Effects of Insecticide Drench Application against Immatures of *Systena frontalis* in Container-grown *Hydrangea paniculata*[1]

Shimat V. Joseph[2*] and **Alejandro I. Del Pozo-Valdivia**[3]

Abstract

Systena frontalis (F.) (Coleoptera: Chrysomelidae), commonly referred to as the redheaded flea beetle, is a serious pest in container nurseries, as adult feeding defoliates nursery crops and affects plant salability. Because the foliar application of insecticides provides inconsistent efficacy, additional and alternative control tactics are sought to target immatures of this pest in growing media. Thus, the objective was to determine the effects of non-neonicotinoid insecticides applied as a drench to growing media on immatures of *S. frontalis*. In 2021 and 2022, nine active ingredients were evaluated in four trials in a Georgia nursery and at a Virginia research and extension center. If available, the maximum label rates for flea beetles or other coleopteran pests were applied once to *Hydrangea paniculata* Siebold containers (11.4 L, 3 gal) as a drench application. The emergence of *S. frontalis* adults from treated growing media and foliar feeding damage was lower for the tetraniliprole (Tetrino™) and spinetoram + sulfoxaflor (XXpire®) treatments than for nontreated plants. Cyclaniliprole (Sarisa™) and chlorantraniliprole (Acelepryn®) suppressed *S. frontalis* adult eclosion with less feeding damage than the nontreated plants. Tetraniliprole, spinetoram + sulfoxaflor, and cyclaniliprole are not labeled for drench application. Dinotefuran (Safari®) effectively reduced adult emergence and feeding damage.

Species used in this study: Redheaded flea beetle, *Systena frontalis* (F.); panicled hydrangea, *Hydrangea paniculata* Siebold.

Chemicals used in this study: Cyantraniliprole (Mainspring®GNL), chlorantraniliprole (Acelepryn®), tetraniliprole (Tetrino™), cyclaniliprole (Sarisa™), Spinetoram + Sulfoxaflor (XXpire®), tolfenpyrad (Apta®), *Chromobacterium* (Grandevo®CG), flupyradifurone (Altus™), dinotefuran (Zylam® Liquid, Safari® 20G), and polyterpenes pinene (NuFilm® P).

Index words: redheaded flea beetle, *Hydrangea paniculata*, nursery, chemical control, ornamentals.

Significance to the Horticulture Industry

Ineffective pest management programs negatively affect several processes in nurseries, including direct losses due to plant injury from pests, as well as increased labor and additional management cost to maintain plant inventory. *Systena frontalis* is a challenging pest for nursery growers across the eastern USA, resulting in the need for multiple foliar applications to reduce adult populations and defoliation damage. Additional control tactics for managing this key pest are needed for the nursery industry, where higher cost and nontarget effects of insecticide applications could be mitigated. In addition, there is an urgent need to evaluate alternative active ingredients to pyrethroids and neonicotinoids. This research investigated nine active ingredients for the management of beetle pests. The novel approach from this project was to use these insecticides as drench applications, targeting the overwintering populations of *S. frontalis* residing in the growing media of infested plant containers. The ultimate goal was to determine effective insecticides that could be used as a drench to reduce *S. frontalis* adult emergence from infested plants. It was anticipated that targeting immatures (larvae and pupae) would reduce adult densities during the growing season, which could ultimately reduce the frequency of foliar insecticide sprays in the container nursery.

Received for publication January 28, 2023; in revised form June 23, 2023.

[1]We thank C. Hardin, R. Arshad, R. Govindaraju, O. Ibiyemi, M. Ghimire, D. Grossman, A. Agi, M. Mitcham, and L. Ibanez from the University of Georgia, and Julie Brindley, Elidah Sisk, Joseph Leo and Kaylee Armstrong from the Virginia Polytechnic Institute and State University for assistance in setting up and evaluating the experimental caged plants. Additionally, we thank the nursery grower for the help with the research site. This research was funded through Georgia Specialty Crop Block Grant # AM200100XXXXG038 and the Virginia Tech Hatch Project VA-160164. Bayer Environmental Sciences (Envu), Corteva Agriscience, Syngenta Crop Protection, PBI-Gordon, Valent Professional, OHP. Inc., Nichino America, and Marrone Bio Innovations provided partial funding and/or insecticides.

[2]Department of Entomology, University of Georgia, 1109 Experiment Street, Griffin, GA 30223, USA.

[3]Department of Entomology, Virginia Polytechnic Institute and State University, 1444 Diamond Springs Road, Virginia Beach, VA 23455, USA.

[*]Corresponding author email: svjoseph@uga.edu.

