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IMPACTS ON NATURAL ENEMIES AND COMPETITOR THRIPS OF INSECTICIDES AGAINST THE WESTERN FLOWER THRIPS (THYSANOPTERA: THRIPIDAE) IN FRUITING VEGETABLES

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Abstract

Newer, selective insecticides with few negative impacts on natural enemies and competitor species are needed for effective, sustainable management of the western flower thrips, *Frankliniella occidentalis* (Pergande). The purpose of this study was to evaluate the impacts on natural enemies and competitor thrips species of insecticides used for control of western flower thrips in fruiting vegetables. Trials with tomato (*Solanum lycopersicum* L.) and with pepper (*Capsicum annuum* L.) were conducted to evaluate insecticide treatment effects on western flower thrips and natural enemies at the North Florida in 2008, 2009, 2010 and 2011. A number of insecticides from different classes showed moderate to high efficacy against western flower thrips. The broad-spectrum insecticides acetamiprid, methomyl, and tolfenpyrad demonstrated activity against the pest, while also reducing populations of the key predator of thrips in pepper, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae). Insecticides that showed little impact on populations of *O. insidiosus* were cyantraniliprole, flonicamid, spirotetramat, and terpenes. Although only moderately active against the western flower thrips, they would be valuable additions to existing management programs for pepper. Insecticides with activity against western flower thrips also showed activity against *Frankliniella tritici* (Fitch). This non-damaging congener species is a beneficial because it out-competes the western flower thrips, especially in tomato where *O. insidiosus* is not a major factor in western flower thrips management. Numerous insecticides were identified with activity against the western flower thrips that are suitable for use in integrated pest management programs of fruiting vegetables.

Key Words: reduced-risk insecticides, biological insecticides, biological control, *Orius*, pepper, tomato

Resumen

Los productores de hortalizas frutales se enfrentan con sólo un número limitado de insecticidas de clase eficaz con actividad contra el trips occidental de las flores, *Frankliniella occidentalis* (Pergande). La dependencia a un número limitado de insecticidas aumenta en gran medida el riesgo de desarrollo de resistencia. Se necesitan nuevos insecticidas selectivos, con poco impacto negativo sobre los enemigos naturales y especies competidoras para un manejo sostenible eficaz. El propósito de este estudio fue evaluar los insecticidas de diferentes clases químicas para la eficacia contra el trips occidental de las flores de pimiento y tomate en condiciones de campo, especialmente insecticidas que conserven los enemigos naturales y las especies competidores de trips. Se realizaron ensayos con tomate (*Solanum lycopersicum* L.) y con chile (*Capsicum annuum* L.) para evaluar los efectos del tratamiento con insecticida en el trips occidental de las flores y los enemigos naturales en el norte de la Florida en el 2008, 2009, 2010 y 2011. Un número de insecticidas de diferentes clases mostró eficacia moderada a alta contra el trips occidental de las flores. Los insecticidas de amplio espectro acetamiprid, metomilo y tolfenpirad demostraron actividad contra la plaga, mientas que también redujeron las poblaciones del depredador clave del trips en chile, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae). Los insecticidas que mostraron poco impacto sobre la poblacion de *O. insidiosus* fueron ciantraniliprole, flonicamid, spirotetramat y terpenos. Aunque estos productos sólo son moderadamente activos contra el trips occidental de las flores, serían una adición valiosa a los programas de manejo existentes para el chile. Los insecticidas con actividad contra el trips occidental de las flores también mostraron actividad contra *Frankliniella tritici* (Fitch). Esta especie congénere no perjudicial es de beneficio porque compite mejor con el trips occidental de las flores, especialmente en tomate donde *O. insidiosus* no es un factor en el manejo del trips occidental de las flores. Numerosos insecticidas fueron identificados con actividad contra el trips occidental de las flores que son adecuados para su uso en programas de manejo integrado de plagas de hortalizas de fruto.

Palabras Clave: insecticidas de riesgo reducido, insecticidas biológicos, control biológico, *Orius*, chile, tomate

Damage from the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), occurs to many crops grown in the field and greenhouse as a result of injury caused by oviposition and feeding and by the vectoring of species of tospoviruses**.** Funderburk (2009) and Demirozer et al. (2012) reviewed information on the effectiveness of different types of preventive and therapeutic tactics for managing western flower thrips and tospoviruses in field-produced fruiting vegetables. These tactics were incorporated into integrated pest management programs for pepper and eggplant (Funderburk et al. 2011a) and tomato (Funderburk et al. 2011b) that have been successfully implemented in Florida. In these programs, scouting and economic thresholds are employed and combined with an emphasis on the integration of effective reduced-risk tactics for management of thrips, tospoviruses and other pests. The programs for pepper and eggplant include conservation of natural populations of *Orius* species (Hemiptera: Anthocoridae), the key natural enemies of thrips in these crops. Control of the native flower thrips species in Florida, *F. tritici* (Fitch), is not recommended in tomato, pepper, or eggplant as this species causes no damage at typical population densities (Funderburk et al. 2011a, b; Demirozer et al. 2012), and *F. tritici* is an effective competitor species of western flower thrips (Paini et al. 2008). Growers of fruiting vegetables in Florida have experienced less damage from western flower thrips and other non-target pests when using these integrated pest management programs. For example, over 90% of pepper growers in Palm Beach County, Florida reported shifting from 'blind sprays' to scouting and other recommended integrated pest management practices (Sui & Funderburk 2010). As a result, damage from pests was reduced, providing these growers over 1 yr with $28.8 million in yield gains and reduced pesticide use.

Reitz (2009) reviewed the scientific literature involving western flower thrips biology, ecology, and insecticide resistance. The population attributes of reproduction on numerous plant species in many plant families, high fecundity, rapid generation time, and high dispersal capability provide for an extraordinary ability to exploit ephemeral crop resources. Populations are able to continue rapid buildup despite attempts at control with repeated application of conventional insecticides (Funderburk et al. 2000). The additional attributes of polyphagy and haplodiploid sex determination result in an ability of populations to develop insecticide resistance quickly (Reitz & Funderburk 2012), and invasive populations largely were resistant to broad-spectrum insecticides before they became invasive (Immaraju et al. 1992). Some populations have since developed resistance to the spinosyn class of insecticides (Weiss et al. 2009). Morse & Hoddle (2006) concluded that the spread of the western flower thrips and species of tospoviruses has resulted in the world-wide destabilization of established integrated pest management programs for many crops grown in the field and greenhouse.

