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Potential of dip treatments to disinfest cuttings of the invasive *Thrips parvispinus* (Thysanoptera: Thripidae)

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Thrips parvispinus (Karny) (Thysanoptera: Thripidae), an invasive thrips species, poses a significant threat to global agriculture due to its polyphagous nature and rapid spread. Its recent arrival in the continental United States raises concerns about potential impacts on ornamental and vegetable crops. Dip treatments might serve as a phytosanitary practice for growers to start with plants free of visible pests. This study aimed to assess the efficacy of dip treatments using 4 biorational and microbial insecticides (mineral oil and *Beauveria bassiana*-based) in controlling *T. parvispinus* on bean seedlings. Following gentle agitation of cuttings, artificially infested with 10 second-instar (L2) larvae, for 15 s in each solution, thrips infestation was evaluated at 1, and 24 h postdipping, scoring the numbers of dislodged and dead larvae. Additionally, we tested whether dipping could cause phytotoxicity on bean (*Phaseolus vulgaris* L.), gardenia (*Gardenia jasminoides* Ellis), and mandevilla (*Mandevilla splendens* (Hook.f.) Woodson) cuttings during a 7-day period. Our results demonstrated that dip treatments effectively dislodged and killed *T. parvispinus* L2 larvae from infested cuttings, with BotaniGard-ES and Suffoil-X exhibiting the highest efficacy and a dislodgment rate of 80%–100%. BotaniGard-ES was the only product causing phytotoxicity on bean seedlings, but not on mandevilla and gardenia. Overall, we demonstrated that dip treatment using biorational insecticides is an additional tool that can be incorporated in the integrated pest management of *T. parvispinus*. These results hold implications for the broader application in the management of thrips across various plants propagated from cuttings.

Key words: bean, gardenia, mandevilla, regulated pest, propagative material, insect pests

Introduction

Thrips parvispinus (Karny) (Thysanoptera: Thripidae), an invasive thrips species native to Asia (Reyes 1994, Johari et al. 2014, Sridhar et al. 2021), has gained increased attention for its polyphagous nature and rapid spread around the world. Over the past 2 decades, *T. parvispinus* has undergone a significant expansion in both geographical distribution and host range. It was first detected in the continental United States in Florida in 2020, raising concerns about its potential impact on a range of crops in the country (Soto-Adames 2020). In a short time period, subsequent interceptions in Georgia, Colorado, North and South Carolina, Pennsylvania, and Ohio have been reported (EPPO Global Database 2024). Additionally, the species has invaded southeastern Canada (Ontario), where it is currently found infesting plants within greenhouse environments (Gleason et al. 2023). This invasive thrips has been documented on over 43 plant species from 19 families across various ornamental and food crops (Thorat et al. 2022). It is highly destructive, causing heavy leaf scars, flower drop, and upward leaf curling (Veeranna et al. 2022). Countries such as India (Sridhar et al. 2021) and Indonesia (Johari et al. 2014) have reported substantial yield losses of up to 70% in chili pepper production due to *T. parvispinus*. It has also been responsible for significant yield reductions in greenhouse gardenia plants (Mound and Collins 2000) and various other crops like green beans, potatoes, strawberries, brinjal (Murai et al. 2009), and papaya (Sugano et al. 2015).

The rapid expansion of *T. parvispinus* in the United States poses a substantial risk to ornamental and vegetable crops, with the potential to affect wholesale values of cut cultivated greens, foliage plants, and potted flowering plants (USDA-NASS 2021). Recognizing the gravity of this threat, the Florida Department of Agriculture and Consumer Services-Division of Plant Industry (FDACS-DPI) regulates this pest by issuing a "stop sale and hold order." Nurseries found with the pest are prohibited from moving any plant materials from the infested area until the pest is eliminated. In times of quarantine, there is an urgent need for monitoring and implementation of strategies for rapid pest control. Insecticide products with minimized nontarget effects stand out as a management practice for rapid and efficient pest control. To this end, we recently tested 32 conventional and biorational insecticides, approved for use in ornamentals cultivated in greenhouses, nurseries, and landscapes, identifying the most efficacious in causing *T. parvispinus* mortality and reducing its feeding activity (Ataide et al. 2024). These initial insecticide trials aid growers in mitigating crop losses but represent only the first step in controlling this invasive and regulated pest. Thrips control requires a multifaceted approach, integrating various tools of integrated pest management (IPM) such as biological control agents, cultural practices, and selective chemical treatments to ensure long-term success.

