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Efficacy of insecticides for season-long control of thrips (Thysanoptera: Thripidae) in winter strawberries in Florida

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ABSTRACT

Flower thrips (primarily *Frankliniella* spp.) can be significant strawberry pests, and recently in Florida, *Scirtothrips dorsalis* Hood has become an established, early-season, foliar pest. Insecticides that were used for flower thrips management are now also used for *S. dorsalis*, resulting in the need to evaluate newer insecticides in order to diversify rotations and mitigate overuse of insecticides with the same mode-of-action. We evaluated 10 and 12 season-long insecticide programs in field plots in central Florida during the 2016–2017 and 2017–2018 winter strawberry seasons, respectively. We found that most programs reduced thrips populations and strawberry injury due to thrips feeding, while having limited effects on *Orius* spp., a primary thrips predator. An early season application of chlorantraniliprole + thiamethoxam, commonly used for other strawberry pests, reduced *S. dorsalis* populations and strawberry injury, although *S. dorsalis* populations were relatively low in both study years. When repeat applications of the same insecticide were made throughout the growing season, cyantraniliprole was nearly as effective as spinetoram against *Frankliniella* spp., while tolfenpyrad and sulfoxaflor did not perform as well. Flupyradifurone was as effective as acetamiprid when used as a follow-up application to spinetoram or cyantraniliprole. Programs including or entirely composed of OMRI-listed insecticides for organic production were not as effective as conventional insecticide programs, with only spinosad providing acceptable thrips control. In conclusion, spinetoram, acetamiprid and spinosad were confirmed to be effective against thrips and can be used as the backbone of rotation programs in conventional and organic strawberry production systems. Diamide insecticides were effective when used repeatedly and in rotation, while flupyradifurone and flonicamid may be used when follow-up applications are needed. Continued research is critical for fine-tuning insecticide programs, with a focus on testing against high *S. dorsalis* populations in early-planted strawberries and on developing effective sampling methods to optimize timing and reduce the number of applications.

1. Introduction

Flower thrips (primarily *Frankliniella* spp.) are found in strawberry fields worldwide. They cause injury to floral tissues including receptacles, pistils, petals, anthers or sepals, resulting in fewer, smaller and malformed, bronzed and cracked fruit (Coll et al., 2006; Steiner and Goodwin, 2005; Strzyzewski, 2017). Regional differences in thrips species composition, environmental conditions or agronomic practices alter thrips-strawberry interactions (Steiner and Goodwin, 2005). In Florida strawberry, the species complex is dominated by the native *Frankliniella bispinosa* Morgan (Cluever et al., 2016). *Frankliniella bispinosa* is a primary pest of blueberry and occasionally of tomatoes, citrus and other crops (Rhodes et al., 2012; Childers, 1992). A related, invasive species, *F. occidentalis* (Pergande), is a well-known pest of many horticultural crops, but in a recent study was only 5–10% of the thrips species complex in Florida strawberry (Cluever et al., 2016; Kirk and Terry, 2003). Other minor thrips species, *Frankliniella schultzei* (Trybom), *Haplothrips gowdeyi* (Franklin), and a *Scolothrips* sp., were also reported from Florida strawberry by Cluever et al. (2016).

Scirtothrips dorsalis (Hood), is invasive to North America and has

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been considered established in Florida since 2005 (Hodges et al., 2005). *Scirtothrips dorsalis* is polyphagous and reported from over 225 plant species, including strawberry (Kumar et al., 2013). Adults and larvae feed on new, expanding leaves and young fruit, but not flowers or pollen, causing leaf discoloration and distortion and small, bronzed, unmarketable strawberries. High populations after transplanting in late September and early October result in stunted, entirely damaged plants. Currently, Florida strawberry growers often apply early-season insecticides prophylactically.

Florida is the second largest domestic producer of US strawberries, at 4000 ha with a value of $281 million USD (USDA/NASS, 2018). Florida has historically been the leader in North American winter strawberry production. However, recent increases in the domestic and international strawberry supply in late winter has resulted in lower prices. Therefore, the Florida annual strawberry industry is moving to improving yields in November and December by planting earlier and developing cultivars suited to early fruit production (Suh et al., 2017; Whitaker et al., 2017). At the same time, strawberry growers are focused on reducing input costs to remain competitive, including improving strategies for optimizing pesticide applications. In addition, there is now an estimated 160 ha of Florida strawberries produced under organic certification standards (Kenneth Parker, personal communication). To maintain and improve the profitability and sustainability of conventional and organic strawberry in Florida, improved thrips management is needed, particularly with the advent of *S. dorsalis* as a major early-season pest.

Thrips are notoriously difficult to control because of their cryptic behaviors, rapid population growth and ability of some species to develop resistance to insecticides (e.g., Wang et al., 2016; Herron et al., 2008). *Frankliniella occidentalis* has been reported resistant to 30 active ingredients (Arthropod Pesticide Resistance Database, 2019). In Florida strawberry, conventional growers mainly rely on spinetoram and acetamiprid and organic growers on spinosad for thrips control. With earlier planting, when Florida conditions are hot, humid and favorable for *S. dorsalis*, an increased number of early-season insecticide applications may be needed to achieve thrips control. Most insecticides that are effective against *S. dorsalis* are also effective against *Frankliniella* spp., creating the potential for a lack of options later in the season if maximum numbers of applications per season are reached. Therefore, there is a critical need to evaluate the efficacy of new insecticides and compare the effectiveness of season-long insecticide rotations for thrips in Florida strawberry.

To diversify thrips control programs, there are a number of new reduced-risk insecticides recently registered in strawberry in the US. Cyantraniliprole (registered March 2017, Exirel® with Cyazypyr®) had moderate to significant lethal and sublethal effects on *F. occidentalis* in tomatoes and peppers, with little impact on *Orius insidiosus* (Say) populations, a valuable thrips predator (Bielza and Guillén, 2015; Srivastava et al., 2014). Abamectin + cyantraniliprole (July 2018, Minecto® Pro) has a potential added benefit in that abamectin was effective against *S. dorsalis* in peppers and had significant lethal and sublethal effects on *F. occidentalis* (Seal et al., 2006; Kontsedalov et al., 1998). Flupyradifurone (May 2016, Sivanto® prime 200 SL) is not labelled for thrips, but was moderately effective against *S. dorsalis* in strawberry (Panthi and Renkema, in press). Sulfoxaflor reduced *Frankliniella* spp. in Florida strawberries by 60–70% compared to spinetoram and was as effective as spinetoram against *S. dorsalis* on roses (Arthurs et al., 2014; Renkema et al., 2018). Tolfenpyrad was as effective as spinetoram against *F. occidentalis* in lettuce and controlled *S. dorsalis* in roses (Sathyan et al., 2017; Dara, 2017). For bioinsecticides, *F. occidentalis* was reduced by applications of Chromobacterium *substugae* strain PRAA4-1 (Grandevo®) and *Burkholderia* spp. Strain A396 (Venerate™ XC) in marigold; other options, such as products with neem oils, provided less than 30% control (Cloyd et al., 2009; Vafaie and Rydzak, 2017). The objective of our study was to determine the effectiveness of reduced-risk insecticide and bioinsecticide season-long programs, including those with repeat applications of single insecticides, against multiple thrips species that threaten Florida strawberries.

2. Materials and methods

Experiments were conducted during the 2016–2017 and 2017–2018 strawberry seasons in research plots at the Gulf Coast Research and Education Center (GCREC), Balm FL (27°45′43″ N; 82°13′38″ W). Bareroot strawberry transplants (cv. 'Radiance') were set October 6th, 2016 and October 9th, 2017 (38 cm in-row spacing) in two rows in a raised, double-pressed, black plastic/virtually impermeable film (Blockade™, Berry Plastics, Evansville IN, USA) mulched beds (1.2 m spacing) that were fumigated with Telone® C-35 (1,3-dicholoroprepene + chloropicrin) at bed formation (September 10th, 2016, early August, 2017). Plants were overhead irrigated for 7–10 days following transplanting and drip fertigated with 0.27 and 0.34 kg N ha^{-1} per day from November to mid-January and mid-January through April, respectively. Herbicides Round-up® (glyphosate) and Chateau® (flumioxazin) were applied to row aisles before transplanting. Plants received regular applications of fungicides to control prominent strawberry diseases and early-season applications each year of DiPel® DF (*Bacillus thuringiensis*, subsp. *kurstaki* Berliner) to control lepidopteran larvae.