It is important to evaluate insecticides for their compatibility with efforts to maintain important natural enemies in cropping systems. For example, spinosyn insecticides have proved to be compatible with *Orius* spp. in the management of the western flower thrips because of their efficacy against the thrips and their minimal adverse impacts on the predators (Funderburk et al. 2000; Srivastava et al. 2008; Williams et al. 2003). However, development of resistance in *F. occidentalis* populations to spinosyn insecticides (e.g., Bielza et al. 2007; Weiss et al. 2009) has resulted in a great need to find additional insecticides with efficacy against *F. occidentalis* but which have little or no impact on populations of *Orius* spp. Insecticides also need to be evaluated for their impacts on the competitor species of the western flower thrips. If multiple insecticides can be identified for fruiting vegetables, an integrated resistance management strategy can be employed in instances when multiple applications of insecticides are needed to keep adult and larval populations of *F. occidentalis* below economic thresholds. The purpose of the present study was to evaluate the compatibility of insecticides with integrated pest management programs for the western flower thrips in fruiting vegetables under field conditions. The specific objectives were to evaluate efficacy of individual insecticides against the western flower thrips, their effects on natural populations of the predator *O.*

insidiosus (Say), and their effects on populations of the competitor species, *F. tritici*. This research is a component of our goal to continuously update and improve our integrated pest management programs for the western flower thrips, tospoviruses, and other pests in fruiting vegetables.

Materials and Methods

Individual trials with tomato (*Solanum lycopersicum* L., 'Florida 47') were conducted in 2008, 2009, 2010, and 2011. Experimental procedures to evaluate insecticide treatment effects on western flower thrips and natural enemies were similar to those established for tomato by Stavisky et al. (2002) and Momol et al. (2004) and for pepper by Funderburk et al. (2000), Reitz et al. (2003), and Srivastava et al. (2008). Individual trials were conducted with 'Camelot' pepper (*Capsicum annuum* L.) in 2008 and 2009 and 'Aristotle X3R' pepper in 2010 and 2011. All trials were conducted at the University of Florida, North Florida Research and Education Center in Quincy (Gadsden County). Six-week-old tomato and pepper seedlings were transplanted in raised beds with trickle-tube irrigation according to typical commercial practices for Florida. Raised beds were 10 cm in height and 91.4 cm in width, with 1.83 m row spacing. Plots were fumigated before black plastic mulch application (Berry Plastics Corp., Evansville, Indiana) with methyl bromide/chloropicrin (98:2) (TriEst Group, Inc., Williamston, North Carolina) at 45 g/m^2. Plots were fertilized with 204, 29, and 170 kg/ha of N, P, and K, respectively. Foliar applications of fungicides were applied as needed for preventative disease control to tomato. No pesticides beyond the insecticide treatments under investigation were applied to pepper.

Experimental design for each of the individual experiments was a randomized complete block, with 4 replications. Pepper plot size was 1 bed by 9 m which consisted of 2 linear rows with a 30-cm-spacing between and within rows for a total of 60 plants per plot. Tomato plot size was 2 beds by 9 m with each bed consisting of 1 linear row with a 45.0-cm-spacing for a total of 40 plants per plot.

The insecticides, along with the active ingredient, formulation, and supplier of each, are given in Table 1. The selection of the insecticides for inclusion in these experiments was based on a previous literature search conducted by Dripps et al. (2010). Additional newer insecticides with potential efficacy also were included. The insecticides were not applied with additives unless specifically stated. To conform with the label recommendations, some of the insecticide treatments were applied with Dyne-Amic®, a modified vegetable oil and organosilicone surfactant (Helena Chemical Co., Collierville, Tennesee), or Induce®, a nonionic low foam wetter/spreader adjuvant (Helena

Table 1. The trade name, common name, Insecticide Resistance Action Committee (IRAC) group, formulation, and supplier of insecticides included in the pepper and tomato insecticide experiments conducted in 2008, 2009, 2010, and 2011 in Quincy, Florida.

Trade name	Common name	IRAC group	Formulation	Supplier
Assail® 30 SG	Acetamiprid	4A	300 g a.i./kg	Cerexagri-Nisso LLC, King of Prussia, PA
Beleaf®50 SG	Flonicamid	9C	500 g a.i./kg	FMC Corporation, Philadelphia, PA
Cyazypyr® 10 SE[a]	Cyantraniliprole	28	100 g a.i./liter	DuPont, Newark, DE
Lannate® LV	Methomyl	1A	288 g a.i./liter	DuPont, Newark, DE
Movento® 240 SC[b]	Spirotetramat	23	240 g a.i./liter	Bayer CropScience LP, Research Triangle Park, NC
Radiant® 1 SC	Spinetoram	5	120 g a.i./liter	Dow AgroSciences LLC, Indianapolis, IN
Requiem® 25 EC	Terpenes	Unknown	152 g a.i./liter	AgraQuest, Inc., Davis, CA
Torac® 15 EC[a]	Tolfenpyrad	21A	150 g a.i./liter	Nichino America, Inc., Wilmington, DE
Warrior with Zeon Technology®	Lambda-cyhalothrin	3	120 g a.i./liter	Syngenta Crop Protection, LLC, Greensboro, NC

[a] Applied with Induce® at 0.25% volume to volume.

[b] Applied with Kinetic Blend Dyn-Amic® at 0.25% volume to volume.

Chemical Co.) (Refer to Table 1 for specific insecticide treatments with these additives).

