Evaluation of reduced-risk insecticides to control chilli thrips (Thysanoptera: Thripidae) and conserve natural enemies on ornamental plants

Adam G. Dale[1,]* *and Matthew A. Borden*[1]

Abstract

Ornamental plants provide valuable services that benefit people and the environment. Herbivorous insects, particularly invasive pests with little resistance from natural enemies or plant defenses, damage plants and reduce the beneficial services they provide. Reduced-risk insecticides are valuable tools to selectively reduce target pests and protect plants while presumably conserving natural enemies. Herein, we conducted 2 separate tests of a new reduced-risk insecticide, cyantraniliprole, and industry standards for the control of *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), a damaging invasive insect pest of ornamental plants. We also evaluated each insecticide's compatibility with *Orius insidiosus* Say (Hemiptera: Anthocoridae), an important natural enemy of *S. dorsalis*. During laboratory evaluations, we found that spinosad was superior in acute toxicity to *S. dorsalis* and compatibility with *O. insidiosus*. Cyantraniliprole was consistently moderately toxic to *S. dorsalis* and *O. insidiosus* under lab conditions. In the field study, we found that all reduced-risk insecticides had no detectable effect on natural enemy abundance. Cyantraniliprole provided the best plant protection, with 70% less damage than the untreated control. Importantly, the effect of cyantraniliprole on *S. dorsalis* and plant protection depended on the application rate, such that the lowest rate tested did not reduce damage. This study demonstrates IPM tactics for managing an important invasive pest with a combination of chemical and biological control. As non-target effects of commonly used insecticides are becoming better understood, safer tools are needed to protect beneficial organisms, ornamental plants, and their services.

Key Words: Exotic pests; IPM; non-target effects; *Scirtothrips dorsalis*

Resumen

Las plantas ornamentales proveen servicios valiosos que benefician a las personas y el medio ambiente. Los insectos herbívoros, particularmente las plagas invasoras con poca resistencia de los enemigos naturales o las defensas de las plantas, dañan las plantas y reducen los servicios beneficiosos que proveen. Los insecticidas de bajo riesgo son herramientas valiosas para reducir selectivamente las plagas objetivo y proteger las plantas, mientras que, presumiblemente, conservan los enemigos naturales. Aquí, realizamos 2 pruebas separadas de un nuevo insecticida de riesgo reducido, ciantraniliprol y estándares industriales para el control de *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), una plaga de insectos invasores que daña las plantas ornamentales. También evaluamos la compatibilidad de cada insecticida con *Orius insidiosus* Say (Hemiptera: Anthocoridae), un enemigo natural importante de *S. dorsalis.* Durante las evaluaciones de laboratorio, encontramos que spinosad fue superior en toxicidad aguda a *S. dorsalis* y compatibilidad con *O. insidiosus*. Cyantraniliprole fue consistentemente moderadamente tóxico para *S. dorsalis* y *O. insidiosus* en condiciones de laboratorio. En el estudio de campo, encontramos que todos los insecticidas de riesgo reducido no tuvieron un efecto detectable en la abundancia del enemigo natural. El ciantraniliprol proveyó la mejor protección para las plantas, con un 70% menos de daño que el control no tratado. Es importante destacar que el efecto del ciantraniliprol sobre *S. dorsalis* y la protección de las plantas dependió de la tasa de aplicación, de modo que la tasa más baja probada no redujo el daño. Este estudio demuestra las tácticas del MIP para el manejo de una plaga invasora importante con una combinación de control químico y biológico. Dado que los efectos no objetivo de los insecticidas de uso común se comprenden mejor, se necesitan herramientas más seguras para proteger a los organismos beneficiosos, las plantas ornamentales y sus servicios.

Palabras Clave: plagas exóticas; MIP; efectos no objetivo; *Scirtothrips dorsalis*

Healthy plants in urban landscapes reduce temperatures, filter the air, and enhance aesthetics, which benefit people and the environment (Oke et al. 1989; Bolund & Hunhammar 1999; Tzoulas et al. 2007; Nowak et al. 2013). Unfortunately, herbivorous insects, particularly exotic species, often are abundant and damaging in urban landscapes, which reduces ornamental plant services and calls for effective management tactics (Raupp et al. 2010; Zvereva et al. 2010; Donovan et al. 2013; Dale & Frank 2014). Integrated pest management (IPM) strategies can safely reduce pests and promote plant services (Bottrell 1979). An important component of IPM is direct and indirect pest reduction through insecticide toxicity and natural enemy conservation, respectively (Gentz et al. 2010). For example, spot-treatments of insecticides target localized pest infestations, conserve resources, and minimize exposure to non-target organisms (Raupp et al. 2001). Reduced-risk insecticides, classified by the U.S. Environmental Protection Agency as those that show high pest selectivity, minimal non-target toxicity, and short persistence in the environment, also provide a valuable IPM tool (EPA 2017). Thus, judicious use of reduced-risk products offers the potential to directly and indirectly manage damaging insect pests.