Plots (10 m × 1 raised bed) were arranged in a randomized complete block design (RCBD) with 4 replications in a checkerboard pattern, so that the raised beds adjacent to each plot were unplanted. In 2016–2017, the total plot area was 40 m × 24 raised beds, and in 2017–2018 it was 80 m × 12 raised beds. Insecticides (Table 1) were applied with one over-the-top pass using a double-nozzle (VisiFlo® Flat Spray Tips, Teejet® Technologies, Glendale Heights IL, USA) hand-held wand sprayer connected to a CO_2-powered backpack sprayer (R&D Sprayers, Opelousas, LA, USA) (4.1 atm at 935 L ha^{-1}). Plots were scouted weekly, and applications commenced when minor *S. dorsalis* injury symptoms were first apparent; subsequent applications were made during flowering periods. In both years during late October, strawberry leaves with injury symptoms in other research plots at GCREC were removed from plants and placed on 5–6 plants in each plot to attempt to increase *S. dorsalis* populations. In 2017–2018, OMRI-listed products (Table 1) were reapplied as suggested on most product labels, with the second application 3–4 days after dates in Tables 7–10.

Ten young, partially-opened leaves were collected approximately weekly from 10 plants per plot into a sealed plastic container (500 mL) or small plastic bag (Ziploc®) from November 24th, 2016 to January 3rd, 2017, March 9th to 24th, 2017, and November 14th to December 5th, 2017. Numbers of thrips and other insects on leaves were evaluated by pouring 70% ethanol into containers, after 1 h swirling each leaf in the ethanol, and then rinsing each leaf with additional ethanol before removing it and counting and identifying adult and larval thrips in the ethanol using a stereomicroscope (e.g., Seal et al., 2006). Ten open flowers and ten small, green fruit were collected in each plot on December 8th, 2016 to January 3rd, 2017, February 14th to March 24th, 2017, November 21st, 2017 to January 3rd, 2018, and February 15th to March 8th, 2018 and processed for counting thrips and other insects in the same way as the leaves, except flowers or fruit were placed directly into centrifuge tubes (50 mL) with ethanol in the field (e.g., Cluever et al., 2016).

Ripe strawberries hand-picked from plots were graded as marketable or unmarketable, with unmarketable fruit further categorized by type/source of damage: thrips-injured (bronzed, cracked), diseased, malformed (poor pollination, seed bug feeding, physiological), undersized or other (sunburned, overripe). Marketable and unmarketable strawberry weight was recorded. In both years, strawberries were picked twice weekly but graded in 2016–2017 on December 8th, 12th, 16th, 20th, 28th, January 2nd, February 17th, 21st, 27th, March 2nd, 9th, 13th, and 16th and in 2017–2018 on December 4th, 11th, 18th, 26th, January 2nd, February 19th, 26th, March 5th and 13th. Twice each year, the number of plants per plot was counted.

Numbers of thrips and thrips predators, *Orius* spp. (Hemiptera:

Table 1
Insecticides evaluated against thrips (Thysanoptera: Thripidae) during two strawberry seasons (November–March) in Florida.

Abbrv[a]	Insecticide	Rate (g a. i.[b]/ha)	Trade name & formulation	Company	a.i.[b] concentration	IRAC-MOA[c]	Season tested 2016–2017	Season tested 2017–2018	OMRI-listed[d]
ab+cy	abamectin + cyantraniliprole	21g + 99 g	Minecto Pro	Syngenta	29 g/L + 135 g/L	28 + 6	X		No
ace	acetamiprid	145g	Assail 30 SG	United Phosphorus Inc.	300 g/kg	4A	X	X	No
aza	azadirachtin	28g	Aza-Direct	Gowan Company	12 g/L	un		X	Yes
az+py	azadirachtin + pyrethrins	28g + 30 g	Azera	Valent BioSciences	12 g/L + 13 g/L	3A		X	Yes
bur	*Burkholderia* spp. (heat killed)	18.7L[e]	Venerate XC	Marrone Bio Innovations	94.46%	–	X	X	Yes
c+g+c	*Capsicum oleorecin* extract + garlic oil + canola oil	2.3L[e]	Captiva Prime	Gowan Company	7.6% + 23.4% + 55%	–		X	Yes
ch+th	chlorantraniliprole + thiamethoxam	70g + 70 g	Voliam Flexi	Syngenta	200 g/kg + 200 g/kg	28 + 4A	X	X	No
chr	*Chromobacterium subtsugae* strain PRAA4-1	1008g	Grandevo WDG	Marrone Bio Innovations	300 g/kg	–	X		Yes
cya	cyantraniliprole	145g	Exirel	DuPont/FMC Corporation	100 g/L	28	X	X	No
flo	flonicamid	100g	Beleaf	FMC Corporation	500 g/kg	9C	X	X	No
flu	flupyradifurone	205g	Sivanto 200 SL	Bayer AG - Crop Science	200 g/L	4D	X	X	No
g+p+r	geraniol + peppermint oil + rosemary oil	4.76L[e]	Ecotec Plus	Brandt Consolidated	5% + 2% + 10%	–		X	Yes
mal	malathion	2100g	Malathion 5 EC	Drexel Chemical	600 g/L	1B	X		No
nee	neem oil extract	10210g	Trilogy	Certis	546 g/L	un	X		Yes
nov	novaluron	88g	Rimon 0.83 EC	ADAMA Ag Solutions	100 g/L	15	X		No
psf	potassium salts of fatty acids	8527g	M-Pede	Gowan Company	456 g/L	–		X	Yes
spi l	spinetoram	53g	Radiant SC - low	Dow AgroSciences	120 g/L	5	X	X	No
spi h	spinetoram	88g	Radiant SC - high		120 g/L	5	X	X	No
spi	spinosad	70g	Entrust	Dow AgroSciences	240 ml/L	5		X	Yes
sul	sulfoxaflor	78g	Closer SC	Dow AgroSciences	240 g/L	4C		X	No
tol	tolfenpyrad	310g	Apta	Nichino America	157 g/L	21A	X		No
thi	thiamethoxam	70g	Actara	Syngenta	250 g/kg	4A	X		No

[a] Abbrv = abbreviations used in Tables 3–10.
[b] a. i. = active ingredient.
[c] IRAC-MOA = Insecticide Resistance Action Committee – Mode of Action http://www.irac-online.org/modes-of-action/.
[d] OMRI = Organic Materials Review Institute https://www.omri.org/omri-lists.
[e] amount of product; proportion a. i. not provided on product label.

Anthocoridae), on leaves and in flowers and green fruit as well as yield data were summed over all sampling or picking dates from the first (November to January) and second halves (February to March) of each season to determine total effects of insecticide rotations post initial application. Statistics were conducted in R (version 3.5.1; R Core Team 2018, Vienna, Austria). All data was square-root transformed to normalize error variance and analyzed with a mixed model analysis of variance (ANOVA) using insecticide program as a fixed effect and block as a random effect with the lme function in the nlme package of R. Means were separated using Tukey's HSD test ($P < 0.05$) in the agricolae package of R. Back-transformed least-square means and 95% confidence intervals are reported. Thrips counts pre insecticide application (only available for November 2017 for applications targeting thrips on leaves and December 2017 and February 2018 for applications targeting thrips in flowers) were analyzed separately in the same way as summed counts post application.

Table 2
Species composition of adult thrips (Thysanoptera) during two seasons from strawberry leaves, flowers and green fruit in field plots (Balm, Florida) sprayed with insecticides.