In North Florida, populations of *F. occidentalis* are typically highest in early May soon after peppers and tomatoes begin flowering, and populations decline rapidly thereafter, except in treatments where populations of *F. tritici* and/or *O. insidiosus* are excluded (Funderburk et al. 2000; Stavisky et al. 2002; Reitz et al. 2003; Momol et al. 2004; Srivastava et al. 2008). For this reason, insecticide applications were begun in each individual pepper and tomato experiments in this study soon after most of the plants began flowering. Densities of adult *F. tritici*, thrips larvae, and *O. insidiosus* become abundant during the later weeks. In order to evaluate the effects of insecticides on the adult thrips of the two species, the thrips larvae, and the adults and nymphs of *O. insidiosus*, insecticides were applied weekly for 3 to 4 weeks, depending on the experiment. Spray treatments were applied with a CO_2-powered backpack sprayer that was equipped with 4 D7-45 nozzles per bed for pepper and with 5 D7-45 nozzles per bed for tomato. The amount of water applied was about 439 liters per ha. The densities of adult *F. occidentalis*, larval *Frankliniella* species, and adult and nymphal *O. insidiosus* in each plot were estimated 2- and 6-days post application each week for pepper and 1-, 3-, and 6-days post application for tomato, by randomly collecting on each sample date 10 flowers per plot in vials of 70% ethyl alcohol. Insects were extracted from the flowers and identified under a stereomicroscope at 17 to 150 X magnification. Voucher specimens are kept in the entomology laboratory at the North Florida Research and Education Center, University of Florida in Quincy.

The number of thrips larvae per adult thrips (*F. tritici* plus *F. occidentalis*) was determined for the untreated controls in each experiment for data pooled over dates as a means to determine if populations were increasing, stable or decreasing. The ratio of total thrips per *O. insidiosus* in the untreated control plots of individual experiments was determined in order to evaluate the effect of the predator on thrips populations in tomato and pepper each year. The effects of the insecticide treatments on the number of adult *F. occidentalis*, adult *F. tritici*, larval *Frankliniella* species, and adult and nymphal *O. insidiosus* were determined using analysis of variance for a randomized complete block design (PROC ANOVA procedure, SAS Institute 2008). Separate analyses were conducted by year, crop, and the number of days after application. Sample date was treated as a repeated measures effect. The insecticide treatment * block interaction was used as the error to evaluate the main effects of insecticide treatment. Pairwise comparisons among insecticide treatments were made using the least significant difference ($P < 0.05$) when the overall treatment effect was significant. Separate analyses were conducted for untransformed data and for data that were transformed to log10 (x + 1.0). We report the analyses in this paper for untransformed data, as there was little difference in probabilities in the results for transformed or untransformed data.

RESULTS

In each experiment each yr, *F. occidentalis* adults were less common than *F. tritici* adults, except for the 2008 pepper experiment. The percentage of the adults that were *F. occidentalis* in the untreated pepper flowers ranged from 4.6 to 66.4% across the different yr. The percentage of the adults that were *F. occidentalis* in the untreated tomato flowers ranged from 1.3 to 25.2% across the different yr. The number of larvae per thrips adult in untreated pepper flowers ranged from 0.12 to 0.61 across the different yr. Thrips reproduced very poorly in tomato. The number of larvae per thrips adult in untreated tomato flowers ranged from 0.006 to 0.061 across the different yr.

The ratio of total thrips to total *O. insidiosus* in untreated pepper flowers was 28.9, 28.2, and 24.0 in 2009, 2010, and 2011, respectively. The number of thrips prey relative to the predator was very high in untreated pepper flowers in 2008 with a ratio of total thrips to total *O. insidiosus* of 334. The number of *O. insidiosus* in untreated or treated tomato flowers was very low each yr. The number of thrips prey to total *O. insidiosus* in untreated pepper flowers was 50.4, 206.5, 143.7, and 246.8 in 2009, 2010, 2011, and 2012, respectively.

Separate analyses of variance were conducted by yr, crop, and the number of days after application. The *F*-values, degrees of freedom, and probabilities for each analysis of variance, along with the treatment means (SEM) separated by the least significant differences are shown in Tables 2 and 3 for pepper and tomato, respectively. All of the insecticides included in the pepper and tomato trials demonstrated activity against adult *F. tritici* (Tables 2 and 3, respectively). Populations of *F. tritici* adults in the treatment containing terpenes were significantly lower compared with the untreated control 2 and 6 days after application in pepper in 2008 and 2009 and 1 day after application in tomato in 2009. Populations of adult *F. tritici* were not reduced on any sample date in the terpene treatment in pepper in 2010 and 2011 or in tomato in 2008 and 2010. Populations of *F. tritici* adults were lower with spirotetramat compared with the control in pepper in 2009, but not in 2010 or 2011. In tomato, populations of *F. tritici* adults were significantly reduced by spirotetramat 6 days after application in 2009, but the differences were not significant at 1 and 3 days after application. Populations were not lower on any sample date in the cyantraniliprole treatment compared with the untreated control in pepper in 2010 and 2011 or in tomato in 2010. Populations were significantly lower in the cyantraniliprole treatment compared with the control in the 2011 tomato experiment 1 and 3 days after application, but not 6 days after application. Flonicamid significantly reduced populations compared with the control in pepper 2 and 6 days after application in 2008 and 2009 and 2 days after application in 2010. It did not reduce populations on any date in the 2011 pepper experiment. Populations in tomato were reduced by flonicamid compared with the control 1, 3, and 6 days after application in 2008 and 1 day after application in 2009. Spinetoram, lambda-cyhalothrin, methomyl, acetamiprid, and tolfenpyrad greatly reduced populations of F. tritici in pepper and tomato.

There were low numbers of *O. insidiosus* in the control in the pepper experiment in 2008; therefore, evaluations of the impacts of the insecticides on their populations were not possible in that yr (Table 2). Evaluations were made based on the results in the 2009, 2010, and 2012 pepper experiments. Spirotetramat was the only insecticide in the pepper experiments that showed no significant lowering of *O. insidiosus* populations in any yr. Flonicamid, the insecticide containing terpenes, spinetoram, cyantraniliprole, and spirotetramat significantly lowered the predator's populations on at least 1 date over the other yr but were not consistently detrimental to *O. insidiosus* populations. Methomyl, lambda-cyhalothrin, and acetamiprid greatly reduced populations 2 and 6 days after application in 2009 and 2010. These were not included in the 2011 pepper experiment. Tolfenpyrad suppressed populations of *O. insidiosus* compared with the control in 2011, the only yr it was evaluated in pepper.

