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Research

Pest Management

Host Preference and Plastic Mulches for Managing Melon Thrips (Thysanoptera: Thripidae) on Field-Grown Vegetable Crops

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Abstract

Melon thrips, *Thrips palmi* Karny (Thysanoptera: Thripidae), is a serious pest of vegetable, ornamental, and fruit crops. As a potential component of an integrated pest management (IPM) program, different plastic mulches including white-on-black, black-on-white, black-on-black, two metalized ultraviolet (UV)-reflective mulches, and a no mulch control were evaluated for managing *T. palmi* on six field-grown vegetable crops (eggplant, cucumber, squash, snap bean, Jalapeno pepper, and tomato) during the Fall of 2015 and 2016. Metalized reflective mulch significantly reduced the number of *T. palmi* in all vegetable crops compared with the other treatments. The highest numbers of *T. palmi* were observed on the white-on-black mulch and control treatments. The numbers of adults and larvae were highest on eggplant followed by cucumber, snap bean, squash, and Jalapeno pepper. The lowest numbers of *T. palmi* were observed on tomato plants. This study indicated that growing vegetable crops on metalized mulch is an effective method of reducing *T. palmi* populations in vegetable crops and should be considered in IPM programs for this insect species.

Key words: *Thrips palmi*, reflective mulch, vegetable crop, integrated pest management

Florida is one of the leading vegetable producing states in the United States. In 2016, vegetable crops including snap beans, bell peppers, tomatoes, eggplants, squash, and cucumbers were grown in Florida on 43,301 ha of land and generated approximately US$1,300 million (USDA NASS 2018). However, Florida vegetable growers have to combat many destructive native and invasive insect pests. Melon thrips, *Thrips palmi* Karny, is an invasive pest species in the United States that is native to Sumatra, Indonesia (Karny 1925, Johnson 1986). Since invading Miami-Dade County, FL, in 1990, *T. palmi* has been a devastating pest, causing severe damage to nearly all vegetable and ornamental crops (Seal and Baranowski 1992). Feeding of *T. palmi* adults and larvae often results in discoloration and distortion of the fruit, which lowers the marketable yield (Kawai 1990, Tsai et al. 1995, Seal et al. 2013). In the absence of effective control measures, when populations are high, complete defoliation of the host plants can occur within 1 wk (Seal 1997).

Thrips palmi is a polyphagous pest that feeds on more than 50 plant species in over 20 families (Walker 1992). In addition to feeding and oviposition injury, *T. palmi* is a vector of six tospoviruses (Pappu et al. 2009). Growers rated incidence of this pest as the greatest concern for vegetable producers in South Florida (Seal and Sabines 2012). Growers use different classes of insecticides (carbamates, organophosphates, growth regulators, botanicals, spinosyn, neonicotinoids, and diamides) to manage *T. palmi* (Seal 2011, Seal et al. 2013). However, repeated application of these foliar-applied insecticides has resulted in reduced susceptibility causing limited control of *T. palmi* (Seal et al. 2013). Furthermore, the persistent use of broad-spectrum insecticides has led to serious problems including negative effects on pollinators and other nontarget organisms (Geiger et al. 2010). There is an increasing market for organic and chemical-free produce (PMA 2017, www.pma.com). Strategies must be developed to reduce reliance on chemical pesticides. Nyoike and Liburd (2010) showed that living and reflective mulches in combination with imidacloprid increased yields of cucurbits.

Plastic mulch is a standard cultural practice for vegetable production because it provides many benefits such as increasing the effectiveness of fumigation, increasing soil temperature and soil moisture retention, reducing weed pressure, and increasing the efficiency of irrigation and fertilization (Lamont 1993). Specific colors and reflectance properties of metalized plastic mulches with a microscopic layer of silver or aluminum on the surface have the potential to deter or attract insects by influencing their vision behavior (Kring and Schuster 1992, Nyoike and Liburd 2010, Summers et al. 2010, Tyler-Julian et al. 2015). These mulches reduced infestation and disease transmission from a wide variety of insects (Rhainds et al. 2001, Summers and Stapleton 2002, Croxton and Stansly 2014, Nottingham and Kuhar 2016), including flower thrips (Reitz et al. 2003, Riley and Pappu 2004), aphids (Csizinszky et al. 1995), and whiteflies (Frank and Liburd 2005) by disorienting insects during flight to the host plants. Suzuki and Miyara (1983) found that the number of *T. palmi* in cucumbers was lowest when plants were grown on metalized mirror mulch.

Proper knowledge of biology, ecology, behavior, and host plant preference of an insect pest is essential in developing an effective and sound management program (Mound and Teulon 1995). However, information about host preference of *T. palmi* is very scanty. Kawai (1990) and Tsai et al. (1995) reported the host preference of *T. palmi* is based primarily on laboratory studies.

Host preference or suitability of *T. palmi* in field conditions within multicropping systems is largely unknown. There is also little information available on the population abundance of *T. palmi* in crops grown on reflective or colored plastic mulches despite the use of plastic mulch for commercial vegetable production in the United States since the early 1960s. The objectives of this research project were to quantify *T. palmi* adult and larval population densities relative to host crop and mulch treatments in the field and to investigate possible interactions between the host crops and mulch treatment on *T. palmi* population density on the crop foliage. The goal of this study was to provide evidence for specific host crop by mulch treatment combinations that could mitigate *T. palmi* damage in commercial vegetable fields.