Introduction

Systena frontalis (F.) (Coleoptera: Chrysomelidae), commonly referred to as the redheaded flea beetle, is a serious insect pest of many ornamental plants in container nurseries in the central and eastern USA (Mahr 2005, Lauderdale 2017, Cloyd and Herrick 2018, Joseph and Hudson 2020, Joseph et al. 2021, Lane 2022, Arshad et al. 2023). In the USA, this pest threatens the container nursery industry, which in 2019 sold $4.5 billion USD of plants (USDA NASS 2020). The adult *S. frontalis* feeds on the foliage, and the affected containers are not marketed, resulting in crop loss due to excessive damage. The non-marketed plants are managed until the subsequent market window, which sustains additional maintenance costs, such as labor in pruning, application of pesticides and fertilizers, and maintenance of equipment (Joseph et al. 2021). *Systena* *frontalis* is a challenging pest to manage, as it is polyphagous, feeding on more than 50 species of plants in container nurseries and having three or more overlapping generations per year (Joseph et al. 2021, Lane 2022), depending on the latitude of affected nurseries. Thus, this insect is regarded as a resident pest in affected nurseries, requiring a continuous management plan to reduce their populations below economic levels. *Systena frontalis* is rarely a pest in urban landscapes where the container plants are purchased and ultimately planted (Joseph et al. 2021). Panicled hydrangea (*Hydrangea paniculata* Siebold), sweetspire (*Itea virginica* L.), weigela (*Weigela* spp. Thunb.), and holly (*Ilex* spp. L.) in container nurseries are the major species of plants affected by this pest, with defoliation damage resulting from infestations (Herrick and Cloyd 2020, Joseph et al. 2021, Lane 2022, Arshad et al. 2023).

In the fall, *S. frontalis* females oviposit eggs in potting media of the plant containers and overwinter as eggs (Lauderdale 2017, Herrick and Cloyd 2020). During the late winter, these eggs hatch, and the larvae feed on the root tissues (Lauderdale 2017). The larvae gradually develop through three to four instars and pupate within the growing media of the container (Joseph unpublished data). The first-generation adults emerge from the containers beginning the first or second week of May in the eastern USA (Kunkel and Colon 2012, Lane 2022, Arshad et al. 2023). At this stage, *S. frontalis* adults actively feed on the foliage of container plants, especially on *H. paniculata,* which seems to be one of the preferred hosts (Herrick and Cloyd 2020). Although larvae feed on the roots, they are rarely reported to cause economic damage.

In container nurseries, *S. frontalis* adults are managed using foliar insecticide sprays (Kunkel 2016, 2021, Joseph et al. 2021, Lane 2022, Arshad et al. 2023). A recent survey showed that container nursery growers use many insecticide products, and a greater proportion of them use neonicotinoids (Joseph et al. 2021). Although neonicotinoids are effective in managing *S. frontalis* adults (Kunkel 2016, 2021, Lane and Del Pozo-Valdivia 2022), they are implicated as harmful to pollinators foraging on neonicotinoid-applied plants (Blacquière et al. 2012). Thus, consumers are demanding neonicotinoid-free plants from retailers (Wollaeger et al. 2015, Getter et al. 2016, Rihn and Khachatryan 2016, Wei et al. 2020). In response to this restriction posed by retailers, some container nursery growers do not use neonicotinoids for *S. frontalis* management (Joseph et al. 2021). Joseph et al. (2021) showed that many wholesale container nursery growers were unsatisfied or thought they did not have enough insecticide tools to manage *S. frontalis* in their operations, limiting their chemical rotation options, and were open to alternative management approaches. Moreover, the damage threshold on the ornamental plants in container nurseries with *S. frontalis* adult feeding has not been determined.

The drench application of insecticides has shown promising results in many agroecosystems, including controlling *Bagrada hilaris* (Burmeister) (Hemiptera: Pentatomidae) adults in broccoli (*Brassica oleracea* var. *italica*) (Joseph et al. 2016), *Frankliniella occidentalis* (Pergande) pupae in container plants in the greenhouse (Li et al. 2019), *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) adults and nymphs in citrus (*Citrus* spp.) trees (Carmo-Sousa et al. 2020), *Delia radicum* (Linnaeus) (Diptera: Anthomyiidae) larvae in broccoli and cauliflower (*Brassica oleracea* var. *botrytis*) (Joseph and Iudice 2020), and *Adelges tsugae* (Annand) (Hemiptera: Adelgidae) adults and nymphs on eastern hemlock (*Tsuga canadensis* L.) trees in forests (Joseph et al. 2011). Specifically, the drench application has shown effective control of *S. frontalis* larvae in cranberry (*Vaccinium* spp.) (Guédot and Hietala-Henschell 2015) and on *H. paniculata* in container nurseries (Kunkel 2016).

In the container nursery, because *S. frontalis* larvae develop by consuming root tissue and pupate in the growing media, the drench application method has a high potential to be effective against immatures (larvae and/or pupae) of this pest. Previously, the drench application of neonicotinoids, such as dinotefuran and imidacloprid (Kunkel 2016), was effective against *S. frontalis* larvae. However, little is known about the efficacy of non-neonicotinoid insecticides applied as a drench. The drench application method can be labor intensive but could be utilized depending on the degree of densities of *S. frontalis* prevalent in the nursery and the timing within the market window requiring plants close to 100% damage free. Thus, the objective of the current study was to determine the effectiveness of drench-applied non-neonicotinoid insecticides against immatures of *S. frontalis* in container plants. Insecticides were selected based on the non-neonicotinoid class and evidence of their effectiveness in other chewing and coleopteran pests across multiple cropping systems. Targeting the control of *S. frontalis* immatures developing in growing media could result in lowering adult densities emerging from those infested and treated containers. Lower adult densities might reduce the number of foliar insecticide applications needed during the growing seasons.

