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Source: Florida Entomologist, 99(2) : 203-209

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.099.0208

Effect of insecticide rotations on density and species composition of thrips (Thysanoptera) in Florida strawberry (Rosales: Rosaceae)

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Abstract

Feeding by *Frankliniella* (Thysanoptera: Thripidae) thrips causes economic damage to strawberry (*Fragaria ananassa* Duchesne; Rosales: Rosaceae) crops in Florida and in other production regions worldwide. Resistance to spinosyn insecticides, particularly in *Frankliniella occidentalis* (Pergande), is a major concern for strawberry and other crops. Experiments were carried out in 2014 and 2015 to evaluate the effect of 6 insecticide programs on the numbers and species composition of thrips attacking strawberry on a season-long basis in Florida. Five insecticide programs included spinetoram applied once, twice, or 3 times in the rotation, alternated with acetamiprid, cyantraniliprole (Cyazypyr®), novaluron, sulfoxaflor, and/or tolfenpyrad. Also included in the treatments were bifenthrin and a non-treated check. Thrips densities were sampled weekly in flowers, and in both flowers and fruits in 2015, 2 d after treatment applications. The primary thrips species recovered from strawberry flowers and fruit was *Frankliniella bispinosa* Morgan. Other species included *F. occidentalis*, *Frankliniella schultzei* (Trybom), *Scirtothrips dorsalis* Hood, *Scolothrips* sp., *Thrips* spp. (all Thripidae), and *Haplothrips gowdeyi* (Franklin) (Phlaeothripidae), *Frankliniella bispinosa* was controlled by all insecticide programs. Numbers of *F. occidentalis* thrips were not reduced by any spinetoram-based rotation relative to the control in either year. Repeated applications of bifenthrin increased numbers of *F. occidentalis* thrips relative to the control each year, and increased numbers of *F. schultzei* thrips relative to the control in 2014. The thrips predator *Orius* sp. (Hemiptera: Anthocoridae) was not observed in the bifenthrin treatment and was rare in other treatments. Insecticide rotations in Florida strawberry appear to shift the species composition from *F. bispinosa* to *F. occidentalis* and other insecticide-tolerant species including *F. schultzei*. Thrips damage to strawberries may be due to the species that is least susceptible to control rather than the species that is most abundant early in the cropping season. However, the relative importance of various stages or species has yet to be critically determined.

Key Words: *Frankliniella bispinosa*; *Frankliniella occidentalis*; *Frankliniella schultzei*; spinetoram; bifenthrin

Resumen

La alimentación de *Frankliniella (*Thysanoptera: Thripidae) trips causa daños económicos al cultivos de fresa (*Fragaria ananassa* Duchesne; Rosales: Rosaceae) en Florida y en otras regiones de producción en todo el mundo. La resistencia a los insecticidas espinosina, en particular en *Frankliniella occidentalis* (Pergande), es una preocupación importante para la fresa y otros cultivos. Se realizaron los experimentos en el 2014 y el 2015 para evaluar el efecto de los 6 programas de insecticidas sobre el número y la composición de especies de trips que atacan la fresa sobre una base durante toda la temporada en la Florida. Cinco programas incluyeron insecticidas espinetoram aplica una vez, dos veces o tres veces en la rotación, alternado con acetamiprid, cyantraniliprole (Cyazypyr®), novalurón, sulfoxaflor, y/o tolfenpirad. También se incluyeron bifentrina y un cheque no tratado en los tratamientos. La densidad de trips se muestrearon semanalmente en las flores, y en ambos flores y frutos en 2015, 2 días después de las aplicaciones de tratamiento. La especie de trips principal recuperada de las flores de fresa y fruta fue *Frankliniella bispinosa* Morgan. Otras especies incluyen *Frankliniella occidentalis* (Pergande), *Frankliniella schultzei* (Trybom), *Scirtothrips dorsalis* Hood, *Scolothrips* sp., *Trips* spp. (todas de la familiaThripidae), *y Haplothrips gowdeyi* (Franklin) (Phlaeothripidae), *Frankliniella bispinosa* fue controlada por todos los programas de insecticidas . El número de *F. occidentalis* trips no se redujeron por cualquier rotación basada en spinetoram con respecto al control, en ninguno de los años. Las aplicaciones repetidas de bifentrina aumento el número de trips *F. occidentalis* en relación con el control en cualquier año, y el número de trips *F. schultzei* no diminuyeron en relación del control en 2014. No se observó el trips depredador *Orius* sp. (Hemiptera: Anthocoridae) en el tratamiento bifentrina y fue poco común en otros tratamientos. Las rotaciones de insecticidas en la fresa en la Florida parecen cambiar la composición de las especies de *F. bispinosa* a *F. occidentalis* y otras especies tolerantes con insecticida incluyendo F. schultzei. El daño causado por trips en fresas puede ser debido a la especie que es menos susceptible a controlar en lugar de las especie que es más abundante a principios de la temporada de cultivo. Sin embargo, la importancia relativa de los varios estadios o especies aún no se ha determinado de manera crítica.

