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Effects of Predators on the Belowground Life Stages (Prepupae and Pupae) of the Western Flower Thrips, *Frankliniella occidentalis* (Thripidae: Thysanoptera): A Review

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Abstract

Western flower thrips, *Frankliniella occidentalis*, is a major cosmopolitan insect pest causing direct and indirect damage to greenhouse-grown horticultural crops. The primary way of managing western flower thrips populations is by routinely applying insecticides, which target the aboveground life stages: larvae and adult. However, insecticides are minimally effective against the pupal stages (prepupae and pupae) that reside in the growing medium or soil. Therefore, soil-dwelling biological control agents including: predatory mites [*Stratiolaelaps scimitus* and *Hypoaspis* = (*Geolaelaps*) *aculeifer*], and a rove beetle, *Dalotia coriaria* may be a viable option to induce mortality on the pupal stages. These predators will feed on the pupal stages of the western flower thrips and can provide mortality on a life stage that is tolerant of insecticide applications. However, these biological control agents need to be used in conjunction with other plant protection strategies, such as insecticides and/or biological control agents that target the aboveground life stages (larvae and adult) to effectively manage western flower thrips populations in greenhouse production systems.

Keywords

Predatory Mites, Rove Beetle, Growing Medium, Biological Control, Predation

1. Introduction

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is one of the most destructive insect pests worldwide associated with

greenhouse-grown horticultural crops, including vegetables and ornamentals [1] [2] [3] [4]. Western flower thrips causes direct and indirect plant damage [5] [6]. Direct damage caused by larvae and adults when feeding on leaves, flowers, and fruits can result in leaf, flower, and fruit scarring; sunken tissues on leaf undersides; distortion and discoloration of flowers; and fruit deformation [2] [7] [8] [9]. Indirect damage is affiliated with adults vectoring plant viruses, including the tospoviruses: *Tomato spotted wilt* and *Impatiens necrotic spot* virus [10] [11] [12]. Consequently, greenhouse producers regularly apply insecticides to suppress western flower thrips populations below damaging levels [4] [13] [14]. However, the cost of continually using insecticides can be expensive [15] [16] and oftentimes leads to resistance developing in western flower thrips populations [17] [18] [19] [20].

The western flower thrips life cycle consists of an egg, two larval stages (instars), two pupal stages (prepupae and pupae), and an adult [21] [22]. Eggs are inserted into plant tissues and first instar larvae eclose from eggs [20] [23]. Second instar larvae eventually stop feeding and migrate down the plant stem or drop onto the surface of the growing medium or soil to pupate [16] [24] [25] [26]. Holmes *et al.* (2012) [27] reported that larvae primarily drop from plants instead of walking down plant stems. As noted, there are two pupal stages: prepupae and pupae. Western flower thrips prepupae take two to three days to develop into pupae, and pupae take one to two days to develop into adults [28] [29].

The pupal stages do not feed and are not as mobile as larvae and adults [29] [30]. In addition, the pupal stages are less susceptible to insecticides commonly applied to suppress populations of the larvae and adults [31]. Western flower thrips pupates in the growing medium of plant containers or in the soil underneath benches in greenhouses. Pupae can reside at a depth of 1.0 to 5.0 mm although this is contingent on the growing medium or soil type [25]. Tommasini and Maini (1995) [21] indicated that pupation occurred at a depth of 1.5 to 2.0 cm and Deligeorgidis and Ipsilandis (2004) [32] reported that almost half of a western flower thrips population pupated in the top 2.0 cm of soil.

Eighty-six to 90% of western flower thrips pupated on the soil with green bean, *Phaseolus vulgaris*, plants [33] [34]. Buitenhuis and Shipp (2008) [35] found that 92 and 93% of western flower thrips pupated in the soil of non-flowering chrysanthemum, *Dendranthema* × *grandiflorum*, and rose, *Rosa* spp., plants, respectively. A study reported that 92 and 99% of larvae associated with flowering chrysanthemum and cucumber, *Cucumis sativus*, plants, respectively, pupated in the soil [27]. Berndt *et al.* (2004) [36] indicated that 98% of a western flower thrips population left bean plants and pupated in the soil. The growing medium and soil likely provide a suitable environment for survival, based on moisture content, relative humidity, physical structure, and temperature [32] [36] [37] [38].

While western flower thrips seems to prefer pupating in the growing medium or soil [39], they will also pupate on aboveground portions such as leaves or

flowers of certain plant types [16] [30] [40] [41]. For example, studies have reported that western flower thrips will pupate in the complex inflorescences (flowers) of chrysanthemum plants [35] [42]. Factors that can influence western flower thrips pupating on plants include: relative humidity, host plant species, and plant growth stage [38] [42].

The proportion of western flower thrips that pupate in the growing medium or soil is likely affected by host plant species [43]. In addition, pupating in the growing medium or soil reduces exposure to aboveground biological control agents [36] including the predatory mite, *Neoseiulus* = (*Amblyseius*) *cucumeris* (Oudemans) (Acari: Phytoseiidae), and the insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) [44] [45] [46] [47] [48].