Thrips species	2016–2017								2017–2018					
	November, December, January				February, March				November, December, January				February, March[a]	
	Leaves		Flowers + green fruit		Leaves		Flowers + green fruit		Leaves		Flowers + green fruit		Flowers + green fruit	
	Number	%[b]	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Frankliniella bispinosa	178	31.4	2893	91.3	81	26.5	3008	93.2	56	29.5	4338	78.1	1595	92.6
Frankliniella occidentalis	0	0.0	2	0.1	1	0.3	31	1.0	0	0.0	14	0.3	2	0.1
Frankliniella schultzei	0	0.0	4	0.1	0	0.0	18	0.6	0	0.0	11	0.2	0	0.0
Haplothrips gowdeyi	10	1.8	168	5.3	0	0.0	51	1.6	20	10.5	1143	20.6	61	3.5
Caliothrips fasciatus	250	44.1	45	1.4	1	0.3	12	0.4	9	4.7	10	0.2	0	0.0
Microcephalus abdominalis	0	0.0	5	0.2	0	0.0	0	0.0	0	0.0	7	0.1	3	0.2
Scirtothrips dorsalis	126	22.2	16	0.1	223	72.9	89	2.8	104	54.7	25	0.5	59	3.4
Other	3	0.5	36	1.1	0	0.0	17	0.5	1	0.5	5	0.1	3	0.2

[a] Leaves were not collected in February and March 2018.
[b] Percentages calculated for each column.

3. Results

3.1. 2016–2017 & 2017–2018, thrips species composition, november–march

Scirtothrips dorsalis was usually the most common species on strawberry leaves, and *F. bispinosa*, was by far the most common species in flowers and green fruit (Table 2). Bean thrips, *Caliothrips fasciatus* (Pergande), was common on leaves November–January 2016–2017, but less common in flowers and on green fruit and at later dates (Table 2). *Frankliniella occidentalis*, was uncommon, never comprising more than 1% of total sampled thrips (Table 2).

3.2. 2016–2017, pre-applications, November & December

There were no differences among plots pre-insecticide applications targeting thrips on leaves (November 10th and 17th, 2016) in numbers of total adult thrips ($F_{9,67} = 0.86$; $P = 0.56$), *S. dorsalis* adults ($F_{9,67} = 1.0$; $P = 0.45$), or total thrips larvae ($F_{9,67} = 0.54$; $P = 0.84$). There were no differences among plots pre-insecticide applications targeting thrips in flowers (December 1st, 2016) in numbers of *Frankliniella* spp. adults ($F_{9,27} = 1.69$; $P = 0.14$) or total adult thrips ($F_{9,27} = 1.52$; $P = 0.19$), but there were differences among plots in total thrips larvae ($F_{9,27} = 2.89$; $P = 0.016$) and *Orius* spp. ($F_{9,27} = 5.7$; $P = 0.0002$) in strawberry flowers.

3.3. 2016–2017, post-applications, November to January

Total adult thrips on leaves were reduced by all insecticide programs compared to the control, with the exception of -/*chr*/-/spi h (Table 3). *Scirtothrips dorsalis* adults were reduced by insecticide programs with th+ch/spi l/nov/ace, th+ch/spi l/-/ace, and -/cy+ab/-/cy+ab compared to the control (Table 3).

Total adult thrips in flowers and green fruit were reduced by all insecticide programs, except with -/*chr*/-/spi h, to 50% or less of that in the control (Table 3). Flower thrips adults were reduced by all insecticide programs, except -/*chr*/-/spi h, compared to the control, but only two applications of cyantraniliprole reduced numbers below those in plots receiving -/*chr*/-/spi h (Table 3). Total thrips larvae were reduced by all insecticide programs compared to the control, except programs with -/*chr*/-/spi h and -/tol/-/tol (Table 3).

There were more marketable strawberries and fewer thrips-injured strawberries for insecticide programs with th+ch/spi l/nov/ace, th+ch/spi l/-/ace, th+ch/spi l/-/flu compared to the control (Table 4). Proportions of marketable yield were increased by all insecticide programs compared to the control, except programs with -/*chr*/-/spi h and -/cya/-/cya (Table 4). Thrips injury on strawberries was reduced by insecticide programs -/spi l/-/ace, -/spi h/-/spi h, and -/cy+ab/-/cy+ab compared to the control, but the amount of reduction was not as great as that in programs that included an early application of th+ch (Table 4). There were no differences among insecticide programs in marketable strawberry weights ($F_{9,27} = 1.19$; $P = 0.34$) or proportions of diseased strawberries ($F_{9,27} = 4.22$; $P = 0.91$).

3.4. 2016–2017, post-applications, February to March

Total adult thrips and *S. dorsalis* adults on leaves were reduced by 75% or more by all insecticide programs compared to the control, except the program with ace/-/mal/thi (Table 5). Programs with spi l/-/flo/flu, ace/-/mal/thi and nee/nee/nee/spi l did not reduce total thrips larvae compare to the control, whereas other programs reduced larval numbers to 15% or less than that of the control (Table 5).

Total adult thrips in flowers and green fruit were reduced by insecticide programs with spi h/-/spi h/spi h, cya/-/cya/cya, and cy+ab/-/cy+ab/cy+ab compared to the control, and similarly *Frankliniella* spp. adults were lower in programs with spi h/-/spi h/spi h and cya/-/cya/cya (Table 5). Total thrips larvae in flowers and green fruit were reduced by insecticide programs with spi l/nov/ace/spi l, spi h/-/spi h/spi h, cya/-/cya/cya, and cy+ab/-/cy+ab/cy+ab compared to the control (Table 5). *Orius* spp. were reduced by all insecticide programs compared to the control, except programs with spi l/-/flo/flu, nee/nee/nee/spi l, and *chr*/-/spi h/*bur* (Table 5).

There were more marketable strawberries due to all insecticide programs compared to the control, except for the program with nee/nee/nee/spi l (Table 6). Thrips injury on strawberries was reduced by all insecticide programs compared to the control, with no differences among programs (Table 6). Marketable strawberry weight was greater with all insecticide programs than the control ($F_{9,27} = 6.20$; $P = 0.001$) except programs with ace/-/mal/thi, *chr*/-spi h/*bur* and cya/-/cya/cya, and there were no differences in proportions of diseased strawberries among insecticide programs ($F_{9,27} = 1.97$; $P = 0.08$).

3.5. 2017–2018, post-applications, November to January

Total adult thrips and *S. dorsalis* adults on leaves were reduced by insecticide programs with th+ch/spi l/-/ace, -/spi l/ace/-, -/cya/ace/spi l, -/flu/ace/cya, -/spi h/spi h/spi h, and -/spi/*bur*/g+p+r compared to the control, with -/sul/sul/sul also reducing *S. dorsalis* adults

Table 3
Least-square mean (95% CI) adult and larval thrips on strawberry leaves and flowers and green fruit ($n = 10$) during the first half of the 2016–2017 growing season in field plots (Balm, Florida) sprayed with 9 insecticide programs.