Materials and Methods

Study Area, Crop Varieties, Plastic Mulches, and Experimental Design

Experiments were conducted in field research plots at the University of Florida, Tropical Research and Education Center (TREC), Homestead, FL, during the Fall of 2015 and 2016, which is the main vegetable growing season in southern Florida. The six vegetable crops investigated were snap bean (*Phaseolus vulgaris* L. var. Opus, Fabaceae), cucumber (*Cucumis sativus* L. var. Poinsett 76, Cucurbitaceae), yellow squash (*Cucurbita pepo* L. var. Straight neck, Cucurbitaceae), eggplant (*Solanum melongena* L. var. Santana, Solanaceae), pepper (*Capsicum annuum* L. var. Jalapeño-Tormenta, Solanaceae), and tomato (*Solanum lycopersicum* L. var. Charger, Solanaceae). For each crop there were six mulch treatments: 1) 'Shine N' Ripe' (1.25 mil Metalized top and black bottom), 2) 'Can-Shine' (1 mil metalized top and white bottom), 3) 'Black' plastic black-on-black (Can-Grow-XSB, 0.6 mil), 4) black-on-white (Can-Grow XSB, 0.9 mil), 5) 'White' plastic; white-on-black (Can-Grow XSB, 0.9 mil), and 6) bare soil with no mulch as the control. The mulches were manufactured by Canslit, Inc., Victoriaville, QC, Canada, and supplied by Imaflex, Inc., Thomasville, NC.

The experiment was arranged in a split-plot design with mulch treatment as the main plot and within each of the six main plots, crop species as the split plots. Main plots were arranged randomly within four blocks (replications). Within each main plot, the six split plots were arranged randomly.

Blocks were separated by 3 m of unplanted area (buffer zone). Crops were planted on raised beds of Krome very gravelly loam soil, classified as a loamy-skeletal, carbonatic, hyperthermic lithic udorthents (Noble et al. 1996). Beds were prepared with a Kennco superbedder (Kenco Manufacturing Company Inc., Atoka, OK). Each bed was 91 cm wide and 15 cm high with 1.83 m between centers. For each crop, granular fertilizer (N-P-K: 6-12-12; Loveland Products Inc., Greely, CO) was applied at 1,307 kg/ha in two furrows, 20 cm from the plant on each side of the bed and was incorporated within the top 15 cm of the soil prior to planting. Halosulfuron methyl (55 g/ha, Sandea, Gowan Company LLC., Yuma, AZ) was applied between rows as a pre-emergence herbicide. Plastic mulch treatments were placed on the beds using a plastic layer (Kennco micro-combo, Kenco Manufacturing Co Inc., Atoka, OK). In 2015, mulches were placed on the beds 2 wk prior to planting, and in 2016, mulches were placed on the beds 3 d prior to planting. The drip tape, which ran the entire length of each bed, had irrigation emitters spaced 30 cm apart. Each bed was divided into six 4.6-m subplots, one for each crop, with a 61-cm nonplanted buffer zone between adjacent subplots.

Crop Establishment

Holes (7 cm diameter) for seeding and transplanting were manually cut into each mulch with a metallic hole digger. Transplants of tomato, eggplant, and pepper were grown in an insect free greenhouse. Five-week-old transplants of tomato, eggplant, and pepper were planted manually within the beds spaced 45, 45, and 31 cm, respectively. Two seeds of squash, three seeds of cucumber and three seeds of snap bean were manually seeded in the field 31, 31, and 15 cm apart, respectively. Following germination, squash and cucumber were thinned to one plant and snap bean to two plants per hole. In 2015 and 2016, planting was done on 13th and 6th November, respectively. Seedlings of tomato, pepper, and eggplant were transplanted on the day that 95% of bean, squash, and cucumber seeds had germinated so that the leaf area was visually similar among all crops and create homogeneous foliage situation for *T. palmi* adults.

Crop Management

After transplanting, approximately 230 ml of starter fertilizer (20-20-20: N-P-K; Diamond R Fertilizer Inc., Ft. Pierce, FL) solution (20 g/3.78 liter of water) was applied as a drench at the base of each transplant (ca. 30 ml) using a manually propelled backpack sprayer (Birchmeier Spruhtechnik AG, Stetten, Switzerland) without a nozzle tip. The crops were irrigated for 30 min twice daily (9:30 a.m. and 3:30 p.m.). The drip irrigation system delivered 1.51 l/min per 30.48 m. Consequently, the total amount of water delivered each day was 181 l/28 m^2. However, for the first 4 wk after planting, irrigation times were reduced to 15 min to avoid overwatering. Three weeks after planting, liquid fertilizer (N-P-K: 3-0-10; Helena Chemical Co., Alachua, FL) was injected through the drip tubes at 325 l/ha to provide 1.6 kg of N_2/ha. To control lepidopteran pests including melonworms, *Diaphania hyalinata* (L.), and pickleworms, *Diaphania nitidalis* (Stoll), the insecticides DiPel DF (*Bacillus thuringiensis* var. Kurstaki strain ABTS-351, Valent Biosciences Co., Walnut Creek, CA) and Xentari DF (*B. thuringiensis* var. Aizawa Valent Biosciences Co., Walnut Creek, CA) each was applied at 2.24 kg/ha as needed. To control bacterial and fungal pathogens, copper hydroxide (0.8 l/ha, Kocide 3000, BASF Ag Products, Research Triangle Park, NC), chlorothalonil (1.75 l/ha, Bravo Weather Stik, Syngenta Crop Protection Inc., Greensboro, NC), and Mancozeb (1.681 kg/ha, Dithane DF, Dow Agro Sciences, Indianapolis, IN) were used in weekly rotation. Weeds were manually removed.

Sampling Leaves for Thrips

In 2015 and 2016, leaf sampling began 3 wk after planting of all crops and continued weekly for 5 wk. Five randomly selected fully expanded leaves, one leaf per plant, from each subplot (crop) in each mulch treatment were collected at each sampling date. Leaves were selected from the middle third of each plant. Sampled leaves were placed in a 1-liter plastic cup with a thrips-proof lid; the cups were marked with the block number, mulch treatment, and crop. All cups were transported to the vegetable IPM laboratory at TREC and leaves were soaked in 75% ethanol for 30 min to dislodge thrips adults and larvae. The leaves were then removed from the cup leaving the thrips in alcohol, which was then passed through a 25-µm metal sieve (325-mesh, USA Standard Testing Sieve, W. S. Tyler, Inc., Mentor, OH) leaving thrips in the sieve. Residue from the sieve was then rinsed with 75% alcohol into a Petri dish. The Petri dish was examined under a stereo microscope (Leica MZ6, Micro-optics of Florida, Inc., Davie, FL) at 10× to determine the number of *T. palmi* adults and larvae in each sample as described by Seal and Baranowski (1992). *Thrips palmi* adults were counted separately as females or males based on the presence or absence of an ovipositor on the ventral surface of the ninth abdominal segment. On each sampling date, 10 leaves for each crop representing all mulch treatments were collected from middle stratum and measured using a leaf area meter (LI-3000C, LI-COR Biosciences, Lincoln, NE). The number of *T. palmi* on each leaf was divided by the mean leaf area to obtain the number of thrips per square centimeter area on a specific crop. The number of *T. palmi* in each square centimeter area was then multiplied by 25 to obtain the number of thrips per unit area for each crop. We selected 25 cm^2 as a unit area because, pepper, the crop with the smallest leaves, had a mean leaf area of about 25 cm^2 on the first sampling date.

