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Authors: Smith, Hugh A., and Nagle, Curtis A.

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COMBINING NOVEL MODES OF ACTION FOR EARLY-SEASON MANAGEMENT OF *BEMISIA TABACI* (HEMIPTERA: ALEYRODIDAE) AND TOMATO YELLOW LEAF CURL VIRUS IN TOMATO

HUGH A. SMITH* AND CURTIS A. NAGLE
University of Florida, Gulf Coast Research and Education Center, 14625 C.R. 672, Wimauma, Florida 33598, USA

*Corresponding author; E-mail: hughasmith@ufl.edu

ABSTRACT

Management of *Tomato yellow leaf curl virus* (TYLCV) in Florida tomato involves destroying inoculum sources, using reflective mulches to repel the vector, growing TYLCV-tolerant varieties, and using insecticidal control. Three new insecticides with distinct modes of action were evaluated for management of *Bemisia tabaci* (Gennadius) and the whitefly-transmitted TYLCV. Chemicals were applied in paired combinations during the first 5 weeks after transplanting. Flupyradifurone (Sivanto) and cyantraniliprole (Cyazypyr™) are systemic insecticides that can be applied to soil or foliage and pyrifluquinazon is a translaminar material for foliar application. In order to determine optimal combination of chemicals with different modes of action for early-season whitefly control and virus suppression, systemic materials were soil-applied at-plant followed by foliar applications of a material with a distinct mode of action. Dinotefuran (Venom) was included as a standard at-plant material for comparison. Field trials were carried out using a split plot design with insecticide programs as main plot treatments which were split into plots covered under a floating row cover for the first 2 weeks after planting or left uncovered. The intention of the row cover treatment was to compare the degree of protection offered by at-plant treatments when the crop was exposed to virus immediately after transplanting to exposure two weeks after transplanting, and to determine if any at-plant treatment were comparable to mechanical exclusion of the vector. In fall 2012, when virus pressure was moderate, end of season virus incidence was lower than the untreated control in all chemical treatments except dinotefuran drench alone or followed by cyantraniliprole. Percentage virus in these 2 treatments were not significantly different from the untreated plots as of 5 weeks after transplanting in both fall trials (2012 and 2013). During both fall trials, percent virus was numerically lowest each week in either the flupyradifurone or flupyradifurone followed by pyrifluquinazon treatments, although the differences from other treatments were not always statistically significant. In spring 2013, when virus pressure was negligible, yield was higher in plots treated with dinotefuran followed by cyantraniliprole than in other treated plots, with the exception of flupyradifurone followed by cyantraniliprole. Row cover treatments were only partially successful, and did not indicate that any at-plant treatment was comparable to mechanical exclusion of the vector. Integration of new materials into insecticide recommendations and resistance management plans for Florida tomato (*Solanum lycopersicum* L.) production are discussed.

Key Words: cyazypyr, cyantraniliprole, flupyradifurone, pyrifluquinazon, vector management, TYLCV, tomato

RESUMEN

El manejo del *Tomato yellow leaf curl virus* (TYLCV) [*virus de la hoja enrollada amarilla del tomate*] en el tomate en la Florida implica la destrucción de fuentes de inóculo, el utilizar coberturas reflectantes para repeler al vector, siembra de variedades tolerantes al TYLCV y el uso de insecticida. Se evaluaron tres nuevos insecticidas con distintos modos de acción para el manejo de *Bemisia tabaci* (Gennadius) y el TYLCV transmitido por la mosca blanca. Se aplicaron productos químicos en combinaciones pareadas durante las primeras 5 semanas después del trasplante. Flupyradifurone (Sivanto) y cyantraniliprole (Cyazypyr ™) son insecticidas sistémicos que pueden aplicarse al suelo o follaje y pyrifluquinazon es un producto translaminar para aplicación foliar. Para determinar la combinación óptima de los productos químicos con diferentes modos de acción para el control de mosca blanca en la temporada temprana y la supresión del virus, se aplicaron productos sistémicos al suelo de la planta seguido por aplicaciones foliares de un producto con un modo distinto de acción. Se incluyó el Dinotefuran (Venom) como un producto estándar a la planta para la comparación. Se realizaron los ensayos de campo utilizando un diseño de parcelas divididas con programas de insecticidas como el tratamiento principal para las parcelas que fueron separadas, una cubierta por una fila de cobertura flotante para las primeras 2 semanas después de la

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siembra y otra dejada descubierta. El proposito del tratamiento de la fila de cobertura fue el comparar el grado de protección ofrecido por los tratamientos en la planta cuando el cultivo fue expuesto al virus inmediatamente después del trasplante hasta la exposición al virus dos semanas después del trasplante, esto para determinar si algunos de los tratamientos en las plantas son comparables a la exclusión del vector mecánicamente. En el otoño del 2012, cuando la presión de virus fue moderada, la incidencia del virus al final de temporada fue menor que en el control sin tratar para todos los tratamientos químicos con excepción del dinotefuran solo empapado al suelo o seguido por cyantraniliprole. El porcentaje del virus en estos dos tratamientos no fueron significativamente diferentes de las parcelas no tratadas después de cinco semanas del transplante en ambos ensayos del otoño (2012 y 2013). Durante ambos ensayos del otoño, el porcentaje del virus fue numéricamente más bajo cada semana tanto en el flupyradifurone como el flupyradifurone seguido por el tratamiento con pyrifluquinazon, aunque las diferencias de los otros tratamientos no siempre fueron estadísticamente significativas. En la primavera del 2013, cuando la presión de virus fue insignificante, el rendimiento fue mayor en las parcelas tratadas con dinotefuran seguido por cyantraniliprole que en las otras parcelas tratadas, con la excepción de flupyradifurone seguido por cyantraniliprole. El tratamiento de la cobertura de fila fue sólo un éxito parcial, y no indicó que alguno de los tratamientos en la planta son comparables a la exclusión mecánica del vector. Se comenta sobre la integración de los nuevos productos en las recomendaciones de insecticidas y el plan del manejo de la resistencia en el tomate (*Solanum lycopersicum* L.) en la Florida.

Palabras Clave: cyazypyr, cyantraniliprole, flupyradifurone, pyrifluquinazon, manejo del vector, TYLCV, tomate

Tomato yellow leaf curl virus (TYLCV) is a member of the genus Begomovirus in the family Geminiviridae that is transmitted in a persistent, circulative manner by its vector, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) (Brown et al. 1995). TYLCV is one of the most broadly distributed and economically damaging species in the virus complex (Glick et al. 2009). *Bemisia tabaci*, the only known vector, can acquire TYLCV as an adult or nymph, and adults remain infective for the duration of their life (Cohen & Nitzhany 1966; Jones 2003). *Bemisia tabaci* adults can acquire the virus from feeding on an infected plant for as little as 15 min, and can transmit the virus less than 24 h after acquiring it (Mansour & Al Musa 1992; Mehta et al. 1994; Czosnek et al. 2002). TYLCV produces distinctive symptoms: upwardly curled leaves that are reduced in size, brightly chlorotic leaf margins and interveinal regions on leaves, shortened petioles and a bushy appearance to plants which are reduced in size if infected early. Viral symptoms typically appear in the plant about two weeks after it has been infected; the earlier the plant is infected, the greater the impact on yield (Levy & Lapidot 2008).

TYLCV causes significant crop losses in tomato growing regions worldwide (Moriones & Castillo 2010; Czosnek & Ghanim 2011). It is a primary production constraint for tomato growers in Florida (Mosler et al. 2009; Schuster et al. 2007), which is a major producer of fresh market tomatoes in the United States (USDA 2013). In Florida, tomato is produced almost year-round in the western, central and southern portions of the state with the exception of the hottest summer months (Jul-Aug). Whitefly pressure is typically higher in the fall crop than the spring early in the season because the pest builds up during the summer on alternate weed and crop hosts. Both B and Q biotypes of *B. tabaci* are present in Florida, and while both biotypes can transmit TYLCV, field-grown horticultural crops are affected almost exclusively by the B biotype (McKenzie et al. 2009). Management of TYLCV in Florida tomato involves destroying inoculum sources, using reflective mulches to repel the vector, planting TYLCV-tolerant varieties, rogueing infected plants, and using insecticidal control (Schuster et al. 2008).

