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Design and deployment of semiochemical traps for capturing *Anthonomus rubi* Herbst (Coleoptera: Curculionidae) and *Lygus rugulipennis* Poppius (Hetereoptera: Miridae) in soft fruit crops

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ABSTRACT

Strawberry blossom weevil (SBW), *Anthonomus rubi* Herbst (Coleoptera: Curculionidae) and European tarnished plant bug (ETB), *Lygus rugulipennis* Poppius (Hetereoptera: Miridae), cause significant damage to strawberry and raspberry crops. Using the SBW aggregation pheromone and ETB sex pheromone we optimized and tested a single trap for both species. A series of field experiments in crops and semi-natural habitats in five European countries tested capture of the target pests and the ability to avoid captures of beneficial arthropods. A Unitrap containing a trapping agent of water and detergent and with a cross vane was more efficient at capturing both species compared to traps which incorporated glue as a trapping agent. Adding a green cross vane deterred attraction of non-pest species such as bees, but did not compromise catches of the target pests. The trap caught higher numbers of ETB and SBW if deployed at ground level and although a cross vane was not important for catches of ETB it was needed for significant captures of SBW. The potential for mass trapping SBW and ETB simultaneously in soft fruit crops is discussed including potential improvements to make this more effective and economic to deploy.

1. Introduction

Across Europe, strawberry blossom weevil (SBW), *Anthonomus rubi* Herbst (Coleoptera: Curculionidae) and European tarnished plant bug (ETB), *Lygus rugulipennis* Poppius (Hetereoptera: Miridae) are serious pests in strawberry and some cane fruits causing economic loss for farmers. SBW females lay eggs in flower buds and then partially sever the peduncles. Damaged buds do not develop further resulting in a loss of yield (Aasen and Trandem, 2006; Jay et al., 2008). ETB pierces and feeds on flowers and developing fruitlets, causing fruit distortion and considerably decreasing fruit quality for market, up to 80% distorted fruits (Cross et al., 2011; Fitzgerald and Jay, 2011).

Foliar applications of insecticides are the main method of controlling these pests. The loss of active compounds through the pesticides approval process, the evolution of pesticide resistance in many pest populations (e.g. in SWB, Aasen and Trandem, 2006), the need for selective control measures to prevent disruption of integrated pest management (IPM) practices (Hillocks, 2012, 2013) and high losses in organic production all require better timed and targeted control applications and alternative control methods for key pest species. In addition, the incidence of pesticide residues in fresh produce (European Food Safety Authority, 2015) and harm to

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beneficial insects (e.g. Croft and Brown, 1975; Cressey, 2015) are all justifications for alternative approaches to pesticide use (Hillocks, 2012, 2013).

In the EU, users of pesticides are required by law to monitor pests when possible, and only apply pesticides when pests are present in damaging numbers and other measures have failed, taking the resistance risk into account (Sustainable Use Directive, 2009/128/EC). The use of pheromone traps for monitoring insect pests is widespread in Europe and other main fruit growing regions of the world (Walton et al., 2004; Teixeira et al., 2009; Haghani et al., 2016). Trap design, placement and attractants may all have an important role in pheromone trap effectiveness, depending on pest behaviour and finding the best combination of these factors will improve trap efficacy (Blackmer et al., 2008; Switzer et al., 2009; Singh et al., 2013; Renkema et al., 2014).

Effective monitoring traps also have the potential to control pests through mass trapping (Faccoli and Stergulc, 2008; Witzgall et al., 2010; Abbes et al., 2012; Mwatawala et al., 2015) aiming to reduce pest numbers, sufficiently, to reduce fruit damage. Mass trapping has been used in the long term management of many pests and has the potential to be exploited for commercial strawberry production by suppressing or even eradicating low-density, isolated pest populations (El-Sayed et al., 2006). The combination of mass trapping and releases of the predator *Nesidiocoris tenuis* (Reuter) resulted in a 50% reduction in tomato fruit infestation by the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), compared to conventional treatments (Abbes et al., 2012). Mass trapping often reduces populations of pests in crops (e.g. Mafra-Neto and Habib, 2003), but there are fewer studies demonstrating successful damage reduction. Examples of successful use of mass trapping against Coleoptera include the spruce bark beetle, *Ips typographus* (L.) (Faccoli and Stergulc, 2008), and the palm weevils *Rhynchophorus palmarum* (L.) (Oehlschlager et al., 2002) and *R. ferrugineus* (Olivier) (Dembilio and Jaques, 2015).