Leaf Trichome Density

In 2016, at 50 d after planting (DAP), three leaves per crop (one leaf per plant) from each crop treatment were collected from the middle third of each sample plant and cut into four 10 mm^2 discs. Trichome density per 1,000 μm^2 area of each leaf disc was determined with digital microscope (VHX-5000, Multi-scan, KEYENCE America) at a 150× magnification for eggplant, cucumber, squash, tomato, and pepper, and 200× magnification for snap bean. Three 1,000 μm^2 areas were observed per disc for 12 replications per crop. Trichome density was quantified at 50 DAP because melon thrips density was higher at 50 DAP than at the previous sampling.

Weather Data

Over the experimental period, monthly weather data (temperature, rainfall, and relative humidity) were obtained from the Homestead station of the Florida Automated Weather Network (FAWN; https://fawn.ifas.ufl.edu/), which was less than 300 m from the field plots.

Data Analyses

The number of *T. palmi* adults and larvae were subjected to a log (sqrt (x) + 0.5) transformation before statistical analyses to meet the assumption of normality. Nontransformed means are reported in the tables and figure. Data were analyzed using mixed model analysis of variance (ANOVA) with sample date, mulch, and crop type as fixed variables (PROC GLIMMIX, SAS version 9.3, SAS Institute Inc., Cary, NC). In the PROC GLIMMIX model, the method of Kenward–Roger was used to estimate degrees of freedom. Replicate and treatment (mulch and crop) were considered as random residuals for repeated-measure analyses. For the number of adults and larvae of *T. palmi* when the *F*-value was significant, differences among means were separated using Tukey's Honestly Significant Difference (P = 0.05) procedure in SAS (SAS Institute Inc. 2013). Trichome density was analyzed using the PROC GLIMMIX model by a one-way ANOVA. Jalapeno pepper was excluded from trichome density data analysis because no trichomes were found in a 1,000 μm^2 area on this crop.

Results

Mulch Effects on the Population Density of *T. palmi*

Adult Density

In both years, mulch treatment and sampling date significantly affected the density of *T. palmi* adults found on the leaves. In addition, there were significant interactions between sampling date and mulch treatment and mulch treatment and crop on adult thrips density (Table 1). Regardless of sampling date and crop, the metalized reflective mulch treatments significantly reduced the adult population density compared with the white-on-black mulch and no mulch control treatments in both years (Table 2). The density of adults was moderate in the black-on-black and black-on-white mulch treatments. From the first to fourth sampling dates in 2015, there were significantly fewer adults in metalized mulch treatments than in the control or white-on-black mulch treatments (Table 3). However, the number of adults in the metalized mulch treatments did not differ significantly from those in the other non-UV-reflective

Table 1. ANOVA of date, mulch, and crop main effects and interactions for the number of adult *Thrips palmi* per 25 cm^2 leaf area

Year	Effect	df	*F*	*P*
2015	Date	4, 522	154.03	<0.0001
	Mulch	5, 18	22.93	<0.0001
	Date × mulch	20, 522	6.84	<0.0001
	Crop	5, 522	127.85	<0.0001
	Date × crop	20, 522	4.44	<0.0001
	Mulch × crop	25, 522	1.87	0.0067
	Date × mulch × crop	100, 522	1.10	0.2537
2016	Date	4, 522	383.77	<0.0001
	Mulch	5, 18	11.44	<0.0001
	Date × mulch	20, 522	4.54	<0.0001
	Crop	5, 522	256.52	<0.0001
	Date × crop	20, 522	8.25	<0.0001
	Mulch × crop	25, 522	3.61	<0.0001
	Date × mulch × crop	100, 522	1.30	0.0355

Table 2. Mean ± SE number of *Thrips palmi* in six mulch treatments based on the number per 25 cm^2 leaf area of six vegetable crops; sampling dates and crops pooled

Mulch	Thrips stage			
	Adult		Larva	
	2015	2016	2015	2016
No mulch	3.3 ± 0.5a[1]	1.4 ± 0.2ab	14.5 ± 1.4a	8.2 ± 1.3ab
White on black	3.6 ± 0.5a	1.4 ± 0.2a	12.8 ± 1.5ab	12.2 ± 2.2a
Black on black	1.5 ± 0.2b	1.2 ± 0.2abc	8.5 ± 1.2bc	9.8 ± 1.8a
Black on white	1.6 ± 0.2b	0.8 ± 0.1bdc	6.4 ± 0.8cd	5.1 ± 0.8b
Silver on white	1.2 ± 0.1b	0.4 ± 0.1d	5.6 ± 0.7cd	3.0 ± 0.6b
Silver on black	1.0 ± 0.1b	0.5 ± 0.1cd	4.2 ± 0.5d	3.0 ± 0.5b
Statistics	$F_{5,18} = 22.93$; $P < 0.0001$	$F_{5,18} = 11.44$; $P < 0.0001$	$F_{5,15} = 22.19$; $P < 0.0001$	$F_{5,18} = 11.30$; $P < 0.0001$

Five sampling dates and six vegetable crops per year and for each mulch sample size, *n* = 120.

[1]Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($P = 0.05$).