Protecting the tomato crop from viral infection during the first 6 weeks after transplanting is crucial to mitigate yield loss (Lapidot & Levy 2010). At-plant and early season applications of insecticides have been key components to managing TYLCV and *B. tabaci* in Florida tomato and elsewhere (Gilbertson et al. 2011; Schuster et al. 2008). However populations of *B. tabaci* biotype B have developed resistance to several modes of action globally (Castle et al. 2010; Ma et al. 2010; Rao et al. 2012), and resistance to neonicotinoids, one of the most useful insecticide groups for managing *B. tabaci*, has been documented in Florida (Schuster et al. 2010). Tomato transplants in Florida are typically treated with a neonicotinoid insecticide in the nursery, at plant, and in the first weeks after establishment either through drip irrigation or foliar application. Imidacloprid (IRAC group 4A) is the most commonly used material. The development of resistance to neonicotinoid insecticides by whiteflies in Florida has led to guidelines emphasizing the use of neonicotinoids during the first five weeks after transplanting but no later (Webb et al. 2013).

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The registration of endosulfan for use on tomato will be withdrawn after 2014. Endosulfan is a cyclodiene insecticide that many tomatoes growers in Florida have relied on over the years to suppress whitefly adults. In order to offset the loss of control options for *B. tabaci* due to the development of resistance and registration withdrawals, materials with alternative modes of action are needed. Insecticides with novel modes of action that are registered or nearing registration for use on *B. tabaci* include cyantraniliprole, flupyradifurone, and pyrifluquinazon. Cyantraniliprole, also called Cyazypyr™, is in the anthranilic diamide group of insecticides that disrupt the functioning of ryanodine receptors. It is a Group 28 insecticide in the International Resistance Action Committee (IRAC) mode of action classification system. Flupyradifurone is a butenolide insecticide (IRAC group 4D) that functions as a nicotinic acetylcholine receptor agonist (Velten et al. 2013). Cyantraniliprole and flupyradifurone are both systemic and can be applied to the roots or foliage. Pyrifluquinazon is a translaminar quinazinalone insecticide which interferes with androgen receptor function (Kang et al. 2012; Yasunga et al. 2012). Its mode of action has not been fully characterized and it does not yet have an IRAC mode of action classification. Flupyradifurone is a Bayer product that will be sold as Sivanto. Cyazypyr™, produced by DuPont, is available in a soil-applied formulation (Verimark) and a foliar formulation (Exirel) for use on vegetables.

Research has implicated treatments of cyantraniliprole, flupyradifurone and pyrifluquinazon with reduction in the incidence of whitefly-transmitted viruses and densities of immature whiteflies (Schuster et al. 2008b; Palumbo 2012a,b; Smith & Giurcanu 2013; Smith & Giurcanu in press). Cyantraniliprole, flupyradifurone and pyrifluquinazon were compared in greenhouse studies at University of Florida, Gulf Coast Research and Education Center (GCREC) in 2011 and 2012 as single applications on tomato seedlings (Smith & Giurcanu 2013; Smith & Giurcanu, in press). These studies confirmed a role for each material in suppressing *B. tabaci* and reducing incidence of TYLCV under controlled conditions.

Field trials were carried out at GCREC to evaluate the effect of applying these new materials in combination during the first five weeks after transplanting on the number of whiteflies and TYLCV incidence. Venom 70 SG (dinotefuran, Valent Corporation; IRAC group 4A) was included as an at-plant material for comparison with at-plant applications of Sivanto and Verimark. Venom is a neonicotinoid insecticide that has been used by Florida tomato growers for whitefly management since 2007. In order to determine the effect of early, complete physical exclusion of vectors from the crop, each treated plot was split into an exposed or completely covered sub plot, by applying an insect-proof row cover for the first two weeks after transplanting. The purpose of these trials was to determine the most efficacious early season combinations of these new materials with the aim of integrating novel modes of action into established insecticide rotations for management of *B. tabaci* and TYLCV.

Materials and Methods

Field trials were carried out during the fall of 2012, and spring and fall of 2013, at the University of Florida Gulf Coast Research and Education Center (GCREC), Wimauma, Florida (N 27° 45.599', W 82° 13.446') to evaluate novel insecticides for suppression of *Bemisia tabaci* and TYLCV on tomato (variety 'Florida 47').

Experimental Design

For each treatment evaluated, one mode of action was applied at-plant (Verimark, Venom or Sivanto) either alone or in combination with a material of a different mode of action, applied as a foliar spray (Exirel, Sivanto or pyrifluquinazon). Because of similarities in the modes of action of Sivanto and Venom, these two materials were not combined in any treatment. Foliar applications were made weekly for 3 weeks starting within 1 week after the row covers were removed (fall 2012 and fall 2013) or later because whitefly pressure was low (spring 2013). The trials were arranged in a split plot design, randomized in complete blocks on raised beds of Myakka fine sand 20 cm-high and 81 cm-wide with 1.5 m centers covered with white virtually impermeable plastic mulch. Treatments were replicated 4 times. Main plots consisted of single beds of 28 plants each and were chemically treated with programs of insecticides. Sub plots consisted of 14 plants each and were either covered for 2 weeks after transplanting or left open.

Treatment Applications

Soil drench treatments were hand ladled on the day of transplanting at the rate of 118 mL (4 fl. oz.) of preparation per plant (1698 L per ha/ 181.5 gal. per acre). Foliar treatments were applied with a hand-held sprayer with a spray wand outfitted with a single nozzle containing a 45° core and a D-5 disk. The sprayer was pressurized by CO_2 to 60 psi and calibrated to deliver 561 L per ha (60 gal. per ac) (Table 1). DuPont Pointbond All Purpose Row – Seed Bed – Insect Covers were applied to 1 sub-plot within each main plot immediately after transplanting and soil treatments were accomplished. A full day was required to establish 2 replications; therefore the

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TABLE 1. INSECTICIDE TREATMENT RATES AND SCHEDULES FOR THREE SEASONS OF TRIALS: FALL 2012, SPRING 2013 AND FALL 2013.

	Trial Season[a]		Application DAT (days after transplant)			
	Fall 2012		(0)	(21)	(27)	(36)
	Spring 2013		(0)	(33)	(40)	(47)
	Fall 2013		(0)	(16)	(24)	(30)
Insecticide treatment (g a.i. L^{-1})[b]	Rate amount/ha	Application site[c]				
Non-treated	—	—	—	—	—	—
Sivanto (200)	2.046 liter	soil	X			
Sivanto (200)	2.046 liter	soil	X			
fb Exirel (100)	1.498 liter	foliar		X	X	X
Sivanto (200)	2.046 liter	soil	X			
fb pyrifluquinazon (200)	0.233 liter					
+ Induce	0.25% vol/vol	foliar		X	X	X
Verimark (200)	1.023 liter	soil	X			
Verimark (200)	1.023 liter	soil	X			
fb Sivanto (200)	1.498 liter	foliar		X	X	X
Verimark (200)	1.023 liter	soil	X			
fb pyrifluquinazon (200)	0.233 liter					
+ Induce	0.25% vol/vol	foliar		X	X	X
Venom 70% a.i.	170.0 g	soil	X			
Venom 70% a.i.	170.0 g	soil	X			
fb Exirel (100)	1.498 liter	foliar		X	X	X
Venom 70% a.i.	170.0 g	soil	X			
fb pyrifluquinazon (200)	0.233 liter					
+ Induce	0.25% vol/vol	foliar		X	X	X

[a]Two of the replications were transplanted, drench treated and covered 1 day later than the others. [b]A '+' sign indicates the products were combined, 'fb' means followed by. [c]Application volumes were 1698 L/ha (soil drench) and 561 L/ha, or 842 L/ha at 27 and 36 DAT in Fall 2012, (foliar spray).

trials were set up over a 2-day period. Row covers for an entire trial were removed on the same day, either 14 or 15 days after covering (Table 2).

Insect Samples

Bemisia tabaci sampling began soon after the row covers were removed and before any foliar applications of insecticides were made. Sampling continued weekly until 1 week after the last foliar treatments were made. All *B. tabaci* sampling occurred on the middle 10 plants of each sub-plot. Adult *B. tabaci* densities were sampled in the field by examining the third leaf from the top on 1 stem per plant and recorded as the number per 10 leaves. Immature *B. tabaci* densities were sampled by removing the terminal leaflet of a 7th or 8th leaf from the top of each plant. The leaflets were examined using a stereo microscope, and data were recorded as *B. tabaci* eggs, 1st, mid (2nd & 3rd), and 4th instars per 10 leaflets. Analysis based on combined nymphal counts is reported.