The global movement of propagative plant material is a major pathway for pest introduction in new environments. In floriculture, pests impact the visual appeal of crops, affecting sales and leading to rejections during export, which can have serious economic consequences for growers. Starting crops with low pest infestations facilitates successful IPM and helps meet high clientele standards, particularly for ornamentals. To enhance sustainability, exploring alternative, non-chemical treatments that can be applied to cuttings before planting is crucial for managing thrip infestations and enabling growers to transport plants beyond quarantine zones. In line with that, dip treatments rise as an alternative to dislodge, reduce, or eliminate pests from cuttings, ensuring the planting of clean propagative material (USDA-APHIS 2023).

Dip treatments using biorational and microbial insecticides such as soaps, oils, and entomopathogens emerged as a promising approach in phytosanitary practices for managing pests and diseases (Buitenhuis et al. 2016, Diczbalis 2018, Revynthi et al. 2020). Considering the thrips minute size, cryptic lifestyle, and rapid population growth (Morse and Hoddle 2006, Reitz 2009, Rodríguez and Coy-Barrera 2023), spraying often falls short in providing the necessary coverage for effective control, particularly on the underside of foliage. On the contrary, dip treatments cover the entire cutting besides dislodging thrips in all their life stages, except eggs. Females lay their eggs inside the leaf tissue, meaning that eggs are unlikely to be washed out or killed through dipping. The efficacy of dipping using biorational and microbial insecticides is accompanied by minimal adverse effects on plant physiology, especially when applied at moderate concentrations (Brownbridge and Buitenhuis 2019, Buitenhuis et al. 2019). Preliminary data show that dip treatments of cuttings using biorational and microbial insecticides are a proven tactic against thrips pest in Canada and hold promise in contributing to *T. parvispinus* control (Jandricic 2024). To explore this approach, we began by identifying which thrips stage was most prevalent in naturally infested cuttings. Because second-instar thrips larvae (L2) were the most abundant stage found in the evaluated cuttings, we artificially infested clean cuttings with 10 L2 larvae and investigated whether dipping them in a solution with mineral oil or products based on the entomopathogenic fungus *Beauveria bassiana* for 15 s can effectively dislodge and/or kill *T. parvispinus* larvae from infested cuttings.

Material and Methods

Thrips parvispinus Colony and Egg Cohort

The *T. parvispinus* colony was established at the Tropical Research and Educational Center in Homestead (TREC), Florida (25.50°N, 80.49°W). This colony originated from individual thrips collected from mandevilla (*Mandevilla splendens* Ellis) plant samples submitted to the Plant Diagnostic Clinic for examination. The specimen's identification was confirmed by FDCAS-DPI. Since then, the colony has been maintained at 27 ± 1 °C, RH 70%, 12:12 h (L:D) photoperiod in a growth chamber (Panasonic Versatile Environmental Test Chamber MLR-352H; permit number #2022-105). The colony was enclosed within a mesh cage (W47.5 cm × D47.5 cm × H93.0 cm; BugDorm-4M4590, BugDorm, Taiwan) inside a growth chamber, securely sealed with 2 doors. To sustain the colony, 4 fresh 2-week-old bean plants were introduced into the cage 3 times a week. Additionally, pollen from *Typha* spp. (Biobest®, Westerlo, Belgium) was evenly distributed using a brush to supplement their diet. Every 2 weeks, the colony was refreshed by removing old and dried plants and autoclaving all waste material before disposal.

To conduct experiments using thrips larvae of the same age, cohorts were created. To do so, adult females were transferred from the stock colony into large Petri dishes ($d = 135$ mm) filled with moistened cotton wool (Fisherbrand, Pittsburgh, PA, USA) and a bean leaf with the abaxial surface facing up. Adults were transferred to the Petri dishes using a manual aspirator, and the dishes were immediately closed with modified lids with a fine mesh (80 × 80, 350 μm aperture) to ensure ventilation. During a 24-h period, the females were allowed to lay eggs. Then, the females were removed, and Petri dishes containing only eggs were placed at 27 ± 1 °C, RH 70%, 12:12 h (L:D) in a growth chamber to support thrips development. Typically, the first larvae hatch from the eggs within 2 days. The nymphal stage consists of 2 phases: L1 larvae, which are transparent white, and L2 larvae, which molt from L1 after approx. a day and turn dark yellow (Hutasoit et al. 2017).