Table 3. Density of *Thrips palmi* adults in six mulch treatments based on the number per 25 cm^2 leaf area of six vegetable crops

Mulch	Sampling date				
	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
2015					
No mulch	2.21 ± 0.80a[1]	6.10 ± 1.81a	3.78 ± 0.67a	1.79 ± 0.32ab	2.76 ± 0.49a
White on black	0.96 ± 0.27a	5.44 ± 1.43a	4.07 ± 0.67a	2.63 ± 0.47a	4.85 ± 1.36a
Black on black	0.15 ± 0.04b	1.32 ± 0.38b	2.87 ± 0.57ab	1.17 ± 0.18b	2.20 ± 0.39a
Black on white	0.15 ± 0.05b	0.85 ± 0.12b	2.92 ± 0.88ab	1.38 ± 0.21ab	2.90 ± 0.52a
Silver on white	0.19 ± 0.07b	0.66 ± 0.13bc	1.86 ± 0.49bc	1.33 ± 0.26b	1.85 ± 0.32a
Silver on black	0.18 ± 0.05b	0.32 ± 0.05c	0.86 ± 0.19c	1.03 ± 0.19b	2.49 ± 0.45a
Statistics	$F_{5,112.6} = 19.60$; $P < 0.0001$	$F_{5,112.6} = 30.27$; $P < 0.0001$	$F_{5,112.6} = 10.93$; $P < 0.0001$	$F_{5,112.6} = 2.84$; $P = 0.02$	$F_{5,112.6} = 1.39$; $P = 0.23$
2016					
No mulch	0.15 ± 0.06ab	0.31 ± 0.09a	2.05 ± 0.5ab	2.01 ± 0.40ab	2.41 ± 0.46ab
White on black	0.22 ± 0.06a	0.19 ± 0.05ab	1.88 ± 0.30a	2.75 ± 0.50a	1.80 ± 0.33abc
Black on black	0.05 ± 0.02b	0.15 ± 0.04ab	1.27 ± 0.35b	1.41 ± 0.25ab	2.97 ± 0.57a
Black on white	0.04 ± 0.01b	0.09 ± 0.02ab	0.97 ± 0.18b	1.56 ± 0.36ab	1.56 ± 0.29abc
Silver on white	0.05 ± 0.01b	0.06 ± 0.02b	0.40 ± 0.13c	0.73 ± 0.17c	0.97 ± 0.20c
Silver on black	0.07 ± 0.02ab	0.07 ± 0.02ab	0.29 ± 0.07c	0.78 ± 0.12bc	1.47 ± 0.36bc
Statistics	$F_{5,86.21} = 3.45$, $P = 0.007$	$F_{5,86.21} = 3.08$; $P = 0.01$	$F_{5,86.21} = 18.46$, $P < 0.0001$	$F_{5,86.21} = 8.28$; $P < 0.0001$	$F_{5,86.21} = 4.80$; $P = 0.0006$

[1]Data are means ± SE. Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test ($P = 0.05$). DAP (days after planting).

mulch treatments. On the fifth sampling date, there were no significant differences in adult thrips density among treatments. There were no significant differences between the control and the white-on-black mulch treatments for the mean number of *T. palmi* adults during 2015. In 2016, there was no difference in the density of adult thrips among mulch treatments the on the first two sampling dates, when thrips population density was low. Reflective plastic mulch treatments significantly reduced the density of *T. palmi* adults on the third and fourth sampling dates as compared with the control and white-on-black plastic mulch treatments, in which the number of thrips was increased. On the fifth sample date, the density of adults in the silver-on-white reflective mulch treatment was significantly lower than in the no mulch control treatment (Table 3).

Larval Density

In both years, density of *T. palmi* larvae was affected by mulch treatment and sampling date (Table 4), and there was a significant interaction between mulch and sampling date for the density of *T. palmi* larvae on leaves. A significant interaction between mulch treatment and crop was observed for the density of larvae only in 2016 (Table 4). Regardless of crop and sampling date, differences in the density of larvae among mulch treatments were significant, with the lowest density of larvae in the metalized reflective mulches followed by the black-on-white and black-on-black mulch treatments (Table 2). The control and black-on-white mulch treatments had the highest density of larvae. In 2015, from the first to fourth sampling date, the number of larvae was highest in the control and white-on-black mulch treatments followed by black-on-black mulch (Table 5). Consistently, a lower density of larvae was found within metalized reflective mulch and black-on-white mulches than in the other mulch treatments. On the fifth sampling date (49 DAP), there was no difference in the density of larvae among mulch treatments. However, the densities of larvae in the control and white-on-black mulch treatments were about 50% higher than that of the reflective mulch treatments. In 2016, the larval densities were similar to those

Table 4. ANOVA of date, mulch, and crop main effects and interactions for the number of larvae of *Thrips palmi* per 25 cm^2 leaf area

Year	Effect	df	*F*	*P*
2015	Date	4, 432	267.16	<0.0001
	Mulch	5, 15	21.19	<0.0001
	Date × mulch	20, 432	5.96	<0.0001
	Crop	5, 90	155.30	<0.0001
	Date × crop	20, 432	15.12	<0.0001
	Mulch × crop	25, 90	0.89	0.62
	Date × mulch × crop	100, 432	1.37	0.017
2016	Date	4, 432	563.68	<0.0001
	Mulch	5, 18	11.30	<0.0001
	Date × mulch	20, 432	5.50	<0.0001
	Crop	5, 90	277.19	<0.0001
	Date × crop	20, 432	13.58	<0.0001
	Mulch × crop	25, 90	3.68	<0.0001
	Date × mulch × crop	100, 432	1.07	0.33

Table 5. Density of *Thrips palmi* larvae in six mulch treatments based on the number per 25 cm^2 leaf area of six vegetable crops