Insecticide[a] by application date				Thrips on leaves Nov 24 + Dec 1 + 8 + 16 + 27 + Jan 3			Thrips in flowers Dec 8 + 16 + green fruit Dec 27 + Jan 3		
Nov 17	Dec 2	Dec 5	Dec 20	Total adults	*S. dorsalis* adults	Total larvae	Total adults	*Frankliniella* spp. adults	Total larvae
th+ch	spi l	nov	ace	6.5 **b** (3.4–10.7)	1.4 **b** (0.4–3.1)	0.0 **c** (0.0–0.0)	64.3 **b** (42.0–91.3)	53.4 **bc** (33.2–78.9)	4.0 **b** (0.0–17.4)
th+ch	spi l	–	ace	6.1 **b** (3.0–10.1)	0.1 **b** (0.1–0.8)	1.5 **bc** (0.1–4.3)	68.2 **b** (45.2–95.9)	58.9 **bc** (33.2–78.9)	11.3 **b** (1.4–30.4)
th+ch	spi l	–	flu	7.7 **b** (4.2–12.2)	2.1 **ab** (0.8–4.0)	1.2 **bc** (0.1–3.8)	49.8 **b** (30.5–73.8)	44.5 **bc** (26.3–67.5)	10.9 **b** (1.3–29.3)
–	spi l	–	ace	10.7 **b** (6.5–15.9)	1.9 **ab** (0.7–3.9)	3.9 **b** (1.3–8.1)	47.7 **b** (28.8–71.2)	42.6 **bc** (24.8–65.2)	10.0 **b** (1.0–28.3)
–	*chr*	–	spi h	16.6 **a** (11.3–22.9)	3.0 **ab** (1.4–5.3)	6.3 **ab** (2.7–11.4)	97.9 **ab** (69.9–130.6)	94.2 **ab** (66.6–126.6)	64.5 **ab** (34.5–103.8)
–	spi h	–	spi h	14.4 **b** (9.5–20.4)	2.7 **ab** (1.2–4.8)	1.9 **bc** (0.3–4.9)	42.9 **b** (22.8–69.2)	35.0 **bc** (17.0–59.3)	7.6 **b** (0.1–28.0)
–	cya	–	cya	10.1 **b** (5.5–16.1)	1.1 **ab** (0.2–2.8)	3.8 **b** (1.2–7.9)	40.2 **b** (20.9–65.7)	27.8 **c** (12.2–49.9)	2.8 **b** (0.7–17.5)
–	tol	–	tol	9.7 **b** (5.8–14.7)	2.0 **ab** (0.7–3.9)	2.4 **bc** (0.5–5.8)	71.3 **b** (47.8–99.6)	67.8 **bc** (44.8–95.7)	20.5 **ab** (5.6–44.7)
–	cy+ab	–	cy+ab	12.8 **b** (8.2–18.5)	1.2 **b** (0.3–2.7)	4.8 **b** (1.8–9.3)	45.3 **b** (27.0–68.4)	42.3 **bc** (24.5–64.7)	5.4 **b** (0.0–20.0)
–	–	–	–	16.5 **a** (11.2–22.8)	5.7 **a** (3.4–8.7)	18.2 **a** (11.6–26.2)	143.1 **a** (108.7–182.1)	139.1 **a** (105.0–177.9)	104.5 **a** (65.1–153.3)
$F_{9,26}$				2.90	4.04	6.68	6.02	6.85	7.05
P				0.0163	0.0024	<0.0001	0.0002	<0.0001	<0.0001

Means followed by the same letter in each column are not significantly different, Tukey's HSD, $\alpha = 0.05$.

[a] See Table 1 for abbreviations used for insecticides.

Table 4
Least-square mean (95% CI) numbers (per plant per harvest on December 8th, 12th, 16th, 20th, 28th, and January 2nd) and proportions (per harvest) of marketable, thrips-injured (bronzed, cracked, scarred) strawberries during the first half of the 2016–2017 growing season in field plots (Balm, Florida) sprayed with 9 insecticide programs.

Insecticide[a] by application date				Marketable strawberries		Thrips-injured strawberries	
Nov 17	Dec 2	Dec 5	Dec 20	Number	Proportion	Number	Proportion
th+ch	spi l	nov	ace	0.94 **abc** (0.82–1.08)	0.73 **abc** (0.66–0.81)	0.09 **c** (0.04–0.14)	0.07 **c** (0.04–0.10)
th+ch	spi l	–	ace	1.03 **ab** (0.90–1.17)	0.75 **ab** (0.67–0.83)	0.09 **c** (0.05–0.15)	0.06 **c** (0.04–0.09)
th+ch	spi l	–	flu	1.06 **a** (0.93–1.20)	0.79 **a** (0.71–0.88)	0.07 **c** (0.03–0.12)	0.05 **c** (0.03–0.08)
–	spi l	–	ace	0.85 **abcd** (0.73–0.98)	0.64 **bcd** (0.57–0.71)	0.18 **bc** (0.12–0.26)	0.19 **b** (0.15–0.24)
–	*chr*	–	spi h	0.78 **bcd** (0.67–0.90)	0.56 **de** (0.49–0.63)	0.26 **abc** (0.18–0.35)	0.21 **ab** (0.16–0.26)
–	spi h	–	spi h	0.73 **cd** (0.62–0.85)	0.60 **cd** (0.53–0.67)	0.18 **bc** (0.11–0.26)	0.18 **b** (0.14–0.23)
–	cya	–	cya	0.63 **d** (0.52–0.75)	0.49 **de** (0.43–0.56)	0.31 **ab** (0.22–0.41)	0.27 **ab** (0.22–0.33)
–	tol	–	tol	0.90 **abcd** (0.78–1.03)	0.60 **cd** (0.53–0.67)	0.24 **abc** (0.16–0.33)	0.22 **ab** (0.17–0.27)
–	cy+ab	–	cy+ab	0.77 **bcd** (0.66–0.89)	0.60 **cd** (0.53–0.67)	0.20 **bc** (0.13–0.28)	0.19 **b** (0.14–0.24)
–	–	–	–	0.63 **d** (0.53–0.74)	0.44 **e** (0.38–0.50)	0.43 **a** (0.33–0.55)	0.31 **a** (0.25–0.38)
$F_{9,27}$				7.46	13.42	8.98	18.98
P				<0.0001	<0.0001	<0.0001	<0.0001

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

Table 5
Least-square mean (95% CI) adult and larval thrips and a thrips predator on strawberry leaves and flowers and green fruit ($n = 10$) during the second half of the 2016–2017 growing season in field plots (Balm, Florida) sprayed with 9 insecticide programs.

Insecticide[a] by application date				Thrips on leaves Mar 9 + 16 + 24			Thrips & predator in flowers Feb 14 + 22 + Mar 2 + green fruit Mar 9 + 16 + 24			
Feb 8	Feb 16	Feb 24	Mar 10	Total adults	*S. dorsalis* adults	Total larvae	Total adults	*Frankliniella* spp. adults	Total larvae	*Orius* spp.
spi l	nov	ace	spi l	2.2 **c** (0.7–4.5)	1.9 **b** (0.5–4.2)	1.1 **bc** (0.1–3.7)	73.3 **bcd** (55.7–97.2)	68.4 **bc** (52.5–86.4)	16.3 **bc** (0.0–17.4)	3.2 **bc** (0.8–7.1)
spi l	–	flo	flu	4.2 **bc** (2.0–7.2)	1.4 **b** (0.3–3.5)	5.1 **abc** (1.0–9.9)	73.6 **bcd** (57.9–91.1)	69.8 **bc** (53.8–88.0)	29.8 **abc** (1.4–30.4)	8.7 **abc** (4.3–14.7)
ace	–	mal	thi	11.6 **ab** (7.7–16.2)	10.0 **a** (6.2–14.7)	8.0 **ab** (3.7–13.8)	74.9 **bcd** (59.1–92.6)	67.9 **bc** (52.0–85.8)	42.2 **abc** (1.3–29.3)	1.1 **c** (0.0–3.7)
nee	nee	nee	spi l	2.8 **c** (1.1–5.4)	1.2 **b** (0.2–3.2)	4.9 **abc** (1.8–9.7)	129.8 **a** (108.7–152.8)	127.4 **a** (105.4–151.6)	67.9 **a** (1.0–28.3)	7.2 **abc** (3.3–12.8)
chr	-	spi h	*bur*	1.9 **c** (0.6–4.1)	0.3 **b** (0.1–1.4)	1.9 **bc** (0.2–5.2)	92.8 **bc** (75.1–112.3)	89.7 **ab** (71.0–110.1)	54.6 **a** (34.5–103.8)	12.7 **ab** (7.2–19.7)
spi h	–	spi h	spi h	3.2 **c** (1.3–5.8)	0.9 **b** (0.1–2.6)	0.5 **bc** (0.1–2.5)	55.0 **d** (41.6–70.3)	53.8 **c** (39.8–69.9)	15.2 **bc** (0.1–28.0)	5.4 **bc** (2.1–10.3)
cya	–	cya	cya	4.1 **bc** (1.9–7.0)	2.2 **b** (0.6–4.6)	2.1 **bc** (0.3–5.4)	56.9 **cd** (43.2–72.4)	54.7 **c** (40.6–70.9)	6.9 **c** (0.7–17.5)	3.0 **c** (0.7–6.8)
tol	–	tol	tol	4.0 **bc** (1.9–6.9)	2.1 **b** (0.6–4.4)	1.9 **bc** (0.2–5.1)	72.9 **bcd** (57.3–90.3)	70.4 **bc** (57.2–88.6)	38.6 **abc** (5.6–44.7)	4.7 **bc** (1.7–9.3)
cy+ab	–	cy+ab	cy+ab	2.4 **c** (0.8–4.7)	0.7 **b** (0.1–2.3)	0.4 **c** (0.1–2.2)	67.3 **cd** (52.4–84.1)	64.9 **bc** (49.4–82.4)	15.0 **bc** (0.0–20.0)	1.7 **c** (0.2–4.7)
–	–	–	–	16.3 **a** (11.6–21.7)	13.9 **a** (9.4–19.4)	15.0 **a** (8.9–22.8)	103.6 **ab** (84.8–124.2)	90.1 **ab** (71.7–110.6)	62.3 **a** (65.1–153.3)	14.8 **a** (8.8–22.4)
$F_{9,26}$				8.73	9.86	5.14	9.14	7.69	7.77	5.22
P				<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	0.0004

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations for insecticides.