There were significant differences among treatments each yr in the mean number of *F. occidentalis* adults and the number of *Frankliniella* larvae 2 and 6 days after insecticide application (Tables 2 and 3). Separate analyses were conducted by yr, crop, and the number of days after application. Spinetoram was included each yr as the standard insecticide for *F. occidentalis*. The average reduction of *F. occidentalis* adults for spinetoram compared with the control over the 4 pepper experiments was 57% (range 37-85%) 2 days after application and 65% (range 32-83%) 6 days after application. The estimated reduction of larval thrips by spinetoram was 80% (range 49-96%) 2 days after application and 93% (range 81-98%) 6 days after application.

The insecticide containing terpenes was included in the pepper trials each yr, and provided significant reduction of adult *F. occidentalis* in 3 of the 4 yr (2008, 2009, and 2011). The reduction of adult *F. occidentalis* averaged over yr in these treatments was 51% (range 37-67%) 2 days after application and 46% (range 21-76%) at 6 days after application. The reduction of the *Frankliniella* larvae over yr in these treatments 2 and 6 days after application was 39% (range 5-81%) and 31% (maximum of 71%).

Acetamiprid significantly reduced *F. occidentalis* adults and thrips larvae in 2 of the 3 yr it was used in pepper trials (2008 and 2009). The average reduction compared with the controls 2 and 6 days after application was 28% (maximum of 43%) and 34% (maximum of 59%) for *F. occidentalis* adults, respectively, and 65% (range 48-87%) and 66% (range 26-91%) for thrips larvae, respectively.

Means for spirotetramat were significantly lower than means for the untreated control 2 of the 3 yr it was tested with the average reduction at 2 and 6 days after application 24% (range 0-47%) and 28% (range 0-60%) for *F. occidentalis* adults, respectively, and 58% (range 37-74%) and 68% (range 56-80%) for larvae, respectively.

Populations of *F. occidentalis* adults and thrips larvae in the lambda-cyhalothrin plots were significantly lower compared with the untreated control at 2 and 6 days after application in 2008, and populations of larvae were significantly lower 2 days after application in 2009. Populations of *F. occidentalis* adults and thrips larvae were significantly greater compared with the untreated control in 2010.

Methomyl significantly reduced populations of adult *F. occidentalis* and larval thrips in both yr of inclusion (Table 2). The average reduction over yr at 2 and 6 days after application was 39% (range 22-56%) and 53% (range 42-64%) for the *F. occidentalis* adults, respectively, and 63% (range 25-100%) and 49% (range 48-49%) for the larvae, respectively. In 2011, tolfenpyrad reduced populations of *F. occidentalis* adults by an estimated 79% 2 days after application and populations of larvae were reduced by an estimated 62 and 89% 2 and 6 days after application, respectively.

The *F*-values, degrees of freedom, and probabilities for each analysis of variance, along with the treatment means (SEM) separated by the least significant differences are shown in Table 3. None of the insecticides included in the 2008, 2009, or 2010 tomato experiments significantly reduced populations of adult *F. occidentalis* or larval thrips compared with the untreated controls. However, there were significant differences among treatments for *F. occidentalis* adults and thrips larvae in the 2011 tomato experiment. Populations of *F. occidentalis* adults in the spinetoram treatment in 2011 were reduced compared with the untreated control by 80, 73, and 54% on 1, 3, and 6 days after application, respectively. Thrips larvae in the spinetoram treatment were reduced 98, 89, and 97% compared with the untreated control on 1, 3, and 6 days after application, respectively. Populations of *F. occidenta-*

Table 2. The mean number (±SEM) in pepper of *Frankliniella occidentalis* adults, *Frankliniella tritici* adults, *Frankliniella* spp. larvae, and *Orius insidiosus* adults and nymphs per ten flowers two and 6 days after insecticide applications (DAA) for data pooled over sample dates for each year in the experiments conducted in Gadsden County, Florida in 2008, 2009, 2010, and 2011 (n for each mean = 12 samples of 10 flowers in 2008 and 16 samples of 10 flowers in 2009, 2010, and 2011). The *F*-values, degrees of freedom, and probabilities for each analysis of variance conducted by year and number of days after application are also shown.