Mulch	Sampling date				
	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
2015					
No mulch	15.20 ± 4.73a[1]	7.81 ± 1.31a	13.84 ± 2.96a	17.92 ± 3.22ab	17.73 ± 2.68a
White on black	3.71 ± 1.66b	5.16 ± 1.08ab	13.29 ± 2.95a	22.63 ± 4.41a	19.25 ± 3.27a
Black on black	2.80 ± 1.25bc	2.56 ± 0.72bc	5.16 ± 1.18 b	16.75 ± 4.06ab	15.37 ± 2.82a
Black on white	1.50 ± 0.62c	2.18 ± 0.49c	4.21 ± 0.86bc	10.08 ± 1.97bc	14.04 ± 2.12a
Silver on white	1.03 ± 0.36c	1.44 ± 0.38c	4.10 ± 0.98bc	11.08 ± 2.56bc	10.22 ± 1.54a
Silver on black	0.93 ± 0.33c	1.57 ± 0.46c	2.17 ± 0.43c	6.39 ± 1.13c	10.12 ± 1.37a
Statistics	$F_{5,61.5}$ = 28.86; P < 0.0001	$F_{5,61.5}$ = 15.85; P < 0.0001	$F_{5,61.5}$ = 14.15, P < 0.0001	$F_{5,61.5}$ = 6.29; P < 0.0001	$F_{5,61.5}$ = 1.55; P = 0.19
2016					
No mulch	1.72 ± 0.69a	1.45 ± 0.56a	2.21 ± 0.71a	19.60 ± 4.41a	16.01 ± 3.07bc
White on black	1.52 ± 0.77a	1.51 ± 0.47a	1.53 ± 0.40ab	29.69 ± 8.06a	26.64 ± 4.46a
Black on black	0.32 ± 0.11b	0.60 ± 0.24ab	1.22 ± 0.38ab	23.44 ± 6.11a	23.30 ± 4.57ab
Black on white	0.34 ± 0.15b	0.41 ± 0.18b	0.86 ± 0.28abc	12.50 ± 2.62a	11.16 ± 2.01bc
Silver on white	0.61 ± 0.21ab	0.66 ± 0.21ab	0.65 ± 0.18bc	3.17 ± 0.70b	10.03 ± 2.32c
Silver on black	0.77 ± 0.29ab	0.82 ± 0.29ab	0.48 ± 0.18c	3.74 ± 0.92b	9.35 ± 1.82c
Statistics	$F_{5,92.86}$ = 5.99; P < 0.0001	$F_{5,92.86}$ = 3.77; P = 0.004	$F_{5,92.86}$ = 6.25; P < 0.0001	$F_{5,92.86}$ = 17.12; P < 0.0001	$F_{5,92.86}$ = 6.68; P < 0.0001

[1]Data are means ± SE. Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test (P = 0.05). DAP (days after planting).

in 2015 except on the first two and the last sampling dates. When the larval population density was highest on all crops (lasting from the third sampling date to the last sampling date), fewer larvae were sampled from plants in either reflective mulch treatments than in the other treatments (Table 5).

Crop Effects on the Population Density of *T. palmi*

Adult Density

In both years, there were significant effects of crop on the density of adult *T. palmi* (Table 2). Regardless of sampling date and mulch treatment, eggplant, cucumber, and squash had the highest number of *T. palmi* adults followed by snap bean (Table 6). Pepper and tomato had significantly the lowest number of *T. palmi* adults in 2015. However, in 2016, significantly more *T. palmi* adults were observed on eggplant than on all other crop treatments. Statistically, the highest number of *T. palmi* adults was found on eggplant followed by cucumber and squash, then snap bean, and pepper, with the number on tomato significantly lower than on all other crops (Table 6). In both years, date and crop showed significant interactions (Table 2). Across the five sampling dates, there were always significant differences in the number of *T. palmi* adults in eggplant, cucumber, and squash, which generally had higher numbers than snap bean, pepper, or tomato (Table 7). However, eggplant had the highest mean numbers on 8 of the 10 sampling dates in both years; all dates except for 28 and 35 DAP in 2015, when cucumbers had the highest mean numbers.

Larval Density

In each year, there was a significant effect of crop and interaction between date and crop for the number of *T. palmi* larvae (Table 4). In 2015, the highest numbers of larvae were on eggplant and snap bean, followed by squash and pepper with the number on tomato significantly lower than other crops (Table 6). In 2016, the highest numbers of *T. palmi* larvae were found on eggplant followed by cucumber, squash, snap bean, and pepper, with the number on tomato again significantly lower than the other crops. In 2015,

Table 6. Mean ± SE number of *Thrips palmi* per 25 cm^2 leaf area of six vegetable crops grown on six mulch treatments; sampling dates and mulch pooled

Crop	Thrips stage					
	Adult		Larva		Total	
	2015	2016	2015	2016	2015	2016
Eggplant	3.22 ± 0.35a[1]	1.82 ± 0.19a	15.86 ± 1.52a	18.35 ± 2.49a	19.08 ± 1.67a	20.17 ± 2.62a
Cucumber	3.63 ± 0.49a	1.46 ± 0.17b	11.16 ± 1.24b	9.90 ± 1.36b	14.79 ± 1.46b	12.51 ± 1.53b
Squash	2.73 ± 0.23a	1.49 ± 0.16b	4.66 ± 0.64c	4.80 ± 0.86c	7.25 ± 0.76c	6.29 ± 0.92d
Snap bean	1.62 ± 0.28b	0.69 ± 0.09c	13.98 ± 1.15a	6.49 ± 0.97c	15.61 ± 1.25a	7.18 ± 1.05c
Pepper	0.67 ± 0.07c	0.20 ± 0.03d	5.49 ± 0.79c	1.48 ± 0.23d	5.28 ± 0.66d	1.68 ± 0.24e
Tomato	0.39 ± 0.03c	0.10 ± 0.02e	0.90 ± 0.10d	0.25 ± 0.06e	1.32 ± 0.12e	0.35 ± 0.06f
Statistics	$F_{5,90}$ = 127.85; P < 0.0001	$F_{5,90}$ = 256.52; P < 0.0001	$F_{5,90}$ = 155.30; P < 0.0001	$F_{5,90}$ = 277.19; P < 0.0001	$F_{5,90}$ = 176.23; P < 0.0001	$F_{5,90}$ = 315.80; P < 0.0001

[1]Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test (P = 0.05). Each year sample size, n = 720.