Identification of the Most Abundant Thrips Stage on Naturally Infested Mandevilla

The goal of this experiment was to determine which thrips developmental stage was most abundant on mandevilla plants under natural field infestations. To do so, *T. parvispinus*-infested mandevilla cuttings were harvested from young (~1 year) mother plants var. Scarlet (*M. splendens*) produced by local nurseries. Under commercial settings, mother plants were treated weekly with conventional insecticides to control *T. parvispinus*. Upon their arrival at TREC, they were inspected for thrips, but no insects were detected. The flowers were also inspected and removed as a precaution. Since thrips eggs could not be detected, the mother plants were transferred to a quarantine greenhouse, where they were monitored for thrips emergence. The mother plants received water twice a week and they were not treated further with insecticides. Approximately 3 weeks, later *T. parvispinus* adults were observed infesting the mother plants. To obtain cuttings measuring 6–7 cm in length, we sampled the growing tip part of mandevilla mother plants by making a diagonal cut below a leaf node. All the leaves were removed from the petiole of the cutting, except for the top 2 leaves. Cuttings were immediately transferred to a containment facility at TREC.

Each cutting was inspected for the presence of first (L1), second-instar larvae (L2), and adult thrips stages using a high magnification (400×) stereoscope (Nikon SMZ1270, Nikon Instruments Inc., Melville, NY, USA). We did not search for thrips eggs because females lay their eggs inside the leaf tissue, meaning that they could not be scored accurately. A total of 140 infested cuttings ($N = 140$) were inspected within 2–3 weeks. Differences in the average number of thrips among the 3 stages (L1, L2, and adults) on the mandevilla cuttings were tested with generalized linear mixed-effect models (GLMM) using the *glmmTMB* package (v1.1.3)

(Brooks et al. 2017), with negative binomial error distribution and including time of sampling as a random factor (Crawley 2012). All statistical analyses were performed using R program version 4.2.1 (R Core Team 2022).

Production of Bean Seedlings for Dip Treatment

Because the thrips colony has been maintained on bean plants and is well-adapted to this host plant (>1 year), we used bean as a host plant to maximize their performance on the host before and after dipping. Bean seedlings (*Phaseolus vulgaris* L. var. Roman) were grown from seeds (Goya Foods, NJ, USA) using soil (ProMix BX Mycorhizae, CO, USA) in 140-ml plastic pots. For germination, the pots were placed in a climate-controlled room at 25 ± 2 °C, RH 50%, and a 12:12 h (L:D) photoperiod. Plants received regular watering 3 times a week. Seedlings used in the experiments were 7 days old with 2 small, developed leaves (cotyledons).

Cuttings were removed from the pots by making a diagonal cut on the stem, approx. 12 cm below the cotyledons, and placed in wet floral foam cubes (Smithers-Oasis North America, OH, USA) within plastic containers (30 ml, Fill-Rite Corp., NJ, USA) saturated with water to remain fresh. The containers with the cuttings were placed in rectangular trays (L38.5 cm × W24.5 cm × H6 cm; New Star Foodservice, China) filled with 350 ml of water-soap solution to prevent thrips from moving from one cutting to another. The 2 leaves of each cutting were infested with a total of 10 L2 larvae, obtained from a cohort previously prepared. Cuttings were infested 30–40 min before the dip treatment (see below).

Dip Treatment of Bean Cuttings

The experiments were performed by immersing infested bean seedlings in 4 biorational and microbial insecticide solutions made of mineral oil or *Beauveria bassiana* (Table 1) along with 2 control treatments (water only and no-dip). In our experiments, we only included products registered by the Environmental Protection Agency for dip treatment in the U.S. The dipping solutions were prepared following the maximum label rates for dipping (Table 1). Ten bean seedlings, prepared as described above, were infested with a total of 10 L2 larvae. The L2 larvae were obtained from egg cohorts previously prepared. The number of thrips on each cutting was double-checked immediately before dipping, ensuring that all 10 L2 larvae were present at the time of treatment. If any thrips were missing, additional larvae were added to maintain a total of 10 L2 larvae on each cutting immediately before the dipping.

The 10 infested seedlings were dipped into each treatment solution. To do so, we submerged an individual cutting into a 500-ml solution and moved constantly in a circular motion for 15 s. After gentle agitation, the 10 cuttings of each treatment were placed in a separate tray (L38.5 cm × W24.5 cm × H6 cm; New Star Foodservice, China) filled with 350 ml of water-soap solution to prevent thrips from moving from one cutting to another. The experiment was repeated twice (blocks), meaning that a total of 20 cuttings ($N = 20$) were obtained for each biorational insecticide and the controls.