		Mean number per 10 flowers (SEM)							
		F. occidentalis adults		*F. tritici* adults		*Frankliniella* larvae		*Orius* adults+nymphs	
Insecticide treatment	Rate g a.i./ha	2 DAA	6 DAA	2 DAA	6 DAA	2 DAA	6 DAA	2 DAA	6 DAA
				2008					
Control		36(8)a	74(29)a	30(10)a	26(4)a	48(16)a	53(12)a	0.2(0.1)	0.6 (0.3)d
Acetamiprid	84	21(6)bcd	30(13)b	10(4)b	10(2)b	14(5)cd	10(4)c	2.2(1.7)	1.3(0.3)cd
Flonicamid	98	6(2)e	17(8)b	6(2)b	7(1)b	2(1)d	5(4)c	3.3(1.2)	4.2(1.5)a
Lambda-cyhalothrin	28	15(3)d	21(7)b	6(2)b	9(3)b	12(3)cd	8(3)c	0.4(0.2)	0.5(0.2)d
Methomyl	1007	28(8)b	25(9)b	16(5)b	8(1)b	36(11)ab	27(10)b	2.4(0.6)	2.8(0.8)abc
Spinetoram	53	23(7)bc	24(10)b	14(5)b	7(1)b	24(7)bc	10(4)c	3.5(0.7)	3.8(0.9)b
Terpenes	2848	18(6)cd	18(6)b	11(2)b	11(2)b	9(3)cd	15(8)bc	1.7(0.4)	2.3(0.5)bcd
ANOVA $F_{6, 18}$		13.2	12.4	4.5	8.3	8.1	14.3	2.3	5.9
P		0.0001	0.0001	0.006	0.0002	0.0002	0.0001	0.07	0.002
				2009					
Control		9(3)a	12(5)ab	40(9)a	53(21)a	13(4)a	13(5)ab	2.3(0.6)a	2.5(0.7)a
Acetamiprid	84	6(2)bc	7(3)bc	3(1)c	7(2)c	1(1)c	1(0)b	0.3(0.1)b	0.5(0.2)b
Flonicamid	98	5(1)bc	6(2)bc	17(8)bc	26(9)b	1(1)c	3(1)b	0.9(0.4)b	2.4(0.7)a
Lambda-cyhalothrin	28	7(2)ab	13(4)a	4(1)c	10(2)bc	3(1)bc	21(11)a	0.4(0.2)b	0.7(0.2)b
Methomyl	1007	4(1)c	7(2)abc	8(3)bc	16(6)bc	0 (0)c	8(7)ab	0.3(0.2)b	0.6(0.2)b
Spinetoram	53	3(1)c	2(1)c	12(4)bc	9(3) bc	1(0)c	0(0)b	1.1(0.2) b	1.7(0.7)ab
Spirotetramat	89	5(1)bc	5(2)c	14(3)bc	15(3)bc	3(2)bc	3(1)b	2.8(0.7)a	1.8(0.6)ab
Terpenes	2848	6(2)bc	5(2)c	24(10)b	19(8)bc	6(2)b	7(3)b	1.2(0.4)b	2.8(0.6)a
ANOVA $F_{7,21}$		4.0	3.7	6.4	7.1	13.4	2.7	7.2	2.8
P		0.006	0.01	0.0004	0.002	0.0001	0.04	0.002	0.03
				2010					
Control		3(1)cd	4(1)bc	74(12)a	68(17)	7(3)b	10(4)	2.6(0.5)a	3.3(0.7)a
Acetamiprid	84	5(1)bc	6(1)ab	30(5)cd	60(13)	4(1)bc	7(2)	0.3(0.1)d	1.3(0.3)c
Cyantraniliprole	100	3(1)cd	4(1)bc	61(11)ab	67(17)	4(1)bc	3(1)	1.1(0.4)bcd	1.6(0.4)bc

Means in the same column of the same year followed by the same letter are not significantly different according to the least significant difference ($P > 0.05$)

TABLE 2. (CONTINUED) THE MEAN NUMBER (±SEM) IN PEPPER OF *FRANKLINIELLA OCCIDENTALIS* ADULTS, *FRANKLINIELLA TRITICI* ADULTS, *FRANKLINIELLA* SPP. LARVAE, AND *ORIUS INSIDIOSUS* ADULTS AND NYMPHS PER TEN FLOWERS TWO AND 6 DAYS AFTER INSECTICIDE APPLICATIONS (DAA) FOR DATA POOLED OVER SAMPLE DATES FOR EACH YEAR IN THE EXPERIMENTS CONDUCTED IN GADSDEN COUNTY, FLORIDA IN 2008, 2009, 2010, AND 2011 (N FOR EACH MEAN = 12 SAMPLES OF 10 FLOWERS IN 2008 AND 16 SAMPLES OF 10 FLOWERS IN 2009, 2010, AND 2011). THE *F*-VALUES, DEGREES OF FREEDOM, AND PROBABILITIES FOR EACH ANALYSIS OF VARIANCE CONDUCTED BY YEAR AND NUMBER OF DAYS AFTER APPLICATION ARE ALSO SHOWN.

		Mean number per 10 flowers (SEM)							
		F. occidentalis adults		*F. tritici* adults		*Frankliniella* larvae		*Orius* adults+nymphs	
Insecticide treatment	Rate g a.i./ha	2 DAA	6 DAA	2 DAA	6 DAA	2 DAA	6 DAA	2 DAA	6 DAA
Flonicamid	98	6(1)b	5(2)bc	65(10)ab	53(15)	6(1)b	8(3)	1.9(0.7)ab	2.4(0.5)ab
Lambda-cyhalothrin	28	10(2)a	8(1)a	13(2)d	41(14)	13(4)a	8(3)	0.7(0.3)cd	1.7(0.4)bc
Spinetoram	53	1(0)d	3(1)c	44(9)bc	54(15)	1(0)c	1(0)	1.7(0.4)abc	2.5(0.5)ab
Spirotetramat	89	4(1)bc	4(1)bc	72(14)a	59(13)	3(1)bc	3(1)	1.8(0.5)ab	2.9(0.4)a
Terpenes	2848	4(1)bc	3(1)c	81(12)a	48(11)	5(2)bc	7(2)	1.9(0.5)ab	2.8(0.5)ab
ANOVA $F_{7,21}$		8.3	3.5	6.9	0.7	5.0	1.9	4.6	3.2
P		0.0001	0.01	0.0003	0.70	0.0002	0.13	0.003	0.02
2011									
Control		14(4)a	5(1)	48(10)a	34(5)b	8(3)a	5.4(1.3)a	2.6(0.8)ab	2.2(0.4)ab
Cyantraniliprole	120	9(3)b	4(1)	50 (10)a	38(9)ab	5(2)abc	1.4(0.6)bc	2.0(0.4)bc	3.1(0.5)a
Spinetoram	99	2(1)c	1(0)	27(7)b	35(10)ab	1(1)c	0.2(0.1)c	1.8(0.5)bc	1.9(0.5)ab
Spirotetramat	89	11(3)b	4(1)	47(11)a	37(9)ab	5(2)ab	2.4(0.7)b	2.4(0.5)ab	2.9(0.6)a
Terpenes	2848	9(3)b	4(1)	39(1)ab	47(14)a	6(2)ab	6.9(2.7)a	3.6(0.6)a	3.0(0.5)a
Tolfenpyrad	225	3(1)c	5(1)	9(1)c	19(4)c	3(1)bc	0.6(0.2)c	1.1(0.3)c	1.0(0.2)b
ANOVA $F_{5,15}$		31.0	2.5	11.6	4.6	4.2	24.1	4.0	3.3
P		0.0001	0.08	0.0001	0.01	0.01	0.0001	0.02	0.03