(Table 7). Total thrips larvae on leaves was reduced by all insecticide programs compared to the control, except programs with -/spi h/sul/spi h and -/az+py/spi/c+g+c, and the program with -/cya/ace/spi l resulted in no larval thrips (Table 7).

Total adult thrips in flowers and on green fruit was reduced by insecticide programs with th+ch/spi l/-/ace and -/cya/flu/spi l compared to the control (Table 7). *Frankliniella* spp. adults in flowers and green fruit were reduced by insecticide programs with thi+ch/spi l/-/ace, -/spi l/ace/-, -/cya/ace/spi l, -/cya/flu/spi l and -/spi h/sul/spi h compared to the control (Table 7). Total thrips larvae was reduced by

Table 6
Least-square mean (95% CI) numbers (per plant per harvest on February 17th, 21st, 27th, March 2nd, 9th, 13th, and 16th) and proportions (per harvest) of marketable, thrips-injured (bronzed, cracked, scarred) strawberries during the second half of the 2016–2017 growing season in field plots (Balm, Florida) sprayed with 9 insecticide programs.

Insecticide[a] by application date				Marketable strawberries		Thrips-injured strawberries	
Feb 8	Feb 16	Feb 24	Mar 10	Number	Proportion	Number	Proportion
spi l	nov	ace	spi l	2.02 **a** (1.77–2.29)	0.60 **a** (0.66–0.81)	0.02 **b** (0.00–0.06)	0.01 **b** (0.00–0.02)
spi l	–	flo	flu	1.82 **ab** (1.58–2.08)	0.51 **ab** (0.67–0.83)	0.05 **b** (0.01–0.12)	0.01 **b** (0.00–0.03)
ace	–	mal	thi	1.79 **ab** (1.55–2.05)	0.50 **ab** (0.71–0.88)	0.21 **b** (0.12–0.33)	0.06 **b** (0.03–0.09)
nee	nee	nee	spi l	1.40 **bc** (1.18–1.62)	0.43 **b** (0.57–0.71)	0.23 **b** (0.13–0.36)	0.07 **b** (0.04–0.11)
chr	-	spi h	*bur*	1.91 **ab** (1.66–2.17)	0.52 **ab** (0.49–0.63)	0.12 **b** (0.05–0.21)	0.03 **b** (0.01–0.06)
spi h	–	spi h	spi h	1.66 **ab** (1.43–1.91)	0.53 **ab** (0.53–0.67)	0.11 **b** (0.05–0.21)	0.04 **b** (0.02–0.06)
cya	–	cya	cya	1.83 **ab** (1.59–2.09)	0.48 **b** (0.43–0.56)	0.05 **b** (0.01–0.12)	0.01 **b** (0.00–0.03)
tol	–	tol	tol	1.95 **ab** (1.70–2.22)	0.52 **ab** (0.53–0.67)	0.03 **b** (0.00–0.08)	0.01 **b** (0.00–0.02)
cy+ab	–	cy+ab	cy+ab	1.94 **ab** (1.69–2.21)	0.54 **ab** (0.53–0.67)	0.02 **b** (0.00–0.07)	0.01 **b** (0.00–0.02)
–	–	–	–	0.97 **c** (0.80–1.17)	0.27 **c** (0.38–0.50)	1.37 **a** (1.12–1.66)	0.39 **a** (0.31–0.47)
$F_{9,27}$				8.05	16.35	30.27	25.80
P				<0.0001	<0.0001	<0.0001	<0.0001

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

Table 7

Least-square mean (95% CI) adult and larval thrips on strawberry leaves and flowers and green fruit ($n = 10$) during the first half of the 2017–2018 growing season in field plots (Balm, Florida) sprayed with 11 insecticide programs.

Insecticide[a] by application date				Thrips on leaves Nov 14 + 21 + 28 + Dec 5			Thrips & predator in flowers Nov 21 + 28 + Dec 5 + green fruit Dec 12 + 20 + 27 + Jan 3			
Nov 7	Nov 15	Nov 29	Dec 13	Total adults	*S. dorsalis* adults	Total larvae	Total adults	*Frankliniella* spp. adults	Total larvae	*Orius* spp.
th+ch	spi l	–	ace	1.5 **b** (0.1–4.2)	0.1 **b** (0.1–1.1)	1.0 **cd** (0.0–3.4)	81.2 **b** (52.4–116.4)	53.5 **b** (28.2–87.0)	20.1 **c** (11.7–30.8)	3.7 **ab** (1.3–7.2)
th+ch	–	spi h	–	3.8 **ab** (1.3–7.8)	2.4 **ab** (0.8–5.0)	5.7 **bcd** (2.4–10.4)	138.9 **ab** (100.2–183.9)	111.8 **ab** (73.4–158.4)	42.0 **bc** (29.3–56.9)	0.9 **ab** (0.0–3.0)
–	spi l	ace	–	1.2 **b** (0.1–3.8)	0.7 **b** (0.0–2.3)	0.9 **cd** (0.0–3.2)	90.3 **ab** (59.7–127.2)	67.1 **b** (38.2–104.1)	26.6 **c** (16.7–38.7)	1.2 **ab** (0.1–3.5)
–	cya	ace	spi l	2.4 **b** (0.5–5.6)	0.3 **b** (0.0–1.4)	0.0 **d** (0.0–0.7)	91.2 **ab** (60.5–128.3)	63.3 **b** (35.4–99.3)	32.2 **c** (21.3–45.5)	0.7 **ab** (0.0–2.7)
–	cya	flu	spi l	6.4 **ab** (2.9–11.3)	3.4 **ab** (1.4–6.4)	1.8 **bcd** (0.3–4.8)	69.7 **b** (43.2–102.5)	44.6 **b** (21.8–75.5)	18.3 **c** (10.3–28.5)	1.5 **ab** (0.2–3.9)
–	flu	ace	cya	0.9 **b** (0.0–3.2)	0.4 **b** (0.0–1.6)	2.9 **bcd** (0.7–6.5)	124.5 **ab** (88.0–167.3)	101.5 **ab** (65.1–146.0)	33.6 **c** (22.4–47.0)	0.1 **b** (0.2–1.3)
–	spi h	sul	spi h	5.0 **ab** (1.9–9.4)	2.7 **ab** (1.0–5.4)	11.5 **ab** (6.5–18.0)	88.5 **ab** (58.2–125.1)	62.4 **b** (34.7–98.2)	34.1 **c** (22.8–47.6)	1.2 **ab** (0.1–3.6)
–	spi h	spi h	spi h	1.8 **b** (0.3–4.8)	0.3 **b** (0.0–1.4)	0.9 **cd** (0.0–3.2)	136.1 **ab** (97.8–180.7)	115.8 **ab** (76.6–163.0)	40.1 **bc** (27.8–54.7)	3.7 **ab** (1.3–7.2)
–	sul	sul	sul	2.5 **ab** (0.6–5.8)	1.5 **b** (0.3–3.7)	6.3 **bcd** (2.8–11.3)	110.8 **ab** (76.6–151.4)	91.3 **ab** (56.9–133.7)	65.6 **ab** (49.5–83.9)	3.4 **ab** (1.1–6.9)
–	az+py	spi	c+g+c	4.2 **ab** (1.5–8.3)	2.4 **ab** (0.8–5.0)	9.7 **abc** (5.1–15.6)	110.0 **ab** (75.9–150.4)	83.2 **ab** (50.6–123.9)	70.6 **ab** (53.8–89.6)	4.5 **ab** (1.8–8.4)
–	spi	*bur*	g+p+r	1.5 **b** (0.2–4.3)	0.1 **b** (0.2–0.9)	4.3 **bcd** (1.2–9.4)	141.2 **ab** (102.1–186.5)	102.9 **ab** (66.2–147.7)	34.9 **c** (23.5–48.6)	6.1 **a** (2.9–10.6)
–	–	–	–	9.4 **a** (5.0–15.3)	6.9 **a** (3.8–10.9)	18.1 **a** (11.7–26.0)	178.1 **a** (133.9–228.7)	158.2 **a** (111.7–212.8)	93.9 **a** (74.4–115.7)	6.4 **a** (3.1–11.0)
$F_{11,33}$				2.51	4.85	8.38	2.74	3.30	13.77	3.25
P				0.0203	0.0002	<0.0001	0.0125	0.0038	<0.0001	0.0042