To ensure that cuttings were less exposed to debris from previous dipping treatment, the 500 ml solution was changed after 5 dips. Therefore, we prepared a L1 solution and divided it into 2 equal parts, each placed in 500 ml beakers, meaning that 2 beakers of solution were assigned to each treatment. Post dipping, the cuttings were air-dried at 26 ± 1 °C, 50 ± 10% RH, and 12:12 h (L:D) for approximately 1 h. Thrips infestation was first scored at 1-h post dipping (hpd) to evaluate the proportion of dislodged larvae. This was determined by counting the number of missing thrips out of the 10 L2 larvae dipped using a high magnification (400×) stereoscope. A subsequent evaluation of the presence of L2 on these cuttings was made at 24 hpd, scoring the number of dead and live larvae to assess the treatment's efficacy in causing thrips mortality. Two calculations for mortality were made: (i) within the starting number of 10 L2 larvae per replicate and (ii) within non-dislodged L2 larvae left per replicate. In addition, evaluations did not continue beyond 24 hpd, as we observed that the remaining number of thrips had significantly decreased by 48 hpd. Thus, we acknowledge that within the evaluated timeframe, the entomopathogens tested would require more time to cause a significant thrips mortality.

Dislodgement is presented as the proportion of dislodged larvae at 1 hpd and mortality as the proportion of dead thrips larvae at 24 hpd. The proportion of dislodged and dead thrips among the treatments was analyzed separately using the nonparametric test Kruskal-Wallis ($\alpha = 0.05$), as the data did not meet the assumptions for any parametric test. Data from the 2 blocks in time were combined in the analysis. Pairwise comparisons among treatments were performed using the function *pairwise.wilcox.test* of the R software.

Evaluation of Phytotoxicity in Cuttings after Dip Treatment

One-year-old mandevilla plants var. Scarlet (*M. splendens*) and gardenia plants (*Gardenia jasminoides* Ellis) were obtained from local nurseries. Both host plants were free of visible pests and were transferred to a non-quarantine greenhouse at 27 ± 1 °C, 60 ± 10% RH, and 12:12 h (L:D). Cuttings measuring 6–7 cm in length were obtained from the growing tip part of mandevilla and gardenia mother plants with a diagonal cut below a leaf node. All the leaves were removed from the cuttings, except for the top 2 leaves. Bean seedlings were obtained as described above. All plants received regular watering 3 times a week. A total of 60 cuttings per host plant were placed in wet floral foam cubes (Smithers-Oasis, OH, USA) saturated with water to remain fresh within plastic containers (30 ml, Fill-Rite Corp., NJ, USA). Ten cuttings per host plant ($N = 10$) were subjected to each of the 6 treatments described above, including no-dip treatment, following the exact same protocol. The containers with the cuttings were placed in rectangular trays, and phytotoxicity

Table 1. List of products used as dipping treatments against *Thrips parvispinus*

Trade name	Active ingredient(s)	Type of insecticide	Rate in L1 solution[a]	Allows dipping on the label	Registration number
Suffoil-X	Mineral oil	Biorational	5 ml	Yes	48813-1-68539
Velifer[b]	*Beauveria bassiana* strain PPRI 5339	Microbial	1.02 ml	Yes	71840-22
BotaniGard 22WP[c]	*Beauveria bassiana* strain GHA	Microbial	3.74 g	Yes	82074-2
BotaniGard ES[b]	*Beauveria bassiana* strain GHA	Microbial	7.81 ml	Yes	82074-1

[a]Rate calculations are based on the maximum label-recommended rate for dipping; [b]Liquid emulsifiable suspension; [c]Wettable powder formulation

symptoms were evaluated daily for a period of 7 days. Since no differential range of phytotoxicity was observed, cuttings showing phytotoxicity symptoms were assigned a score of "1," while those without symptoms were scored "0" at each evaluation timepoint. Differences in phytotoxicity among treatments were tested with Kruskal-Wallis ($\alpha = 0.05$), as the data did not meet the assumptions for any parametric test. Pairwise comparisons among treatments were performed using the function *pairwise.wilcox.test* of the R software. Pictures of the phytotoxicity symptoms were taken using an Apple iPhone 14 (f/1.8; 1/60 s; ISO-125).

Results

Identification of the Most Abundant Thrips Stage on Naturally Infested Mandevilla

The average number of L1, L2, and adult thrips on mandevilla cuttings naturally infested by *T. parvispinus* differed significantly, with the L2 developmental stage being the most abundant (GLMM, $\chi^2 = 58.6$; $df = 2$; $P < 0.001$, Fig. 1).