Palabras Clave: *Frankliniella bispinosa*; *Frankliniella occidentalis*; *Frankliniella schultzei*; espinetoram; bifentrina

Thrips (Thysanoptera) cause economic damage to strawberry (*Fragaria ananassa* Duchesne; Rosales: Rosaceae) crops in many production regions, including the United States, Latin America, Europe, the Mediterranean, Australia, and Japan (Buxton & Easterbrook

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1988; González-Zamora & Garcia-Marí 2003; Katayama 2005; Steiner & Goodwin 2005; Coll et al. 2007; Koike et al. 2009; Nondillo et al. 2010). Feeding by *Frankliniella* (Thripidae) thrips causes abortion of flower and fruitlets as well as bronzing and malformation of fruit (Koike et al. 2009). Globally, the western flower thrips, *Frankliniella occidentalis* (Pergande), causes the greatest damage to strawberry. *Frankliniella occidentalis* is a cosmopolitan pest of many horticultural crops (Lewis 1997). It is difficult to manage with insecticides because of its cryptic behavior, its ability to reproduce rapidly, and its tendency to develop tolerance to a broad range of insecticide modes of action (Funderburk 2009; Gao et al. 2012). The spinosyns have been among the most effective insecticides for managing western flower thrips (Funderburk 2009). However, resistance to spinosyns among western flower thrips has been documented (Loughner et al. 2005; Bielza et al. 2007; Zhang et al. 2008). Predatory anthocorids in the genus *Orius* Wolff (Hemiptera: Anthocoridae) have demonstrated efficacy in suppressing thrips in fruiting vegetables and strawberries if compatible insecticide regimes are employed (Funderburk et al. 2000; Bennison et al. 2011).

Frankliniella occidentalis became established in Florida in 1982 (Kirk & Terry 2003) and was first reported affecting Florida strawberry production in 2004 (Whidden 2004, 2008). However, the predominant thrips species in cultivated and wild plants in the southern portion of Florida, including strawberry-producing areas, is *Frankliniella bispinosa* Morgan, locally known as the Florida flower thrips (Frantz & Mellinger 1990; Childers & Nakahara 2006). *Frankliniella bispinosa,* which is native to Florida, is a primary pest of blueberries (*Vaccinium corymbosum* L., *Vaccinium darrowii* Camp; Ericales: Ericaceae) (Rhodes et al. 2012) and has been known as an occasional pest of strawberries, tomatoes (Solanales: Solanaceae), citrus (Sapindales: Rutaceae), and other crops in Florida for over a century (Quaintance 1898; Watson 1922; Childers & Achor 1991). Sampling methods and action thresholds for *F. occidentalis* in strawberry have been developed in various regions (González-Zamora & Garcia-Marí 2003; Katayama 2005; Coll et al. 2007; Nondillo et al. 2009, 2010); however, the comparative economic importance of *F. occidentalis*, *F. bispinosa*, and other thrips in Florida strawberry remains relatively unstudied. Thrips species may vary according to the damage they cause and their susceptibility to insecticides and predation (Reitz et al. 2003, 2006; Steiner & Goodwin 2005). Steiner & Goodwin (2005) developed distinct action thresholds for *F. occidentalis* and *Thrips imaginis* Bagnall (Thripidae) for hydroponically grown strawberry in Australia.

Frantz & Mellinger (1990) first observed the tendency of *F. occidentalis* to displace *F. bispinosa* in intensively sprayed pepper (*Capsicum annuum* L.; Solanales: Solanaceae) fields in southeast Florida. They attributed this displacement to the use of pyrethroid insecticides (Frantz & Mellinger 2009). Dow AgroSciences voluntarily withdrew spinosyn insecticides from 2 Florida counties from 2008 to 2011 because of evidence that *F. occidentalis* affecting pepper had become resistant to the material (Hou et al. 2014). Increases in populations of *F. occidentalis* after the application of pyrethroid insecticides in fruiting vegetables also are associated with the suppression of *Orius* populations (Funderburk et al. 2000; Ramachandran et al. 2001; Reitz et al. 2003) and the elimination of congeneric competitor species including *F*. *bispinosa* (Funderburk et al. 2015).

Strawberries in Florida are grown primarily in Hillsborough County. They are planted in Oct, and overhead irrigation is applied for approximately 10 d to aid in transplant establishment, after which fields are irrigated with drip irrigation. Florida strawberry growers typically apply a "clean-up" spray of a pyrethroid insecticide after the initial period of overhead irrigation. Depending on the severity of the winter weather, thrips establish in strawberry as early as Dec or as late as Mar. Strawberries are typically harvested in Florida from Nov through Apr. Intensive surveys of thrips species associated with strawberry in Hillsborough County have not been carried out before the present study. *Frankliniella* adults and larvae feed preferentially on pollen and floral parts but will also feed on foliage (Reitz 2009). Damage to flowers and developing fruit directly impacts fruit quality and quantity.