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

all insecticide programs compared to the control, except programs with -/sul/sul/sul and -/az+py/spi/c+g+c (Table 7). *Orius* spp. were only reduced by the insecticide program with -/flu/ace/cya compared to the control (Table 7).

Marketable strawberries were not affected by insecticide programs, but proportions of marketable yield were improved by insecticide programs with -/spi l/ace/- and -/cya/ace/spi l compared to the control (Table 8). Thrips-injured strawberries were reduced by the program with -/spi l/ace/-, and proportions of thrips-injured strawberries were reduced by programs with th+ch/spi l/-/ace, -/spi l/ace/-, -/cya/ace/spi l and -/cya/flu/spi l compared to the control (Table 8). There were no differences among programs in marketable strawberry weights ($F_{11,33} = 0.68$; $P = 0.75$) or proportions of diseased strawberries ($F_{11,33} = 0.77$; $P = 0.67$).

3.6. *2017–2018, pre-applications, February*

There were no differences among plots pre-insecticide applications (February 8th, 2018) for total adult thrips ($F_{11,33} = 0.75$; $P = 0.69$), *Frankliniella* spp. adults ($F_{11,33} = 0.70$; $P = 0.73$), total thrips larvae ($F_{11,33} = 1.11$; $P = 0.38$), or *Orius* spp. ($F_{11,33} = 0.90$; $P = 0.55$) in flowers.

3.7. *2017–2018, post-applications, February to March*

Total adult thrips in flowers and green fruit was reduced by insecticide programs with spi l/-/ace and ace/flo/cya compared to the control, whereas *Frankliniella* spp. adults were reduced only by the insecticide program with ace/flo/cya compared to the control (Table 9). Total thrips larvae were reduced by all insecticide programs compared to the control, except the program with *bur*/aza/c+g+c (Table 9). There were no differences among insecticide programs for numbers of *Orius* spp. ($F_{11,32} = 1.08$; $P = 0.41$).

There were more marketable strawberries due to all insecticide programs compared to control, except programs with -/spi h/-, spi h/sul/spi h and *bur*/aza/c+g+c, and increased proportions of yield that was marketable due to all insecticide rotations compared to control, except rotation 10 (Table 10). Thrips injury to strawberries was reduced by all insecticide programs compared to the control (Table 10). There were no differences in marketable strawberry weights due to insecticide program ($F_{11,33} = 0.43$; $P = 0.93$), but there was a decrease in the proportion of diseased strawberries in the program with ace/flo/cya compared to the program with cya/spi l/ace ($F_{11,33} = 2.99$; $P = 0.007$).

4. Discussion

With a few exceptions, all insecticide programs controlled thrips in winter strawberry production in Florida, resulting in few thrips-injured strawberries. Similar to recent studies, *F. bispinosa* was the dominant species in flowers and green fruit in winter-grown strawberries in Florida (Cluever et al., 2016; Renkema et al., 2018). *Frankliniella bispinosa* is found in Florida, the southeastern US and a few Caribbean countries but not in other major strawberry growing areas, e.g., California (Hoddle et al., 2012). A study with potted strawberry resulted in fewer properly formed fruit with two adult *F. bispinosa* in a flower for two days compared to controls without thrips (Strzyzewski, 2017); however, *F. bispinosa* damage to strawberry flowers and fruit has not yet been characterized in the field. Strzyzewski (2017) also showed that *F. occidentalis* caused fewer, smaller and more deformed strawberry fruit than *F. bispinosa*. Competition from native *Frankliniella* spp. can significantly limit *F. occidentalis* populations in Florida crops (Paini et al., 2008; Funderburk et al., 2016; Garrick et al., 2016); however, in one case, a competitive effect of *F. bispinosa* was not evident (Northfield et al., 2011). *Frankliniella occidentalis* is more problematic in Florida fruiting vegetables when broad spectrum insecticides or single modes of action are used repeatedly, resulting in resistant *F. occidentalis*

Table 8

Least-square mean (95% CI) numbers (per plant per harvest on December 4th, 11th, 18th, 26th, and January 2nd) and proportions (per harvest) of marketable, thrips-injured (bronzed, cracked, scarred) strawberries during the first half of the 2017–2018 growing season in field plots (Balm, Florida) sprayed with 11 insecticide programs.

Insecticide[a] by application date				Marketable strawberries		Thrips-injured strawberries	
Nov 7	Nov 15	Nov 29	Dec 13	Number	Proportion	Number	Proportion
th+ch	spi l	–	ace	0.74 (0.60–0.90)	0.66 **ab** (0.58–0.76)	0.39 **ab** (0.27–0.53)	0.18 **bc** (0.12–0.25)
th+ch	–	spi h	–	0.77 (0.62–0.93)	0.60 **ab** (0.51–0.69)	0.51 **ab** (0.37–0.67)	0.31 **abc** (0.23–0.40)
–	spi l	ace	–	0.97 (0.81–1.16)	0.76 **a** (0.67–0.86)	0.30 **b** (0.20–0.43)	0.15 **bc** (0.10–0.21)
–	cya	ace	spi l	0.87 (0.71–1.04)	0.73 **a** (0.63–0.82)	0.33 **ab** (0.22–0.46)	0.12 **c** (0.07–0.18)
–	cya	flu	spi l	0.78 (0.63–0.94)	0.68 **ab** (0.59–0.77)	0.35 **ab** (0.23–0.48)	0.16 **bc** (0.10–0.23)
–	flu	ace	cya	0.89 (0.73–1.06)	0.69 **ab** (0.60–0.79)	0.38 **ab** (0.26–0.52)	0.19 **abc** (0.13–0.27)
–	spi h	sul	spi h	0.66 (0.53–0.82)	0.56 **ab** (0.48–0.65)	0.52 **ab** (0.38–0.68)	0.33 **ab** (0.24–0.42)
–	spi h	spi h	spi h	0.88 (0.72–1.05)	0.68 **ab** (0.59–0.78)	0.42 **ab** (0.29–0.56)	0.21 **abc** (0.14–0.29)
–	sul	sul	sul	0.75 (0.61–0.92)	0.57 **ab** (0.49–0.66)	0.55 **ab** (0.41–0.71)	0.24 **abc** (0.17–0.32)
–	az+py	spi	c+g+c	0.72 (0.57–0.87)	0.63 **ab** (0.54–0.72)	0.40 **ab** (0.28–0.55)	0.30 **abc** (0.22–0.39)
–	spi	*bur*	g+p+r	0.67 (0.54–0.83)	0.55 **ab** (0.47–0.64)	0.56 **ab** (0.41–0.73)	0.29 **abc** (0.21–0.38)
–	–	–	–	0.60 (0.47–0.74)	0.49 **b** (0.42–0.57)	0.65 **a** (0.49–0.83)	0.39 **a** (0.30–0.49)
$F_{11,33}$				1.97	3.13	2.64	4.69
P				0.065	0.0054	0.0154	0.0003

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

Table 9

Least-square mean (95% CI) adult and larval thrips on strawberry flowers and green fruit ($n = 10$) during the second half of the 2017–2018 growing season in field plots (Balm, Florida) sprayed with 11 insecticide programs.