TABLE 2. KEY DATES FOR EACH TRIAL TO EVALUATE NOVEL INSECTICIDES FOR SUPPRESSION OF *BEMISIA TABACI* AND TYLCV ON TOMATO (VARIETY 'FLORIDA 47').

Trial Season	Transplant drench & row cover treatments	Row covers removed	Foliar treatments	Harvest
Fall 2012	25, 26 Sep	11 Oct	16, 22, 31 Oct	19 Dec
Spring 2013	27, 28 Feb	14 Mar	1, 8, 15 Apr	22 May
Fall 2013	30, 31 Jul	14 Aug	15, 23, 29 Aug	10 Oct

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TYLCV Assessment

All plants within each sub-plot were inspected weekly in the field and those which possessed clear symptoms of TYLCV were marked by applying spray paint to the plastic mulch at the base of the plant, recorded and the data added to the previous week's data to determine the cumulative weekly % virus incidence.

Yield Assessment

A single harvest was made for each trial during the early fruiting period of the crop. Fruit were harvested from the middle 10 plants of each sub-plot and were graded for size and defects according to industry standards, and categorized as extra large (> 2.75 inches [> 7 cm] in diam or ca. 7 cm), large (2.51 to 2.75 inches [6.4 – 7 cm] in diam), medium (2.26 to 2.5 inches [5.7 -6.4 cm] in diam) and small (2.25 inches [5.7 cm] or less in diam), or culled if defective. Numbers and weights of all categories were recorded; only weights of marketable fruits and culls are reported.

Statistical Analysis

Bemisia tabaci adult, egg and combined 1st through 4th instar densities were analyzed by sample week and combined over all sample weeks (trial-total densities). All data were transformed √(x+0.5) prior to analysis of variance for split plot design (PROC ANOVA procedure, SAS institute 2008) to meet assumptions of normality. The main plot factor was insecticide treatment. The subplot factor was insect exclusion row cover or no row cover during the first two weeks after planting. Cumulative weekly % virus incidences were calculated as % TYLCV = (no. symptomatic plants/total no. live plants) × 100, then transformed arcsine[√(%TYLCV/100)] prior to ANOVA. Yield data were not transformed. Means were separated by Fisher's Protected LSD ($P \leq 0.05$). All means are reported in the original scale.

Results

Bemisia tabaci Response

Average densities of whitefly adults remained less than 4.0 per 10 leaves per week in fall 2012 and less than 1.0 in spring 2013. There were no statistical differences in adult densities between covered and non-covered treatments on any week in the fall 2012 or spring 2013 trials. Trial-total adult densities were lowest in fall 2012 with treatments of Sivanto, alone or followed by pyrifluquinazon, or Verimark, alone or followed by pyrifluquinazon and there were no significant sub plot (cover) or interaction effects (Table 3). No significant differences between chemical treatments were found in spring 2013; however, adult densities were lower in the covered plots than in the non-covered plots that season and there was significant interaction between chemical and row cover effects (Table 3). Because of overall lack of significance and low counts in the fall of 2012 and spring of 2013, adult counts were not collected in fall 2013.

With the exception of the Venom drench, trial-total egg densities of *B. tabaci* were lower in both fall 2012 and fall 2013 trials with any chemical treatment than in the untreated check (UTC) (Table 4). No difference due to row cover was observed in the fall 2012 or spring 2013 trials for eggs; high plant mortality due to excessive heat under the covered plots in the fall 2013 trial caused the covered portion of the experiment to be abandoned (Table 4). When examined on a week by week basis, egg densities were significantly higher 6 weeks after transplanting in the UTC (4.5 per 10 leaflets) (SE = 1.3) than all other treatments (~0.5 per 10 leaflets) (SE = 0.1) ($F_{9, 27}$ = 9.27; $P < 0.01$), and higher in the UTC (1.3 per 10 leaflets) (SE = 0.6) than all other treatments except the Venom drench (0.6 per 10 leaflets) (SE = 0.4) ($F_{9, 27}$ = 3.01; $P < 0.05$) 7 weeks after transplanting in the fall 2012 season. In fall 2013, egg densities were statistically higher in the UTC (3.5 per 10 leaflets) (SE = 1.2) than all treatments except Venom followed by pyrifluquinazon (1.5 per 10 leaflets) (SE = 0.5) 4 weeks after transplanting ($F_{9, 27}$ = 2.84; $P < 0.05$). In that trial, all treatments had statistically fewer eggs than the UTC (12.0 per 10 leaflets) (SE = 4.2) 6 weeks after transplanting with the exception of Venom treatments (Venom drench: 7.0 per 10 leaflets) (SE = 3.0); Venom fb Exirel: (6.0 per 10 leaflets) (SE = 3.0); Venom fb pyrifluquinazon: (4.5 per 10 leaflets) (SE = 2.7) and Verimark followed by pyrifluquinazon (7.3 per 10 leaflets) (SE = 5.4) ($F_{9, 27}$ = 2.40; $P < 0.05$). There were no statistical differences among treatments with regard to egg densities on any week in spring 2013.

Mean *B. tabaci* combined instar densities, combined over all sample weeks, were lower with any chemical treatment than UTC in all three trials, except Venom alone in fall 2012 (Table 4). In fall 2012, nymphs were detected on the first sample week, 21 days after transplant (DAT), on non-covered plants only. Trial-total combined instar densities were lower in covered plots than in non-covered in the fall 2012 trial only (Table 4). In the fall of 2013 combined instar densities were significantly higher in the UTC than in any other treatment for each sample week, except 6 weeks after transplant ($F_{9, 27}$ = 1.98; P = 0.08), (Data not presented).

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TABLE 3. MEAN NUMBER (±SEM) OF *BEMISIA TABACI* ADULTS PER TEN LEAVES TOTALLED OVER ALL SAMPLE DATES (FALL 2012 CONSISTS OF 5 WEEKLY SAMPLES; SPRING 2013 CONSISTS OF 6 WEEKLY SAMPLES).

		Mean number of *B. tabaci* adults (SEM)	
Insecticide treatment (g a.i. L^{-1})[a]	Rate amount/ha	per 50 leaves	per 60 leaves
Section 1. Main plot effects (chemical)		Fall 2012	Spring 2013
Non-treated	—	3.9(0.5)ab	0.8(0.3)a
Sivanto (200)	2.046 liter	1.1(0.2)d	0.5(0.2)a
Sivanto (200) fb Exirel (100)	2.046 liter 1.498 liter	2.3(0.7)b-d	0.9(0.3)a
Sivanto (200) fb pyrifluquinazon (200) + Induce	2.046 liter 0.233 liter 0.25% vol/vol	1.5(0.3)cd	0.5(0.2)a
Verimark (200)	1.023 liter	1.6(0.5)cd	0.8(0.3)a
Verimark (200) fb Sivanto (200)	1.023 liter 1.498 liter	2.6(0.8)b-d	0.4(0.2)a
Verimark (200) fb pyrifluquinazon (200) + Induce	1.023 liter 0.233 liter 0.25% vol/vol	1.9(0.6)cd	0.4(0.3)a
Venom 70% a.i.	170.0 g	5.5(1.4)a	0.8(0.2)a
Venom 70% a.i. fb Exirel (100)	170.0 g 1.498 liter	3.5(0.9)a-c	0.5(0.3)a
Venom 70% a.i. fb pyrifluquinazon (200) + Induce	170.0 g 0.233 liter 0.25% vol/vol	2.8(0.8)b-d	0.5(0.2)a
$F_{9,27}$		3.26	0.47
P-value		0.0083	0.8787
Row-cover treatment	Timing		
Section 2. Sub-plot effects (cover)			
Non-covered	—	2.8(0.4)a	0.8(0.1)a
Cover installed fb cover removed	at plant 14 DAT[b]	2.5(0.4)a	0.4(0.1)b
$F_{1,30}$		0.73	8.48
P-value		0.3994	0.0067
Section 3. Interaction effects (chemical x cover)			
$F_{9,30}$		1.13	3.30
P-value		0.3716	0.0065

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] DAT = days after transplant.