In the spring of 2013, *Frankliniella* populations reached high densities in strawberry in Hillsborough and adjacent counties, causing significant bronzing to the crop (Smith & Whidden 2014). Growers observed that applications of insecticides, including the spinosyn spinetoram (Radiant SC; Dow Agrosciences, Indianapolis, Indiana), did not consistently reduce the numbers of thrips in the field. In response to concerns that spinetoram was losing efficacy, experiments were carried out at the University of Florida's Gulf Coast Research and Education Center in 2014 and 2015 to evaluate insecticide rotations that emphasized alternative modes of action to spinetoram. The goal was to determine if insecticide programs consisting of only 1 or 2 applications of spinetoram out of 4 weekly sprays (1 spray per week over 4 wk) would be as effective in suppressing thrips as a program with 3 applications of spinetoram and 1 alternative mode of action over a 4 wk period. Active ingredients that have demonstrated efficacy against *F. occidentalis* in previous studies include acetamiprid (Assail 30 SG; United Phosphorus, Inc., King of Prussia, Pennsylvania), cyantraniliprole (Exirel; DuPont, Wilmington, Delaware), novaluron (Rimon 0.83 EC; Makhteshim Chemical Works Ltd, Be'er Sheva, Israel), and tolfenpyrad (Apta 1.3 SC; Nichino America, Wilmington, Delaware) (Willmot et al. 2013; Funderburk et al. 2014; Srivastava et al. 2014). These materials were evaluated in rotations with spinetoram. Sulfoxaflor (Closer SC), a new insecticide produced by Dow Agrosciences, was also included. Bifenthrin (Brigade WSB; FMC Corporation, Philadelphia, Pennsylvania) is a pyrethroid insecticide commonly used by Florida strawberry growers as a "clean-up" spray and to control various pests during the growing season. Bifenthrin was tested as a stand-alone material to evaluate the effect of repeated applications of a pyrethroid on numbers and species of thrips.

Spinetoram affects nicotinic/gamma amino butyric acid–gated chloride channels. The other insecticides represent different modes of action. Acetamiprid and sulfoxaflor are nicotinic acetylcholine receptor agonists. Cyantraniliprole is an anthranilic diamide insecticide that kills by disrupting calcium metabolism via the ryanodine receptors. Novaluron is a chitin biosynthesis inhibitor and the only insecticide included without efficacy against adult thrips. Tolfenpyrad is a mitochondrial complex I electron transport inhibitor. Bifenthrin is a sodium channel modulator.

Adult thrips in strawberry flowers were identified to species in order to describe the thrips species complex associated with strawberry in central Florida and to determine how the various insecticide programs affected thrips species. In 2015, adult and 2nd instar thrips on fruit were also tabulated at the species level. In addition, treatment impacts on numbers of *Orius* predators and on strawberry yield were evaluated.

Materials and Methods

The efficacy of 6 programs of insecticide products were compared with an untreated control for flower thrips control in strawberry at the Gulf Coast Research and Education Center, Wimauma, Florida (27.7599833°N, 82.2241000°W) in the winter–spring of 2013–14 and 2014–15. 'Strawberry Festival' transplants were set in the field on 8 Oct 2013 and on 14 Oct 2014 in plastic mulched beds, 33 cm high and 69 cm across the top, and with 1.2 m bed spacing. Overhead irrigation was applied for about 2 wk after setting to aid in establishment of the transplants. Drip irrigation was used for the remainder of the experiment. Plots were 3.8 m in length and consisted of 20 plants in two 10-plant rows per bed. The study area was treated with fungicides and *Bacillus thuringiensis*–based products only while waiting for natural populations of flower thrips to build to a level of about 20 or more adults per 10 flowers. Treatment applications began on 11 Mar 2014 and on 10 Feb 2015 and consisted of 4 weekly applications of products (Table 1).

Treatments were replicated 4 times in a randomized complete block design and were applied using a hand-held sprayer with a spray wand outfitted with a nozzle containing a 45° core and a number 4 disc. The sprayer was pressurized by CO_2 to 40 psi and calibrated to deliver 934 L/ha (100 gallons/acre). Samples were collected before treatment applications began and then weekly, 2 d after a treatment application, and consisted of 10 open flowers per plot, placed in vials of 70% isopropyl alcohol that were agitated to dislodge thrips from the plant material. In 2015, 5 green and 5 pink fruits per plot were also sampled similarly to the flowers. Data were recorded initially as adult or larval thrips and *Orius* spp. per 10 flowers. All specimens of adult thrips were retained, slide mounted, and identified to species. Second instar larvae collected from fruit were also slide mounted and identified to species. Data were transformed by $\log_{10}(x + 1)$ before ANOVA using a factorial model statement with experiment-year and chemical rotations as factors. Means were separated by Tukey's studentized range test ($\alpha = 0.05$) (SAS Software 2008). Means are reported in the original scale. Yield data were collected once a week for 5 wk each year.

