

THE POTENTIAL USE OF LURES FOR THRIPS BIOLOGICAL CONTROL IN GREENHOUSES: PRACTICE AND THEORY

**D.A.J. Teulon¹, M.M. Davidson¹, M.-C. Nielsen¹, N.B. Perry¹,
R.W.H.M. van Tol², & W.-J. De Kogel²**

¹New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch, New Zealand, teulond@crop.cri.nz, davidsonm@crop.cri.nz, nielsenm@crop.cri.nz, perryn@crop.cri.nz;

²Plant Research International, 6708 PB, Wageningen, the Netherlands, rob.vantol@wur.nl, willemjan.dekogel@wur.nl

ABSTRACT.

Exploiting the response of thrips pest species to odours has long been a goal for improving thrips pest management including biological control. Applications of attractants could include improved monitoring, push-pull (in conjunction with a repellent odour), lure and kill, and lure and infect technologies, and surveillance for invasive organisms. We have recently discovered that 4-pyridyl carbonyl compounds can elicit responses from a range of thrips species (*Thrips tabaci*, *T. major*, *T. obscuratus* and *Frankliniella occidentalis*) in the laboratory, in glasshouses and in open field bioassays. Some of these compounds can increase the trap capture of these thrips species in both commercial greenhouses and broad acre commercial crops where these species are considered pests. However, our understanding of the mechanisms eliciting this response in thrips is still only rudimentary. Greater knowledge of the underlying behavioural mechanisms, including the intrinsic and extrinsic factors that may affect these responses, as well as optimal trap design and configuration, and odour formulation, will be essential if semiochemical-based approaches are to be integrated into thrips management programmes.

INTRODUCTION.

Thrips, including *Frankliniella occidentalis* Pergande, *Thrips tabaci* L. and *T. palmi* Karny (Thysanoptera: Thripidae), are key pests of greenhouses and outdoor crops (Lewis 1997; Kirk & Terry 2003; Cannon *et al.* 2007) because of their ability to damage plants directly through feeding and indirectly through transmission of plant viruses. Biological attributes such as polyphagy, vagility, rapid reproduction, cryptic behaviour and insecticide resistance make them particularly difficult to manage (Mound & Teulon 1995; Morse & Hoddle 2006). Consequently, there has been considerable interest in developing a range of new methods for thrips pest management, including the use of semiochemicals as lures (Koschier 2008).

So far adult thrips lures fall into two main groups: (1) aggregation pheromones identified for *F. occidentalis* (de Kogel & van Deventer 2003; Kirk & Hamilton 2004; Hamilton *et al.* 2005); and (2) kairomone attractant chemicals derived from host plants and related compounds (Kirk 1985; Teulon *et al.* 1993, 2007a; Davidson *et al.* 2008). An alarm pheromone has also been identified from *F. occidentalis* (Teerling *et al.* 1993; MacDonald *et al.* 2002). In this paper we will concentrate on the kairomone lures as these have been the main focus of our research in recent years and there are some examples where such volatiles bring about large increases in thrips capture compared to control treatments (e.g. NZ flower thrips / ethyl nicotinate >100x (Teulon

et al. 1993), *Thrips hawaiiensis* (Morgan) (Thysanoptera: Thripidae) / methyl anthranilate >800x (Murai *et al.* 2000)).

The first report of volatile odours increasing capture of thrips was by Howlett (1914). Since then a range of methods have been used to study thrips (including greenhouse pest species) semiochemicals, including air entrainment, head space analysis, gas chromatography and mass spectrometry (GC-MS), electro-antennography (EAG), and Y-tube olfactometers, flight chambers, and field experiments (outdoors or indoors) (Koschier 2008). Some methods provide no information on the behavioural response of the thrips (e.g. EAG), while others may only measure the response of walking thrips (e.g. Y-tubes), flying thrips (flight chamber) or both (outdoor field bioassays).

A comprehensive review of the volatile compounds that attract adult thrips has recently been completed by Koschier (2008). In this paper we summarise potential practical uses of chemical lures, especially for biological control, and the theoretical understanding of their effects. We use the term lure to describe chemicals that elicit a positive response from thrips.

PRACTICE.

The main semiochemical-based pest management approaches are: mass trapping, lure and kill and mating disruption (El-Sayed *et al.* 2006) and improved monitoring.

Improved Monitoring and Mass Trapping.