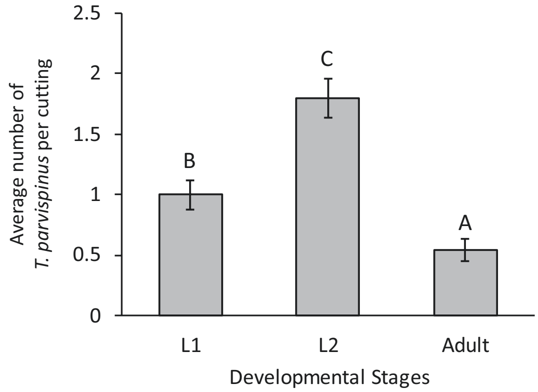

Fig. 1. Most abundant stage of *Thrips parvispinus* on naturally infested mandevilla cuttings. Bars represent the average number (±SE) of thrips larvae (L1 and L2) and adults collected from infested mandevilla cuttings obtained from mother plants from a local nursery ($N = 140$). Uppercase letters denote significant differences among treatments (GLMM, $P \le 0.05$).

Dip Treatment of Bean Cuttings

Dipping bean seedlings for 15 s in biorational and microbial insecticides led to significant differences in the dislodgement (Fig. 2) and mortality (Fig. 3) of *T. parvispinus*. The proportion of dislodged *T. parvispinus* varied significantly across the 6 treatments (Kruskal-Wallis, $\chi^2 = 87.1$; $df = 5$; $P < 0.001$, Fig. 2). The no-dip control treatment and dipping in water alone ($P = 0.1$) or the wettable powder formulation of *B. bassiana* strain GHA (BotaniGard-WP) ($P = 0.1$), did not result in significant larval displacement. However, dipping in mineral oil (Suffoil-X, 0.5%) displaced approx. 80% of the larvae ($P \le 0.001$), while the oil formulation of *B. bassiana* strain GHA (BotaniGard-ES) displaced nearly 100% ($P \le 0.001$).

Thrips parvispinus mortality was significantly different across the 6 treatments (Kruskal-Wallis, $\chi^2 = 41.1$; $df = 5$; $P < 0.001$, Fig. 3A). The proportion of dead *T. parvispinus* larvae at 24 hpd was significantly higher in mineral oil (Suffoil-X, 0.5%) and *B. bassiana* strain PPRI 5339 (Velifer) than in the other treatments. This outcome was slightly different when larval mortality was corrected for the number of remaining thrips after dipping (Kruskal-Wallis, $\chi^2 = 18.3$; $df = 5$; $P = 0.003$, Fig. 3B). In this case, pairwise comparisons were significantly different between BotaniGard-ES and Velifer ($P = 0.03$) and BotaniGard-ES and Suffoil-X ($P = 0.03$) only.

Evaluation of Phytotoxicity in Cuttings after Dip Treatment

None of the products caused phytotoxicity on gardenia cuttings, while mandevilla cuttings were slightly susceptible but not significantly affected ($P = 0.17$, Fig. 4A) by mineral oil (Suffoil-X, 0.5%). Beans were highly affected by BotaniGard-ES ($P < 0.001$, Fig. 4A and C), but not by other treatments (Fig. 4A and B). BotaniGard-ES did not cause phytotoxicity on mandevilla and gardenia cuttings.

Discussion

Through a series of samplings of naturally infested mandevilla plants, we first demonstrated that L2 larvae were the most abundant stage of *T. parvispinus* on this host plant (Fig. 1). Then, we artificially infested bean seedlings with a well-adapted *T. parvispinus* population on beans and demonstrated that dip treatment was efficacious in decreasing L2 larval infestations from cuttings. Across all tested products, Suffoil-X and BotaniGard-ES achieved the best results with