[1]University of Florida, Entomology & Nematology Department, PO Box 110620, Gainesville, Florida 32611, USA; E-mail: agdale@ufl.edu (A. G. D.); m.borden@ufl.edu (M. A. B.)
*Corresponding author; E-mail: agdale@ufl.edu

Progress has been made in urban landscape IPM over recent decades (Raupp et al. 1992; Held & Potter 2012). However, due to cost, convenience, and rapid results, many landscape professionals still rely on indiscriminant use of broad-spectrum insecticides (Held & Potter 2012). Although broad-spectrum products can provide immediate relief of pests, they also reduce natural enemies, which creates enemy-free space and may allow herbivores to proliferate (Raupp et al. 2001). Pyrethroids and organophosphates, the most common insecticides used in urban landscape pest management, are broad spectrum and associated with reduced natural enemies, and secondary pest outbreaks (Hardman et al. 2007; Frank & Sadof 2011; Atwood & Paisley-Jones 2017). However, recent evidence suggests that neonicotinoids may present greater risks to beneficial insects than previously thought (Larson et al. 2012, 2013; Goulson et al. 2015). Reduced-risk insecticides may provide effective alternatives to broad spectrum products and industry-standard neonicotinoids (Frank 2012). Therefore, it is critical to understand the efficacy and non-target risks of alternative products available to landscape pest managers.

Scirtothrips dorsalis Hood (Thysanoptera: Thripidae) is among the most damaging exotic insect pests of ornamental plants in the southeastern U.S. (Kumar et al. 2013). This invasive insect damages plant leaves, buds, and fruits by scraping the surface of plant tissue and consuming plant sap. Feeding causes leaf, bud, and fruit distortion, which reduces growth, aesthetic quality, and plant services (Kumar et al. 2013). *Scirtothrips dorsalis* attacks over 100 plant species, several of which are commonly used ornamental landscape plants in the southeastern U.S. (Seal & Kumar 2010; Kumar et al. 2013). Due to its small size, mobility, and ability to cause rapid damage, current *S. dorsalis* management in landscapes relies largely on chemical control (Kumar et al. 2013). Several neonicotinoids (e.g., imidacloprid, acetamiprid) effectively reduce *S. dorsalis* abundance and are typically recommended for control (Seal & Kumar 2010; Kumar et al. 2016). However, evidence of the negative effects of neonicotinoids on non-target beneficial arthropods has highlighted the need for alternative products that can be incorporated into IPM programs (Larson et al. 2012; Goulson & Kleijn 2013; Larson et al. 2013). Fortunately, alternative technologies have proven effective and new chemistries are becoming available for ornamental plant protection (Doğramaci et al. 2011; Arthurs et al. 2012; Kumar et al. 2016; Aristizábal et al. 2017).

Anthranilic diamides, a group of ryanodine receptor modulators, were introduced to the U.S. market in 2007 as a new class of reduced-risk insecticide for ornamental plants (Cordova et al. 2006). These insecticides (chlorantraniliprole, cyantraniliprole) act by causing an uncontrolled calcium release from insect muscle cells, leading to paralysis, feeding inhibition, and death (Cordova et al. 2006). Chlorantraniliprole effectively controls insect pests with reduced risk to non-target organisms (Sial & Brunner 2010; Larson et al. 2012, 2013). For example, Larson et al. (2013) found that bumble bees foraging on chlorantraniliprole-treated white clover flowers were unaffected, whereas those foraging on clothianidin- or carbaryl-treated clover developed more slowly and did not produce a viable queen. Moreover, residential lawns treated with chlorantraniliprole had more predatory beetles and beneficial arthropods than those treated with clothianidin, bifenthrin, or chlorpyrifos (Larson et al. 2012). Cyantraniliprole, the most recently registered anthranilic diamide labeled for landscape pest control use, effectively controls other insect pests, including several thrips species (Bielza & Guillen 2015; Kodandaram et al. 2015).