Results

In 2014, thrips adults collected from flowers in the control from 5 Mar through 1 Apr consisted of 77.68% *F. bispinosa*, 7.00% *Haplothrips gowdeyi* (Franklin) (Phlaeothripidae), 4.86% *F. occidentalis*, 3.70% *Frankliniella schultzei* (Trybom) (Thripidae) and 0.06% *Scolothrips* sp. (Thripidae). Because of damage, 6.70% could not be identified. In 2015, thrips adults collected from flowers in the control from 12 Feb through 4 Mar consisted of 87.09% *F. bispinosa*, 10.14% *F. occidentalis*, 1.25% *H. gowdeyi*, 0.74% *Thrips* spp., and 0.39% unknown.

Season-long response variables were analyzed with year, treatment, and the year by treatment interaction as factors. The effect of treatment was significant each year for numbers of adult thrips (2014: $F = 6.50$; df = 6,102; $P < 0.0001$; 2015: $F = 6.78$; df = 6,102; $P < 0.0001$) and larval thrips (2014: $F = 27.82$; df = 6,102; $P < 0.0001$; 2015: $F = 5.29$; df = 6,102; $P < 0.0001$), and for numbers of *F. bispinosa* (2014: $F = 11.06$; df = 6,102; $P < 0.0001$; 2015: $F = 6.92$; df = 6,102; $P < 0.0001$) collected from flower samples. The year by treatment interaction for flower samples was significant for total thrips adults ($F = 2.48$; df = 6,207; $P = 0.024$), total thrips larvae ($F = 11.60$; df = 6,207; $P < 0.0001$), and *F. schultzei* adults ($F = 16.0$; df = 6,207; $P < 0.0001$). The year by treatment interaction was not significant for *F. bispinosa* ($F = 0.85$; df = 6,207; $P = 0.536$) or *F. occidentalis* adults ($F = 1.85$; df = 6,207; $P = 0.091$). Therefore, treatment effects on season-long densities of total thrips adults, larvae, and *F. schultzei* adults will be discussed by year, and treatment effects on *F. bispinosa* and *F. occidentalis* adults for 2014 and 2015 will be discussed with years combined.

TOTAL THRIPS ADULTS AND LARVAE IN FLOWER SAMPLES

In 2014, total adult thrips numbers were significantly lower in all spinetoram treatments than in the control, and there were no statistical differences among spinetoram treatments with regard to total adult thrips numbers (Table 2). Numbers of total adult thrips in the bifenthrin treatment (program 7) were not different from the control (program 1) or 3 of the spinetoram treatments (programs 3, 4, and 6). In 2014, densities of larval thrips were significantly higher in the bifenthrin treatment (program 7) than in all other treatments. Also that year, densities of larval thrips were higher in the control (program 1) than in all insecticide rotations except for the tolfenpyrad-sulfoxaflor-acetamiprid-spinetoram treatment (program 6). In 2015, numbers of total adult thrips and larvae were significantly lower in all insecticide

Table 1. Schedule of treatment applications, with chemical names, application rates, trade names and formulations, concentrations of 495 active ingredients (a.i.), and Insecticide Resistance Action Committee (IRAC) mode of action codes of products, used in the 2014 and 496 2015 experiments in Wimauma, Florida.

					Timing of treatment applications[c]			
Treatment program no.& chemical name(s)[a]	Rate g a.i./ha[b]	Trade name & formulation	a.i. con-centration	IRAC code	wk 1	wk 2	wk 3	wk 4
1. Untreated control	—	—	—	—				
2. Spinetoram	87.57	Radiant SC	119.8 g/L	5	X	X	X	
Sulfoxaflor	78.81	Closer SC	239.6 g/L	4C			X	
3. Sulfoxaflor	78.81	Closer SC	239.6 g/L	4C	X			
Spinetoram	87.57	Radiant SC	119.8 g/L	5		X		
Acetamiprid	145.01	Assail 30SG	300.0 g/kg	4A			X	
4. Spinetoram	87.57	Radiant SC	119.8 g/L	5	X			
Acetamiprid	145.01	Assail 30SG	300.0 g/kg	4A		X		
Novaluron	87.22	Rimon 0.83EC	99.4 g/L	15			X	
5. Cyantraniliprole	148.99	Exirel 10.2 SE	99.4 g/L	28	X			
Spinetoram	87.57	Radiant SC	119.8 g/L	5		X		
Sulfoxaflor	78.81	Closer SC	239.6 g/L	4C			X	
Acetamiprid	145.01	Assail 30SG	300.0 g/kg	4A				X
6. Tolfenpyrad +	239.06	Apta 15 SC	156.9 g/L	21A				
Surfactant[d]	0.25% v/v	Induce	—	--	X			
Sulfoxaflor	78.81	Closer SC	239.6 g/L	4C		X		
Acetamiprid	145.01	Assail 30SG	300.0 g/kg	4A			X	
Spinetoram	87.57	Radiant SC	119.8 g/L	5				X
7. Bifenthrin	140.10	Brigade WSB	100.0 g/kg	3A	X	X	X	X

Table 2. Mean (± SE) larval and adult thrips densities in flowers, pooled over the 4 sampling dates (each 2 d after application) in the 2014 and 2015 experiments in Wimauma, Florida.