Information obtained from coloured sticky boards on the presence/absence and seasonal abundance of thrips in greenhouses is critical for the appropriate timing, choice and quantity of (bio)control agents released for thrips control (Yano 2004). The addition of lures to coloured traps increases trap efficacy (Teulon *et al.* 1993; Davidson *et al.* 2007) and thus makes earlier and more accurate detection possible. The use of lures is likely to be most beneficial when thrips populations are low and traps without lures do not indicate the presence of thrips populations. Currently, two commercial products make claims to attract thrips in glasshouse crops: Thripline^{ams}[®] based on the *F. occidentalis* aggregation pheromone (www.syngentabioline.co.uk/productdocs/html/Thripline.htm) and LUREM-TR[®] based on a putative kairomone (www.koppert.com/Products_monitoring.LUREM-TR..14727+M52c9fe7ecac.0.html).

The use of semiochemicals for mass trapping thrips has been explored by a number of researchers (e.g. Kawai & Kitamura 1987; Roditakis *et al.* 2002; Natwick *et al.* 2007) but has not become an established practice. An effective mass trapping method would require a very strong lure and likely be effective only in the presence of several other mortality factors such as biocontrol agents.

Lure and Kill (lure and infect, trap crop, push-pull).

Semiochemicals can be used in other ways to lure thrips to a place where they may be killed (either immediately or at a later time), but none of these approaches

have become established practice. Ludwig & Oetting (2002) investigated a 'lure (Lure®) and infect' [*Beauveria bassiana* (Balsamo) Vuillemin (Hypocreales: Clavicipitaceae)] approach without any apparent improvement of *F. occidentalis* control as a result of the addition of the lure. Trap crops, using cultivars or other plant species that are more attractive to *F. occidentalis* than the main crop, have been proposed by several researchers (Bennison *et al.* 2001; Warnock & Loughner 2004; Matsuura *et al.* 2006). Bennison *et al.* (2001) also used the thrips lure (*E*)- β -farnesene to enhance the pull of the trap plant. Thrips can be killed on the trap crops by a number of means, including biological control agents. A slight modification of the trap plant approach is 'push-pull' where repellent compounds are used to push the thrips from the crop (Koschier 2008). Proof of concept of this approach was recently demonstrated by van Tol *et al.* (2007a) with *T. tabaci*, ethyl isonicotinate (lure) and *Origanum majorana* L. (Lamiaceae) (repellent).

Mating Disruption.

It is difficult to conceptualise how mating disruption might work with thrips given the inability to find true sex pheromones and thrips' unique biology. In thelytokous thrips species such as *T. tabaci* (Jenser & Szénási 2004) the inability to find a mate is irrelevant as all the populations are entirely female and unmated females produce only females. However, in arrhenotokous thrips species such as *F. occidentalis* (Brødsgaard 1989) unmated females produce males only and the loss of females from such a population should eventually lead to a population crash.

THEORY.

Research on thrips kairomone lures is still at a rudimentary stage. Some important areas for future research that will help greatly in the development of lures for thrips pest management are outlined below.

Host Finding Behaviour.

The response of thrips to colour and odour in experimental bioassays implicates vision and olfaction as important host finding cues for thrips (Brødsgaard 1990; Teulon *et al.* 1999; Smits *et al.* 2000). Just how thrips use these cues and how they are integrated for host finding are still not understood. There have been many studies examining the response of thrips to lures that measure the end process (i.e. number of thrips caught in a trap) without providing any information on the behavioural process(es) that lead to that outcome. Wind-tunnel bioassays (Teulon *et al.* 1999; Berry *et al.* 2006) indicated that the main response of thrips to a colour cue was directed movement toward the cue but when exposed to an odour cue thrips flight was inhibited. Whether these results are representative of thrips behaviour in more natural conditions or whether this was an artefact of the experimental design (e.g. too a high or too low a chemical dose) is still not clear. van Tol *et al.* (2007a) provided a compelling hypothesis for the behavioural responses to odour and visual cues that included a visual dominated landing response followed by odour dominated upwind movement after landing, but this has yet to be verified with additional experiments.

Mechanism of Olfactory Responses.

While some of the known thrips lures are commonly found in thrips host plants (especially flowers) (Teulon *et al.* 1993) and are therefore presumably involved in the natural thrips host plant finding processes, a number of lures, including some that elicit strong thrips responses (e.g. ethyl nicotinate/*Thrips obscuratus* (Teulon *et al.* 1993), ethyl isonicotinate/*Thrips tabaci* (Teulon *et al.* 2007a), are very rare in nature. Either these 'artificial' lures are much more common in nature than we realise (currently below the level of detection) or they mimic 'natural' lures in binding strongly to olfactory receptors. We can speculate on structural factors affecting binding to such receptors, but studies of insect olfactory receptors are at an early stage (Keller & Vosshall 2007) and no thrips receptors have been studied. We have reported a strong relationship between attractant vapour pressure and lure potency for a series of 4-pyridyl carbonyl compounds (Davidson *et al.* 2008), which may be useful for understanding changes in thrips responses in different environments.

Thrips Physiology.