Insecticide[a] by application date			Thrips in flowers Feb 15 + green fruit Feb 22 + Mar 1 + 8		
Feb 8	Feb 15	Mar 1	Total adults	*Frankliniella* spp. adults	Total larvae
spi l	–	ace	17.3 **b** (5.4–36.0)	15.4 **ab** (3.8–34.9)	1.0 **c** (0.0–4.5)
–	spi h	–	48.9 **ab** (26.5–77.9)	43.7 **ab** (21.4–73.8)	10.1 **bc** (4.3–18.5)
spi l	ace	flu	40.5 **ab** (18.5–70.8)	39.5 **ab** (16.8–72.0)	2.4 **bc** (0.1–8.0)
cya	ace	flo	29.1 **ab** (12.6–52.3)	26.0 **ab** (9.7–50.1)	5.0 **bc** (1.2–11.2)
cya	spi l	ace	22.8 **ab** (8.6–43.8)	21.3 **ab** (7.0–43.6)	2.1 **bc** (0.1–6.6)
ace	flo	cya	12.5 **b** (2.9–28.9)	11.6 **b** (2.0–28.9)	0.5 **c** (0.2–3.2)
spi h	sul	spi h	32.8 **ab** (15.1–57.2)	28.4 **ab** (11.2–53.4)	7.2 **bc** (2.5–14.5)
spi h	spi h	spi h	22.8 **ab** (8.6–43.7)	20.2 **ab** (6.3–41.9)	4.4 **bc** (1.0–10.4)
sul	sul	sul	46.7 **ab** (24.9–75.2)	45.5 **ab** (22.7–76.1)	7.4 **bc** (2.6–14.7)
bur	aza	c+g+c	40.4 **ab** (20.4–67.1)	36.2 **ab** (16.3–64.0)	14.9 **ab** (7.5–24.9)
spi	g+p+r	psf	36.5 **ab** (17.6–62.0)	35.6 **ab** (15.9–63.1)	4.5 **bc** (1.0–10.5)
–	–	–	66.5 **a** (39.9–99.8)	58.3 **a** (32.0–92.4)	22.8 **a** (13.4–34.7)
$F_{11,32}$			2.86	2.43	5.67
P			0.0101	0.025	<0.0001

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

populations and elimination of competitor *Frankliniella* spp. and natural enemies, particularly *Orius* spp. (Funderburk, 2009). Strawberry growers in Florida face a similar challenge: successfully limiting *F. bispinosa* populations to minimize yield loss while refraining from over applying particular insecticides, which may result in *F. occidentalis* dominance and greater losses than with a *F. bispinosa*-dominant thrips community.

The first two insecticide applications in November were pre-flowering tactics for control of *S. dorsalis* on strawberry foliage. In both years, despite efforts to introduce *S. dorsalis* into research plots, populations were low in late October and early November and usually less than a working threshold of five adults per new leaf (Babu Panthi, unpublished data). Strawberry growers in Florida typically find *S. dorsalis* more problematic in fields with plug transplants set in late September than in fields with bare-root transplants set in the first two weeks of October, but bare-root transplanted fields still dominate Florida acreage (70–75%, Kenneth Parker, personal communication). At low *S. dorsalis* populations in plots, programs with an early application (mid-November 2016) of chlorantraniliprole + thiamethoxam resulted in better thrips control on leaves and less thrips damage on strawberries than most other programs. Thrips are not on the chlorantraniliprole + thiamethoxam (VoliamFlexi®) label, but this product is used by some growers 2–3 weeks following strawberry planting as a "clean-up" spray for aphids, leafhoppers, whiteflies, Lepidopteran pests, beetles, and plant bugs that arrived on transplants or invaded newly planted fields. Chlorantraniliprole + thiamethoxam was effective on *S. dorsalis* up to 10 and 15 d after curative and preventative applications, respectively, on greenhouse peppers (Kumar et al., 2017). In 2017, we tested the effect of eliminating an application of spinetoram about a week after chlorantraniliprole + thiamethoxam, but found this ineffective for thrips control on leaves and flowers and for reducing thrips injury on strawberries. The advent of *S. dorsalis* as a pest in Florida strawberry requiring early season control has meant that growers need to carefully consider when to use effective thrips insecticides (e.g., spinetoram, acetamiprid), but that the combination of chlorantraniliprole + thiamethoxam has secondary thrips control benefits when used against other pests.

An objective of this study was to evaluate repeat applications of newer, reduced-risk insecticides in comparison to spinetoram, which is commonly used for thrips in Florida strawberry. In 2016–2017, cyantraniliprole, cyantraniliprole + abamectin, and a high rate of spinetoram resulted in similar numbers of thrips and amounts of thrips-injured strawberries. Cyantraniliprole is a anthranilic diamide with a unique mode of action, acting on the ryanodine receptors in insect muscle cells and targeting sucking insect pests and Lepidopterans (Sattelle et al., 2008). Tolfenpyrad was not as effective against thrips as spinetoram or the diamides, but levels of thrips-injured strawberries were similar to

Table 10

Least-square mean (95% CI) numbers (per plant per harvest on February 19th, 26th, March 5th, and 13th) and proportions (per harvest) of marketable, thrips-injured (bronzed, cracked, scarred) strawberries during the second half of the 2017–2018 growing season in field plots (Balm, Florida) sprayed with 11 insecticide programs.

Insecticide[a] by application date			Marketable strawberries		Thrips-injured strawberries	
Feb 8	Feb 15	Mar 1	Number	Proportion	Number	Proportion
spi l	–	ace	2.68 **a** (2.30–3.09)	0.58 **a** (0.52–0.64)	0.05 **d** (0.01–0.10)	0.01 **c** (0.00–0.03)
–	spi h	–	2.04 **abcd** (1.71–2.41)	0.47 **bc** (0.42–0.52)	0.79 **b** (0.63–0.98)	0.20 **b** (0.15–0.26)
spi l	ace	flu	2.86 **a** (2.46–3.28)	0.65 **a** (0.60–0.71)	0.04 **d** (0.01–0.08)	0.01 **c** (0.00–0.02)
cya	ace	flo	2.43 **ab** (2.07–2.83)	0.57 **ab** (0.51–0.62)	0.08 **d** (0.03–0.14)	0.02 **c** (0.01–0.04)
cya	spi l	ace	2.37 **abc** (2.01–2.76)	0.59 **a** (0.54–0.65)	0.04 **d** (0.01–0.10)	0.01 **c** (0.00–0.03)
ace	flo	cya	2.59 **a** (2.21–3.00)	0.59 **a** (0.54–0.64)	0.02 **d** (0.00–0.06)	0.01 **c** (0.00–0.02)
spi h	sul	spi h	1.74 **bcd** (1.44–2.08)	0.46 **bc** (0.42–0.51)	0.32 **cd** (0.21–0.44)	0.10 **bc** (0.07–0.14)
spi h	spi h	spi h	2.48 **ab** (2.11–2.88)	0.56 **ab** (0.51–0.61)	0.04 **d** (0.01–0.10)	0.01 **c** (0.00–0.03)
sul	sul	sul	2.79 **a** (2.40–3.21)	0.56 **ab** (0.51–0.62)	0.04 **d** (0.01–0.09)	0.01 **c** (0.00–0.02)
bur	aza	c+g+c	1.57 **cd** (1.28–1.89)	0.40 **cd** (0.36–0.45)	0.60 **bc** (0.46–0.77)	0.18 **b** (0.13–0.23)
spi	g+p+r	psf	2.37 **abc** (2.01–2.76)	0.54 **ab** (0.49–0.59)	0.14 **d** (0.07–0.22)	0.04 **c** (0.02–0.06)
–	–	–	1.20 **d** (0.95–1.49)	0.31 **d** (0.27–0.35)	1.39 **a** (1.16–1.63)	0.44 **a** (0.37–0.52)
$F_{11,33}$			10.19	17.60	47.27	45.61
P			<0.0001	<0.0001	<0.0001	<0.0001

Means followed by the same letter in each column are not significantly different, Tukey's HSD, α = 0.05.

