plants. *O. laevigatus* was attracted to WFT-damaged 'Swingtime' buds and to EBF, and both adults and third-instar nymphs were effective predators of both WFT adults and larvae in 'Swingtime' flowers. Rosemary leaves and volatiles were repellent to WFT but were also repellent to *O. laevigatus*. A plant-derived extract from *Tasmannia* spp. containing high levels of the antifeedant polygodial reduced the number of WFT settling and remaining on chrysanthemum plants but did not repel *Orius*. However, when sprayed to the plants, the antifeedant caused petal damage and was difficult to obtain, so no further development was done with it as a repellent volatile for use as a 'push' component. The later development and commercial availability of other products (the WFT aggregation pheromone and LUREM-TR) may explain why there was no further development of EBF as a commercial thrips lure.

Several other compounds have since been found to be repellent to thrips (Koschier et al., 2007), such as oregano oil, which reduced the number of onion thrips (*T. tabaci*) caught on coloured plates by 86% (van Tol et al., 2007). Although several essential oils are repellent to thrips, none are commercially available as they are needed in large quantities and cannot be patented because their effects are already known and have been published (only newly discovered repellents would be able to be patented). Therefore, companies are unwilling to invest in product development. However, a current promising candidate is the generalist insect repellent methyl salicylate (now available commercially in the UK as PrediPal® for use in protected crops and MagiPal® for use in outdoor crops). Methyl salicylate is a volatile compound produced by plants in response to pest feeding that is currently being marketed as an attractant for natural enemies. This compound is also reported to be a general pest repellent (Sampson, personal communication, 2019). Methyl salicylate was repellent to WFT in laboratory olfactometer tests (Chermenskaya et al., 2001) and is a potential innovative new tool for pest management, warranting further independent research in crop-scale experiments.

A preliminary study using PrediPal® as a 'push' component in 2019 in a commercial tunnel-grown ever-bearer strawberry crop (in the UK) tested a potential push-pull strategy for the control of WFT within an IPM programme (Griffiths & Sampson, personal communication). PrediPal® blister packs were placed on the tabletops and the 'pull' component was the use of 'mass monitoring' blue sticky roller traps together with the WFT aggregation pheromone lure, fixed below the tabletops, 20 cm above the ground. Using this system, significantly fewer thrips were found in flower samples in August in all treatments applied to replicate plots (PrediPal® alone, PrediPal® with roller traps and WFT pheromone, roller traps and WFT pheromone alone) than in control plots. However, thrips numbers were low even in control plots (less than one per flower). Significantly more thrips (both WFT and 'other' species) were recorded on the roller traps in plots with PrediPal® than in plots without in both August and October. Although these ‘other’ species of thrips on the traps were not identified, prior to the study, thrips identified from strawberry flowers included WFT, *T. fuscipennis* and *T. major.* Mean percentage fruit area bronzed was low during the trial period. However, significantly more fruit with over 10% fruit area damaged (the usual ‘threshold’ for downgrading) was recorded in control plots than in all treated plots. There were no significant differences in percentage natural parasitism of aphids in any of the treatments, indicating that the push-pull strategy for thrips control would be compatible with biological control of aphids within an IPM programme. Very few bumble bees, *Orius* spp., hoverflies, lacewings and ladybirds were recorded on the roller traps. However, pest densities in the strawberry flowers were low during the study and this could explain why only low numbers of predators were recorded. Further work is justified on developing a push-pull strategy within an IPM programme for the thrips species mix causing damage to strawberry and, ideally, the strategy should be tested in crops with higher thrips pressure than in the preliminary study.

## Intercropping

Intercropping, where different plants are grown among the crop plants to deter pests from the crop, has been tested to evaluate reductions in onion thrips, *T. tabaci* in allium field crops with mixed results. For example, intercropping with carrot reduced numbers of *T. tabaci* in onion but reduced yield (Gachu et al., 2012; Vijayalakshmi et al., 2018). Similarly, intercropping with maize reduced numbers of *T. tabaci* in leek, but the maize competed with the leek plants for space and reduced yield (Santillano-Cázares et al., 2019). Intercropping leek with strawberry clover (*Trifolium fragiferum*) suppressed the numbers of *T. tabaci* by 67% (den Belder et al., 2000), although the clovers were not an effective ‘trap’ or host plant for *T. tabaci* in onion (Legutowska & Theunissen, 2003). However, it is of interest that *T. fuscipennis* females, males and larvae were recorded on the strawberry clover tested as an intercrop. Recent work indicated that sugar snap peas could be a potential trap crop for *T. tabaci* in leek (Lippens, personal communication), although higher levels of thrips damage were recorded in the crop plants close to the sugar snaps than further away. Another potential benefit of intercrops is boosting numbers of beneficial insects. Plots of cabbage used as an intercrop in an onion crop in Ethiopia reduced numbers of *T. tabaci* in the onions more than in plots treated with insecticide and this was attributed to higher numbers of the predatory thrips *Aeolothrips* spp. (Zereabruk et al., 2018). Use of intercropping in strawberry has not been tested, although alyssum has been researched in the UK and the USA to boost numbers of *Orius* spp. for thrips control in strawberry (see Biological Control section).