Means in the same column of the same year followed by the same letter are not significantly different according to the least significant difference ($P > 0.05$)

Table 3. The mean number (±SEM) in tomato of *Frankliniella occidentalis* adults, *Frankliniella tritici* adults, and *Frankliniella* spp. larvae per ten flowers one, three, and six days after insecticide applications (DAA) for data pooled each year over sample date in the experiments conducted in Gadsden County, Florida in 2008, 2009, 2010, and 2011 (n for each mean = 12 samples of ten flowers in 2009 and 16 samples of ten flowers in 2008, 2010, and 2011).Means in the same column of the same year followed by the same letter are not significantly different according to the least significant difference ($P > 0.05$)

		Mean number per 10 flowers (SEM)											
		F. occidentalis adults			*F. tritici* adults			*Frankliniella* larvae			*Orius adults+nymphs*		
Insecticide treatment	Rate g a.i./ha	1 DAA	3DAA	6DAA	1 DAA	3DAA	6 DAA	1 DAA	3 DAA	6DAA	1 DAA	3 DAA	6DAA
						2008							
Control		3.5(1.0)a	3.9(1.0)	4.1(1.5)	14(4)b	10(3)b	9(2)b	0.4(0.2)	0.3(0.2)	0.2(0.1)	0.6 (0.2)	0.3 (0.1)	0(0)
Flonicamid	98	1.5(0.5)b	1.1(0.4)	1.6(0.6)	7(1)b	5(1)c	7(1)c	0.1(0.1)	0(0)	0(0)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
Lambda-cyhalothrin	28	3.4(1.0)a	3.4(1.1)	3.5(1.1)	29(6)a	14(3)a	15(3)a	0.3(0.2)	0.3(0.1)	0.3(0.2)	1 (0.3)	0.7 (0.2)	0.3 (0.1)
Spinetoram	53	4.3(1.1)a	1.6(0.4)	2.6(0.9)	30(10)a	11(2)b	15(3)a	0.4(0.2)	0.1(0.1)	0(0)	0.7 (0.3)	0.3 (0.2)	0.2 (0.1)
Terpenes	2848	3.1(0.8)a	2.6(1.4)	2.6(0.9)	20(8)a	12(2)ab	13(2)a	0.1(0.1)	0.4(0.2)	0(0)	0.6 (0.3)	0.3 (0.1)	0.2 (0.1)
ANOVA $F_{4,12}$		5.0	2.5	2.6	14.6	9.6	8.9	2.4	2.9	3.12	—	—	—
P		0.01	0.10	0.09	0.0001	0.001	0.001	0.11	0.07	0.06	—	—	—
						2009							
Control		6.0(3.1)	2.7(0.9)	1.6(0.6)bc	32(11)a	51(11)a	112(21)a	0.3(0.1)	0.1(0.1)	0.8(0.3)	0.3 (0.1)	0.4 (0.2)	0.3 (0.2)
Acetamiprid	84	1.4(0.5)	1.8(0.4)	2.8(1.5)abc	4(1)d	7(2)d	29(6)c	0.5(0.3)	0.1(0.1)	0.6(0.5)	0(0)	0.1 (0.1)	0.2 (0.2)
Flonicamid	98	2.8(1.2)	2.0(0.5)	4.9(2.2)a	13(4)cd	37(8)ab	102(19)a	0.4(0.2)	0.1(0.1)	0(0)	0(0)	0(0)	0.8 (0.3)
Lambda-cyhalothrin	28	1.9(0.6)	2.9(0.3)	2.8(0.6)abc	5(1)d	11(3)cd	25(4)c	0.1(0.1)	0.3(0.3)	0.3(0.3)	0(0)	0.1 (0.1)	0.1 (0.1)
Methomyl	1007	1.3(0.4)	1.9(0.5)	3.8(0.8)ab	4(1)d	15(4)cd	53(10)bc	0.3(0.3)	0(0)	0(0)	0(0)	0(0)	0.1 (0.1)
Spinetoram	53	1.7(0.8)	2.0(0.7)	0.9(0.4)c	10(2)cd	25(5)bc	54(5)bc	0.6(0.4)	0.1(0.1)	0.2(0.1)	0(0)	0.2 (0.1)	0.5 (0.2)
Spirotetramat	89	4.3(2.2)	2.8(1.5)	3.9(1.5)ab	24(8)ab	40(7)ab	58(11)bc	0.3(0.1)	0(0)	0.1(0.1)	0(0)	0.3 (0.2)	0.3 (0.1)
Terpenes	2848	3.4(1.7)	2.5(0.8)	4.3(1.5)ab	19(5)bc	37(8)ab	86(14)ab	0.1(0.1)	0.1(0.1)	0.4(0.2)	0(0)	0.3 (0.1)	0.8 (0.3)
ANOVA $F_{7,21}$		1.3	0.4	3.1	11.3	7.0	5.8	0.70	0.49	1.57	—	—	—
P		0.28	0.91	0.02	0.0001	0.0002	0.0008	0.67	0.83	0.19	—	—	—
						2010							
Control		0.8(0.4)	0.4(0.2)	0.4(0.2)	44(9)a	40(8)	41(10)	1.3(0.5)	0.8(0.2)	0.6(0.2)a	0.3 (0.1)	0.2 (0.1)	0.4 (0.2)
Cyantraniliprole	100	0.8(0.3)	0.4(0.2)	0.5(0.2)	30(8)ab	44(11)	39(9)	0.8(0.5)	0.3(0.1)	0.2(0.1)b	0(0)	0.1 (0.1)	0.2 (0.1)
Spinetoram	53	0.6(0.2)	0.3(0.1)	0.3(0.2)	20(4)b	33(8)	32(9)	1.4(0.5)	0.5(0.2)	0.1(0.1)b	0.6 (0.2)	0.1 (0.1)	0.3 (0.1)
Terpenes	2848	0.8(0.3)	0.4(0.2)	0.6(0.3)	43(9)a	47(9)	48(11)	1.4(0.5)	0.5(0.2)	0.1(0.1)b	0(0)	0(0)	0.1 (0.1)