Recently fed thrips show a weaker response to odour cues than starved thrips (Davidson *et al.* 2006), indicating that lures may be more effective against invading thrips than those resident within the crop. In a wind tunnel experiment odour did not affect the percentage of young (3 day post-emergence) or older (10-13 day post emergence) WFT females landing on a visual cue (Davidson *et al.* 2006). However, more older thrips landed on a yellow visual cue than younger thrips, although a similar percentage of either age group flew in the presence of the yellow cue.

Males and females from arrhenotokous species (e.g. *T. obscuratus*) and females from thelytokous species (e.g. *T. tabaci*) both respond strongly to certain lures (Teulon *et al.* 2007a), providing strong evidence that the lures are not sex pheromones.

Species-specific Responses.

Most lures identified provide responses for thrips species belonging to the genera *Frankliniella* and *Thrips* (Koschier 2008). These genera include many flower-inhabiting species that are key plant pests, including glasshouse pest species (Lewis 1997). However, currently there are no reported lures for *T. palmi*. Many thrips lures attract a range of different thrips species (Koschier 2008) but the strength of response to a given lure differs between thrips species. For example, the proportion of *T. obscuratus* caught in traps with ethyl nicotinate (up to 100x cf. controls) is much greater than for other thrips species (Teulon *et al.* 1993, 2007a). Similarly, the proportion of *T. tabaci* caught in traps with ethyl isonicotinate (up to 62x cf. controls) is much greater than of other species (Teulon *et al.* 2007a). This may be because different lures match different preferred natural attractants. Understanding such specific preferences could lead to the development of species-specific lures.

Dose-dependent Responses.

Y-tube olfactometer experiments, which restricts thrips' response to walking to a specific dose of a given volatile compound, have demonstrated dose-dependent

responses to a range of odours (Koschier *et al.* 2000; Davidson *et al.* 2008). For example *para*-anisaldehyde, at selected doses less than 1 µl, resulted in more western flower thrips females walking up the odour arm, while at 1 µl, a similar number walked up the clean air or odour-loaded arm (Koschier *et al.* 2000).

Lure Mixtures.

Only simple trials have been undertaken to blend two or more lures to increase the overall attractiveness. For *T. tabaci*, mixtures of *para*-anisaldehyde and methyl isonicotinate proved to be only as strong as the most powerful lure on its own, (i.e. methyl isonicotinate) (Teulon *et al.* 2007b). However, mixing the strongest known lures for *T. obscuratus* (ethyl nicotinate) and for *T. tabaci* (ethyl isonicotinate) resulted in a similar number of each species captured in a single trap with the mixture compared to separate traps for each odour. (Davidson & Teulon unpub. data). Combining the aggregation pheromone (Thripline_{ams}[®]) and the kairomone (LUREM-TR[®]) currently used in greenhouse crops to trap *F. occidentalis* may prove very fruitful as it would seem plausible that they both act on different receptors.

Host Plant Odour Masking.

While the potential for host plant odours to mask the lure odour has not been studied in detail there is some suggestion that lure effectiveness may be influenced by plants. Trap catches of onion thrips are much higher (cf. controls) in grass fields (84x) (a non-host) than in an onion crop (18x) (a host plant) (Davidson *et al. in press*) although other plant/crop specific characteristics may also be important (e.g. host plant colour). Nevertheless, the efficacy of kairomone lures has been demonstrated in a range of greenhouse vegetable and ornamental crops (van Tol *et al.* 2007b).

Greenhouse Conditions.

The efficacy of kairomone lures has also been demonstrated in a range of different countries from Oceania, Europe, North & South America and Africa (Davidson *et al.* 2007; de Kogel & Teulon unpublished data) although the degree of effectiveness may vary. We are currently investigating the ambient conditions (e.g. temperature, humidity, air flow) that may influence the response of thrips to kairomone lures and how this information may be used to optimise thrips management in different conditions.

Effective Lure Spacing.

In outdoor experiments traps with odour lures influenced trap capture of traps without odour lures 10 m away (Teulon *et al.* 2007c). In greenhouses, where there is generally considerably less air movement than outdoors care is needed to ensure odour lures are placed at appropriate distances from each other to maximise efficacy for the range of management techniques that may be developed with thrips lures. For research purposes it is important to realise that odour-baited traps may influence nearby control traps. From a practical point of view it means that odour-baited traps may also increase the efficacy of nearby unbaited traps.

CONCLUSIONS.

Exploiting the response of thrips pest species to odours has strong potential for improving thrips pest management, including biological control. A greater understanding of the behavioural response of thrips to these odours, including the intrinsic and extrinsic factors that may affect these responses, as well as optimal trap design and odour formulation, will be essential if semiochemical-based approaches are to be integrated into thrips management programmes.

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