However, pupating in the growing medium or soil exposes prepupae and pupae to soil-dwelling predators [49] [50], and, because they are less mobile than larvae and adults, this increases their risk of predation [30] [51]. Due to the short duration time of the prepupae and pupae (one to three days), predators only have a "narrow window of opportunity" to prey upon the pupal stages [38] [52]. Soil-dwelling predatory mites and a rove beetle can cause mortality on the pupal stages of western flower thrips residing in the growing medium or soil [36] [52].

However, these biological control agents need to be used in conjunction with other plant protection strategies, such as insecticides and/or biological control agents that target the aboveground life stages (larvae and adult) so as to effectively manage western flower thrips populations in greenhouse production systems.

2. Predatory Mites

The soil-dwelling predatory mites, *Stratiolaelaps scimitus* (Womersley) (Acari: Laelapidae), which was formerly called "*Hypoaspis miles*" (Berlese), and *Hypoaspis* = (*Geolaelaps*) *aculeifer* Canestrini (Acarina: Laelapidae), have been used to regulate populations of the pupal stages of western flower thrips residing in the soil [36] [53]. Females are 0.7 to 1.0 mm in length and possess a pale-brown dorsal shield [54] [55] [56]. *Hypoaspis aculeifer* may feed on western flower thrips pupal stages more so than *S. scimitus* [26]. Berndt *et al.* (2004) [36] reported that releasing *H. miles* or *H. aculeifer*, respectively, resulted in a 44.9 to 57.6% population reduction in western flower thrips densities. The results suggest that *H. aculeifer* may have a higher predation efficacy than *H. miles*. However, western flower thrips pupae may not be a preferred food source (prey) for these two predatory mites [36]. Consequently, this would reduce their efficacy in regulating populations of the pupal stages in the growing medium or soil in the presence of alternate prey.

Studies have evaluated the potential of releasing two predatory mites simultaneously [57]. For instance, Wiethoff *et al.* (2004) [26] found that combining the predatory mite, *N. cucumers*, for the aboveground life stages with the predatory mite, *H. aculeifer*, for the belowground life stages, did not increase control of

western flower thrips compared to just using *N. cucumeris* alone. In addition, predatory mites have been applied in conjunction with entomopathogenic nematodes [50] [58]. A study found that combining the predatory mite, *H. aculeifer*, with the entomopathogenic nematodes, *Steinernema feltiae* Filipjev and *Heterorhabditis bacteriophora* Poinar, reduced western flower thrips adult eclosion by 71 to 82% [59]. However, Manners *et al.* (2013) [16] found that applying aboveground and belowground predators was no more effective in reducing western flower thrips numbers than only applying aboveground predators. In addition, releasing two biological control agents simultaneously may be cost prohibitive [16] or lead to intraguild predation, where multiple predators interfere with each other for a shared prey source [60] [61].

3. Predatory Beetle

The soil-dwelling predatory rove beetle, *Dalotia* (formerly *Atheta*) *coriaria* (Kraatz) (Coleoptera: Staphylinidae), is commercially available from most biological control suppliers [62] [63]. Adults are dark-brown to shiny-black and 3 to 4 mm in length [64]. The early instar larvae are creamy white, whereas later instar larvae are yellow-brown [56]. Both adults and larvae are predacious, feeding on the larval stages of a number of greenhouse insect pests including: shore fly (*Scatella* spp.) and fungus gnat (*Bradysia* spp.) larvae [56] [65] [66]. Moreover, rove beetles will feed on western flower thrips prepupae and pupae. For example, Carney *et al.* (2002) [67] reported that one *D. coriaria* adult consumed 78 western flower thrips pupae in 24 hours, whereas another study found that one *D. coriaria* adult preyed upon approximately 28 prepupae in 24 hours (Yinping Li, unpublished data). Both studies were conducted in petri dishes under laboratory conditions. A recent study conducted in 11.5 and 15.2 cm plastic containers under laboratory conditions found that rove beetles feed on the pupal stages (prepupae and pupae) of western flower thrips and can substantially lower adult emergence from the growing medium [52]. The study determined that the number of rove beetles released influences predation efficacy. For example, at least three rove beetle adults are needed to provide sufficient regulation of western flower thrips pupal populations based on predation under the initial numbers of western flower thrips prepupae and pupae (15, 20, 25, and 30) tested. In addition, a 1:15 predator-prey ratio (rove beetle adult-western flower thrips pupal stages) resulted in the highest predation efficacy (<40% of western flower thrips adults captured on yellow sticky cards) associated with *D. coriaria* [52].

4. Conclusions

Studies show that certain predatory mites and the rove beetle, *D. coriaria*, may be viable biological control options targeting the pupal stages of western flower thrips in the growing medium or soil [52]. Consequently, the release of predatory mites and rove beetles in greenhouse production systems may induce mortality on a life stage that has been difficult to suppress using insecticides. In addi-

tion, releasing predatory mites and/or rove beetles may reduce inputs from insecticide applications; thus mitigating issues associated with insecticide resistance.

However, the predatory mites and rove beetle cannot be relied upon as the only source of mortality for western flower thrips in greenhouse production systems. Nonetheless, both may be used in conjunction with aboveground biological control agents that feed on the larvae and adult life stages of western flower thrips [36] [49] [59], or foliar applications of insecticides, especially since a mixed population structure (eggs, larvae, pupae, and adults) of western flower thrips will likely be present under greenhouse conditions.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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