To successfully manage insect pests, one must take a systems approach by directly targeting the pest, conserving natural enemies, and promoting plant health (Gentz et al. 2010). Factors such as direct toxicity, natural enemy abundance, and arthropod-inflicted plant damage are important to quantify over time (Wennergren & Stark 2000). Evaluating these factors under laboratory and field conditions can give more comprehensive results that help direct IPM decision making (Desneux et al. 2007). In this study, our objective was to determine the direct and indirect effects of cyantraniliprole and other reduced-risk insecticides on *S. dorsalis* control and plant protection. To determine the effects of cyantraniliprole and other insecticides on *S. dorsalis* and its natural enemies, we conducted a series of laboratory and field experiments. First, we measured direct insecticide toxicity over time to *S. dorsalis* and a key natural enemy, *Orius insidiosus* Say (Hemiptera: Anthocoridae). In a second study, we determined the effect of reduced-risk insecticides on natural enemy abundance and plant protection by quantifying *S. dorsalis* damage in the field.

Materials and Methods

STUDY ORGANISMS

We used Indian hawthorn, *Rhaphiolepsis indica* (L.) (Rosaceae), as the focal host plant because it is one of the most common ornamental landscape plants in southeastern U.S. landscapes and a preferred host of *S. dorsalis* (Kumar et al. 2013). Additionally, *S. dorsalis* feeding-induced red-to-silver discoloration, scarring, and leaf distortion can be quantified easily (Kumar et al. 2016). One of the most important predators of *S. dorsalis* is the insidious flower bug, *O. insidiosus* (Doğramaci et al. 2011). This highly effective native predator is widely distributed in both managed agroecosystems and landscapes in the southern U.S. (Lattin 1999). It is mass-reared and commercially available for biological control programs, and most commonly used in greenhouse plant production (Ramakers 1995). Several studies have demonstrated that *O. insidiosus* can reduce *S. dorsalis* abundance effectively, as well as damage to ornamental plants (Silveira et al. 2004; Doğramaci et al. 2011).

For the laboratory portion of this study, we maintained a colony of *S. dorsalis* in a greenhouse on conventional cotton plants grown from seed (Deltapine DP 0935 B2RF) in Gainesville, Florida, USA. *Scirtothrips dorsalis* in our colony were composed of individuals originating from a colony maintained in Apopka, Florida, and a separate colony maintained in Balm, Florida. We kept the cotton plants in 0.6 m cube PVC cages covered in fine mesh (white organza, JoAnn Fabrics, Hudson, Ohio, USA) cages to contain thrips and prevent infestation by other organisms. Newly grown plants were added as needed to sustain the thrips colony. We purchased *O. insidiosus* for the laboratory bioassay from 2 commercial sources, Arbico Organics (Oro Valley, Arizona, USA) and Rincon-Vitova Insectaries (Ventura, California, USA).

Scirtothrips dorsalis used for the field portion of this study were natural infestations that established on the host plants under open field conditions. Infestations were detected by monitoring plants for initial signs of damage and identifying individuals collected from symptomatic plant material. The field portion of this study was located at the University of Florida Institute of Food and Agriculture Sciences, Plant Science Research and Education Unit in Citra, Florida.

INSECTICIDES

We selected insecticides commonly used to control *S. dorsalis* on woody ornamental plants. For the laboratory bioassay, we used spinosad, a low and high rate of cyantraniliprole, and a combination product containing imidacloprid, bifenthrin, and zeta-cypermethrin (Table 1). The latter product was selected because of its popularity in the landscape pest control industry and the known broad-spectrum activity of pyrethroids. For the field trial portion of this study, the neonicoti-

Table 1. Insecticide treatments and rates applied to *Rhaphiolepsis indica* shrubs for laboratory bioassays.