	Mean ± SE number per 10 flowers[b]			
	Larvae		Adults	
Treatment program no. & chemical name(s)[a]	2014	2015	2014	2015
1. Untreated control	7.4 ± 0.9b	24.3 ± 4.7a	14.5 ± 2.2a	18.4 ± 2.7a
2. Spinetoram-spinetoram-sulfoxaflor-spinetoram	1.6 ± 0.5c	7.4 ± 2.8b	3.1 ± 0.7c	4.8 ± 0.8b
3. Sulfoxaflor-spinetoram-acetamiprid-spinetoram	1.3 ± 0.5c	7.1 ± 2.8b	4.7 ± 1.2bc	4.8 ± 0.9b
4. Spinetoram-acetamiprid-novaluron-spinetoram	2.9 ± 0.8c	5.3 ± 1.6b	6.9 ± 1.8bc	8.9 ± 2.2b
5. Cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid	1.3 ± 0.6c	4.8 ± 1.9b	3.6 ± 0.9c	5.1 ± 1.0b
6. Tolfenpyrad+surfactant-sulfoxaflor-acetamiprid-spinetoram	3.6 ± 0.9bc	7.9 ± 2.3b	6.1 ± 1.1bc	4.2 ± 1.0b
7. Bifenthrin (4 times)	31.5 ± 5.1a	6.9 ± 1.7b	10.3 ± 1.9ab	3.9 ± 1.2b
ANOVA $F_{6,102}$	27.82	5.29	7.67	6.78
P	<0.0001	<0.0001	<0.0001	<0.0001

[a]Treatment programs consisted of 4 weekly applications of products; a '+' sign indicates the products were combined (see Table 1 for rates and volumes).
[b]Means within a column not followed by the same letter are significantly different by Tukey's studentized range test (α = 0.05). Data were transformed by $\log_{10}(x + 1)$ before ANOVA, means are reported in the original scale.

treatments than in the control but did not differ significantly among insecticide treatments.

ADULTS OF *F. BISPINOSA* IN FLOWER SAMPLES (2014–2015 COMBINED ANALYSIS)

Season-long densities of *F. bispinosa* adults were significantly lower in all insecticide treatments than in the control (program 1) (Table 3) each year. Densities of *F. bispinosa* adults were not significantly different among insecticide programs containing spinetoram (programs 2–6), whereas densities of *F. bispinosa* adults were significantly lower in the bifenthrin treatment (program 7) than in the other insecticide programs.

ADULTS OF *F. OCCIDENTALIS* IN FLOWER SAMPLES (2014–2015 COMBINED ANALYSIS)

Densities of *F. occidentalis* adults were significantly higher in the bifenthrin treatment (program 7) than in all other treatments, including the control (program 1), except for the spinetoram-acetamiprid-novaluron-spinetoram treatment (program 4) (Table 3). Densities of *F. occidentalis* adults were not significantly different among spinetoram-based insecticide rotations (programs 2–6) or the control (program 1) either year.

ADULTS OF *F. SCHULTZEI* IN FLOWER SAMPLES

In 2014, there were significantly more *F. schultzei* adults in the bifenthrin treatment (program 7) than in all other treatments, none of which were significantly different from each other (Table 3). In 2015, numbers of *F. schultzei* adults were very low; there were no significant differences among treatments that year.

ADULT THRIPS ON FRUIT IN 2015

The numbers of adults collected from fruit were low (Table 4). The majority collected were *F. bispinosa*, *F. occidentalis*, *F. schultzei,* and *Scirtothrips dorsalis* Hood (Thripidae). There were significantly fewer

Table 3. Mean (± SE) densities of *Frankliniella bispinosa* and *Frankliniella occidentalis* adults in flowers, pooled over the 4 sampling dates (each 2 d after application) and over both 2014 and 2015 experiments. Mean (± SE) densities of *Frankliniella schultzei* adults in flowers, pooled over the 4 sampling dates (each 2 d after application) in each of the 2014 and 2015 experiments in Wimauma, Florida.