Table 7. Adult *Thrips palmi* density per 25 cm^2 leaf area of six vegetable crops grown on six mulch treatments

Crop	Sampling date				
	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
2015					
Eggplant	1.05 ± 0.37a[1]	2.82 ± 0.68a	3.75 ± 0.58ab	2.53 ± 0.39a	5.92 ± 1.21a
Cucumber	0.43 ± 0.16b	5.60 ± 1.97a	5.30 ± 1.10a	2.49 ± 0.36a	4.34 ± 0.50a
Squash	1.67 ± 0.76a	1.78 ± 0.30a	3.71 ± 0.45a	2.28 ± 0.20a	4.22 ± 0.42a
Snap bean	0.43 ± 0.24b	3.21 ± 1.31a	1.91 ± 0.27b	1.07 ± 0.17b	1.48 ± 0.15b
Pepper	0.09 ± 0.04c	0.81 ± 0.21b	1.02 ± 0.18c	0.65 ± 0.10bc	0.80 ± 0.13c
Tomato	0.18 ± 0.06bc	0.48 ± 0.08b	0.67 ± 0.09c	0.31 ± 0.06c	0.31 ± 0.05d
Statistics	$F_{5,522}$ = 27.37; P < 0.0001	$F_{5,522}$ = 16.29; P < 0.0001	$F_{5,522}$ = 23.47; P < 0.0001	$F_{5,522}$ = 26.68; P < 0.0001	$F_{5,522}$ = 51.78; P < 0.0001
2016					
Eggplant	0.29 ± 0.07a	0.39 ± 0.08a	2.21 ± 0.33a	2.89 ± 0.50a	3.31 ± 0.41a
Cucumber	0.12 ± 0.02a	0.18 ± 0.04b	2.04 ± 0.48a	2.17 ± 0.37a	2.79 ± 0.37a
Squash	0.12 ± 0.02a	0.19 ± 0.02ab	1.78 ± 0.28a	2.21 ± 0.25a	3.13 ± 0.46a
Snap bean	0.03 ± 0.01b	0.04 ± 0.02c	0.44 ± 0.10b	1.43 ± 0.25b	1.52 ± 0.23b
Pepper	0.03 ± 0.02b	0.04 ± 0.02c	0.33 ± 0.08b	0.29 ± 0.06c	0.30 ± 0.05c
Tomato	0.01 ± 0.008b	0.04 ± 0.01c	0.06 ± 0.01c	0.26 ± 0.05c	0.13 ± 0.02d
Statistics	$F_{5,522}$ = 25.43; P < 0.0001	$F_{5,522}$ = 34.41; P < 0.0001	$F_{5,522}$ = 79.52; P < 0.0001	$F_{5,522}$ = 61.07; P < 0.0001	$F_{5,522}$ = 89.11; P < 0.0001

[1]Data are means ± SE. Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test (P = 0.05). DAP is Days after planting.

weekly sampling results showed that, with little variation, the number of *T. palmi* larvae was highest on eggplant, snap bean, and cucumber (Table 8), except 49 DAP, when larval density on snap bean exceeded cucumber. On every sampling date, unlike adult density, larval density on snap bean and pepper was greater than on squash. Tomato had significantly the fewest *T. palmi* larvae (Table 8). Similar to *T. palmi* adult abundance, the highest numbers of larvae were observed on eggplant followed by cucumber at every sampling date in 2016. The number of *T. palmi* larvae on snap bean was higher than on squash. However, in contrast to 2015, *T. palmi* larval density on squash was higher than on pepper. Consistent with adults, the lowest number of *T. palmi* larvae was found on tomato. On the last sampling day (49 DAP) in 2016, when thrips populations peaked in all crops, larval density on eggplant was 95–97% higher than on tomato (Table 8).

Trichome Density

Trichome density per 1,000 μm^2 leaf area was significantly higher in tomato than in squash, cucumber, or eggplant with the fewest in snap bean. There were no trichomes found in Jalapeno pepper (Fig. 1).

Weather Conditions

Average temperature, humidity, and rainfall were higher during the experiment in 2015 than in 2016. There was 89% more rainfall during the experiment in 2015 than in 2016 (Table 9).

Discussion

Until the second sampling date (28 DAP), there was little variation in the abundance of *T. palmi* among the black-surfaced plastic

Table 8. Density of *Thrips palmi* larvae per 25 cm^2 leaf area of six vegetable crops grown on six mulch treatments

Crop	Sampling date				
	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
2015					
Eggplant	13.59 ± 4.40a[1]	4.46 ± 0.98b	12.05 ± 2.46a	26.81 ± 3.79a	22.40 ± 2.36a
Cucumber	1.27 ± 0.44c	3.70 ± 0.86b	12.02 ± 3.07a	18.85 ± 3.39a	19.94 ± 2.32a
Squash	4.51 ± 2.27b	1.35 ± 0.53c	1.94 ± 0.31bc	4.50 ± 0.63b	11.01 ± 1.44c
Snap bean	5.10 ± 1.88b	8.43 ± 1.26a	12.06 ± 1.98a	26.11 ± 3.28a	18.21 ± 1.55ab
Pepper	0.20 ± 0.06d	2.09 ± 0.29b	3.59 ± 0.60b	7.43 ± 1.13b	14.15 ± 3.03bc
Tomato	0.51 ± 0.21d	0.69 ± 0.17c	1.12 ± 0.27c	1.16 ± 0.29c	1.02 ± 0.14d
Statistics	$F_{5,483}$ = 72.63; P < 0.0001	$F_{5,483}$ = 37.20; P < 0.0001	$F_{5,483}$ = 37.20; P < 0.0001	$F_{5,483}$ = 70.91; P < 0.0001	$F_{5,483}$ = 53.81; P < 0.0001
2016					
Eggplant	3.81 ± 0.90a	3.52 ± 0.58a	3.66 ± 0.64a	48.46 ± 8.19a	32.27 ± 4.05a
Cucumber	0.36 ± 0.09bc	0.93 ± 0.15b	1.41 ± 0.33b	21.54 ± 3.53b	25.52 ± 2.83ab
Squash	0.62 ± 0.16b	0.17 ± 0.04c	0.35 ± 0.09d	5.71 ± 0.99cd	17.15 ± 2.98b
Snap bean	0.26 ± 0.06c	0.31 ± 0.08c	1.30 ± 0.35bc	11.66 ± 2.30c	18.93 ± 2.54b
Pepper	0.19 ± 0.11d	0.48 ± 0.23c	0.47 ± 0.11cd	3.99 ± 0.77d	2.28 ± 0.46c
Tomato	0.03 ± 0.01d	0.05 ± 0.02d	0.03 ± 0.01e	0.76 ± 0.23e	0.36 ± 0.09d
Statistics	$F_{5,510.7}$ = 54.84; P < 0.0001	$F_{5,510.7}$ = 48.84; P < 0.0001	$F_{5,510.7}$ = 49.74; P < 0.0001	$F_{5,510.7}$ = 87.60; P < 0.0001	$F_{5,510.7}$ = 128.26; P < 0.0001