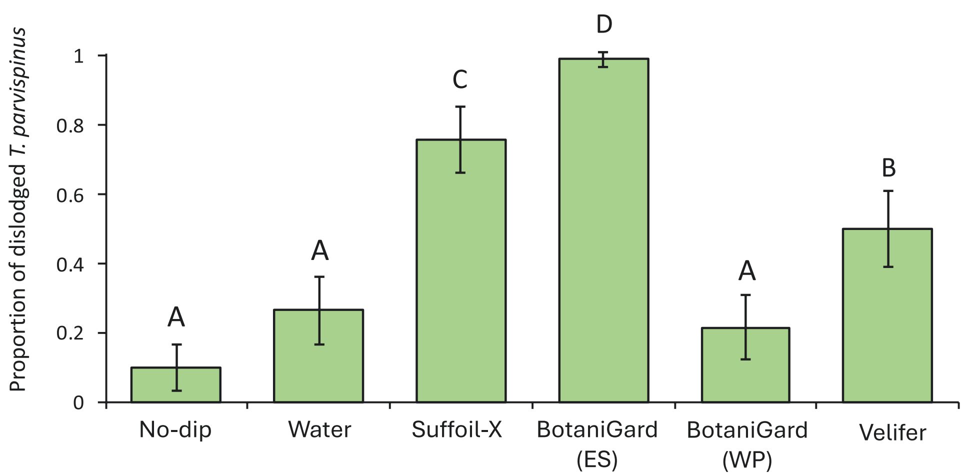

Fig. 2. Proportion (±SE) of dislodged *Thrips parvispinus* larvae (L2) from infested bean seedlings 1 h post-dip treatment ($N = 20$). Uppercase letters denote significant differences among treatments (Kruskal-Wallis, $P \le 0.05$).

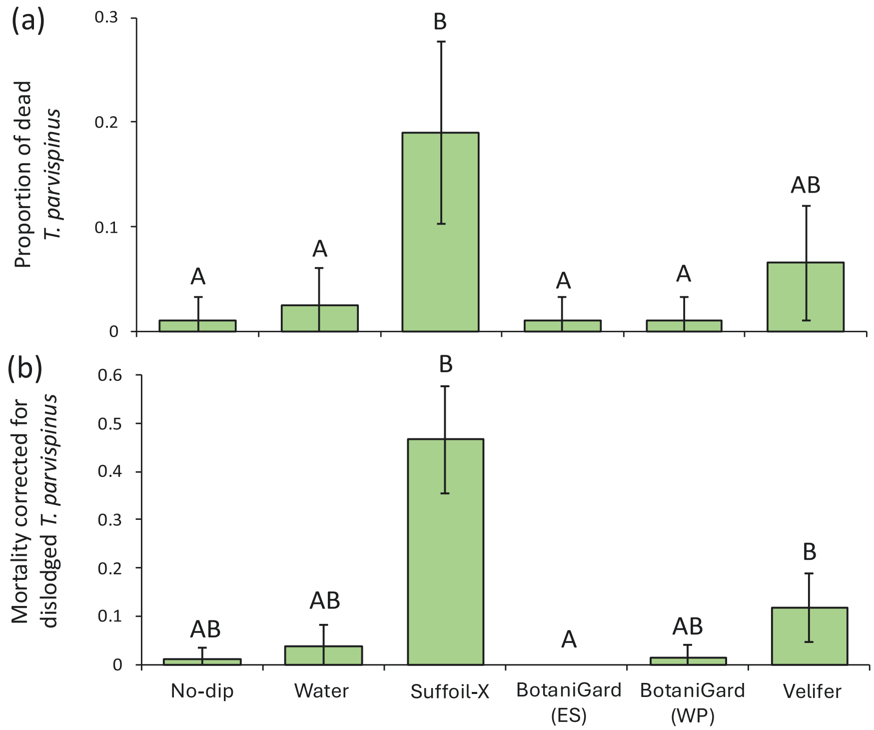

Fig. 3. Proportion of dead *Thrips parvispinus* larvae (L2) from infested bean seedlings 24 h post-dip treatment ($N = 20$). Panel (A) shows larval mortality from the starting number of 10 L2 larvae per replicate. Panel (B) shows larval mortality considering the number of non-dislodged L2 larvae left after dipping per replicate. Uppercase letters denote significant differences among treatments (Kruskal-Wallis, $P \leq 0.05$).

a dislodgement rate of 80%–100% (Fig. 2). Suffoil-X was also found to be the most efficacious in terms of mortality (Fig. 3). Therefore, in addition to being highly effective at dislodging L2 thrips larvae from the cuttings through dip treatment, mineral oil (Suffoil-X, 5%) provided the further advantage of killing the remaining live thrips on the cuttings with minimal adverse effects on plant health. This was not the case for BotaniGard-ES, which was found to cause high phytotoxicity on bean seedlings (Fig. 4). Bean seedlings were clearly more sensitive to BotaniGard-ES than mandevilla and gardenia cuttings, possibly due to their young age and softer tissue. Mandevilla and gardenia cuttings have thicker leaves and exhibited greater resilience than bean seedlings to the dip treatments.