Materials and Methods

Georgia study site. In 2021 and 2022, three experiments were conducted at a wholesale container nursery in McDuffie County, GA, USA. The nursery is 330 ha (815.4 acre) in production, but the experimental site was 6,527 m^2 (70,256.0 ft^2). This experimental site was surrounded by other container plants ($\sim$ 300 plants), such as crape myrtle (*Lagerstroemia indica* L.), panicled hydrangea (*H. paniculata* Siebold), and rose (*Rosa* sp.). A woodlot was present on one side of the nursery. *Systena frontalis* utilized these plants as adults, and their feeding activity was steadily observed. A permanent sprinkler irrigation system was installed at the experimental site.

For the experiments, 11.4 L (3 gal) *H. paniculata* cv. 'Lime Light' plants in containers (24 cm [9.4 inch] top and 20.4 cm [8.0 inch] bottom diameter) with 100% pine bark were used. During the pre-experiment stage, 60-120 *H. paniculata* containers were selected and maintained at a specific site in the nursery. The selected *H. paniculata* containers were moved to the experimental site a month before the initiation of three experiments in June 2021 and March and June 2022. They were referred to as trials 1, 2 and 3, respectively. The plants were exposed to naturally occurring and

Table 1. Insecticide products, active ingredients, and application rates used in drench trials against *Systena frontalis* immatures in Georgia and Virginia[z].

Insecticide product[x]	Active ingredient (%)	IRAC group	Rate (Product per 378.5 L [100 gal] water)	Manufacturer	Trial 1[v]	Trial 2[v]	Trial 3[v]	Trial 4[w]
Mainspring®GNL (L)	Cyantraniliprole (18.66%)	28	236.6 mL (8 fl oz)	Syngenta, Greensboro, NC	*[y]	*		
Mainspring®GNL (H)			354.9 mL (12 fl oz)					*
Acelepryn®	Chlorantraniliprole (18.4%)	28	236.6 mL (8 fl oz)	Syngenta, Greensboro, NC	*	*		
Tetrino™[u]	Tetraniliprole (4.07%)	28	946.4 mL (32 fl oz)	Bayer Environmental Science, Cary, NC		*	*	*
Sarisa™ (L)[t]	Cyclaniliprole (4.55%)	28	532.3 mL (18 fl oz)	OHP. Inc., Morrisville, NC		*		
Sarisa™ (M)			650.6 mL (22 fl oz)			*		
Sarisa™ (H)			798.5 mL (27 fl oz)		*	*	*	
XXpire® (L)[t]	Spinetoram (20%) +		56.7 g (2 oz)	Corteva Agriscience,		*		*
XXpire® (M)	Sulfoxaflor (20%)	5 + 4C	77.9 g (2.75 oz)	Indianapolis, IN	*	*	*	
XXpire® (H)			99.2 g (3.5 oz)			*		*
Apta®[s]	Tolfenpyrad (15%)	21A	798.5 mL (27 fl oz)	Nichino America, Wilmington, DE				*
Grandevo®CG	*Chromobacterium* (30%)[r]	-	1360.8 g (48 oz)	Marrone Bio Innovations, Davis, CA				*
Altus™	Flupyradifurone (17.09%)	4D	828.1 mL (28 fl oz)	Bayer Environmental Science, Cary, NC	*			*
Zylam® Liquid	Dinotefuran (10%)	4A	473.2 mL (16 fl oz)	PBI/Gordon Corporation, Shawnee, KS	*			
Safari® 20G	Dinotefuran (20%)	4A	680.4 g (24 oz)	Valent Professional, San Ramon, CA		*	*	

[z]Trials 1-3 were conducted at a nursery in GA, whereas trial 4 was conducted at Agricultural Research and Extension Center in Virginia Beach, VA.

[y]*Indicates insecticide included in the trial.

[x]Certain insecticides were used at various rates in the experiment and were abbreviated as; L, low; M, medium; and H, high. The water volume was 378.5 L (100 gal).

[w]NuFilm P [Pinene (polyterpenes) Polymers, petrolatum, alkyl amine ethoxylate] at 236.6 mL (8 fl oz) per 378.5 L was added as an adjuvant for all treatments in trial 4. The manufacturer of NuFilm P is Miller Chemical & Fertilizer, LLC, Hanover, PA.

[v]For trials 1-3, 709.5 mL (24 fl oz) of insecticidal solution was drenched in the growing media of each 11.4 L (3 gal) container, whereas for trial 4, 354.9 mL (12 fl oz) of insecticidal solution was drenched in the growing media of each 11.4 L container.

[u]Not registered for ornamental use. The rate adopted from use in golf courses.

[t]Registered for ornamental use, but the use pattern (drench) is not on the label.

[s]Not registered for ornamental use. The rate adopted from agricultural use.

[r]*Chromobacterium subtsugae* strain PRAA4-1T and spent fermentation media.

at least one generation of an *S. frontalis* adult population during each year. The plants were irrigated for 15 mins at least once a day using an overhead sprinkler system during the pre-experiment period. Plants were fertilized (Osmocote Pro, 18:9:10 [N:P:K], ICL Specialty Fertilizers, Summerville, SC, USA) at 7.59 kg per m^2 (1.6 lb per ft^2) by top dressing in April every year. *S. frontalis* adults were expected to oviposit on the growing medium. The assumption was all the containers were similarly oviposited with *S. frontalis* eggs as the containers were maintained in similar conditions as a block of plants. *Systena frontalis* adults are mobile in the nursery (Joseph personal observations) and high densities of *S. frontalis* adults were observed on the plants throughout the two growing seasons. The specific densities of immatures of *S. frontalis* in the containers were not quantified to avoid destroying the actual experimental units since immature scouting requires sifting through the growing media (Lane 2022).