[1]Data are means ± SE. Means within the same column followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference test (P = 0.05). DAP (days after planting).

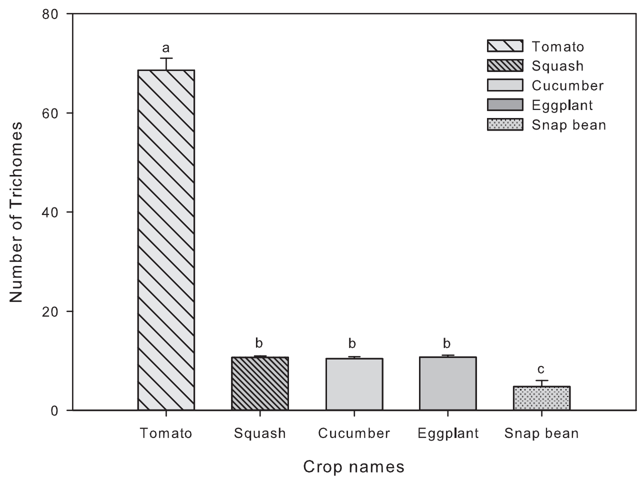

Fig. 1. Density of trichomes per square micrometer leaf area of five host crops. Data are mean ± SE. Means followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference (P = 0.05).

mulches and metalized UV-reflective mulches, which might be due to lower counts of *T. palmi* in those treatments. When population size increased, treatment effects were more pronounced. The lowest numbers of *T. palmi* (adults and larvae) were observed in reflective mulch treatments. The black mulch had an intermediate effect on reducing the *T. palmi* population. Throughout the sampling period, the no mulch control and white-on-black mulch treatments harbored the highest number of *T. palmi*. These findings are in agreement with previous reports for *Frankliniella* spp., *Sericothrips variabilis*, and *Thrips tabaci* L. (Kring and Schuster 1992, Reitz et al. 2003, Riley and Pappu 2004, Summers et al. 2010, Riley et al. 2012). Our results also corroborate previous reports on the effects of metalized reflective film and UV-light on *T. palmi* (Suzuki and Miyara 1983, Makino 1984, Nonaka and Nagai 1984). In addition to various thrips species, a wide variety of insect species were controlled by either aluminum- or silver-infused reflective mulches compared with no mulch or non-UV-reflective mulch treatments (Csizinszky et al. 1995, Stansly and Schuster 1999, Frank and Liburd 2005, Summers et al. 2010, Croxton and Stansly 2014, Nottingham and Kuhar 2016).

Specific photoreceptors within the compound eyes of insects help in sensing the light signals in the UV range (300–400 nm), which can affect insect behavior, orientation, navigation, feeding, and interactions between the sexes (McEnrone and Dronka 1966, Nguyen et al. 2009, Antignus 2014). UV-reflective mulch disrupts the ability of flower thrips to find their hosts, which reduced the number of thrips alighted on the plants (Kring and Schuster 1992, Reitz et al. 2003, Riley and Pappu 2004, Summers et al. 2010, Riley et al. 2012, Tyler-Julian et al. 2015). We assume that similar to other insects and thrips species, *T. palmi* may be able to discriminate between different wavelengths, and intensities of light and is repelled by the UV and high intensity of light reflected from metalized mulches. After the plant canopy shaded the mulched areas at 49 DAP, the treatment differences

Table 9. Weekly climate in the study area in 2015 and 2016

Month	Week	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	
		2015	2016	2015	2016	2015	2016
Nov.	First	26.82	23.37	85	17.71	0	1.25
Nov.	Second	25.73	21.54	87.43	79.86	0.5	0
Nov.	Third	25.61	19.82	88.14	74.14	1.5	0.5
Nov.	Fourth	22.82	21.11	82.11	78.14	4.75	0.1
Dec.	First	23.66	24.32	93.85	85.29	30.5	0.2
Dec.	Second	22.88	23.12	90.57	89.14	0.5	2.5
Dec.	Third	23.75	23.3	85.57	86.86	0.5	0
Dec.	Fourth	25.39	22.54	89	86.29	9	0.5

disappeared. As the reflectance from reflective mulch was reduced by the shade of the plants, the efficacy decreased in reducing the number of thrips, which is evident from the adult numbers (Table 5). This substantiates our previous finding that UV-light emanated from metalized plastic mulch was responsible for repelling *T. palmi* when plant size is small. Our results are consistent with previous reports in controlling potato leafhopper (Wells et al. 1984), aphids (Csizinszky et al. 1995), flower thrips, and other thrips species (Kring and Schuster 1992, Reitz et al. 2003, Summers et al. 2010) using reflective mulch on different vegetable crops such as tomato, cucumber, and pepper. Further study is required to determine whether *T. palmi* adults are disoriented before landing on plants or repelled after landing due to the reflected light from UV-reflective mulch.

There were slight differences in the results in 2016 than in 2015, until the fifth sampling date; the reflective mulch had lower numbers of *T. palmi*. These differences (from the results of 2015) may have been due to excessive rain in 2015, which caused partial erosion of the silver film coating on the mulch, which may have decreased the reflectivity. Moreover, in 2015, mulches were placed in the field 2 wk prior to planting. However, in 2016, mulches were placed in the field 3 d prior to planting. The combined effect of rain and dust accumulation resulted in the partial erosion of the silver-reflective layer from the surface, which may have led to reduced performance of the mulch to control the thrips population in 2015.