Means in the same column of the same year followed by the same letter are not significantly different according to the least significant difference ($P > 0.05$)

TABLE 3. (CONTINUED) THE MEAN NUMBER (±SEM) IN TOMATO OF *FRANKLINIELLA OCCIDENTALIS* ADULTS, *FRANKLINIELLA TRITICI* ADULTS, AND *FRANKLINIELLA* SPP. LARVAE PER TEN FLOWERS ONE, THREE, AND SIX DAYS AFTER INSECTICIDE APPLICATIONS (DAA) FOR DATA POOLED EACH YEAR OVER SAMPLE DATE IN THE EXPERIMENTS CONDUCTED IN GADSDEN COUNTY, FLORIDA IN 2008, 2009, 2010, AND 2011 (N FOR EACH MEAN = 12 SAMPLES OF TEN FLOWERS IN 2009 AND 16 SAMPLES OF TEN FLOWERS IN 2008, 2010, AND 2011).MEANS IN THE SAME COLUMN OF THE SAME YEAR FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT ACCORDING TO THE LEAST SIGNIFICANT DIFFERENCE ($P > 0.05$)

		Mean number per 10 flowers (SEM)											
	Rate	*F. occidentalis* adults			*F. tritici* adults			*Frankliniella* larvae			*Orius adults+nymphs*		
Insecticide treatment	g a.i./ ha	1 DAA	3DAA	6DAA	1 DAA	3DAA	6 DAA	1 DAA	3 DAA	6DAA	1 DAA	3 DAA	6DAA
ANOVA $F_{3,9}$		0.36	0.28	0.5	7.0	2.5	1.7	1.8	1.7	5.4	—	—	—
P		0.78	0.83	0.59	0.01	0.12	0.23	0.22	0.23	0.02	—	—	—
						2011							
Control		12(2.8)a	10(2.4)a	14.1(2.1)a	86(15)a	80(12)a	77(13)	6.3(1.8)a	2.8(0.9)	7.9(1.5)a	0.3 (0.1)	0.6 (0.2)	0.3 (0.1)
Cyantraniliprole	100	8.6(1.5)a	7.8(2.5)b	8.4(1.5)b	56(9)b	58(11)b	84(15)	2.5(0.8)b	2.0(1.0)	2.8(0.7)	0.6 (0.2)	0.6 (0.2)	0.3 (0.1)
Spinetoram	63	2.4(0.6)b	2.7(1.1)c	6.5(2.1)b	27(4)c	34(11)c	59(15)	0.1(0.1)b	0.3(0.3)	0.2(0.1)c	0.1 (0.1)	0.3 (0.1)	0.3 (0.1)
ANOVA $F_{2,6}$		23.3	35.5	8.5	109.4	34.3	2.7	15.6	4.4	168.5	—	—	—
P		0.001	0.0005	0.02	0.0001	0.0005	0.14	0.003	0.07	0.0001	—	—	—

Means in the same column of the same year followed by the same letter are not significantly different according to the least significant difference ($P > 0.05$)

lis adults in the cyantraniliprole treatment were reduced compared with the untreated control 28, 22, and 60% on 1, 3, and 6 days after application, respectively. The larvae in the cyantraniliprole treatment were reduced 60, 29, and, 65% on 1, 3, and 6 days after application, respectively.

DISCUSSION

Adults of *F. occidentalis* and *F. tritici* inhabited the tomato flowers in these studies, but based on the ratios of larval thrips to adults, reproduction was very poor. Ratios of < 1, 1, and > 1 are indicative of a declining, stable, and increasing population, respectively (Northfield et al. 2008). Momol et al. (2004) and Baez et al. (2012) previously found that tomato was a poor reproductive host for *F. occidentalis* and *F. tritici*, indicating that the vast majority of thrips in tomato disperse into the crop from outside sources. Momol et al. (2004) and Baez et al. (2012) also found that natural populations of *O. insidiosus* were not sufficient in tomato to provide control of flower thrips.

Pepper was a better reproductive host than tomato based on the proportion of larvae per adult. The dynamic relationship between predator and prey in pepper flowers has been well studied under field conditions in North Florida (Funderburk et al. 2000; Ramachandran et al. 2001; Reitz et al. 2003; Baez et al. 2012). About 1 *O. insidiosus* for every 180 thrips was sufficient in the abovementioned studies for suppression of the populations of thrips in pepper. This ratio is similar to the ratio of 1 per 217 thrips predicted by a model developed by Sabelis & van Rijn (1997) to lead to the extinction of a local western flower thrips population. As in these previous studies, the number of *O. insidiosus* in the untreated pepper plots in 2009, 2010, and 2011 were sufficient to result in suppression of thrips populations. However, *O. insidiosus* were not sufficient, based on the predator to prey ratios in the untreated plots to suppress thrips in the 2008 pepper experiment, and this suggests why densities of adult western flower thrips and thrips larvae were much greater in 2008 than in 2009, 2010, and 2011. The predator preferentially preys on the larvae followed by the adults of the western flower thrips (Baez et al. 2004; Reitz et al. 2006).

The development of insecticide resistance in western flower thrips populations has greatly hampered effective integrated pest management of this pest (Weiss et al. 2009). Dripps et al. (2010) found after a review of the scientific literature that few insecticides are highly effective against western flower thrips and that the spinosyns have been the only highly effective insecticides that also conserve populations of *O. insidiosus*. They found that rotating highly active insecticides with moderately active insecticides could achieve good levels of control of the western flower thrips while mitigating the development of resistance to all insecticides in the rotation. Efficacy of spinetoram against the western flower thrips was high in both pepper and tomato in our experiments, while impacts on populations of *O. insidiosus* in pepper were minimal. Other insecticides that demonstrated high levels of efficacy against the western flower thrips adults and *Frankliniella* larvae in our pepper trials were methomyl, acetamiprid, and tolfenpyrad; however, these insecticides reduced populations of *O. insidiosus*. Neither methomyl nor acetamiprid were effective against the western flower thrips adults in tomato, although they significantly reduced *F. tritici* populations. Likewise, Broughton & Herron (2009) reported that acetamiprid was as effective as spinosad against the western flower thrips adults and larvae in pepper, but neither insecticide was effective in tomato.