[a] See Table 1 for abbreviations used for insecticides.

those in plots with the other newer insecticides. Tolfenpyrad is a broad-spectrum pyrazole insecticide, targeting the mitochondrial complex I inhibitor and inhibiting respiration and causing cessation of movement and feeding on contact (Okada et al., 1999). Cluever et al. (2016) found more larval *F. occidentalis* in strawberry using a rotation with tolfenpyrad applied first than when spinetoram or cyantraniliprole were applied first, although Srivastava et al. (2014) found the same number or fewer *Frankliniella* spp. in pepper using tolfenpyrad compared to spinetoram and cyantraniliprole. Similar to Renkema et al. (2018), sulfoxaflor was not as effective as spinetoram, but in this study the levels of thrips-injured strawberries were nearly identical between the two insecticides. Sulfoxamines and neonicotinoids act on the nicotinic acetylcholine receptors, but sulfoxaflor functions in a distinct manner and has activity against a broad range of sucking insects (Sparks et al., 2013). Cyantraniliprole (Exirel®) and cyantraniliprole + abamectin (Minecto Pro®) are now labelled for thrips in strawberry, while tolfenpyrad (Apta®) and sulfoxaflor (Closer®) are not currently labelled.

Some of the most effective thrips predators in agricultural systems are minute pirate bugs (*Orius* spp.). *Orius insidiosus* are common in southeastern USA, although *Orius pumilio* (Champion) has been reported as a sympatric species in Florida (Shapiro et al., 2010). We did not find strong effects of insecticide programs on *Orius* spp. even though thrips numbers varied among programs. Many of the insecticides tested are moderately- or non-toxic to *Orius* spp. (e.g., Barbosa et al., 2017; Liburd et al., 2017), and we did not use insecticides (except malathion once) that are acutely toxic to *Orius* spp. for comparison (Broughton et al., 2014; Elzen, 2001). Lower numbers of *Orius* spp. during some sampling periods (particularly the second half of the 2016–2017) in some insecticide programs compared to the control is likely due to a combination of a reduced food source (thrips) and moderate effects of some insecticides in particular programs. For example, malathion was included once to evaluate efficacy against Pamera seed bug, *Neopamera bilobata* (Say), an emerging pest in Florida strawberry and resulted in 8X fewer *Orius* spp. despite more thrips larvae than a program of spinetoram, flonicamid and flupyradifurone. Rotating reduced-risk insecticides with good activity against thrips but mild effects on beneficials, particularly *Orius* spp., is key to developing an effective biological control component of an integrated pest management strategy in Florida strawberry.

A limitation in interpreting insecticide efficacy results from proximal small plots is the likelihood of interplot interference. Adult flower thrips are relatively strong fliers and would be capable of rapidly re-colonizing sprayed plots in these experiments from control plots, plots sprayed with insecticides with low efficacy, or flowering vegetation surrounding the research field (Ramachandran et al., 2001; Nyasani et al., 2017). Using larval thrips numbers as the primary end point to compare insecticide programs may be most judicious, as larvae cannot move among plants and their numbers reflect an insecticide's acute toxicity as well as any delayed antifeedant, deterrent, repellent or physiological effects (Wise and Whalon, 2009). Furthermore, it has been suggested, although not explicitly tested, that larval feeding on developing strawberries may be the primary cause of bronzing and cracking on ripe fruit rather than adult and larval feeding and activity in flowers (Strzyzewski, 2017).

Using OMRI-listed products, either with spinetoram in 2016–2017 or exclusively in 2017–2018, were generally not as effective as using conventional insecticides, but some reductions in thrips and thrips-injured strawberries occurred. Spinosad (Entrust®) has the same mode of action as spinetoram but shorter residual activity (the reason why all OMRI-listed products were reapplied in 3–4 days in 2017–2018). Spinosad is recommended for thrips control in other crops (e.g., onion thrips, *Thrips tabaci* Lindeman, in onions (Gill et al., 2015)), but overuse has led to resistance development by *F. occidentalis* (e.g., Bielza et al., 2007). Following spinosad with *Burkholderia* spp. (Venerate™ XC), which appeared to have some efficacy in the latter half of the 2016–2017 season (program with *chr*/-/spi h/*bur*), resulted in larval thrips numbers comparable to programs of conventional insecticides but somewhat lower marketable yields and greater levels of thrips-injured strawberries. Venerate™ XC has been used with some success against thrips larvae (Vafaie and Nemati, 2018), but using it upfront in the latter half of 2017–2018 instead of spinosad resulted in more thrips larvae and thrips-damaged strawberries. With increasing Florida strawberry acreage under organic certification, there will be a continuing need to evaluate OMRI-listed products for thrips control to partner with the proven efficacy of Entrust and moderate activity of Venerate™ XC.

Few, but well-timed, insecticide applications that maintain effective thrips control in Florida strawberry would be economically, environmentally and societally beneficial. In 2017–2018, an application of spinetoram in mid-November followed by acetamiprid in 2 weeks, was as effective as rotations with three conventional insecticide applications. Spinetoram had the highest *S. dorsalis* mortality rates, > 99% for larvae, when applied preventatively to pepper plants, indicating residual activity for more than 20 days post-application (Kumar et al., 2017). Delaying the application of spinetoram from mid to late November (program with th+ch/-/spi h/-) although chlorantraniliprole + thiamethoxam was applied in early November, and similarly later in the season from early to mid-February compromised flower thrips control and marketable yields. Both chlorantraniliprole and thiamethoxam had shorter periods of residual activity than spinetoram on chilli thrips (Kumar et al., 2017). In Florida strawberry, using spinetoram at or just prior to peak flowering/flower thrips population levels should provide residual activity and effective control for at least two weeks. Other insecticides with thrips activity (e.g., acetamiprid, cyantraniliprole) may be used, if needed, prior to or two weeks after spinetoram. Spinosad and acetamiprid evaluated separately were the most effective of seven insecticides against *F. bispinosa* in southern highbush blueberries (Liburd et al., 2017). In order to transition from weekly, calendar-based insecticide applications and reduce grower input costs, more research is needed on methods for effective thrips monitoring and tools for predicting periods of peak thrips populations.

In conclusion, the reduced-risk insecticides cyantraniliprole (Exirel®) and cyantraniliprole + abamectin (Minecto Pro®) were as effective as spinetoram (Radiant® SC) against thrips and reducing thrips injury to strawberries. Exirel® and Minecto Pro® should be rotated with spinetoram or acetamiprid but not with each other, as they contain the same active ingredient. In addition, abamectin may be used as a standalone miticide (Agri-Mek® SC), and resistance to abamectin by twospotted spider mite (*Tetranychus urticae*) in Florida strawberries previously occurred (Price et al., 2002). A greater diversity of insecticides for thrips control does not necessarily mean that more applications are needed, as just two well-timed applications of spinetoram (low rate) and acetamiprid during each of the first and second period of peak flowering were effective. For organic production, spinosad (Entrust®) should be the backbone of a thrips management strategy and used at peak flowering/thrips populations. However, none of the other OMRI-listed products tested maintained thrips numbers at levels achieved using conventional insecticides, with the exception of *Burkholderia* spp. (Venerate™ XC) showing some efficacy. More research is needed to evaluate other OMRI-listed products and fine-tune conventional insecticide rotations for optimal thrips control, with a focus on early season/high chilli thrips populations using optimal combinations and timing of diamide insecticides with spinetoram and acetamiprid applications. Finally, with ongoing research of using flowering plants on field edges (J. Renkema, unpublished data) to increase natural enemy populations in Florida strawberry fields, future thrips-insecticide experimentation should be conducted with the goal of integrating biological and chemical controls for thrips management.

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