The insecticides used in the experiments and associated information are listed in Table 1. Ten replicates of each insecticide treatment were assigned to *H. paniculata* plant containers according to a randomized complete block design (RCBD). The treatments were blocked from one end to the other end of the nursery, anticipating unknown variability in the field. An individual caged 11.4 L *H. paniculata* plant container was the experimental unit. The number of plants used in the experiment varied as it was dependent on the number of treatments. Cyantraniliprole (Mainspring®), chlorantraniliprole (Acelepryn®), flupyradifurone (Altus™), and dinotefuran (Zylam® and Safari®) are registered for flea beetle control in ornamental nurseries. Also, these insecticides are registered for "soil drench" use patterns. Tetraniliprole (Tetrino™) is registered for use on golf courses but not for use on ornamental nurseries. Cyclaniliprole (Sarisa™) and spinetoram + sulfoxaflor (XXpire®) are registered for ornamental plants but not as a drench application. Tetraniliprole, cyclaniliprole and spinetoram + sulfoxaflor were selected based on their efficacy against either coleopteran or other chewing insect pests.

The insecticide solutions were prepared using the maximum label rate in 378.5 L (100 gal) water as listed in Table 1. The insecticide solution was applied by pouring 709.5 mL (24 fl oz) on to the surface of the growing media using a graduated plastic mug. The insecticide solution was applied uniformly to the growing surface. The volume applied was enough to percolate through the growing medium with

Table 2. **The application and evaluation dates for drench trials against *Systena frontalis* in Georgia and Virginia.**

Trial	Location	Year	Drench application date	Evaluation date (days after application)
1	Georgia	2021	27 July	29, 69
2	Georgia	2022	25 April	24, 31
3	Georgia	2022	19 July	21, 28
4	Virginia	2022	15 April	31

minimal leachate. The dates of the drench application are listed in Table 2. An adjuvant was not used in GA trials. After application, the 50-100 plants, depending on the number of treatments in a trial, were individually placed into cages (BugDorm-4E4590, 47.5 [W] × 47.5 [D] × 93.0 [H] cm, MegaView Science Co., Ltd., Taiwan). Any emerging adults were trapped inside the cage and allowed to feed on the plant. Damage caused by the emerged adults on the foliage was evaluated. The evaluation dates of various trials are indicated in Table 2.

Virginia study site. In 2022, an experiment was conducted at the Hampton Roads Agricultural Research and Extension Center (HRAREC) in Virginia Beach, VA, USA. The experimental plants were grown under open-field conditions at a 0.04-ha (0.9 acres) gravel pad following commercial standards, with overhead sprinkler irrigation. High populations of *S. frontalis* were recorded the previous year since this location did not receive any foliar insecticides to control this pest. Therefore, naturally occurring eggs were expected to be distributed across all containers at this location. Selected plants (60 container plants) for the experiment were caged and maintained in a greenhouse after the drench applications. Greenhouse conditions were 26 ± 3 C (F), 60 ± 5% and 14:10 light: dark conditions.

Two-year-old *H. paniculata* plants cv. 'Lime Light' were used in this experiment (Trial 4). The plants were in 11.4 L black plastic containers (24 cm [9.4 inch] top and 20.4 cm [8.0 inch] bottom diameter), with 100% pine-bark growing medium and fertilized as in the GA trials. The plants were maintained at the HRAREC. *Hydrangea paniculata* received irrigation twice a day for 15 minutes using an overhead sprinkler system. Plants were exposed to natural populations of *S. frontalis* adults and did not receive any foliar insecticide applications during the whole previous growing season. Exposing plants to natural populations of insect pests is a conventional procedure when evaluating insecticide efficacy for most field studies. It creates natural variability in infestations and the efficacy of insecticide is determined when the insecticide treatments explain the variability. Similar to GA trials, the expectation was to have an already existing population of *S. frontalis* eggs in selected containers for this experiment, and densities of *S. frontalis* eggs and immatures were not collected from selected containers for this experiment.

The insecticide treatments used in trial 4 are listed in Table 1. The treatments were arranged in a RCBD with five replications. The treatments were blocked, as indicated in the previous section. The tolfenpyrad (Apta®) was only evaluated at the VA trial and is not registered for ornamental use. Tolfenpyrad was selected for its documented activity on Coleoptera from other crop systems. *Chromobacterium* (Grandevo®) was only evaluated at the VA site and is organically approved with no crop or site-specific registration. The drench volume used at the VA site was 354.9 mL (12 fl oz) in each container. NuFilm® P [Pinene (polyterpenes) Polymers, petrolatum, alkyl amine ethoxylate, Miller Chemical and Fertilizer, LLC, Hanover, PA, USA] was mixed at 236.6 mL (8 fl oz) per 378.5 L water to all treatments and was added as an adjuvant during this experiment. After drench applications in April 2022 (Table 2), plants were caged and moved to the greenhouse. The mesh cages used for this experiment were 60 [W] × 60 [D] × 91 [H] cm (Butterfly Habitat XL, RestCloud, Zhejiang, China). The remaining procedures were the same as in GA trials.