Cyantraniliprole, flonicamid, spirotetramat, and the insecticide containing terpenes significantly reduced the western flower thrips adults and *Frankliniella* larvae in pepper and tomato but these products were only moderately active compared with spinetoram. Although these materials were not highly efficacious against the western flower thrips, they only had minor impacts on *O. insidiosus* populations in pepper. Funderburk et al. (2013) previously reported that foliar applications of cyantraniliprole showed no significant suppression of *O. insidiosus* populations in pepper. Populations of *O. insidiosus* are valuable for managing thrips, as they prey preferentially on the adults of the western flower thrips over the adults of the non-damaging *F. tritici*, and they most prefer the thrips larvae (Baez et al. 2004; Reitz et al. 2006). Adults of *O. insidiosus* are highly vagile, and they rapidly invade pepper and eggplant fields to control the western flower thrips adults and larvae (Ramachandran et al. 2001). However, they must be conserved with judicious insecticide use. We conclude that cynatraniliprole, flonicamid, spirotetramat, and the insecticide containing terpenes are useful as selective insecticides for use against *F. occidentalis* that conserve, at the same time, populations of *O. insidiosus*.

Avoiding the flaring of western flower thrips populations and other pests by the use of broad-spectrum synthetic insecticides that eliminate natural enemies and competitor species is a critical factor in insecticide recommendations for fruiting vegetables (Demirozer et al. 2012; Reitz & Funderburk 2012). We noted increases in western flower thrips adults and larvae in plots treated with the pyrethroid lambda-cyhalothrin compared with the control in the 2010 experiment, but numbers were similar to untreated pepper in the 2008 and 2009 experiments. Funderburk et al. (2000) and Reitz et al. (2003) previously reported that applications of other pyrethroids suppressed populations of *O. insidiosus* and *F. tritici* while increasing populations of the western flower thrips in pepper. All of the insecticides included in the present trials that had activity against the western flower thrips also showed activity against *F. tritici*. Therefore, we were not able to identify any insecticides that had selective activity against the western flower thrips and not *F. tritici*.

The negative impacts of broad-spectrum insecticides on natural enemies and competitor species are not the only reason that growers have been encouraged to move to newer, more selective insecticides. Invasive populations of the western flower thrips probably arrived with some level of resistance to broad-spectrum insecticides (Immaraju et al. 1992). Unfortunately, growers of fruiting vegetables are faced with having only a limited number of efficacious classes of insecticides, which greatly increases the risk of resistance development (Broughton & Herron 2009, Reitz & Funderburk 2012). Further, the implementation of an integrated resistance management strategy is limited by the continuous, overlapping generations typical for western flower thrips populations in crops (Reitz & Funderburk 2012).

Bielza (2008) outlined a general resistance management protocol that is a good foundation for a sound integrated pest management program; namely, apply insecticides only when required, make accurate and precise insecticide applications, diversify the types of management methods used in the crop, and conserve natural enemies. Demirozer et al. (2012) developed and implemented such plans for fruiting vegetables that are effective, economical, and ecologically sound. The components include the following: define pest status (economic thresholds), increase biotic resistance (natural enemies and competition), integrate preventive and therapeutic tactics (scouting, ultraviolet-reflective mulch technologies, biological control, compatible insecticides, companion plants, and fertility), vertically integrate the programs with other pests, and continuously communicate with end-users. These programs have been widely implemented in Florida, and have significantly improved management of the western flower thrips and thrips-transmitted viruses. In order for the efficacy of insecticides to be sustained, they recommended that an integrated resistance management strategy be employed only as a component of the integrated pest management program; that is, only in instances when multiple applications of insecticides are needed to keep adult and larval populations of the western flower thrips below economic thresholds.

In these field studies, we compared insecticide treatments against an untreated control where natural enemies and natural populations of competitor thrips reduced populations of western flower thrips. Therefore, the level of reduction of western flower thrips populations represented a conservative estimate of the toxic effects attributable to the individual insecticide treatments. We identified a number of insecticides from different classes that demonstrated moderate to high efficacy against the western flower thrips. Some are broad-spectrum and some are newer insecticides that showed little impact on populations of the key predator of thrips, *O. insidiosus*. The fact that many of these newer insecticides are not as efficacious as the spinosyns should not deter their inclusion in integrated pest management programs (Demirozer et al. 2012; Reitz & Funderburk 2012). The focus of management should not be placed on killing the maximum number of thrips. Rather the focus should be on minimizing damage below economically injurious levels. Even limited suppression of the western flower thrips adults and thrips larvae can maintain damage from oviposition and feeding within economically tolerable limits. Secondary spread of *Tomato spotted wilt virus* can also be limited by suppression of populations rather than by complete control (Momol et al. 2004). In pepper, conservation of *O. insidiosus* significantly reduces both primary and secondary spread of tomato spotted wilt (Funderburk et al. 2000; Reitz et al. 2003). Here we evaluated multiple applications of the same insecticide in order to estimate their individual efficacies against western flower thrips. In actual practice, growers are recommended to rotate between different chemical classes in an integrated resistance management strategy when multiple applications are needed to prevent western flower thrips populations from reaching economic thresholds (Funderburk et al. 2011a, b; Demirozer et al. 2012). Although growers are encouraged to use more selective insecticides in different chemical classes, the use of certain organophosphate, carbamate, and neonicotinoid insecticides against the western flower thrips may be warranted in particular instances when non-target effects would be minimal. Demirozer et al. (2012) and Reitz & Funderburk (2012) recommended that their use be reserved for times near the end of the growing season, if needed, to prevent scarring damage to fruit.

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