TYLCV Response

Fall 2012: TYLCV pressure was moderate, reaching 65% in the chemically untreated plots 9 days before harvest. In the covered plots, symptoms were first observed 35 DAT, 18 days after the covers were removed; at that time there were no differences in % virus incidence between any chemical treatment and the UTC (Table 5). Chemical treatments of Sivanto, alone or followed by pyrifluquinazon, resulted in the lowest % virus incidence observed on each of the 9 weeks of assessment, although these were not always significantly different from other treatments ($F_{9,27}$; $P > 0.05$). The % virus incidence was greater in the non-covered than in the covered plots on each of the 9 weeks that assessments were made ($F_{1,30}$; $P \leq 0.016$) and there were no interactions between chemical treatment and cover effects ($F_{9,30}$; $P \geq 0.11$).

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TABLE 4. MEAN NUMBER (±SEM) OF *BEMISIA TABACI* EGGS AND NYMPHS PER TEN LEAFLETS TOTALLED OVER ALL SAMPLE DATES (FALL 2012 CONSISTS OF 5 WEEKLY SAMPLES; SPRING AND FALL 2013 CONSISTS OF 6 WEEKLY SAMPLES).

	Rate	Mean number of eggs (SEM) per			Mean number of 1st -4th instars (SEM) per		
	amount/ha	50 leaflets	60 leaflets	60 leaflets	50 leaflets	60 leaflets	60 leaflets
Insecticide treatment (g a.i. L^{-1})[a]		Fall 2012	Sp. 2013	Fall 2013[b]	Fall 2012	Sp. 2013	Fall 2013[b]
Section 1. Main plot effects (chemical)							
Non-treated	—	10.6(2.5)a	5.0(1.4)a	37.3(6.7)a	32.9(12.4)a	11.0(3.8)a	164.3(33.9)a
Sivanto (200)	2.046 liter	2.3(1.3)b-d	4.8(2.6)a	9.5(2.2)de	3.1(1.4)c	4.5(1.5)b	15.5(6.1)bc
Sivanto (200) fb Exirel (100)	2.046 liter 1.498 liter	2.3(0.9)b-d	5.3(3.2)a	10.0(2.4)de	0.9(0.6)c	0.5(0.2)c	8.8(2.9)bc
Sivanto (200) fb pyrifluquinazon (200) + Induce	2.046 liter 0.233 liter 0.25% vol/vol	1.9(1.2)cd	4.8(1.5)a	4.3(1.1)e	0.5(0.3)c	1.1(0.2)bc	12.0(3.3)bc
Verimark (200)	1.023 liter	2.8(1.5)b-d	3.0(1.3)a	11.5(2.1)b-d	0.4(0.2)c	2.6(1.3)bc	21.0(5.7)b
Verimark (200) fb Sivanto (200)	1.023 liter 1.498 liter	1.1(0.6)d	1.0(0.5)a	13.0(2.5)b-d	0.4(0.4)c	0.6(0.4)c	7.3(2.3)bc
Verimark (200) fb pyrifluquinazon (200) + Induce	1.023 liter 0.233 liter 0.25% vol/vol	0.9(0.4)d	2.5(1.9)a	15.8(5.8)b-d	0.5(0.4)c	1.0(0.8)c	14.8(4.2)bc
Venom 70% a.i.	170.0 g	6.0(2.4)ab	2.6(1.2)a	19.8(2.8)b	21.6(10.6)ab	2.4(1.0)bc	24.3(8.4)b
Venom 70% a.i. fb Exirel (100)	170.0 g 1.498 liter	4.9(1.5)bc	0.1(0.1)a	19.3(4.2)bc	6.6(4.9)bc	1.0(0.7)c	4.8(2.4)c
Venom 70% a.i. fb pyrifluquinazon (200) + Induce	170.0 g 0.233 liter 0.25% vol/vol	3.6(1.6)b-d	1.6(0.9)a	10.5(2.5)c-e	3.4(0.8)c	0.8(0.3)c	16.5(6.4)bc
$F_{9,27}$		3.90	1.96	6.62	4.99	5.51	16.85
P-value		0.0029	0.0852	<0.0001	0.0005	0.0003	<0.0001
Row-cover treatment	Timing						

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] Fall 2013 means reflect only data from the non-covered plots. [c] DAT = days after transplant.

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TABLE 4. (CONTINUED) MEAN NUMBER (±SEM) OF *BEMISIA TABACI* EGGS AND NYMPHS PER TEN LEAFLETS TOTALLED OVER ALL SAMPLE DATES (FALL 2012 CONSISTS OF 5 WEEKLY SAMPLES; SPRING AND FALL 2013 CONSISTS OF 6 WEEKLY SAMPLES).

	Rate	Mean number of eggs (SEM) per			Mean number of 1st -4th instars (SEM) per		
	amount/ha	50 leaflets	60 leaflets	60 leaflets	50 leaflets	60 leaflets	60 leaflets
Insecticide treatment (g a.i. L^{-1})[a]		Fall 2012	Sp. 2013	Fall 2013[b]	Fall 2012	Sp. 2013	Fall 2013[b]
Section 2. Sub-plot effects (cover)							
Non-covered	—	3.8 a(0.9)	3.6 a(0.9)	15.1(1.7)	10.3 a(3.8)	2.6 a(0.7)	28.9(8.0)
Cover installed	at plant						
fb cover removed	14 DAT[c]	3.5 a(0.7)	2.6 a(0.6)	—	3.7 b(1.2)	2.5 a(0.9)	—
$F_{1,30}$		0.0	1.90	—	4.88	0.04	—
P-value		0.9685	0.1785	—	0.0350	0.8396	—
Section 3. Interaction effects (chemical x cover)							
$F_{9,30}$		0.43	0.85	—	1.60	0.46	—
P-value		0.9068	0.5755	—	0.1604	0.8869	—

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] Fall 2013 means reflect only data from the non-covered plots. [c] DAT = days after transplant.

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TABLE 5. MEAN CUMULATIVE % (±SEM) OF PLANTS (PER 14-PLANT PLOT) WITH TYLCV SYMPTOMS IN THE FALL 2012 TRIAL TO EVALUATE NOVEL INSECTICIDES FOR SUPPRESSION OF *BEMISIA TABACI* AND TYLCV ON TOMATO (VARIETY 'FLORIDA 47').

		Cumulative % of plants with virus symptoms (SEM)								
		DAT[b]								
Insecticide treatment (g a.i. L^{-1})[a]	Rate amount/ha	21	28	35	42	50	56	63	70	77
Section 1. Main plot effects (chemical)										
Non-treated	—	2.7(1.9)a	2.7(1.9)a	6.3(4.6)a	28.6(6.5)a	33.0(5.9)a	40.2(6.3)a	57.1(7.0)a	58.0(6.9)a	65.2(7.1)a
Sivanto (200)	2.046 liter	0.0(0.0)a	0.0(0.0)a	1.8(1.2)a	4.5(2.7)a	8.9(2.9)c	17.0(2.7)cd	23.3(4.8)bc	29.5(6.7)a	30.4(6.6)b-d
Sivanto (200) fb Exirel (100)	2.046 liter 1.498 liter	0.0(0.0)a	0.0(0.0)a	9.8(2.3)a	17.0(5.2)a	18.8(5.0)a-c	21.4(5.1)b-d	25.0(5.2)bc	30.4(5.4)a	36.6(5.1)b-d
Sivanto (200) fb pyrifluquinazon (200) + Induce	2.046 liter 0.233 liter 0.25% vol/vol	0.0(0.0)a	0.9(0.9)a	2.7(1.3)a	10.7(3.0)a	12.5(4.0)bc	14.3(3.6)d	18.8(4.3)c	22.3(5.1)a	23.2(5.5)d
Verimark (200)	1.023 liter	1.8(1.2)a	4.5(2.3)a	5.4(2.9)a	13.4(3.7)a	20.5(3.4)a-c	25.9(2.7)a-d	33.9(3.2)a-c	35.7(3.0)a	42.0(4.4)bc
Verimark (200) fb Sivanto (200)	1.023 liter 1.498 liter	0.9(0.9)a	1.8(1.8)a	8.9(3.8)a	22.3(5.1)a	25.9(4.5)ab	27.7(4.6)a-d	31.3(3.8)bc	33.0(3.6)a	37.5(3.2)b-d
Verimark (200) fb pyrifluquinazon (200) + Induce	1.023 liter 0.233 liter 0.25% vol/vol	1.8(1.2)a	3.6(2.3)a	6.3(3.1)a	19.6(5.5)a	19.6(5.5)a-c	20.5(5.6)cd	24.1(5.2)bc	25.9(5.0)a	25.9(5.0)cd
Venom 70% a.i.	170.0 g	0.9(0.9)a	2.7(1.9)a	6.3(4.1)a	22.3(6.5)a	31.3(7.0)a	36.6(7.2)ab	44.6(8.9)ab	48.2(8.7)a	50.9(8.8)ab
Venom 70% a.i. fb Exirel (100)	170.0 g 1.498 liter	0.9(0.9)a	2.7(2.7)a	7.1(2.7)a	26.8(4.6)a	33.9(5.8)a	36.6(6.7)a-c	42.9(8.9)ab	45.5(8.4)a	49.1(8.0)ab
Venom 70% a.i. fb pyrifluquinazon (200) + Induce	170.0 g 0.233 liter 0.25% vol/vol	1.8(1.2)a	2.7(1.9)a	6.3(2.1)a	15.2(4.9)a	17.9(4.5)a-c	18.8(4.5)cd	28.6(6.3)bc	30.4(5.7)a	32.1(5.2)b-d
$F_{9,27}$		1.18	0.99	0.99	2.09	2.25	2.40	2.50	2.11	3.16
P-value		0.3480	0.4681	0.4726	0.0666	0.0502	0.0379	0.0319	0.0642	0.0097
Row-cover treatment	Timing									