Evaluation. The number of adults inside each cage was counted after spending 1 min per cage in all trials. The plants were evaluated on various days after application (see Table 2). The feeding damage of *S. frontalis* adults was rated or scored using a scale system from 0 to 10, where 0 = no feeding damage and 10 = 100% of all leaves were fed upon. Observations were made at ∼11:30 during every sampling date for all trials 1-3, since *S. frontalis* adults are most active during that time of the day (Lane 2022). All evaluations were conducted at the nursery or at the greenhouse, and no samples were destructively collected.

Statistical analysis. All the analyses were performed using SAS v. 9.4 (SAS Institute 2016). The residuals were tested for normality using the PROC UNIVARIATE procedure. The *S. frontalis* adult densities and feeding damage rating data from Georgia and Virginia sites were subjected to the general linear model using the PROC GLM procedure after natural log-transformation (ln[x + 1]). The insecticide treatments were the only fixed effect, and replication was the random effect in the model. Data from individual trials were analyzed separately. The means were separated, post ANOVA, using the least square differences (LSD) method at $\alpha = 0.05$.

Results and Discussion

Trial 1. At 29 d after the drench application, the numbers of *S. frontalis* adults were significantly lower for the spinetoram + sulfoxaflor (XXpire®), chlorantraniliprole (Acelepryn®), and cyclaniliprole (Sarisa™) treatments than for the nontreated plants (Fig. 1A; Table 3). At 69 d after application, there was no difference in the number of *S. frontalis* adults among treatments. Adults observed at 69 d may include those that were counted at 29 d. However, the total numbers of *S. frontalis* adults were significantly lower for the spinetoram + sulfoxaflor, chlorantraniliprole, and cyclaniliprole treatments than for the nontreated plants (Fig. 1A).

The feeding damage scores at 29 d after drench application were significantly lower for the spinetoram + sulfoxaflor and cyclaniliprole treatments compared to nontreated plants (Fig. 1B; Table 3). In addition, the damage was significantly lower for the chlorantraniliprole treatment than for the nontreated plants. There was no significant difference

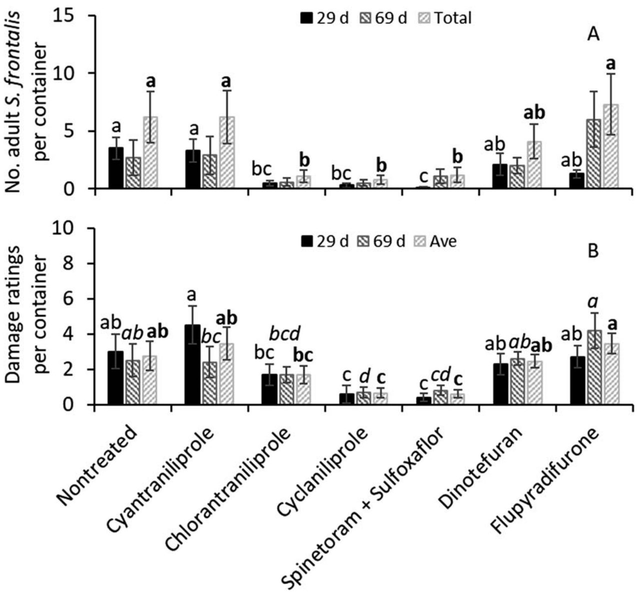

Fig. 1. **(A) The number of live adult *S. frontalis* collected, and (B) feeding damage on foliage at 29 and 69 d after drenching various insecticides to 11.4 L (3 gal) container plants on 27 July 2021 (Trial 1). The total number of *S. frontalis* adults and average feeding damage were also compared among treatments. Bars with the same letter types (regular, italics, and bold fonts) were compared among treatments, and the same letters were not significantly different (LSD Test, α = 0.05).**

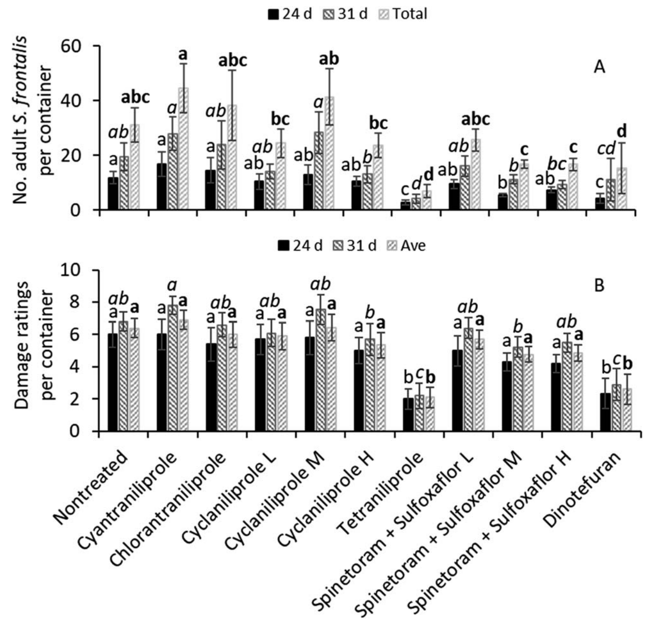

Fig. 2. **(A) The number of live adult *S. frontalis* collected, and (B) feeding damage on foliage at 24 and 31 d after drenching various insecticides to 11.4 L (3 gal) container plants on 25 April 2022 (Trial 2). The total number of *S. frontalis* adults and average feeding damage were also compared among treatments. Bars with the same letter types (regular, italics, and bold fonts) were compared among treatments, and the same letters were not significantly different (LSD Test, α = 0.05).**

in the damage score values among the chlorantraniliprole, spinetoram + sulfoxaflor, and cyclaniliprole treatments. At 69 d after drench application, feeding damage scores were significantly lower for the cyclaniliprole and spinetoram + sulfoxaflor treatments than the nontreated plants (Fig. 1B). The average damage values were significantly lower in the spinetoram + sulfoxaflor and cyclaniliprole insecticide treatments than in the nontreated plants (Fig. 1B). The damage scores and counts were not different between the dinotefuran-treated plants and the nontreated ones (Fig. 1).