Insecticide Class (IRAC number)	Active Ingredient(s)	Trade name	Rate (mL) per 378.5 L	Volume of spray used (mL)	
				Laboratory Trial	Field Trial
Anthranilic diamide (28)	Cyantraniliprole	Mainspring GNL	59.1 (low)	340	210
Anthranilic diamide (28)	Cyantraniliprole	Mainspring GNL	236.6 (high)	380	220
Spinosyn (5)	Spinosad	Conserve SC	177.4	380	250
Neonicotinoid (4A) and Pyrethroids (3A)	Imidacloprid, Bifenthrin, Z-cypermethrin	Triple Crown T&O	221.8	280	Not included

noid/pyrethroid combination product was deleted (Table 1). Spinosad is a reduced-risk insecticide currently recommended as an effective *S. dorsalis* management tool (Ludwig & Bogran 2007; Kumar et al. 2013; Aristizábal et al. 2017). Cyantraniliprole also is a reduced-risk product labeled for thrips control on ornamental plants (EPA 2017). However, limited information is available on its efficacy for thrips on landscape ornamentals. In both experiments, we compared the effects of each treatment to those observed on a replicated untreated control that received no insecticide applications.

LABORATORY BIOASSAYS

For the laboratory component of this study, we used 36 *R. indica* shrubs planted in 11.4 L pots filled with Fafard® 3B Mix (Agawam, Massachusetts, USA) professional potting soil. We applied insecticides under field conditions of 28 °C, 80% RH, wind gusts < 2 mps, and sunny skies using a CO_2 pressurized backpack sprayer system on 29 Jun 2016. After the foliage was completely dry, we arranged the shrubs into six 2 × 2 m blocks with each treatment randomly located per block and separated by 1 m. For the duration of the laboratory bioassay, these plants were maintained outdoors and irrigated as needed at the University of Florida in Gainesville, Florida.

To evaluate residual toxicity of our treatments to *S. dorsalis*, we collected leaf samples from each shrub at 4 time intervals. The first collection was made 1 day prior to treatment to ensure there was no pretreatment effect of any plants on the insects. We collected the remaining samples on 1, 7, and 14 d after treatment. For each collection, we picked 1 fully expanded leaf from recent growth on the outermost portion of the branch because this is where *S. dorsalis* preferentially feed (Aristizabal et al. 2016). We put leaves from each plant into individual plastic bags, placed them into a cooler, and transported them to the laboratory where we brushed them with a stiff paintbrush to remove any surface debris and arthropods. We cut 30 mm diam leaf discs from each leaf and placed the uniform disks, along with one Whatman™ 42.5 mm filter paper in a Falcon® 50 × 9 mm tight-fit lid Petri dish, adding 350 µl of deionized water to each filter paper to maintain humidity and reduce leaf desiccation. For the duration of the assay, the closed dishes were stored in an incubator (Percival Scientific, Perry, Iowa, USA) set to 27 °C, and 60% RH, and with a 14:10 h (L:D) photoperiod.

SCIRTOTHRIPS DORSALIS TOXICITY

Using a fine-tip paintbrush, we transferred 4, instar 4 or 5, *S. dorsalis* nymphs from the greenhouse colony directly onto the leaf disk in the prepared Petri dish. We observed the dishes 6 and 24 h later, recording the nymphs as dead, intoxicated, or alive. Insects were considered intoxicated if they were unable to right themselves within 1 min after being flipped onto their dorsal side. During the 6 h evaluation, any live nymphs found off the leaf disk were manually returned to the leaf surface using a fine-tip paintbrush. Between time points, all dishes were tightly closed and stored in the incubator. Insecticide toxicity to *S. dorsalis* was analyzed by comparing % knockdown, which combines dead and intoxicated individuals into a single category. Although *S. dorsalis* individuals were not observed beyond the time points reported, no intoxicated individuals ever were observed recovering from an intoxicated state over time.

ORIUS INSIDIOSUS TOXICITY

Immediately after recording *S. dorsalis* observations at 24 h post-treatment, we used an aspirator to transfer 4 *O. insidiosus* adults into each dish. *Orius insidiosus* were free to feed on the thrips nymphs, although this was not observed. We recorded *O. insidiosus* toxicity 24 and 48 h after introduction by recording the number dead, intoxicated, and alive as in the *S. dorsalis* experiment above. During periods between counting, all dishes were tightly closed and stored in the incubator. Insecticide toxicity to *O. insidiosus* was analyzed by comparing % knockdown, which combines dead and intoxicated individuals into a single category. Although *O. insidiosus* individuals were not observed beyond the time points reported, no intoxicated individuals ever were observed recovering from an intoxicated state over time.