	Mean ± SE number adults per 10 flowers[b]			
	F. bispinosa	*F. occidentalis*	*F. schultzei*	
Treatment program no. & chemical name(s)[a]	pooled over 2014 & 2015		2014	2015
1. Untreated control	14.2 ± 1.8a	0.8 ± 0.1b	0.6 ± 0.2b	0.0 ± 0.0a
2. Spinetoram-spinetoram-sulfoxaflor-spinetoram	2.8 ± 0.5b	0.9 ± 0.2b	0.0 ± 0.0b	0.1 ± 0.1a
3. Sulfoxaflor-spinetoram-acetamiprid-spinetoram	3.7 ± 0.6b	0.6 ± 0.2b	0.1 ± 0.1b	0.3 ± 0.1a
4. Spinetoram-acetamiprid-novaluron-spinetoram	6.0 ± 1.4b	1.5 ± 0.3ab	0.1 ± 0.1b	0.1 ± 0.1a
5. Cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid	3.4 ± 0.7b	0.6 ± 0.2b	0.1 ± 0.1b	0.1 ± 0.1a
6. Tolfenpyrad+surfactant-sulfoxaflor-acetamiprid-spinetoram	3.9 ± 0.7b	0.9 ± 0.2b	0.2 ± 0.1b	0.1 ± 0.1a
7. Bifenthrin (4 times)	0.6 ± 0.1c	3.8 ± 1.0a	4.6 ± 1.2a	0.3 ± 0.2a
ANOVA $F_{6,214}$	16.27	5.74	$F_{6,102}$ 24.56	1.23
P	<0.0001	<0.0001	<0.0001	0.2967

[a]Treatment programs consisted of 4 weekly applications of products; a '+' sign indicates the products were combined (see Table 1 for rates and volumes).
[b]Means within a column not followed by the same letter are significantly different by Tukey's studentized range test (α = 0.05). Data were transformed by $\log_{10}(x + 1)$ before ANOVA, means are reported in the original scale. The year by treatment interactions for *F. bispinosa* and *F. occidentalis* were not significant; so results from each year were pooled; the year by treatment interaction for *F. schultzei* was significant, so results from each year were shown separately.

Table 4. Mean (± SE) densities of adult thrips in pink and green fruits, by combined and individual species, pooled over the 4 sampling dates (each 2 d after application) in the 2015 experiment in Wimauma, Florida.

Treatment program no. & chemical name(s)[a]	Mean ± SE number adults per 5 green + 5 pink fruits[b]				
	Total[c]	*F. bispinosa*	*F. occidentalis*	*F. schultzei*	*S. dorsalis*
1. Untreated control	2.3 ± 0.6ab	1.9 ± 0.7ab	0.1 ± 0.1a	0.0 ± 0.0a	0.1 ± 0.1a
2. Spinetoram-spinetoram-sulfoxaflor-spinetoram	1.8 ± 0.4ab	1.3 ± 0.3ab	0.2 ± 0.1a	0.1 ± 0.1a	0.0 ± 0.0a
3. Sulfoxaflor-spinetoram-acetamiprid-spinetoram	2.4 ± 0.5ab	1.8 ± 0.5ab	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a
4. Spinetoram-acetamiprid-novaluron-spinetoram	1.2 ± 0.3b	0.8 ± 0.3b	0.2 ± 0.1a	0.0 ± 0.0a	0.0 ± 0.0a
5. Cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid	3.5 ± 0.6a	2.8 ± 0.4a	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a
6. Tolfenpyrad+surfactant-sulfoxaflor-acetamiprid-spinetoram	2.9 ± 0.5ab	1.9 ± 0.6ab	0.4 ± 0.2a	0.1 ± 0.1a	0.3 ± 0.1a
7. Bifenthrin (4 times)	1.1 ± 0.3b	0.7 ± 0.2b	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a
ANOVA $F_{6,102}$	3.14	2.68	1.05	0.34	1.24
P	0.0073	0.0185	0.3987	0.9165	0.2946

[a]Treatment programs consisted of 4 weekly applications of products; a '+' sign indicates the products were combined (see Table 1 for rates and volumes).
[b]Means within a column not followed by the same letter are significantly different by Tukey's studentized range test (α = 0.05). Data were transformed by $\log_{10}(x + 1)$ before ANOVA, means are reported in the original scale.
[c]The total column includes minor species and unidentified specimens.

total adult thrips and *F. bispinosa* adults on fruit in the spinetoram-acetamiprid-novaluron-spinetoram (program 4) and bifenthrin (program 7) treatments than in the cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid treatment (program 5). The numbers of *F. occidentalis*, *F. schultzei*, or *S. dorsalis* adults on fruit did not differ significantly among treatments.

LARVAL, PREPUPAL, AND PUPAL THRIPS ON FRUIT IN 2015

Larvae were more numerous than adults on fruit. The majority of 2nd instar larvae were *F. bispinosa* (Table 5). There were significantly fewer 1st instar, 2nd instar, and total larvae on fruit in the bifenthrin treatment (program 7) than in the control. Second instar larvae were significantly less abundant in all spinetoram rotations than in the control, but there were no significant differences in abundance of 1st instars between the spinetoram treatments and the control. There were significantly fewer total larvae on fruit in the spinetoram-spinetoram-sulfoxaflor-spinetoram (program 2) and the spinetoram-acetamiprid-novaluron-spinetoram (program 4) treatments than in the control (program 1).