Table 3. **Analysis of variance for insecticide treatment effects on live *S. frontalis* adults and their feeding damage.**

Observation date	Adults			Feeding damage[y]		
	F	df	*P*	*F*	df	*P*
Trial 1 (2021)						
29 d	4.7	6,54	0.001	4.7	6,54	0.001
69 d	1.6	6,54	0.155	4.2	6,54	0.002
Total/average[z]	2.9	6,54	0.017	5.7	6,54	< 0.001
Trial 2 (2022)						
24 d	5.8	10,89	< 0.001	4.1	10,89	< 0.001
31 d	6.0	10,87	< 0.001	8.8	10,87	< 0.001
Total/average	8.8	10,87	< 0.001	8.8	10,87	< 0.001
Trial 3 (2022)						
21 d	3.5	4,36	0.016	2.2	4,36	0.095
28 d	4.8	4,36	0.004	3.4	4,36	0.018
Total/average	4.7	4,36	0.004	2.9	4,36	0.033
Trial 4 (2022)						
31 d	2.4	7,25	0.044	3.1	7,25	0.018

[z]Total number of beetles after adding beetles from two sample dates and the average damage was calculated from two sample dates. Adults were quantified within a cage after spending one minute per cage (trials 1-3).

[y]*S. frontalis* feeding damage was evaluated using damage scores (0, no damage; and 10 = all the leaves damaged from *S. frontalis* adult feeding). Trials 1-3 were conducted in a Georgia nursery, and trial 4 was conducted at Agricultural Research and Extension Center in Virginia Beach, VA.

Trial 2. At 24 d after drench application, the numbers of *S. frontalis* adults were significantly lower for the tetraniliprole (Tetrino™) and dinotefuran (Safari® 20SG) treatments than for the spinetoram + sulfoxaflor (XXpire®) medium rate treatment, and with higher numbers in the other insecticide treatments and the nontreated plants (Fig. 2A; Table 3). At 31 d after drench application, significantly lower numbers of *S. frontalis* adults were found for the tetraniliprole and dinotefuran treatments than for the high rate of cyclaniliprole (Sarisa™) and medium rate of spinetoram + sulfoxaflor treatments, but a medium rate of cyclaniliprole and cyantraniliprole (Mainspring®GNL) treatments had higher numbers than in the spinetoram + sulforaflor treatment (Fig. 2A). When compared with nontreated plants, only application of tetraniliprole and dinotefuran treatments resulted in a significant decrease in *S. frontalis* adults. The total numbers of *S. frontalis* adults were significantly lower for the tetraniliprole and dinotefuran treatments than for the high and medium rates of spinetoram + sulfoxaflor treatments and the cyantraniliprole treatment (Fig. 2A). Only plants treated with tetraniliprole and dinotefuran treatments had significantly lower densities of *S. frontalis* adults than for the nontreated plants.

For the *S. frontalis* adult feeding damage at 24 d, a significantly lower score of damages was observed for the tetraniliprole and dinotefuran treatments than for the

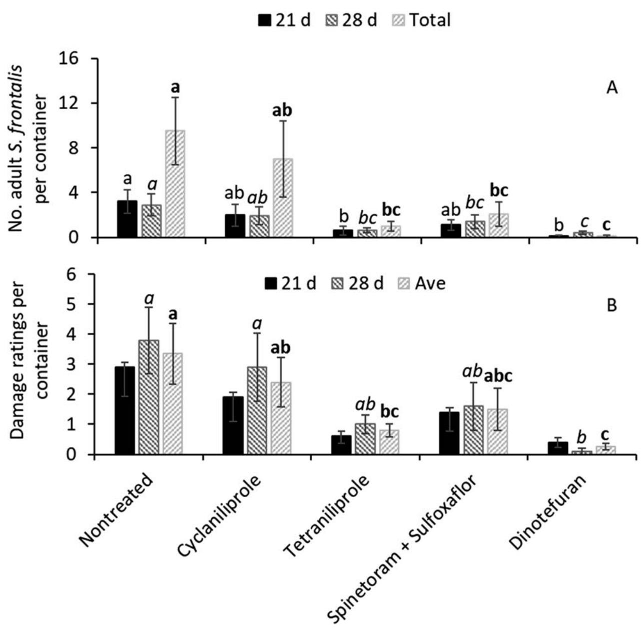

Fig. 3. **(A) The number of live adult *S. frontalis* collected, and (B) feeding damage on foliage at 21 and 28 d after drenching various insecticides to 11.4 L (3 gal) container plants on 19 July 2022 (Trial 3). The total number of *S. frontalis* adults and average feeding damage were also compared among treatments. Bars with the same letter types (regular, italics, and bold fonts) were compared among treatments, and the same letters were not significantly different (LSD Test, α = 0.05).**