FIELD TRIAL

Sixteen wk following the laboratory evaluations, we used the same *R. indica* plants in 11.4 L pots to conduct a field trial at the University of Florida Plant Science Research and Education Unit in Citra, Florida, to determine the effect of reduced-risk insecticides on *S. dorsalis* plant protection and natural enemy abundance. Individual plants were treated with the same products as in the previous laboratory trial treatments, except that the pyrethroid-neonicotinoid combination product and its plants were removed. We arranged shrubs into 6 groups of 5, placed them in 2 × 2 m plots, and made treatment applications under optimal weather conditions, using the same CO_2 pressurized backpack sprayer system as before. Once the plant foliage was dry, we arranged them into a randomized complete block design with 6 rows (blocks) and each treatment randomly positioned per row. Blocks were separated by 2 m and each plant within a block separated by 1 m.

PREDATOR ABUNDANCE ON *RHAPHIOLEPSIS INDICA*

To determine the effect of insecticide treatment on natural enemy abundance, we surveyed each plant for natural enemies 1, 7, and 20 d after application. To survey natural enemies, we grasped the main trunk of a plant and beat it 5 times onto a 30.5 × 46 cm white plastic tray as in Frank (2012). We immediately misted the tray with 70% ethanol to prevent arthropod escape and rinsed the contents into 50 mL Falcon® centrifuge tubes. Next, we examined the contents of each vial using a dissecting microscope and identified all collected arthropods to family. Collected natural enemies included spiders (Acari: Araneae), predatory bugs (Hemiptera: Reduviidae and Anthocoridae), and ants (Hymenoptera: Formicidae). We log transformed natural enemy abundance at 7 and 20 d after treatment to increase normality of the residuals.

SCIRTOTHRIPS DORSALIS DAMAGE TO *RHAPHIOLEPSIS INDICA*

We assessed plant damage by calculating % thrips damage per 20 leaves and by quantifying the percentage of leaves on the entire plant exhibiting damage from *S. dorsalis*. To quantify % damage per leaf by thrips, similarly to Aristizabal et al. (2016), we picked 5 fully expanded terminal leaves from 4 randomly selected branches (1 from each cardinal direction) on each shrub, totaling 20 leaves per plant. We placed the leaves onto white paper and scanned them to create a digital image of the upper (adaxial) surface and lower (abaxial) surface of each leaf. Using ImageJ software, we converted each image to 8-bit grayscale and binary, allowing the program to distinguish green tissue from the scarring of thrips damage (Schneider et al. 2012). We then quantified % damaged area on the upper and lower surfaces of each leaf, and calculated the average % damage per 20 leaves for each plant. Leaf samples were collected 1 d pre-treatment, plus 14 and 35 d post-treatment.

Six wk after treatment (42 d post-treatment), we inspected each plant to quantify overall plant damage by recording the number of leaves with *S. dorsalis* feeding damage, and counting the total number of leaves per plant. From these counts, we calculated the % of each plant that had some level of *S. dorsalis* feeding damage.

STATISTICAL ANALYSIS

Both laboratory and field experiments were set up as randomized complete blocks, with each treatment randomized among 6 blocks. All statistical analyses were conducted using one-way analysis of variance (ANOVA) in SAS 9.4 with PROC MIXED and LS MEANS, including block as a random effect, insecticide treatment as the independent variable and each measured response as the dependent variable (SAS 2017). Treatment means were compared among each other and the untreated control using Tukey-Kramer HSD. *P*-values < 0.05 were considered significant for all tests.

Results

SCIRTOTHRIPS DORSALIS TOXICITY

As expected, there was a significant effect of time ($F_{2,8}$ = 11.56; P < 0.0001) on the efficacy of all treatments. The effect of time on efficacy was nearly significantly different between treatments ($F_{2,8}$ = 1.82; P < 0.0858). At 1 d post-treatment, spinosad was the only product that caused knockdown greater than the untreated control. Although not statistically significant, mean *S. dorsalis* % knockdown on spinosad-treated leaves was nearly twice that of cyantraniliprole-treated leaves (Table 2). At 7 and 14 d post-treatment, no product caused *S. dorsalis* knockdown different from one another or the untreated control (Table 2). Despite this, at 14 d post-treatment, spinosad had the least effect on *S. dorsalis*, approximately 25% the knockdown caused by all other treatments. The pyrethroid/neonicotinoid combination product and cyantraniliprole treatments were moderately toxic to *S. dorsalis* throughout the duration of the experiment (Table 2).