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \le 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] DAT = days after transplant.

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TABLE 5. (CONTINUED) MEAN CUMULATIVE % (±SEM) OF PLANTS (PER 14-PLANT PLOT) WITH TYLCV SYMPTOMS IN THE FALL 2012 TRIAL TO EVALUATE NOVEL INSECTICIDES FOR SUPPRESSION OF *BEMISIA TABACI* AND TYLCV ON TOMATO (VARIETY 'FLORIDA 47').

		Cumulative % of plants with virus symptoms (SEM)								
		DAT[b]								
Insecticide treatment (g a.i. L^{-1})[a]	Rate amount/ha	21	28	35	42	50	56	63	70	77
Section 2. Sub-plot effects (cover)										
Non-covered	—	2.1(0.6)a	4.3(1.0)a	9.6(1.5)a	23.9(2.6)a	27.1(2.7)a	31.4(2.7)a	38.0(3.4)a	40.0(3.3)a	43.6(3.5)a
Cover installed	at plant									
fb cover removed	14 DAT	0.0(0.0)b	0.0(0.0)b	2.5(0.7)b	12.1(1.7)b	17.3(2.0)b	20.4(2.1)b	27.9(2.6)b	31.8(2.7)b	35.0(2.8)b
$F_{1,30}$		14.37	19.49	17.67	17.80	12.06	15.83	11.64	7.41	9.36
P-value		0.0007	0.0001	0.0002	0.0002	0.016	0.0004	0.0019	0.0107	0.0046
Section 3. Interaction effects (chemical x cover)										
$F_{9,30}$		0.96	0.90	0.75	0.87	0.63	0.71	1.34	1.37	1.79
P-value		0.4921	0.5363	0.6616	0.5619	0.7624	0.6973	0.2590	0.2439	0.1128

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] DAT = days after transplant.

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Spring 2013: Virus pressure was negligible, probably due to unusually cold weather, and TYLCV symptoms were not observed in any plot before 54 DAT (Data not presented). Nine days before harvest, mean virus incidence was not greater than 4% in any chemical treatment and there were no significant differences between covered and non-covered treatments or interactions between chemical treatment and cover effects.

Fall 2013: Virus pressure (Table 6) and *B. tabaci* levels (Table 4) were at their highest of the three trials; also there were no data from covered plots in this trial, which tended to make virus levels appear larger when compared with the fall 2012 trial. Nevertheless, by 27 DAT, virus incidence was lower in all chemical treatments, except Venom, alone or followed by pyrifluquinazon, than in the UTC (Table 6). Sivanto followed by pyrifluquinazon was the only chemical treatment which resulted in significantly lower virus incidence than the UTC at 47 DAT (Table 6). This combination tended to have the lowest percent virus in 2012 also (Table 5).

Yield Response

There were no statistical differences in marketable yield among treatments in fall 2012 ($F_{9, 27}$ = 2.18; P = 0.056) (trial mean: 53.3 lb per 10 plants) (SE = 1.3). In the spring of 2013, marketable yields were significantly higher in plots treated with Venom followed by Exirel than in plots of all other chemical treatments, except Sivanto followed by Exirel (Table 7). In the fall of 2013, there were no statistical differences among treatments in marketable yield, which was very low overall ($F_{9, 27}$ = 2.00; P = 0.079) (trial mean 5.0 lb per 10 plants) (SE = 0.7).

Discussion

Whitefly numbers overall tended to be low during these 3 trials, yet during the 2 fall seasons, virus incidence was substantial. These results are not atypical, as it is not unusual for TYLCV incidence to be high in commercial tomato fields when whitefly counts are low. This phenomenon may be explained by the influence of the virus on the behavior of *B. tabaci*. There is evidence that TYLCV affects the settling, probing and feeding behavior of *B. tabaci* in ways that enhance transmission of the virus (Liu et al. 2013; Moreno-Delafuente et al. 2013). In addition, Liu et al. (2013) determined that viruliferous tomatoes may be more attractive to *B. tabaci* than uninfected tomato.

The exclusion tunnel treatment failed in fall 2013 because of high temperatures under the tunnel. Data from previous seasons indicate that no at-plant systemic treatment was comparable to mechanical exclusion of the pest. The ability of cyantraniliprole, flupyradifurone and pyrifluquinazon to reduce transmission of TYLCV in greenhouse studies has been demonstrated (Smith & Giurcanu in press), and the antifeedant properties of some of these compounds are discussed below. Under the actual field conditions of our trials significant levels of TYLCV infection were observed on treated plants. *Bemisia tabaci* can infect a tomato plant with TYLCV with as little as 15 min of feeding (Mehta et al. 1994; Czosnek et al. 2002). Our data indicate that no mode of action can consistently prevent transmission of virus under field conditions and that growers must employ strategies in addition to chemical control in order to protect tomato crops from moderate and severe virus pressure, such as planting TYLCV-tolerant varieties of tomato.

Most insecticide treatments in these trials reduced densities of whitefly compared to the untreated control. With the exception of Venom treatments, most insecticide treatments did not separate statistically from one another, indicating a similar level of efficacy in suppressing whitefly. During the 2 fall trials, treatments with Sivanto tended to have the numerically lowest percentage of virus, although in 2013 this was only observed earlier in the crop season, and differences were not always statistically significant from other treatments. It should be kept in mind that sizeable differences in virus incidence may not produce statistical differences among treatments because of variability, but may produce economic yield differences in commercially-grown tomato. We did not observe statistically significant yield differences during the 2 fall trials, when virus pressure was either moderate or high. It is not unusual to observe little or no difference in tomato yield due to treatment in small plot *B. tabaci* management evaluations, even when treatment effects on the pest are significant (Stansly et al. 2008; Schuster et al. 2009a, b, c). We only collected yield data once, while growers harvest multiple times. Our primary goal was to evaluate early season insecticide and row cover effects on whitefly density and virus incidence, not to compare full season whitefly management programs which may have produced greater treatment effects on yield.

On the whole, Venom was less effective than other materials in these trials. Ongoing monitoring of *B. tabaci* to dinotefuran and other group 4 insecticides indicates that whitefly populations in south Florida continue to be susceptible to dinotefuran, but that susceptibility varies in different populations (Smith & Nagel 2014). The results of these trials indicate a role for each material evaluated in managing *B. tabaci* and TYLCV. These results also confirm that chemical control alone may not provide sufficient protection from virus transmission and that growers must employ other tactics, including reflective mulches and TYLCV-tolerant varieties.