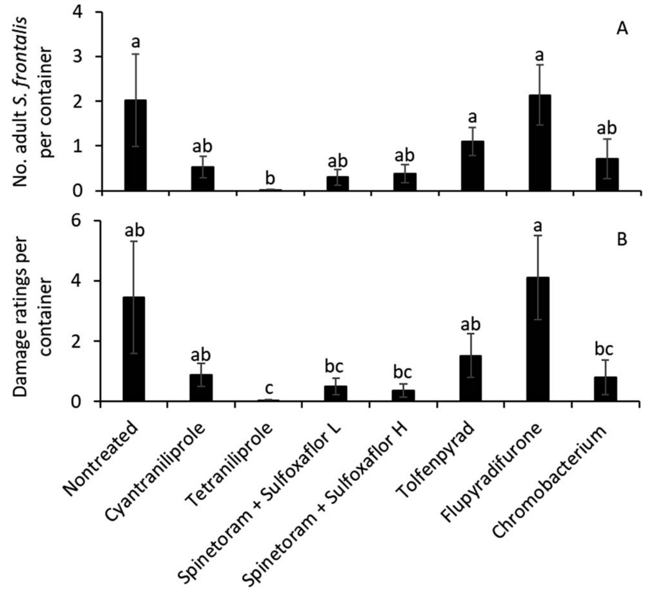

Fig. 4. **(A) The number of live adult *S. frontalis* collected, and (B) feeding damage on foliage at 31 d after drenching various insecticides to 11.4 L (3 gal) container plants on 15 April 2022 (Trial 4). Bars with the same letters among treatments were not significantly different (LSD Test, α = 0.05).**

remaining treatments, including the nontreated plants (Fig. 2B; Table 3). At 31 d, the adult feeding damage scores were significantly lower for the tetraniliprole and dinotefuran treatments than for the medium rate of spinetoram + sulfoxaflor and the high rate of cyclaniliprole treatments, and the cyantraniliprole treatment (Fig. 2B). At 31 d, only tetraniliprole- and dinotefuran-treated plants had significantly lower damage from *S. frontalis* adults than for the nontreated plants (Fig. 2B). The average damage (between 24 and 31 d evaluations) was similar to results at 31 d.

Trial 3. At 24 d after drench application, the numbers of *S. frontalis* adults were significantly lower for the tetraniliprole (Tetrino™) and dinotefuran (Safari® 20SG) treatments than for the nontreated plants (Fig. 3A; Table 3). At 28 d after drench application, the numbers of *S. frontalis* adults were significantly lower for the tetraniliprole, spinetoram + sulfoxaflor (XXpire®), and dinotefuran treatments than for the nontreated plants (Fig. 3A). The total numbers of *S. frontalis* adults were significantly lower for the tetraniliprole, spinetoram + sulfoxaflor, and dinotefuran treatments than for the nontreated plants (Fig. 3A).

For the *S. frontalis* adult feeding damage at 24 and 28 d, a significantly lower score of damages was observed for the dinotefuran treatment than for the remaining treatments (Fig. 3B; Table 3). At 28 d, the adult feeding damage scores were significantly lower for the tetraniliprole, and dinotefuran treatments than for the spinetoram + sulfoxaflor and cyclaniliprole treatments and the cyantraniliprole (Mainspring®GNL) treatment (Fig. 3B). Only plants treated with tetraniliprole and dinotefuran treatments had significantly lower average feeding damage than nontreated plants (Fig. 3B).

Trial 4. At 31 d after drench application, the numbers of *S. frontalis* adults were significantly lower for the tetraniliprole (Tetrino™) treatment than for the nontreated plants (Table 3, Fig. 4A). The percent feeding damage was significantly lower for the tetraniliprole treatment than for the nontreated plants (Table 3, Fig. 4B). There were no significant differences in adult densities and their feeding damage on foliage among the tetraniliprole, spinetoram + sulfoxaflor (both high and low rates) (XXpire®), and *Chromobacterium* sp. (Grandevo® CG) treatments (Fig. 4A and B).

Tetraniliprole and the combination of spinetoram + sulfoxaflor consistently reduced the emergence of *S. frontalis* adults from drench-treated potting media and prevented high rates of foliar damage. Tetraniliprole is a new anthranilic diamide insecticide and controls lepidopteran and coleopteran pests (Tetrino 2022). Because diamide insecticides target ryanodine receptors, the exposed insect dies because of muscle contraction and paralysis (Uesugi et al. 2020, Samurkas et al. 2022). Although tetraniliprole is not registered for use in ornamentals, it appears to be a potential candidate for registration as a drench application in container nurseries. The second product that showed consistent efficacy was spinetoram + sulfoxaflor. Spinetoram, which contains modified compounds of spinosyns (spinosyn J and spinosyn L), is derived from *Saccharopolyspora spinosa* Mertz and Yao (Bacteria: Actinobacteridae) (Dripps et al. 2011), and has proven efficacy against coleopteran pests (Vassilakos et al. 2012). Sulfoxaflor, a sulfoximide, controls piercing and sucking insects (Watson et al. 2021). Thus, the observed effectiveness against immatures of *S.*

frontalis in the current study is likely because of spinetoram. This product is registered as a foliar spray on ornamental crops in nurseries, but the drench application use pattern is not included in the current label. Thus, the data suggest that spinetoram + sulfoxaflor is a potential product for drench application in container nurseries against immatures of *S. frontalis*.