The broad host range and short developmental cycle of *T. parvispinus* are key factors driving its rapid expansion into new geographic areas. Among its life stages, the larval stages, particularly L2, remain on the plant longer and cause more direct damage to leaves (Hutasoit et al. 2017). Our data corroborates this expectation for *T. parvispinus* on mandevilla plants. By focusing on the L2 stage, we partially addressed the potential of dip treatments as a first step in thrips management, but further studies addressing how dipping affects other thrips developmental stages, including eggs, L1, and adults, are still needed. With thrips eggs being laid inside the leaf tissue, it is unlikely that dipping will be effective in killing or removing them from the plant. This is also true for chemical control applications using contact insecticides. Despite the weekly insecticide treatments, mandevilla plants produced commercially had *T. parvispinus* eggs, which eventually hatched and gave rise to a new thrips population.

Cutting dips using either conventional or biorational insecticides have been proven effective as a phytosanitary treatment against mites and insect pests (Buitenhuis et al. 2016, Diczbalis 2018, Revynthi et al. 2020). For instance, immersing cassava cuttings in the pesticide flupyradifurone resulted in a 50% reduction in both adults and nymphs of *Bemisia tabaci* (Issa et al., 2022; Caspary et al., 2023), decreasing the incidence of the cassava mosaic disease (Caspary et al. 2023). Buitenhuis et al. (2016) demonstrated that Suffoil-X (mineral oil, 0.1%) and Bug B Gon (insecticidal soap, 0.5%) + BotaniGard 22WP (*Beauveria bassiana*) reduced *B. tabaci* infestation by 70% in poinsettia cuttings, even 8 weeks post treatment. In addition, phytotoxicity risks of these treatments were acceptable, and dip residues had little effect on survival of 2 *B. tabaci* parasitoids (Buitenhuis et al. 2016). Biorational insecticides such as insecticidal soaps (e.g., Kopa), mineral oils (e.g., Landscape oil, Suffoil-X, and Vegol), and biocontrol agents (e.g., BotaniGard, Nemasys) have been tested against the western flower thrips (WFT) *Frankliniella occidentalis*. Oil-based dips had the highest efficacy against WFT, reducing its populations in mums by up to 65% and in chrysanthemums and mini-roses by up to 95% (Buitenhuis et al. 2019). Our study corroborates observations from previous studies on thrips and whiteflies.

Moreover, our study emphasizes the use of biorational and microbial insecticides due to their advantages over synthetic insecticides. Given their efficacy against soft-bodied insects and their minimal toxicity to biological control agents (Buitenhuis et al. 2016, Brownbridge and Buitenhuis 2019) and mammals (Lopez and Liburd 2023), biorational and microbial insecticides represent a remarkable option in thrips pest management. Mineral oil is a petroleum-based oil product that can kill insects through suffocation (Najar-Rodriguez et al. 2008) and is authorized for use in Florida. Since insects cannot develop resistance to suffocation, oils are an excellent tool in resistance management and rotation programs. The use of mineral oil in post-harvest dips has demonstrated effectiveness in eliminating surface-dwelling insects and mites from lychee fruit (Diczbalis 2018, Revynthi et al. 2020). Although oil efficacy varies