Numbers of 2nd instar *F. occidentalis*, *F. schultzei*, and *S. dorsalis* larvae were low in the control (0.1 ± 0.1 per 10 fruit), and they did not attain high densities in most treatments during the 4 wk of sampling. Numbers of 2nd instar *F. occidentalis* larvae were higher in the tolfenpyrad-sulfoxaflor-acetamiprid-spinetoram treatment (program 6) than in the spinetoram-acetamiprid-novaluron-spinetoram (program 4) and the cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid (program 5) treatments; however, densities of *F. occidentalis* larvae were probably not economically significant on fruit even at their most abundant. There were no significant differences among treatments with regard to numbers of 2nd instar larvae of *F. schultzei* and *S. dorsalis* on fruit.

Low levels of thrips prepupae and pupae were collected on green and pink fruit, usually on the portion of the fruit in contact with the plastic mulch. The numbers of prepupae and pupae, which collectively averaged less than 1 quiescent stage per 10 fruit, did not differ significantly among treatments ($F = 0.77$; df = 6,102; $P = 0.593$).

Table 5. Mean (± SE) larval thrips densities in pink and green fruits, by combined and individual species, pooled over the 4 sampling dates (each 2 d after application) in the 2015 experiment in Wimauma, Florida.

Treatment program no. & chemical name(s)[a]	Mean ± SE number larvae per 5 green + 5 pink fruits[b]					
	Total 1st instar	2nd instar larvae				Total 1st + 2nd instars
		F. bispinosa	*F. occidentalis*	*F. schultzei*	Total[c]	
1. Untreated control	7.8 ± 1.2a	6.4 ± 1.0a	0.1 ± 0.1ab	0.1 ± 0.1a	8.1 ± 1.2a	15.8 ± 2.1a
2. Spinetoram-spinetoram-sulfoxaflor-spinetoram	7.2 ± 2.5ab	0.6 ± 0.3b	0.4 ± 0.2ab	0.0 ± 0.0a	1.4 ± 0.3b	8.6 ± 2.7bc
3. Sulfoxaflor-spinetoram-acetamiprid-spinetoram	5.3 ± 1.2ab	1.9 ± 0.7b	0.1 ± 0.1ab	0.1 ± 0.1a	2.6 ± 0.8b	7.9 ± 1.4abc
4. Spinetoram-acetamiprid-novaluron-spinetoram	4.8 ± 1.9ab	0.9 ± 0.4b	0.1 ± 0.1b	0.0 ± 0.0a	1.6 ± 0.4b	6.4 ± 2.2bc
5. Cyantraniliprole-spinetoram-sulfoxaflor-acetamiprid	5.8 ± 1.2ab	2.1 ± 1.0b	0.0 ± 0.0b	0.1 ± 0.1a	3.0 ± 1.1b	8.8 ± 1.7abc
6. Tolfenpyrad+surfactant-sulfoxaflor-acetamiprid-spinetoram	7.4 ± 1.0a	1.4 ± 0.4b	0.8 ± 0.3a	0.0 ± 0.0a	3.1 ± 0.6b	10.4 ± 1.2ab
7. Bifenthrin (four times)	2.6 ± 0.7b	0.4 ± 0.2b	0.4 ± 0.2ab	0.0 ± 0.0a	1.1 ± 0.3b	3.6 ± 0.8c
ANOVA $F_{6,102}$	3.73	11.57	3.45	0.67	9.52	6.84
P	0.0022	<0.0001	0.0038	0.6732	<0.0001	<0.0001

[a]Treatment programs consisted of 4 weekly applications of products; a '+' sign indicates the products were combined (see Table 1 for rates and volumes).
[b]Means within a column not followed by the same letter are significantly different by Tukey's studentized range test (α = 0.05). Data were transformed by $\log_{10}(x + 1)$ before ANOVA, means are reported in the original scale. Only 2nd instar larvae could be identified to species. First instar larvae and the total of 2nd instar larvae include all species and any specimens which could not be identified to species, respectively.
[c]Includes the family Phlaeothripidae.

ORIUS

The numbers of adults and nymphs of *Orius* sp. collected from strawberry flowers were low in each experiment. Numbers of *Orius* adults were not significantly different among treatments in either year (2014: $F = 1.70$; df = 6,102; $P = 0.129$; 2015: $F = 1.94$; df = 6,102; $P = 0.08$). In 2014, numbers of *Orius* adults and nymphs combined (1.7 ± 0.7 per 10 flowers) were significantly higher in the control than in all other treatments ($F = 5.31$; df = 6,102; $P < 0.0001$). In 2015, numbers of *Orius* adults and nymphs combined were significantly higher in the control (0.8 ± 0.2 per 10 flowers) than in the spinetoram-spinetoram-sulfoxaflor-spinetoram treatment (program 2) (0.1 ± 0.1 per 10 flowers) and the bifenthrin treatment (program 7) ($F = 3.01$; df = 6,102; $P = 0.009$). No *Orius* were collected from the bifenthrin treatment (program 7) in either year.

