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Single versus multiple releases of predatory mites combined with spinosad for the management of western flower thrips in strawberry

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ABSTRACT

Western flower thrips, *Frankliniella occidentalis* (Pergande), is a major pest of strawberry and other horticultural and ornamental crops. Biological control of *F. occidentalis* with predatory mites is recommended as an additional management strategy to chemical control in glasshouse and protected crops. However, it is not known whether multiple (two or three) species releases of predatory mites are more effective than single species releases. The effect of an application of spinosad followed by mite releases could further increase suppression of *F. occidentalis*. In a series of trials in the glasshouse, we evaluated three commercially available predatory mite species, *Typhlodromips montdorensis* (Schicha), *Neoseiulus cucumeris* (Oudemans) and *Hypoaspis miles* (Berlese). Strawberry plants were sprayed once with either spinosad at the recommended rate or with water. *F. occidentalis* adults were released onto plants 24 h after spraying, and mites were released six days later. Spinosad significantly reduced *F. occidentalis* compared to the control (water). *T. montdorensis*, *N. cucumeris* and *H. miles* significantly reduced *F. occidentalis* compared to the 'no mite' treatment. Spinosad had no effect on *T. montdorensis* and *N. cucumeris*, as their numbers did not differ between the spinosad and control treatments; *H. miles* was not recovered. When mites were released after an application of spinosad, greater suppression of *F. occidentalis* was achieved than with releases of predatory mites alone. When released as a double species combination, '*T. montdorensis* and *H. miles*' was the most effective combination. There was no difference in efficacy between releases of '*T. montdorensis* and *H. miles*' or '*T. montdorensis*, *N. cucumeris* and *H. miles*'. We conclude that multiple species releases are more effective than single species releases, and that biological control of *F. occidentalis* with predatory mites can be used together with spinosad.

1. Introduction

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is an economic pest of horticultural crops worldwide, causing extensive crop losses through direct and indirect damage (Brødsgaard and Albajes, 1999; Jones et al., 2002; Kirk and Terry, 2003). In strawberry, *Fragaria x ananassa* (Rosaceae), *F. occidentalis* damage to flowers is characterized by brown and withered stigma and anthers, slight necrotic spots on the calyx of the flower (Steiner and Goodwin, 2005a; Coll et al., 2006) and reduction in flower receptacle size at high thrips density (>25 WFT per flower) (Coll et al., 2006). Larval and adult feeding by *F. occidentalis* on the fruit surface causes net-like russetting (Steiner and Goodwin, 2005a; Coll et al., 2006), which reduces shelf-life and fruit appearance (Coll et al., 2006). Thrips feeding on pink fruits causes bronzing (Coll et al., 2005). On older fruit, adult and larval feeding causes russetting around the seed (achene) (Steiner and Goodwin, 2005b; Coll et al., 2006). Damage to strawberry by *F. occidentalis* has been recorded from Argentina (Gambardella and Pertuzé, 2006), Australia (Steiner and Goodwin, 2005a), Brazil (Gambardella and Pertuzé, 2006; Nondillo et al., 2008), Chile (Gambardella and Pertuzé, 2006), the USA (Zalom et al., 2008), Israel (Coll et al., 2005, 2006) and central, southern and northern Europe (Cross et al., 2001; Gonzalez-Zamora and Garcia-Mari, 2003).

To control *F. occidentalis* in strawberry and other crops, growers often use insecticides as the main control strategy (Cook, 2000; Contreras et al., 2001; Bielza, 2008; Broughton and Herron, 2009a). However, because of its small size, secretive habit, and high reproductive potential, management of *F. occidentalis* with insecticides can be difficult (Jensen, 2000). In addition, *F. occidentalis*

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develops insecticide resistance, and glasshouse and field populations resistant to insecticides in the older chemical classes have been recorded in field and protected crops worldwide (Brødsgaard, 1994; Broadbent and Pree, 1997; Jensen, 1998, 2000). Populations resistant to the 'newer' chemistry insecticides imidacloprid, fipronil (Zhao et al., 1994, 1995; Herron and James, 2005), and spinosad (Herron and James, 2005; Loughner et al., 2005; Bielza et al., 2007; Zhang et al., 2008) have also been detected. For these reasons, diverse control strategies are required to ensure that growers are able to maintain control of *F. occidentalis*.

Biological control with predatory mites and bugs has been used to suppress *F. occidentalis* in strawberry (Steiner, 2002; Steiner and Medhurst, 2003; Coll et al., 2005, 2006; Shakya et al., 2010), thereby reducing the risk of insecticide resistance. Of the natural enemies used for biological control of thrips, predatory mites have been used successfully in field and protected crops (Chant, 1985; van Lenteren and Woets, 1988; McMurtry and Croft, 1997). The use of two or more species to suppress insect pest populations may also be more effective than single species releases. By releasing multiple species, the pressure on the pest population is increased, particularly if they attack different developmental stages of the pest. However, whilst some studies are supportive of the notion that multiple biocontrol agents are compatible (Gillespie and Quiring, 1992; Wittmann and Leather, 1997; Brødsgaard and Enkegaard, 2005), others oppose this view (Magalhães et al., 2004; Sanderson et al., 2005). For example, interspecific competition may occur when different species of natural enemies are combined together (Schausberger and Walzer, 2001), including predation of other natural enemies in addition to the target prey (intraguild predation) (Brødsgaard and Enkegaard, 2005; Hatherly et al., 2005). An ideal biological control strategy for *F. occidentalis* would target the foliage-inhabiting adult and larval stages, and the soil-dwelling pupal stage. *Typhlodromips montdorensis* Schicha (Phytoseiidae) predates on first and second instar larvae of *F. occidentalis* and forages on all parts of the host plant (Steiner and Goodwin, 2002; Hatherly et al., 2004). *Neoseiulus cucumeris* (Oudemans) (Phytoseiidae) predates on first instar *F. occidentalis* larvae (Bakker and Sabelis, 1989) and prefers the lower part of the host plant (Messelink et al., 2006). *Hypoaspis miles* (Berlese) (Laelapidae) is a soil-dwelling predatory mite that predates on the prepupal and pupal stages (Glockemann, 1992), although some studies suggest that it may also prey on late second instar larvae (Berndt, 2003). Because of the differences in preferred position on the plant and the prey stages of *F. occidentalis* consumed by each species, it is expected that they will be compatible and their effect will be complementary.