In the current study, the plant containers drenched with cyclaniliprole and chlorantraniliprole had fewer densities of *S. frontalis* adults emerging from the containers. Compared to nontreated plants, the feeding damage was suppressed with cyclaniliprole and chlorantraniliprole, although these effects were inconsistent in all the trials. In cranberry, drench applications of chlorantraniliprole were effective against immatures of *S. frontalis* in soil (Guédot and Hietala-Henschell 2015). The diamides cyclaniliprole and chlorantraniliprole target ryanodine receptors of insects, and their muscular activity is impacted upon exposure. These active ingredients are registered on ornamental crops, but the drench application use pattern is only registered for chlorantraniliprole and not for cyclaniliprole. *Chromobacterium* sp. was evaluated only once, and it reduced the emergence of *S. frontalis* adults. Based on adult emergence data consistent with the damage they caused to the foliage and finding no dead adults inside the cages, the insecticide treatments targeted the immatures in the growing media.

Although the exact reasons for why some insecticides, such as cyclaniliprole and chlorantraniliprole performed in one trial versus others are not clear, there could be a few possibilities. First, the *H. paniculata* containers were randomly selected from the nurseries and the gravel pad for these studies. There could be inherent variability in the density of the *S. frontalis* populations in the containers, which could have contributed to the variation. A mitigation practice for this potential drawback was to have more than five replications per treatment at each trial. However, the plant containers were not individually assessed for infestation, and the number of immatures was not quantified. Second, the water volume requirement could vary by the insecticides used in the study as the insecticide may have moved into the potting media at varied rates. This nonuniform movement of insecticides within the container, either moving slowly or rapidly through the growing media, may have affected the efficacy among trials. Third, we did not accurately determine the life stage (s) of the immature already present in the selected containers for these trials. It is unclear if certain life stages, such as early instars, late instars, or pupae, were specifically susceptible to certain insecticides. In addition, the effective mode of exposure to immatures can vary by insecticide active ingredient. For example, insecticides such as chlorantraniliprole or cyantraniliprole are effective when residues are ingested with plant tissue by the target organism rather than through contact exposure (Rezende-Teixeira et al. 2022). Finally, we randomly selected the application rates of certain insecticides, such as tetraniliprole, cyclaniliprole or spinetoram + sulfoxaflor, based on the maximum rate for foliar sprays or approved for different targeted pests. These selected rates may not be appropriate for drench application to effectively suppress immatures of *S. frontalis*. These products warrant further investigation as drench application against immatures of *S. frontalis* for consistent results.

Dinotefuran was used in this study as a positive control treatment in three trials since nursery growers indicated that they already use neonicotinoids for *S. frontalis* control (Joseph et al. 2021, Arshad et al. 2023). This active ingredient is a competitive modulator of a nicotinic acetylcholine receptor (nAChR). It effectively competes with the acetylcholine neurotransmitter and binds at the nAChR receptor in the synapse region of the insect central nervous system (IRAC 2022). Based on results from the current study, it provided an adequate reduction in adult beetle emergence and feeding damage in two trials but not in the first trial. This variation in the results could be the function of concentrations of the dinotefuran present in products and the rate of these products used in those trials. In trial 1, the dinotefuran product used was Zylam®Liquid (1.25 mL product per L water) which contains 10% dinotefuran, whereas, in trials 2 and 3, the product used was Safari®20SG (1.79 g product per L water) which contains 20% dinotefuran (Zylam 2022, Safari 2022). Previously, dinotefuran (Safari 20SG) and imidacloprid were shown to be effective against immatures of *S. frontalis* as drench application before blooming periods (Kunkel 2016).

In summary, the results showed that tetraniliprole, spinetoram + sulfoxaflor, cyclaniliprole, chlorantraniliprole, and *Chromobacterium* sp. effectively reduced the survival of *S. frontalis* immatures and reduced foliar damage. Most of these products are not registered for use in ornamentals, or in some cases, the drench use pattern is not approved. More research is warranted to determine the effective insecticide rate, application procedures, such as water volume and irrigation requirements, and application timing reflecting the phenology of *S. frontalis* targeting susceptible immature stages in the container, and mode of exposure for each active ingredient. The current study is a proof of concept for using a drench application with neonicotinoid and pyrethroid alternatives to control the immature stage of *S. frontalis* located in container-grown hydrangeas. The overall idea of this approach was to target the resident *S. frontalis* population inside containers, reducing the number of adults eclosing from those infested containers. Both adult densities and plant injury were reduced during the trials after the drench application. Beginning the growing season with low adult densities with drench application might further reduce the number of foliar insecticide applications during the growing season.

Although the drench application method can be labor-intensive and cost-prohibitive to some nursery growers, it is certainly an option for growers to protect affected plants, at least to meet shorter-term goals or suppress the *S. frontalis* population in the facility at selected hotspots where *S. frontalis* infestation rates are really high. These effective active ingredients could be alternatives to using neonicotinoids in open-field nurseries. More studies should be conducted to determine the toxicity of these active ingredients following direct and indirect exposure to beneficial insects, including pollinators, under field conditions. Previously, Larson et al. (2012 and 2013) showed that beneficial insects and pollinators were less sensitive to chlorantraniliprole than neonicotinoids. Thus, future studies should evaluate the acute and chronic effects of the potential presence of tetraniliprole and cyclaniliprole on beneficial arthropods to develop effective integrated pest management strategies for *S. frontalis*.

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