Similar to *T. palmi* adults, the number of *T. palmi* larvae was lower in the reflective mulch treatments compared with the control and other non-UV-reflective mulch treatments. The reason may be partially due to fewer adults in the reflective mulches laying fewer eggs. A second reason could be due to reflected intense light, which would have a deleterious impact on the egg hatchability or help increased larval mortality (Miller 1930, Qian et al. 2016). In agreement with previous reports for *T. palmi* and *Frankliniella* thrips (Nonaka and Nagai 1984, Childers and Brecht 1996), we found the highest density of *T. palmi* in the standard white-on-black mulch treatment.

Host plants have significant effects on the life history of insects, and the same host can affect different species of insects in the same genus differently. For example, cucumber leaves were more suitable than tomato leaves for *Frankliniella occidentalis* and *Frankliniella intonsa* based on fecundity, fertility, female longevity, and intrinsic rate of increase. However, on cucumber leaves, the population increase was higher for *F. intonsa* than for *F. occidentalis* (Li et al. 2015). Food quality also plays an important role with regard to the development, longevity, and oviposition of an arthropod (Van Lenteren and Noldus 1990, Delisle et al. 2015). The present study demonstrated that *T. palmi* were most attracted to eggplant followed by cucumber, snap bean, squash, and Jalapeno pepper with tomato being the least attractive. Broadly, we can speculate that there might be a difference in fecundity, fertility, and development of *T. palmi* in the different hosts tested in this experiment. Tsai et al. (1995) reported that larval and pupal development time and survival were lower in bell pepper compared with eggplant, cucumber, and winter melon. Moreover, the egg production rate decreased if adults fed on bell pepper leaves. *Thrips palmi* does not complete its life cycle if fed on tomato and strawberry leaves (Kawai 1990).

The reason for preference of one host over another may be partially due to differences in volatiles from host plants perceived by insects. The chemical identity of volatile compounds differs among plant species and the herbivorous insect species (Mulligan and Kevan 1973, Paré and Tumlinson 1999). Allelochemical compounds, such as higher levels of gossypol or condensed tannins, made the host less suitable for thrips, *T. tabaci* L. (Arif et al. 2004, Balakrisnan 2006). The low density of *T. palmi* in tomato may have been due to the unsuitability of this crop as a host of this species because of α-tomatine. Hirano et al. (1994) identified α-tomatine as a feeding deterrent for *T. palmi* in tomato. Other factors, such as glandular trichomes (Scott Brown and Simmonds 2006) and hairs or trichome densities (Pfannenstiel and Turner 1998), play determining role in host plant selection and abundance of an insect on a specific crop. In the present study, the variation in *T. palmi* density may be attributed, at least in part, to trichome density. Trichome density was significantly higher in tomato leaves compared with the other crops tested (Fig. 1). Therefore, the higher density of glandular trichomes could be another determining factor for *T. palmi* being less abundant on tomato than the other crops tested in this study. Nonglandular trichome number was similar in eggplant, cucumber, and squash followed by snap bean. However, trichomes in eggplant are stellar shaped with six projections, this created a denser structure on eggplant than on squash, cucumber, or snap bean, which might be an impediment to a thrips enemy or a conducive microclimate (e.g., humidity) for population increases of *T. palmi*. Cotton genotypes with dense leaf hairs (Quisenberry and Rummel 1979, Arif et al. 2004) or very few or no leaf hairs (Leigh 1995) were reported to be more thrips resistant. In this study, trichomes were completely absent in Jalapeno pepper leaves. Therefore, we assume that leaf surfaces with variable numbers of trichomes might have played a role in the selection and host preference of *T. palmi*.

A combination of antixenosis and antibiosis resistance factors are thought to be important in determining host choice and damage potential by thrips (Leigh 1995, Frei et al. 2003). The extent of antibiosis of some vegetable crops to *F. occidentalis* was correlated with low concentrations of total aromatic amino acids relative to total leaf proteins (Mollema and Cole 1996). Higher concentration of phenolics, lignin, and phytoalexins in the leaf tissue reportedly increases tissue hardness, decreases nutritional quality, and digestibility of the cells and ultimately impacts on fecundity, fertility, and survivability of several sap sucking insects including whitefly, aphids, and melon thrips (Correa et al. 2005, Almeida et al. 2008). A hard cuticular layer might create a physical impediment for egg laying or scraping the leaf tissues for feeding of both adults and larvae. Strong antixenotic effects on adult *F. occidentalis* were due to differences in the structure of internal mesophyll cells of several *Lycopersicon* (now *Solanum*) species (Kumar et al. 1995). Thicker lower epidermal tissue and extent of leaf thickness have also been attributed to resistance to *T. tabaci* L. (Abdel-Gawaad et al. 1973, Arif et al. 2004).

In 2015, the total number of thrips in snap bean was similar to that in eggplant, whereas in 2016, the total thrips density (highest to lowest) was in eggplant, cucumber, squash, snap bean, Jalapeno pepper, and tomato. The reason for the difference may be due to a nearby snap bean field, which was highly infested with *T. palmi*. Adults might have migrated after harvest (5 January 2016) and infested snap bean in the research field and with a buildup of the population. Adult density increased dramatically on 28 DAP (Table 7). Seal (2001) reported that adult immigration from adjoining fields is very common in initiating thrips infestation in a new field.

Results of this study demonstrated that growing vegetable crops on metalized UV-reflective plastic mulches reduces the density of *T. palmi*. However, this study concentrated only on mulch effects for *T. palmi* management in vegetable crops. It is also necessary to explore whether planting vegetable crops on reflective mulches increased crop growth and yield because metalized reflective mulch is costlier than other commonly used plastic mulches. Host range and results of the weekly population density study in different crops will help in decision making for treatment schedules to manage *T. palmi* on the most commonly cultivated vegetable crops in southern Florida and other areas with similar growing conditions because prevention of thrips outbreaks is often easier than eradication and control.

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