However, as natural enemies may not always be sufficient to suppress the pest population, particularly in crops with low economic thresholds (Gillespie and Ramey, 1988; Bakker and Sabelis, 1989; Gillespie, 1989), biological control could be integrated with chemical control. The use of 'softer' insecticides has been successfully integrated with mite releases (Reuveni, 1995; Kongchuensin and Takafuji, 2006), though there are concerns about the detrimental effects of pesticides on predatory mites. Sequential applications of insecticide followed by releases of natural enemies is one proposed solution to this problem (Rhodes and Liburd, 2006). Spinosad is often used in integrated pest management and organic production, since it is highly efficacious against *F. occidentalis* in a range of crops including strawberry (Steiner and Medhurst, 2003; Broughton and Herron, 2009b), with low to moderate toxicity to predatory mites (Pietrantonio and Benedict, 1999; Williams et al., 2003; Jones et al., 2005). Spinosad has been integrated successfully with biological control to manage *F. occidentalis* in field peppers and glasshouse-grown marigolds (Funderburk et al., 2000; Ludwig and Oetting, 2001).

To develop an integrated approach to managing *F. occidentalis* in strawberry, we evaluated the effect of releases of *T. montdorensis*, *N. cucumeris* and *H. miles* on *F. occidentalis*, combined with an application of spinosad. Our specific objectives were to (i) evaluate the effectiveness of single versus combined release of predatory mites for the management of *F. occidentalis*, and (ii) evaluate the effectiveness of predatory mites released after an application of spinosad.

2. Materials and methods

The experiment was conducted in a glasshouse (25 ± 2 °C, 50–60% RH, 16:8 L:D cycle) at the University of Western Australia (UWA) from November 2007 to January 2008. The above conditions were considered most suitable for *F. occidentalis* oviposition (Marullo and Tremblay, 1993). At 16.6–36.6 °C the total development period from egg to adult of *F. occidentalis* on chrysanthemum is 13–7 days (Robb, 1989).

2.1. Insect and plant rearing

Strawberry, *Fragaria x ananassa* Duchesne (Rosaceae) cv Camino Real short-day length cultivar, developed by the University of California (Shaw and Larson, 2008), was used in all experiments. Runners of Camino Real were obtained from a commercial grower and propagated in pots (325 mm L × 325 mm W × 405 mm H) containing potting mix (Baileys Fertilizers, Rockingham, WA) in glasshouses at the Department of Agriculture and Food Western Australia (DAFWA) and at UWA. All pots were fitted with drippers operated by an automatic timer to water plants every third day. A liquid fertilizer (Thrive®, Yates, Australia; NPK: 12.4:3:6.2; rate: 5 ml/2 l water) was applied once a week. Pots were covered in a thrips-proof mesh cage, 450 mm × 350 mm, made from 105 μ mesh net (Sefar Filter Specialists Pty Ltd., Malaga, WA) fitted over a steel-rod stand.

F. occidentalis were initiated from individuals collected from calendula, *Calendula officinalis* L. (Asteraceae) at DAFWA, and were reared on calendula planted in potting mix in plastic pots (50 mm × 100 mm). Planted pots were placed in thrips - proof Perspex cages (500 mm × 420 mm × 400 mm). The sides of the cage were covered with 105 μ mesh net, and the front of the cage was fitted with a removable cover, held in place with magnetic strips. The cage was placed on top of a Nylex tote box (cage tray, 432 mm × 320 mm × 127 mm, Blyth Enterprises Ptd Ltd, Australia). All pots were fitted with drippers with an automatic timer as previously described. Cages were kept in tunnel houses (insect proof net house) at UWA. Every second week, adults were collected from caged plants with an aspirator and released onto new potted calendula plants to ensure the continuous availability of thrips for experiments.

To obtain uniformly aged thrips, adult females (20 individuals) were collected from the colony, released onto fresh plants, and allowed to lay eggs for 24 h. After 24 h, females were removed with an aspirator. The plants were checked daily for larval emergence. Newly hatched larvae were removed and released onto a strawberry leaf on a moistened filter paper in a Petri dish (150 × 15 mm). The leaf petiole was covered with cotton, soaked in 10% sugar solution to extend leaf life. The top of the Petri dish was covered with thrips-proof mesh (105 μ) and the edges of the Petri dish and mesh were sealed with paraffin film (Parafilm M®, Micro Analytix Pty Ltd) and kept in a controlled temperature room (25 ± 1 °C, 50–60% RH, 16:8 h L:D regime). Larvae that hatched on the same day were transferred to a new Petri dish as above and allowed to pupate. Adults that emerged on the same day were used in trials.

Predatory mites (*T. montdorensis*, *N. cucumeris* and *H. miles*) used in the study were sourced from commercial suppliers (Biological Services, South Australia; Chilman IPM Services, Western Australia;