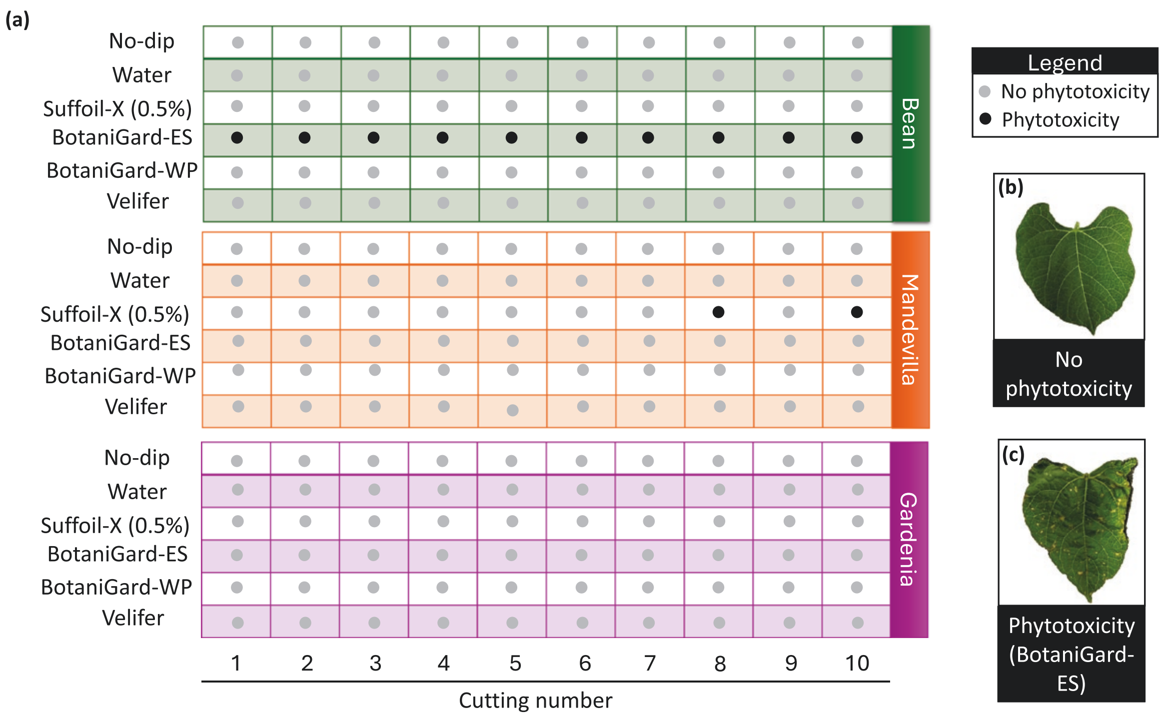

Fig. 4. Effect of dip treatment on plant phytotoxicity. Panel (A) shows number of bean (green), mandevilla (orange), and gardenia (purple) cuttings showing phytotoxic response to dipping during a 7-day period after treatment ($N = 10$). Pictures show (B) no phytotoxicity and (C) maximum phytotoxicity observed only for BotaniGard-ES.

and may not be as potent as conventional insecticides for some thrips species (Cloyd et al. 2009, Vassiliou 2011), we have previously shown that spray applications of mineral oil (2%–3%) increased mortality and reduced feeding activity of *T. parvispinus* (Ataide et al., 2024). In the present study, mineral oil (Suffoil-X, 0.5%) has also proved to be efficient in dislodging and killing L2 thrips larvae from cuttings, emerging as the top-performing product for dip treatment. For the microbials based on *B. bassiana* that we tested, we did not observe a significant effect in mortality. Most fungal entomopathogens require at least 2–3 days to infect and kill their hosts (Charnley 2003). Thus, the lack of effect observed may be attributed to the short duration of this experiment, and further testing is required to better understand the role of this entomopathogen in thrips control.

Oils can induce phytotoxicity depending on their concentration. Additionally, rinsing the cuttings with clean water after application does not mitigate the phytotoxic effects of these treatments (Liu 2011). Buitenhuis et al. (2016) observed some degree of phytotoxicity in poinsettia cuttings when employing oil alone or in combination with entomopathogens through dip treatments. We observed BotaniGard-ES phytotoxicity on bean cuttings but not on madevilla and gardenia.

Dips are likely to play a crucial role in an IPM program for *T. parvispinus*, especially as a preventative measure during the early stages of crop production. By dislodging and killing larvae present on cuttings before planting, dips can help reduce initial pest populations, making it easier to manage thrips infestations as the crop matures. However, dips should not be considered a stand-alone solution. Thrips control requires a multifaceted approach, incorporating additional tactics such as biological control agents, cultural practices, and selective chemical treatments. Together, these tools can manage *T. parvispinus* populations more effectively throughout the growing cycle, ensuring long-term success. Finally, the findings and recommendations from our study could potentially apply to other ornamental plants propagated from cuttings. Nevertheless, caution is advised regarding their concentrations and the potential phytotoxic effects on different host plants. We recommend that growers follow the label recommendations and conduct tests to ensure that the rates and products are appropriate for each plant before implementation.

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Author contributions

Livia Ataide (Formal analysis [equal], Investigation [equal], Methodology [equal], Visualization [equal], Writing—original draft [equal], Writing—review & editing [equal]), Yisell Velazquez-Hernandez (Investigation [equal], Methodology [equal]), Isamar Reyes-Arauz (Investigation [equal], Methodology [equal]), Paola Villamarin (Investigation [equal], Methodology [equal]), Maria Canon (Investigation [equal], Methodology [equal]), and Alexandra Revynthi (Investigation [equal], Methodology [equal], Project administration [equal], Resources [equal], Supervision [equal], Writing—original draft [equal], Writing—review & editing [equal])

Data availability

The datasets generated and analyzed during the current study are available in the figshare repository under the doi: 10.6084/m9.figshare.27478068.

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