The male-produced aggregation pheromone of SBW was identified as a blend of Grandlure I, Grandlure II and lavandulol by Innocenzi et al. (2001), and further work was carried out to make the blend more cost-effective by Innocenzi et al. (2001) and Cross et al. (2006b). In addition, the effect of host plant volatiles on SBW was investigated. Bichão et al. (2005a,b) showed that some neurons on the antenna of *A. rubi* are narrowly tuned to a few structurally related sesquiterpenes, aromatics or monoterpenes. Adding these plant volatiles to the aggregation pheromone has the potential to increase the attractiveness to SBW (Cross et al., 2006b; Wibe et al., 2011, 2014). Currently a blend of SBW aggregation pheromone and one plant volatile, 1,4-dimethoxybenzene, is widely used for SBW monitoring (Wibe et al., 2011, 2014).

Three compounds have been identified as components of the ETB female sex pheromone (Innocenzi et al., 2004; Frati et al., 2009) and a blend of these was further optimised and tested in field trials (Innocenzi et al., 2004, 2005; Fountain et al., 2008, 2011; Cross et al., 2011) to develop an effective lure and trap for monitoring males (Fountain et al., 2014). In addition, some plant volatiles such as phenylacetaldehyde have been identified as attractants for female ETB (Frati et al., 2009; Fountain et al., 2010; Koczor et al., 2012).

For both target species, initial testing assessed different trap types and colours, most frequently using traps which incorporated sticky glue as the trapping agent (Innocenzi et al., 2001; Cross et al., 2006a, 2006b; Jay et al., 2008). These traps were not optimal for SBW as weevils were often found around the traps, but not in or on them (Cross et al., 2006a). Initial experiments for attracting ETB employed various sticky trap designs and colours but this was before the pheromone was widely available (Holopainen et al., 2001; Blackmer et al., 2008).

Changes in trap design leading to improved pest capture will make a monitoring trap more sensitive and mass trapping more effective. Traps must be competitive with the surrounding crop, ensure the pest is captured and not kill or disrupt significant numbers of natural enemies and other beneficial insects, e.g. pollinators. In addition, it should not become saturated with bycatch and it should be easy to use and maintain, and be cost effective.

To help reduce pesticide inputs, further development of the traps was necessary to a) improve target pest capture, b) combine traps for two common species in strawberry and c) develop a trap which was easy to maintain and economically viable for future mass trapping. Studies were carried out in Denmark, Latvia, Norway, Switzerland and the UK comparing the effect of various trap designs on captures of the target pests including non-target, beneficial, species.

2. Materials and methods

2.1. Traps

Two basic designs of trap were evaluated; delta traps (20 cm × 20 cm) with white sticky inserts and green Unitraps consisting of a bucket with a funnelled entrance and green or white cross vanes between the bucket and the roof (bucket 16 cm dia, 12.5 cm high with 3 cm dia opening, cross vanes 10 cm high, cover 16.5 cm dia). The latter trap, from hereon in, will be referred to as Unitraps. Water (250 ml) and a drop of detergent was added to the Unitraps as killing agent. Traps were purchased from Agrisense (Treforest, Pontypridd, UK), International Pheromone Systems Ltd. (The Wirral, Merseyside, UK) or Agralan (Swindon, UK).

2.2. Lures

For trapping ETB with live females, individual mature, virgin, female ETB from a laboratory culture were contained in a cage (hair roller 6 cm × 3 cm with gauze around the outside and a lid at either end, holding the gauze in place). The cage contained a piece of damp paper and a section of bean as food and was anchored into the top of the trap under the roof. Female ETB were replaced weekly.

Lures for SBW were polyethylene sachets containing 100 μl of 1:4:1 blend of Grandlure I: Grandlure II: lavandulol plus 200 mg 1,4-dimethoxybenzene (Wibe et al., 2014) (International Pheromone Systems Ltd.). Lures for ETB were pipette tips containing 10 μg hexyl butyrate, 0.3 μg (*E*)-2-hexenyl butyrate and 2 μg (*E*)-4-oxo-2-hexenal in 100 μl sunflower oil (Fountain et al., 2014), prepared at the Natural Resources Institute. Lures were hung from the roof of delta traps or the cover of Unitraps.

2.3. Comparison of delta traps and Unitraps for trapping ETB

Two experiments were carried out in a weed field (*Chenopodium* and *Matricaria*) at NIAB EMR in the UK (Lat: 51.285494 north, Long: 0.461177 east) using virgin female ETB as bait (Table 1). In Experiment A (27 June – 11 July 2008), delta traps and Unitraps were compared with different materials for retaining the insects. The delta traps had either the standard wet glue inserts, dry glue inserts (Agrisense), wet glue inserts with additional sticker or wet glue inserts sprayed with cypermethrin (0.0014 ml sticky base^{-1}, equivalent to 0.35 L ha^{-1}). The Unitraps had white cross vanes or cross vanes constructed from white insect trapping cards impregnated with lambda-cyhalothrin. A clear delta trap was also tested, made of clear vinyl sheets held together at the top with a paper binder and with a white, wet, glue insert (Table 1).

In Experiment B (27 August – 1 September 2008), different