## Netting and colour-absorbing screens

Netting or screens can be used to reduce the number of immigrant insect pests, including thrips, from gaining access to protected crops, particularly in the Mediterranean countries and Africa where there is high pest pressure outdoors, e.g. in tomato in Kenya (Gogo et al., 2014) and in sweet pepper in Israel (Legarrea et al., 2010). However, netting with fine mesh size to exclude thrips significantly reduces ventilation in glasshouses or polytunnels. This can lead to poor plant growth due to excessive temperatures, e.g. in tomato production in Morocco (Fatnassi et al., 2002), and increased disease problems due to high humidities. Trials using netting with a mesh size larger than thrips-proof netting allowed increased air circulation. Treating it with deltamethrin, the numbers of WFT infesting a bean crop were reduced by 52–70% compared with where no netting was used and by 43% compared with where untreated netting was used (Arthurs et al., 2018). Use of yellow or blue nets has been reported to give improved protection against thrips and this was improved further in protected chive and cucumber by weaving aluminium strips into the netting to reduce infestation by WFT and *T. tabaci* (Ben-Yakir et al., 2008). Some UK growers are now using insect-proof netting on polytunnel doors to reduce access to spotted wing drosophila and this may also reduce immigration of thrips. One grower has observed fewer thrips problems in strawberry where thrips-proof netting has been used on tunnel doors (McGuffie, personal communication).

## Cultivar choice and host plant resistance

Although there has been a lot of research on breeding strawberry cultivars with resistance to diseases, very little research has been done on strawberry host plant resistance or tolerance to pests including thrips. Three strawberry cultivars (Albion, Camarosa and Camino Real) were compared for their suitability as host plants for WFT (Rahman et al., 2010). WFT was attracted more to cv. Camarosa than the other two cultivars and feeding damage, survival rate and egg laying were also highest on Camarosa. It is commonly observed in UK commercial strawberry crops that more fruit damage occurs on some cultivars, whereas others show little or no fruit damage even with high numbers of thrips in the flowers (ADAS, unpublished, and Hubert, personal communication). For example, high levels of fruit damage and crop losses have been reported in the June-bearer cultivar Malling Centenary and it has been suggested that this may be partly due to its large, upward-facing flowers that could be attractive to thrips and suitable for their feeding and reproduction. Mature flowers at the top of ever-bearer strawberry plants cv. Camarillo had twice as many adult WFT as flowers at the side (Sampson & Kirk, 2012). The ever-bearer cultivar Murano also has highly visible flowers at the top of the plants and this, together with its earlier flowering time, was suggested to be the reason for recording higher thrips populations (mainly *F. intonsa* and *T. tabaci*) on cv. Murano than cv. Favori in Denmark (Nielsen, 2019). It is also possible that cv. Favori is more tolerant of thrips fruit damage, as high numbers of WFT adults (over 20 per flower) have been recorded in the UK on a crop of this cultivar yielding class-A fruit (Hubert, personal communication, 2019).

There could be many plant traits that confer host suitability to thrips. Although strawberry cultivars are only commercially available for a few years before being replaced with new ones, it would be very useful to identify the traits that could allow plant breeders to select for cultivars that either have some host plant resistance or tolerance to thrips.

### Chemical control with conventional plant protection products

At sites where the IPM programme used for WFT control has not been effective against other thrips species and where fruit damage has occurred, some growers have needed to apply plant protection products to prevent further damage. Growers have often used spinosad (Tracer), which is currently effective against all thrips species occurring on strawberry, except for WFT. However, there is concern that, like WFT, other thrips could develop resistance to Tracer and other control products. Resistance to the synthetic pyrethroid deltamethrin has been reported in populations of *T. tabaci* from UK leek and salad onion crops and is considered to be widespread (Foster et al., 2010), so pyrethroids or pyrethrins may not give control of this species on strawberry. In addition, the number of Tracer applications permitted on each crop is limited and growers may prefer to reserve these for control of spotted wing drosophila (SWD). Cyantraniliprole (Benevia 10OD) has also been used for SWD control on strawberry using an emergency authorisation and this may have given some incidental control of a mix of thrips species in UK strawberry crops (SF 156, 2018 annual report). Cyantraniliprole was effective against *Scirtothrips dorsalis* (chilli thrips) and *Frankliniella bispinosa* (Florida flower thrips) in Florida strawberry crops (Renkema et al., 2020). Neither of these species is native to the UK (Collins, 2010). Cyantraniliprole can be integrated safely with *Orius,* whereas Tracer is moderately harmful to *Orius* up to one week after application (Koppert, n.d.). Thiacloprid (Calypso) is often used on strawberry for control of strawberry blossom weevil and capsids and this is likely to give some incidental control of thrips species other than WFT. However, thiacloprid is due to be withdrawn (sale up to October 2021 and use-up date October 2022) and is harmful to *Orius* for two weeks (Koppert, n.d.). Growers wish to reduce their reliance on chemical plant protection products, so an effective IPM solution for the mix of thrips species on strawberry is needed.

## Promising avenues of research

This review has highlighted a number of areas deserving of further investigation or development which could lead to new and alternative methods of controlling thrips species other than WFT.

- Use of thrips repellents and attractants for push-pull of thrips adults
- Netting at tunnel ends as a barrier for thrips adults
- Boosting numbers of *Orius* and potentially *Aeolothrips* with ‘banker’ plants or pollen
- Establishing which thrips species damage and breed on strawberry and confirming pupation sites to aid decision-making about appropriate control measures
- Identifying strawberry plant traits conferring resistance to thrips or tolerance of fruit damage to enable plant breeding of thrips-resistant cultivars
- Determining whether entomopathogenic nematode species applied for vine weevil control can also contribute to thrips control

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