ORIUS INSIDIOSUS TOXICITY

The effects of insecticide toxicity on *O. insidiosus* were much more pronounced than their effects on *S. dorsalis*. Percent knockdown was significantly associated with time ($F_{2,8}$ = 3.19; P = 0.0469) after treatment, but also dependent on the insecticide used ($F_{2,8}$ = 4.93; P < 0.0001). In addition, leaves treated with the pyrethroid/neonicotinoid product caused significantly greater *O. insidiosus* knockdown than all other treatments and the control over 14 d ($F_{4,8}$ = 24.71; P < 0.0001), although it became significantly less toxic with time.

At 1 d post-treatment, 100% of *O. insidiosus* exposed to pyrethroid/neonicotinoid treated leaves became intoxicated or died, which was over 4 times the knockdown of the other treatments and the control (Table 3). One wk later, % knockdown was much lower on the pyrethroid/neonicotinoid treated leaves, although still significantly greater than the untreated control and the low rate of cyantraniliprole (Table 3). Interestingly, *O. insidiosus* % knockdown slightly increased over time on leaves treated with the high rate of cyantraniliprole such that at 14 d post-treatment it was significantly greater than the untreated plants and the low rate of cyantraniliprole (Table 3). Two wk after treatment (14 d post-treatment), the high rate of cyantraniliprole and the pyrethroid/neonicotinoid product caused 46 and 33% knockdown, respectively (Table 3).

PREDATOR ABUNDANCE ON *RHAPHIOLEPSIS INDICA*

Natural enemies collected by beat sampling *R. indica* shrubs included spiders (Araneae), ants (Formicidae), and predatory bugs (Anthocoridae and Reduviidae). Although all insecticide-treated plants averaged fewer predators than the control, spinosad-treated plants were the only treatment with significantly fewer (Table 4). Plants treated with insecticides supported equally abundant predator populations.

SCIRTOTHRIPS DORSALIS DAMAGE TO *RHAPHIOLEPSIS INDICA*

All *R. indica* shrubs exhibited some level of *S. dorsalis* feeding damage; however, % herbivory per leaf was low across all treatments. Because of this, we were unable to detect an effect of insecticide treatment on % damage per leaf (Table 5). *Scirtothrips dorsalis* damage on the upper surface of leaves was not different from the lower surface, and the 2 were strongly significantly correlated on all dates (0.71 ≤ r ≤ 0.91; P < 0.0001). This suggests that future studies could evaluate *S. dorsalis* damage by quantifying it on only 1 side of the leaf.

Table 2. Mean % knockdown (± SEM) of *Scirtothrips dorsalis* when exposed to *Rhaphiolepsis indica* leaves for 24 h at 1, 7, and 14 days post-treatment.

		Days post-treatment		
Active Ingredient	Rate (mL) per 378.5 L	1	7	14
Untreated Control	—	15.28 ± 11.06b	4.17 ± 4.17	12.50 ± 8.54
Cyantraniliprole	59.1 mL (low)	26.94 ± 6.81ab	15.28 ± 8.17	18.06 ± 5.86
Cyantraniliprole	236.6 mL (high)	29.17 ± 7.68ab	8.89 ± 5.88	22.22 ± 7.95
Spinosad	177.4	56.94 ± 6.24a	12.22 ± 7.78	4.17 ± 4.17
Imidacloprid + Bifenthrin + Z-cypermethrin	221.8	41.67 ± 11.39ab	19.44 ± 11.92	16.67 ± 5.27
$F_{20,29}$		3.20	0.63	1.13
P		0.0350	0.6462	0.3714

Different letters within a column indicate significant differences between treatments using Tukey-Kramer HSD means comparison (P < 0.05).

Table 3. Mean % knockdown (± SEM) of *Orius insidiosus* when exposed to *Rhaphiolepsis indica* leaves for 48 h at 2, 8, and 15 days post-treatment.

		Days post-treatment		
Product	Rate (mL) per 378.5 L	2	8	15
Untreated Control	—	8.33 ± 5.27b	9.72 ± 6.24b	4.17 ± 4.17b
Cyantraniliprole	59.1 mL (low)	16.67 ± 5.27b	12.50 ± 8.54b	9.72 ± 6.24b
Cyantraniliprole	236.6 mL (high)	25.00 ± 6.45b	31.94 ± 9.48ab	45.83 ± 15.02a
Spinosad	177.4	16.67 ± 8.33b	25.00 ± 9.13ab	12.50 ± 8.54ab
Imidacloprid + Bifenthrin + Z-cypermethrin	221.8	100 ± 0.0a	52.78 ± 2.78a	33.33 ± 8.33ab
$F_{20,29}$		41.84	4.87	4.39
P		< 0.0001	0.0066	0.0104

Different letters within a column indicate significant differences between treatments using Tukey-Kramer HSD means comparison (P < 0.05).