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TABLE 6. MEAN CUMULATIVE % (±SEM) OF PLANTS (PER 14-PLANT PLOT) WITH TYLCV SYMPTOMS IN THE FALL 2013 TRIAL TO EVALUATE NOVEL INSECTICIDES FOR SUPPRESSION OF *BEMISIA TABACI* AND TYLCV ON TOMATO (VARIETY 'FLORIDA 47').

		Cumulative % of plants with virus symptoms (SEM)				
		DAT[b]				
Insecticide treatment (g a.i. L^{-1})[a]	Rate amount/ha	27	34	40	47	61
Non-treated	—	51.9(17.2)a	77.2(18.4)a	86.8(9.1)a	90.5(7.3)ab	98.2(1.8)a
Sivanto (200)	2.046 liter	12.5(3.4)bc	41.1(10.7)a	64.3(16.8)a	78.6(16.8)bc	96.4(3.6)a
Sivanto (200) fb Exirel (100)	2.046 liter 1.498 liter	7.1(2.9)bc	37.5(11.1)a	51.8(15.3)a	76.8(14.1)bc	96.4(2.1)a
Sivanto (200) fb pyrifluquinazon (200) + Induce	2.046 liter 0.233 liter 0.25% vol/vol	3.6(3.6)c	16.1(9.4)a	33.9(7.4)a	71.4(10.5)c	100.0(0.0)a
Verimark (200)	1.023 liter	20.5(12.0)bc	65.1(19.7)a	74.6(18.5)a	85.3(8.9)a-c	100.0(0.0)a
Verimark (200) fb Sivanto (200)	1.023 liter 1.498 liter	26.8(14.7)b	50.0(21.6)a	60.7(17.6)a	89.3(6.2)a-c	100.0(0.0)a
Verimark (200) fb pyrifluquinazon (200) + Induce	1.023 liter 0.233 liter 0.25% vol/vol	17.9(4.6)b	48.2(12.8)a	66.1(12.8)a	91.1(5.4)ab	98.2(1.8)a
Venom 70% a.i.	170.0 g	26.8(11.1)ab	75.0(6.2)a	87.5(3.4)a	98.2(1.8)a	100.0(0.0)a
Venom 70% a.i. fb Exirel (100)	170.0 g 1.498 liter	14.6(2.9)bc	53.2(10.0)a	74.7(6.0)a	96.4(2.1)ab	100.0(0.0)a
Venom 70% a.i. fb pyrifluquinazon (200) + Induce	170.0 g 0.233 liter 0.25% vol/vol	28.6(9.7)ab	58.9(12.5)a	76.8(7.9)a	100.0(0.0)a	100.0(0.0)a
$F_{9,27}$		2.78	2.18	2.17	2.44	1.13
P-value		0.0192	0.0568	0.0584	0.0355	0.3792

Means within columns not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a] A '+' sign indicates the products were combined, 'fb' means followed by. [b] Fall 2013 means reflect only data from the non-covered plots. DAT = days after transplant.

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TABLE 7. MEAN YIELD, LBS./10 PLANTS, (±SEM) FROM A SINGLE HARVEST (22 MAY) OF THE SPRING 2013 TRIAL TO EVALUATE NOVEL INSECTICIDES FOR SUPPRESSION OF *BEMISIA TABACI* AND TYLCV ON TOMATO (VARIETY 'FLORIDA 47').

		Yield (22 May 2013)		
	Rate	Marketable[b]	Cull	Total
Insecticide treatment (g a.i. L^{-1})[a]	amount/ha	lbs./10 plants (SEM)		
Section 1. Main plot effects (chemical)				
Non-treated	—	20.9(2.4)cd	3.0(0.4)c-e	23.9(2.4)d
Sivanto (200)	2.046 liter	20.5(1.8)d	3.4(0.5)c-e	23.9(1.9)d
Sivanto (200)	2.046 liter			
fb Exirel (100)	1.498 liter	43.2(1.5)ab	5.7(0.7)a	48.9(1.3)ab
Sivanto (200)	2.046 liter			
fb pyrifluquinazon (200)	0.233 liter			
+ Induce	0.25% vol/vol	24.1(1.2)cd	3.7(0.8)cd	27.8(1.3)cd
Verimark (200)	1.023 liter	28.4(9.8)cd	2.5(0.4)de	30.9(9.7)cd
Verimark (200)	1.023 liter			
fb Sivanto (200)	1.498 liter	32.6(1.7)bc	5.5(0.4)ab	38.1(1.7)bc
Verimark (200)	1.023 liter			
fb pyrifluquinazon (200)	0.233 liter			
+ Induce	0.25% vol/vol	26.0(1.8)cd	3.7(0.5)cd	29.7(2.0)cd
Venom 70% a.i.	170.0 g	20.3(1.6)d	2.0(0.5)e	22.3(1.7)d
Venom 70% a.i.	170.0 g			
fb Exirel (100)	1.498 liter	46.0(2.9)a	5.4(0.7)ab	51.4(3.1)a
Venom 70% a.i.	170.0 g			
fb pyrifluquinazon (200)	0.233 liter			
+ Induce	0.25% vol/vol	27.6(2.1)cd	4.1(0.6)bc	31.7(2.5)cd
$F_{9,27}$		5.07	6.75	6.41
P-value		0.0005	<0.0001	<0.0001
Row-cover treatment	Timing			
Section 2. Sub-plot effects (cover)				
Non-covered	—	29.8(2.4)a	4.1(0.3)a	33.9(2.5)a
Cover installed	at plant			
fb cover removed	14 DAT[c]	28.2(1.6)a	3.6(0.3)a	31.8(1.8)a
$F_{1,30}$		0.51	2.38	0.82
P-value		0.4804	0.1335	0.3726
Section 3. Interaction effects (chemical x cover)				
$F_{9,30}$		0.79	0.45	0.75
P-value		0.6238	0.8966	0.6650

Means within columns of a section not followed by the same letter are significantly different using Fisher's Protected LSD ($P \leq 0.05$). [a]A '+' sign indicates the products were combined, 'fb' means followed by. [b] Marketable includes small, medium, large and extra large size fruit which were free of defects. [c] DAT = days after transplant.

Florida's subtropical conditions produce year-round pest pressure, which in turn leads growers to spray intensively to manage pests of high value horticultural crops such as tomato. Programs to manage whitefly-transmitted viruses in Florida focus on the integration of tactics to alleviate constant spray pressure and the resulting development of insecticide resistance (Adkins et al. 2011). Crop hygiene, reflective mulches and virus-resistant varieties contribute to whitefly suppression,

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however chemical control remains the primary tactic to suppress *B. tabaci* and the viruses it vectors (Webb et al. 2013).

Reliance on insecticides has led to the development of "treatment windows" for resistance management whereby a given mode of action is applied during specific stages of the crop's development and deliberately avoided during subsequent intervals (Flood & Wyman 2005). The treatment window approach aims to avoid treating sequential generations of a given pest with the same mode of action. The treatment window that encompasses the first 5 or 6 weeks after transplanting is possibly the most important for management of *B. tabaci* and TYLCV. Data presented here confirm that novel modes of action that are newly available or nearing registration for use on tomato can be effectively combined during this treatment window to reduce transmission of TYLCV compared with untreated plants. From the perspective of both resistance management and virus suppression the availability of several insecticides with distinct modes of action and antifeedant properties is advantageous. We deliberately focused on early-season protection rather than season-long whitefly management in our evaluation of new materials because yield losses diminish the later the crop is infected with TYLCV. Our efforts to compare the efficacy of at-plant treatments when plants were exposed to viruliferous whiteflies at planting versus 2 weeks after planting by protecting plots with row covers met with limited success because virus pressure was very low in the spring trial and the row cover treatment failed in the fall 2013. However results from fall 2012 indicate that no at-plant treatment was comparable to complete mechanical exclusion of whitefly during the first 2 weeks post-transplant.