YIELD

There were no significant differences in yield attributable to treatment in either year. Average yield (total of 5 harvests), across treatments, in 2015 was 7.5 t/ha ± 0.18 [SE] (6,700 lb/acre ± 162 [SE]); yields were slightly less in 2014.

Discussion

Frankliniella bispinosa was the predominant species collected in flowers each season and on fruit in 2015. Low numbers of *F. occidentalis*, *F. schultzei*, *H. gowdeyi*, and other species were also collected each season. *Frankliniella schultzei* was first detected in south Florida in 1997 (Frantz & Fasulo 1997). Like *F. bispinosa* and *F. occidentalis*, *F. schultzei* has a broad host range and is a pest of concern in several crops because it transmits tospoviruses (Kakkar et al. 2012; Webster et al. 2015). *Haplothrips gowdeyi* is a flower feeder and not considered to be of economic importance (Childers & Nakahara 2006).

Season-long densities of *F. bispinosa* populations were reduced equally by all insecticide rotations each season regardless of the number of spinetoram applications. This indicates that *F. bispinosa* is broadly susceptible to a range of modes of action, including spinetoram. By contrast, season-long densities of *F. occidentalis* populations were unaffected by insecticide rotation applications, regardless of the number of spinetoram applications. Lack of treatment effects on *F. occidentalis* may have been influenced by the low numbers of *F. occidentalis* in this study. However, these results indicate a lack of susceptibility of *F. occidentalis* not just to spinetoram but also to products with other modes of action.

Repeated applications of bifenthrin reduced *F. bispinosa* populations to levels significantly lower than those found with spinetoram-based rotations. However, the abundance of *F. occidentalis* was actually increased relative to other treatments, including the untreated control, by repeated applications of bifenthrin. This may be explained by release of *F. occidentalis* from both competition with *F. bispinosa* and predation by *Orius* (Funderburk et al. 2015), because no *Orius* were recovered from the bifenthrin treatment in either year. Reitz et al. (2003) found that applications of esfenvalerate and acephate reduced numbers of *Frankliniella tritici* (Fitch) and *F. bispinosa* in field pepper but increased numbers of *F. occidentalis*. Numbers of total thrips larvae and *F. schultzei* adults were also significantly higher in the bifenthrin treatment in 2014 but not in 2015.

Frankliniella bispinosa is clearly the most abundant thrips species on strawberries in Florida's major strawberry-producing region, but it is also more susceptible to insecticidal control than *F. occidentalis*. Our results suggest that as insecticide applications are made during the course of the season, populations of *F. bispinosa* will be reduced and *F. occidentalis* may become more abundant. Thus, thrips damage to strawberries may be due to the species that is least susceptible to control rather than the species that is most abundant early in the cropping season. However, the relative importance of various stages or species has yet to be critically determined.

The reason that thrips populations reached uncontrollable levels in the spring of 2013 remains uncertain; however, it is possible that environmental factors contributed to the population build-up. *Frankliniella bispinosa* has many cultivated and wild hosts in central Florida, including perennial hosts such as citrus and oak (Fagales: Fagaceae) (Frantz & Mellinger 1990; Childers & Nakahara 2006). Spring was unusually cool in 2013. Wild hosts such as *Raphanus raphanistrum* L. (Brassicales: Brassicaceae) continued to flower abundantly, providing resources to *F. bispinosa* later into the spring than is usual. Samples of strawberry and other infested plants brought to the diagnostic clinic at the Gulf Coast Research and Education Center in the spring of 2013 contained primarily adult thrips, which suggests the infestations may have been the result of large migrations of thrips from wild hosts into cultivated fields.

Historically, thrips have been a sporadic pest in Florida strawberry (Whidden 2004, 2008). The intensive harvest schedule for the crop reduces opportunities for thrips to damage ripened fruit. Spider mites (*Tetranychus* species; Acari: Prostigmata: Tetranychidae) and armyworms (*Spodoptera* species; Lepidoptera: Noctuidae) are habitual pests of strawberry, and growers apply insecticides routinely to control them. Spotted wing drosophila (*Drosophila suzukii* [Matsumura]; Diptera: Drosophilidae) has recently become established as a pest of strawberry and other crops in Florida. When broad-spectrum insecticides such as pyrethroids are sprayed to control these primary pests, a species shift toward *F. occidentalis* may occur. Presumably, thrips damage occurs 1) when high numbers of adults migrate from neighboring habitat (i.e., wild hosts or end-of-season crops that are being destroyed); 2) when lapses in monitoring allow thrips to build up and feed on green and pink fruit; or 3) when insecticide sprays reduce natural enemies such as *Orius* and shift the population so that insecticide-tolerant individuals predominate.

Acknowledgments

Justin Carter, Laurie Chambers, WinDi Sanchez and Deborah Farr assisted with this research, which was supported in part with funding from the Florida Strawberry Growers Association.

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