Table 4. Natural enemy abundance (mean ± SEM) on *Rhaphiolepsis indica* shrubs at 1, 7, and 20 days post-treatment.

		Days post-treatment		
Untreated Control	—	1.40 ± 0.29	1.00 ± 0.52	2.33 ± 0.56a
Cyantraniliprole	59.1 mL (low)	2.67 ± 0.95	2.67 ± 1.54	1.83 ± 1.10ab
Cyantraniliprole	236.6 mL (high)	0.83 ± 0.65	0.33 ± 0.21	1.33 ± 0.56ab
Spinosad	177.4 mL	0.83 ± 0.31	1.00 ± 0.52	0.67 ± 0.33b
$F_{3,15}$		2.30	1.30	3.83
P		0.1192	0.3114	0.0335

Different letters within a column indicate significant differences between treatments using Tukey-Kramer HSD means comparison (P < 0.05).

Table 5. *Scirtothrips dorsalis* percent herbivory (mean ± SEM) per 20 leaves on *Rhaphiolepsis indica* shrubs 0, 14, and 35 days post-treatment.

		Days post-treatment		
Product	Rate per 378.5 L	0	14	35
Untreated Control	—	5.48 ± 1.18	2.79 ± 0.76	1.76 ± 0.25
Cyantraniliprole	59.1 mL (low)	5.46 ± 1.94	2.00 ± 0.35	1.34 ± 0.24
Cyantraniliprole	236.6 mL (high)	3.21 ± 0.95	1.54 ± 0.29	1.28 ± 0.17
Spinosad	177.4 mL	3.88 ± 0.82	3.05 ± 1.05	1.77 ± 0.46
$F_{3,15}$		0.68	0.98	1.13
P		0.5756	0.4291	0.3669

The effect of insecticide treatment was more apparent at the whole plant level. Although % *S. dorsalis* damage did not differ between insecticide treatments, plants treated with the high rate of cyantraniliprole were significantly less damaged than the untreated control ($F_{3,15}$ = 3.98; P = 0.0285) (Fig. 1). On average, plants treated with spinosad and the high rate of cyantraniliprole had the lowest % of *S. dorsalis* damage among treatments.

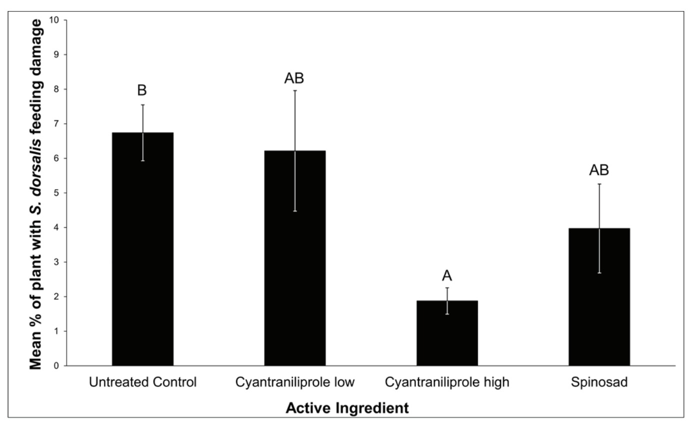

Fig. 1. Mean percentage (± SEM) of *Rhaphiolepsis indica* foliage with *Scirtothrips dorsalis* feeding damage 42 days after insecticide treatment. Different letters indicate significant differences between treatments using Tukey-Kramer HSD means comparison (P < 0.05). Cyantraniliprole low (59.1 mL per 378.5 L) and cyantraniliprole high (236.6 mL per378.5 L).

Discussion

Ornamental plant managers depend on pesticides for insect pest control and plant protection. Pyrethroids and neonicotinoids comprise 43% of global insecticide sales, yet both face regulatory threats due to environmental and human health concerns, particularly for urban landscape use (Troczka 2013; Goulson et al. 2015; EPA 2016). Thus, effective alternatives must be identified to reduce exotic pests and their damage, and maximize the services provided by urban plants. Through a combination of lab and field experiments, we found that cyantraniliprole, a new reduced-risk insecticide for use on ornamental plants in urban landscapes, provided equal or better control of *S. dorsalis* than current industry standards, while having minimal effect on key predators. This latter component is important because unlike many invasive pests, *S. dorsalis* is attacked by an abundant and effective native predator, *O. insidiosus*, which means that conserving predators is critical for *S. dorsalis* IPM programs (Gentz et al. 2010; Doğramaci et al. 2011).