Given that viruliferous *B. tabaci* can transmit TYLCV within approximately 15 min of feeding, antifeedant properties in an insecticide are essential for managing the vector and the virus (Mehta et al. 1994). Cyantraniliprole and pyrifluquinazon have each demonstrated antifeedant properties in laboratory studies. Kang et al. (2012) observed inhibition of feeding behavior among *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) treated with pyrifluquinazon. Jacobson & Kennedy (2013a) documented a reduction in feeding probes by *M. persicae* on pepper (*Capsicum annuum*) treated with cyantraniliprole 10 days post-treatment. The same authors (2013b) measured a reduction in the number and duration of probes by *Frankliniella fusca* (Thysanoptera: Thripidae) feeding on pepper treated with cyantraniliprole. Cameron et al. (2013) used fluorescent dye to show feeding reduction on the part of *B. tabaci* nymphs on cotton treated with cyantraniliprole. In addition, settling and feeding behavior of *Diaphorini citri* Kuwayama (Hemiptera: Psyllidae) was reduced on citrus treated with cyantraniliprole (Tiwari & Stelinski 2013). Cyantraniliprole, flupyradifurone and pyrifluquinazon have also reduced egg-laying by *B. tabaci* in greenhouse studies (Tokumaru et al. 2010, Smith and Giurcanu 2013).

Antifeedant properties have also been identified in established insecticides that are available for whitefly management. These include pymetrozine (Fulfill®, Syngenta Crop Protection, Greensboro NC; IRAC group 9B) and bifenthrin (many formulations; IRAC group 3A). Pymetrozine interferes with the functioning of the cibarial pump in certain hemipterans. Hai-Hong et al. (2011) demonstrated that at 300 mg/L pymetrozine inhibits stylet penetration by *B. tabaci*, and Polston & Sherwood (2003) implicated pymetrozine in the reduction of transmission of TYLCV. He et al. (2013) demonstrated that sublethal doses of bifenthrin reduced phloem feeding by *B. tabaci* on cotton, a behavior change that may reduce transmission of TYLCV and other viruses in susceptible crops. Smith & Giurcanu (in press) found that an insecticide containing bifenthrin and zeta-cypermethrin (Hero®, FMC Corporation, Philadelphia PA) suppressed transmission of TYLCV in greenhouse studies on a level similar to flupyridifurone in tomato that were exposed to viruliferous whitefly 3 and 7 days after treatment. Current recommendations are that broad spectrum insecticides such as pyrethroids be reserved for use later in the tomato cropping season (Mossler et al. 2009). However there may be justification for the targeted use of materials such as bifenthrin within the first 6 weeks of transplanting as part of a diversified rotation of modes of action with antifeedant properties that can reduce transmission of TYLCV.

Additional field trials are needed to determine optimal rotations of new and established materials for suppressing TYLCV while offsetting the development of resistance. Pre-plant, at-plant and early drip injected treatments will employ systemic materials primarily in the group 4 and group 28 categories. The use of alternative modes of action is advised for the second post-transplant treatment window. While dinotefuran continues to offer effective suppression of TYLCV in many regions, its efficacy was not comparable to newer materials in these trials, underlining the need for additional modes of action. Sivanto has a similar mode of action as the neonicotinoid insecticides and should probably be treated as a neonicotinoid from the perspective of resistance management. Its efficacy in suppressing TYLCV, particularly in combination with pyrifluquinazon, is noteworthy in these trials.

The role of Verimark and Exirel in suppressing TYLCV during the first treatment window will influence decisions growers make regarding the use of diamides to manage caterpillars and leafminers in subsequent treatment windows. Resistance

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management guidelines for diamides have been developed for Florida tomato (Smith 2013). Unlike the other diamides used for management of caterpillars and leafminers on tomato, cyantraniliprole has major efficacy against sucking insects and has been implicated in the reduction of transmission of TYLCV. Growers who plan to use Verimark for protection of tomato against TYLCV during the first five weeks after transplanting are advised to use alternatives to diamides to manage caterpillars and leafminers for the second five-week window should these pests be detected at economic levels during that time frame (Smith 2013). The yield data from spring 2013, when whitefly and virus pressure was low, indicated that cyantraniliprole-treated plants had higher yield than other plants.

The availability of three new modes of action for managing TYLCV provides new tools to growers who rely heavily on insecticide applications to manage the virus. The continued efficacy of these products will require that growers practice good resistance management tactics. This includes integrating chemical control with the use of reflective mulches and resistant varieties, and destructing virus reservoirs such as harvested tomato fields.

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References Cited

Adkins, S., Webster, C. G., Kousik, C. S., Webb, S. E., Roberts, P. D., Stansly, P. A., and Turechek, W. W. 2011. Ecology and management of whitefly-transmitted viruses of vegetable crops in Florida. Virus Res. 159(2): 110-114.

Brown, J. K., Frohlich, D. R., and Rosell, R. C. 1995. The sweetpotato or silverleaf whiteflies: biotypes of *Bemisia tabaci* or a species complex? Annu. Rev. Entomol. 40: 511-534.

Cameron, R., Lang, E. B., Annan, I. B. Protillo, H. E., and Alvarez, J. M. 2013. Use of fluorescence, a novel technique to determine reduction in *Bemisia tabaci* nymph feeding when exposed to Benevia and other insecticides. J. Econ. Entomol. 106(2): 597-603.

Castle, S. J., Palumbo, J. C., Prabhaker, N., Horowitz, A. R., and Denholm, I. 2010. Ecological determinants of *Bemisia tabaci* resistance to insecticides. Ch. 16, pp. 423-465 *In* P. Stansly and S. E. Naranjo [eds.], *Bemisia*: Bionomics and Management of a Global Pest. Springer Science and Business Media B. V., Dordrecht, Netherlands.

Cohen, S., and Nitzhany, F. E. 1966. Transmission and host range of the tomato yellow leaf curl virus. Phytopathology 56: 1127-1131.

Czosnek, H., Ghanim, M., and Ghanim, M. 2002. The circulative pathway of begomoviruses in the whitefly vector *Bemisia tabaci* – insights from studies with *Tomato yellow leaf curl virus*. Ann. Appl. Biol. 140: 215-231.

Czosnek, H., and Ghanim, M. 2011. *Bemisia tabaci* – Tomato Yellow Leaf Curl Virus Interaction causing worldwide epidemics. Ch. 3, pp. 51- 67 *In* W. M. O. Winston [ed.], The whitefly *Bemisia tabaci* : Interaction with Geminivirus-Infected Host Plants. Springer.

Flood, B., and Wyman, J. A. 2005. Ch. 3 *In* Beans in Vegetable Insect Management. Meister Publishing Company, Willoughby, OH.

Gilbertson, R. L., Rojas, M., and Natwick, E. 2011. Development of Integrated Pest management Strategies for whitefly-transmissible geminiviruses. Ch. 12 *In* W. M. O. Winston [ed.], The Whitefly *Bemisia tabaci*: Interaction with Geminivirus Infected Host Planst. Spring Science+Business Media BV.

Glick, E., Levy, Y., and Gafni, Y. 2009. The viral etiology of Tomato yellow leaf curl disease – a review. Plant Prot. Sci. 3: 81-97.

He, Y., Zhao, J., Zheng, Y., Weng, Q., Biondi, A., Desneux, N., and Wu, K. 2013. Assessment of potential sublethal effects of various insecticides on key biological traits of the tobacco whitefly, *Bemisia tabaci*. Intl. J. Biol. Sci. 9(3): 246-255.

Jacobson, A. L., and Kennedy, G. G. 2013a. Electrical penetration graph studies to investigate the effects of cyantraniliprole on feeding behavior of *Myzus persicae* on *Capsicum annuum*. Pest Mgt. Sci. 70(5): 836-840.

Jacobson, A. L., and Kennedy, G. G. 2013b. Effect of cyantraniliprole on feeding behavior and virus transmission of *Frankliniella fusca* and *Frankliniella occidentalis* on *Capsicum annuum*. Crop Prot. 54: 251-258.

Jones, D. R. 2003. Plant viruses transmitted by whiteflies. European J. Plant Pathol. 109: 195-219.

Kang, M. A., Seo, M. J., Hwang, I. C., Jang, C., Park, H. J., Yu, Y. M., and Youn, Y. N. 2012. Insecticidal activity and feeding behavior of the green peach aphid, *Myzus persicae*, after treatment with nano types of pyrifluquinazon. J. Asia-Pacific Entomol. 15(4): 533-541.

Lapidot, M., and Levy, D. 2010. The effect of TYLCV on tomato yield depends upon the age of the plant at time of inoculation, pp. 16-19 *In* Proc. Florida Tomato Inst. Univ. Florida, Naples, FL.

Levy, D., and Lapidot, M. 2008. Effect of plant age at inoculation on expression of genetic resistance to tomato yellow leaf curl virus. Arch. Virol. 153: 171-179.