Landscape pest managers often use broad-spectrum insecticides like pyrethroids and organophosphates because they are inexpensive and can provide rapid results. Several products combine pyrethroids and neonicotinoids with the goal of providing immediate contact-toxicity as well as residual systemic control. However, little research has investigated the effect of such products on pests and beneficial insects. We found that an insecticide containing 2 pyrethroids (bifenthrin and zeta-cypermethrin) and a neonicotinoid (imidacloprid) caused between 33 and 100% knockdown to *O. insidiosus* through 14 d post-treatment, whereas reduced-risk products never caused over 46% knockdown. Moreover, the pyrethroid/neonicotinoid combination product did not provide greater *S. dorsalis* toxicity than cyantraniliprole or the industry standard (spinosad) in laboratory trials. Although our results did not capture the direct effects of these products past 14 d, this is enough time for *S. dorsalis* to complete 1 generation (Kumar et al. 2013). Greater predator knockdown beyond this time may allow thrips to develop and feed in enemy-free space, facilitating population growth.

Natural enemies can reduce thrips abundance in greenhouse, nursery, and landscape systems (Doğramaci et al. 2011; Kumar et al. 2013). Conserving natural enemies in urban landscapes is critical because populations are more difficult or cost-inhibitive to augment with commercially purchased organisms (Paine et al. 1997). Reassuringly, we found no effect of cyantraniliprole on predator abundance over 20 d in the field when compared to the untreated control. Although we did find that the high rate of cyantraniliprole caused significantly greater *O. insidiosus* knockdown 14 d post-treatment than the control in laboratory trials, our field results suggest that this did not affect predator abundance or plant protection beyond this time point. We did find that spinosad-treated plants harbored fewer predators than untreated plants; however, we cannot explain the mechanism for this. Plants treated with insecticides harbored equivalent predator populations, which averaged fewer than the untreated control. This could suggest that treated plants either had fewer herbivore food resources to support predators or had a negative effect on predator establishment. Future studies should further investigate this association.

People depend on ornamental plants to provide valuable services in habitats where impervious surfaces are rapidly replacing vegetation (Nowak & Greenfield 2012). Plants with less insect damage can photosynthesize, grow, and provide more services than those with damage (Zvereva et al. 2010; Dale & Frank 2014). We found that the high rate of cyantraniliprole provided the best control of *S. dorsalis*, such that plants treated with it had 70% less damage than the untreated control. This may be explained by cyantraniliprole providing direct and indirect control through moderate *S. dorsalis* toxicity, and moderate to low natural enemy knockdown. Our results also support previous research that has found spinosad to effectively reduce *S. dorsalis* abundance and protect plant health (Aristizabal et al. 2016). Aristizabal et al. (2016) also found that spinosad conserved natural enemies, which matches our laboratory results but is not reflected in our field trial. Despite this, given our efficacy results and those of others, an effective *S. dorsalis* IPM program may include an initial application of spinosad to reduce pest abundance followed by a high rate application of cyantraniliprole, which provided extended protection through 35 d in the field (Bielza & Guillen 2015; Aristizábal et al. 2017).

Over recent years, anthranilic diamides have gained a reputation for being highly pest-selective and relatively safe for non-target organisms (Larson et al. 2012, 2013; Troczka 2013; Kodandaram et al. 2015). Because it has been the only commercially available active ingredient, chlorantraniliprole has been the primary driver of this reputation. Our results suggest that cyantraniliprole is like chlorantraniliprole in that it provided the best control of the target pest, *S. dorsalis*, while posing little risk to natural enemies. Importantly, this efficacy was dependent on the rate at which it was applied, such that the lowest label rate provided little control, while the highest rate was most effective of all treatments. To effectively and safely manage landscape plant pests, professionals must understand the direct, indirect, and rate-dependent effects of products they are using. We have demonstrated that a new reduced-risk product conserves natural enemies and provides an effective tool for managing an important exotic insect pest of ornamental plants.

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