Liu, B., Preisser, E. L., Chu, D., Pan, H., Xie, W., Wang, S., Wu, Q., Zhou, X., and Zhang, Y. 2013. Multiple forms of vector manipulation by a plant-infecting virus: *Bemisia tabaci* and *Tomato yellow leaf curl virus*. J. Virol. 87: 4929-4937.

Ma, W., Li, X., Dennehy, T. J., Lei, C., Wang, M., Degain, B. A., and Nichols, R. I. 2010. Pyriproxifen resistance of *Bemisia tabaci* biotype B: metabolic mechanism. J. Econ. Entomol. 103(1): 158-165.

Mansour, A., and Al-Musa, A. 1992. Tomato yellow leaf curl: host-range and virus-vector relationships. Plant Pathol. 41: 122-125.

McKenzie, C. L., Hodges, G., Osborne, L. S., Byrne, F. J., and Shatters, R. G. 2009. Distribution of *Be-*

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misia tabaci biotypes in Florida - Investigating the Q invasion. J. Econ. Entomol. 102(2): 670-676.

MEHTA, P., WYMAN, J. A., NAHKLA, M. K., AND MAXWELL, D. P. 1994. Transmission of tomato yellow leaf curl geminivirus by *Bemisia tabaci*. J. Econ. Entomol. 87: 1291-1297.

MORENO-DELAFUENTE, A, GARZO, E., MORENO, A., AND FERERES, A. 2013. A plant virus manipulates the behavior of its whitefly vector to enhance its transmission efficiency and spread. PLoS One 8, e61543,

MORIONES, E., AND NAVAS-CASTILLO, J. 2010. Tomato yellow leaf curl disease epidemics. Ch. 8, pp. 259-282 *In Bemisia*: Bionomics and Management of a Global Pest. Springer Science+Business Media B. V.

MOSLER, M., AERTS, M. J., AND NESHEIM, O. N. 2009. Florida Crop/Pest Management Profiles: Tomatoes. Univ. Florida, IFAS Coop. Ext. Circular 1238.

PALUMBO, J. C. 2012a. Sweetpotato whitefly control with foliar insecticides on fall cantaloupes, 2011. Arthropod Mgt. Tests 37: E19.

PALUMBO, J. C. 2012b. Control of sweetpotato whitefly adults and virus incidence with foliar insecticides on spring cantaloupes, 2011. Arthropod Mgt. Tests 37: E20.

POLSTON, J. E., AND SHERWOOD, T. 2003. Pymetrozine interferes with transmission of Tomato yellow leaf curl virus by the whitefly *Bemisia tabaci*. Phytoparasitica 31(5): 490-498.

RAO, Q., XU, Y. H., LUO, H. Y., ZHANG, C. M., DEVINE, G. J., GORMAN, K., AND DENHOM, I. 2012. Characterization of neonicotinoid and pymetrozine resistance in strains of *Bemisia tabaci* (Hemiptera: Aleyrodidae) from China. J. Integr. Agric. 11(2): 321-326.

SAS INSTITUTE INC. 2008. SAS Institute Inc SAS.STAT user guide version 9.2. SAS Institute Inc., Cary, NC.

SCHUSTER, D. J. 2001. Relationship of silverleaf whitefly density to severity of irregular ripening of tomato. HortScience 36: 1089-1091.

SCHUSTER, D. J. 2002. Action threshold for applying growth regulators to tomato for management of irregular ripening caused by *Bemisia argentifolii* (Homoptera: Aleyrodidae). J. Econ. Entomol. 95(2): 372-376.

SCHUSTER, D. J., STANSLY, P. A., POLSTON, J. E., GILREATH, P. R., AND MCAVOY, E. 2007. Management of whiteflies, whitefly vectored plant virus and insecticide resistance for vegetable production in southern Florida. Univ. Florida, IFAS. EDIS Publ. ENY 735.

SCHUSTER, D. J., STANSLY, P. A., GILREATH, P. R., AND POLSTON, J. E. 2008. Management of *Bemisia*, TYLCV, and insecticide resistance in Florida vegetables. J. Insect Sci. 8(4): 43-44. insectscience.org/8.04.

SCHUSTER, D. J., PERES, N. A., WILLIAMS, R. W., MARCON, P. C., AND PORTILLO, H. E. 2008b. DuPont Rynaxypyr™ (DPX-E2Y45): A novel anthranilamide insecticide for managing *Bemisia tabaci* and interfering with transmission of Tomato yellow leaf curl virus on tomato transplants. J. Insect Sci. 8(4): 43. insectscience.org/8.04.

SCHUSTER, D. J. SHURTLEFF, A., AND KALB, S. 2009a. Soil and foliar insecticide applications for control of silverleaf whitefly in fresh market tomatoes, fall 2006. Arthropod Mgt. Tests 34: E73.

SCHUSTER, D. J. SHURTLEFF, A., AND KALB, S. 2009b. Control of the silverleaf whitefly on fresh market tomatoes with soil and foliar insecticide applications, Spring 2007. Arthropod Mgt. Tests 34: E76.

SCHUSTER, D. J. SHURTLEFF, A., AND KALB, S. 2009c. Soil and foliar insecticide applications for control of silverleaf whitefly in fresh market tomatoes, Fall 2007. Arthropod Mgt. Tests 34: E77.

SCHUSTER, D. J., MANN, R. S., TOAPANTA, M., CORDERO, R., THOMPSON, S., CYMAN, S., SHURTLEFF, A., AND MORRIS II, R. F. 2010. Monitoring neonicotinoid resistance in biotype B of *Bemisia tabaci* in Florida. Pest Mgt. Sci. 66(2): 186-195.

SMITH, H. A., AND GIURCANU, M. C. 2013. Residual effects of new insecticides on egg and nymph densities of *Bemisia tabaci*. Florida Entomol. 96(2): 504-511.

SMITH, H. A. 2013. Managing diamide resistance in Florida tomato. ENY867, UF/IFAS, Gainesville, FL. 3 pp.

SMITH, H. A., AND GIURCANU, M. C. 2014. New insecticides for management of Tomato yellow leaf curl, a virus vectored by *Bemisia tabaci*. J. Insect Sci. (in press).

SMITH, H. A., AND NAGLE, C. A. 2014. Susceptibility of *Bemisia tabaci* to group 4 insecticides. Tomato Research Report. Univ. Florida, IFAS. Gainesville FL. pp. 20-22.

STANSLY, P. A., KOSTYK, B., AND REIFER R. 2008. Control of silverleaf whitefly and spread of Tomato yellow leaf virus on staked tomato with insecticides, 2007. Arthropod Mgt. Tests E51.

TIWARI, S., AND STELINSKI, L. L. 2013. Effects of cyantraniliprole, a novel anthranilic diamide, against Asian citrus psyllid under laboratory and field conditions. Pest Mgt. Sci. 69(9): 1066-1072.

TOKUMARU, S., AND HAYASHIDA, Y. 2010. Pesticide susceptibility of Q-biotype *Bemisia tabaci*. Japanese J. Appl. Entomol. Zool. 54: 13-21.

VELTEN, R., JESCHKE, P., HAAS, M., AND KUNZ, K. 2013. Discovery of Sivanto™, a new butenolide insecticide. Abstracts of American Chem. Soc. 246: 238-AGRO.

YASUNGA, R., IKUTA, J., MURATA, Y., INOUE, K., KOGA, H., MASAKI, T., AND TAMURA, H. 2012. Ligand-independent androgen receptor antagonism caused by the newly developed insecticide pyrifluquinazon. Reproductive Toxicol. 35: 1-6.

USDA NASS. 2013. http://usda01.library.cornell.edu/usda/current/VegeSumm/VegeSumm-01-29-2013.pdf .

WANG, H., LEI, Z., L., YUE, M., LI, S., AND JI, Y. 2011. Effect of pymetrozine interferes with feeding behavior of *Bemisia tabaci*. Chinese J. Appl. Entomol. 48(1): 54-59.

WEBB, S. E., STANSLY, P. A., SCHUSTER, D. J., FUNDERBURK, J. E., AND SMITH, H. A. 2013. Insect management for tomatoes, peppers, and eggplant. ENY461. UF/IFAS, Gainesville, FL.

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