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Research

Biological Control - Parasitoids and Predators

Within-plant Distributions and Density of *Amblyseius swirskii* (Acari: Phytoseiidae) as Influenced by Interactions Between Plastic Mulch and Vegetable Crop Species

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Abstract

Plastic mulch of different colors and ultraviolet (UV) reflectivity individually or combined with released arthropod predators is an important component of an integrated pest management strategy. In 2015 and 2016, we evaluated the density and within-plant distribution of a released predatory mite, *Amblyseius swirskii* Athius-Henriot (Acari: Phytoseiidae) in snap bean (*Phaseolus vulgaris* L.), cucumber (*Cucumis sativus* L.), yellow squash (*Cucurbita pepo* L.), eggplant (*Solanum melongena* L.), Jalapeno pepper (*Capsicum annuum* L.), and tomato (*Solanum lycopersicum* L.) grown on different plastic mulches. The mulch treatments evaluated were: metalized top and black bottom, metalized top and white bottom, black-on-black, black-on-white, white-on-black, and bare soil with no mulch. Crop species had a significant effect on the density of *A. swirskii*. Eggplant and cucumber had higher numbers of *A. swirskii* than the other crops tested in 2015. In 2016, the density of *A. swirskii* was higher on eggplant than on cucumber. There was a variation in the distribution of *A. swirskii* in different strata of the plant canopies with the highest number in the bottom stratum of each crop, which was positively correlated with the population of *Thrips palmi* Karny (Thysanoptera: Thripidae). Mulch type had no effect on the density or distribution of *A. swirskii* in any strata of any of the crops tested. The results of this study indicate that releasing *A. swirskii* is compatible with the use of UV-reflective mulch. This information about host preference and within-plant distribution of *A. swirskii* should be of value in pest management programs for the crops studied.

Key words: mite, thrips, mulch, vegetable crop, stratum

Amblyseius swirskii Athius-Henriot (Acari: Phytoseiidae), a generalist predatory mite, has been reported as a biological control agent since 1962 and commercially used for biocontrol since 2005 (Messelink et al. 2008, van Lenteren 2012). It has the potential to control several phytophagous pest species, including sweet potato whiteflies, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) (Messelink et al. 2005, Calvo et al. 2011); chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae)) (Arthurs et al. 2009, Dogramaci et al. 2011); broad mites, *Polyphagotarsonemus latus* (Banks) Trombidiformes: Tarsonemidae). (Stansly and Castilo 2009); and spider mites, *Tetranychus urticae* Koch (Trombidiformes: Tetranychidae) (van Houten et al. 2007) in vegetable and ornamental crops.

Several types of colored and metalized plastic mulch have been used, singly or combined with released arthropod predators to manage insect and mite pests in commercial agriculture. In addition to pest management, benefits of using plastic mulch include reduced weed and disease pressure, efficient use of fertilizer and water, maintaining a balanced microclimate for plants, which results in better plant growth, and earlier and increased marketable yield with higher fruit quality (Lamont 1993, Stapleton and Summers 2002, Summers et al. 2010, Nottingham and Kuhar 2016). Specific color and reflectance properties of plastic mulches have the potential to deter or attract arthropods influencing their vision behavior (Summers et al. 2010, Antignus 2014). Mulch surfaces metalized with a microscopic layer of aluminum or silver are highly UV-reflective and have been reported to effectively manage insect pests, viz. whitefly, aphid, thrips, etc. (Stapleton and Summers 2002, Simmons et al. 2010, Razzak et al. 2019). However, in field-grown pepper, UV-reflective mulch significantly lowered numbers of the predator *Orius insidiosus* (Say) compared with the black mulch treatments (Reitz et al. 2003). Aphid parasitism by *Aphidius ervi* (Haliday) was reduced by UV-reflection from aluminum foil mulch until foliar growth of Chinese cabbage obscured the mulch (Zalom and Cranshaw 1981). Honey bees visited squash plants more frequently when grown on aluminum or white plastic mulch compared to non-mulched plots or black plastic mulch (Moore et al. 1965, Wolfenbarger and Moore 1968). In contrast, Frank and Liburd (2005), Simmons et al. (2010), and Nottingham and Kuhar (2016) reported that species diversity and density of arthropod predators and parasitoids of whiteflies did not vary among living mulch, synthetic reflective mulch, and colored mulch treatments. However, several laboratory studies revealed the deleterious effects of UV-radiation on the survivability and biology of predatory mites, and the interactions between these mites and their prey (Ohtsuka and Osakabe 2009, Onzo et al. 2010, Ghazy et al. 2016, Koveos et al. 2017). Legarrea et al. (2010) reported that *A. swirskii* tends to evade the area of comparatively higher UV-B radiation in the laboratory. *Amblyseius swirskii* typically inhabit the undersides of the leaves (Messelink 2005, Ohtsuka and Osakabe 2009) and the lower and middle strata of the plant canopy (Fatnassi et al. 2015, Razzak 2018. Therefore, we hypothesized that metalized UV reflective and colored mulch would have impact on the density of *A. swirskii* in field-grown vegetable crops.

Mite density and distribution often varies among different plant species and different strata in plant canopies. Important structures such as leaf domatium, trichome, hair and pubescence, and volatile chemicals in host plants determine the density of phytoseiid mite predators (O'Dowd and Willson 1991; Walter and O'Dowd 1992a, 1992b; McMurty and Croft 1997; Margolies et al. 1997). The *Amblyseius swirskii* population increased on eggplant (Shibao et al. 2010), pepper, and cucumber in greenhouses (Calvo et al. 2011) but did not increase on tomato (Paspati 2019). In the present field experiment, we evaluated the density of *A. swirskii* on six vegetable crops. Phytophagous and predatory mites are inclined to create guilds in refuges of plant structures where the intensity of UV radiation is attenuated, such as the abaxial surface of leaves (Ohtsuka and Osakabe 2009). The phytoseiid predator, *Neoseiulus cucumeris* (Oudemans) was inclined to aggregate in the bottom stratum of eggplant, which was consistent with an increased population of *Thrips palmi* (Castineirus et al. 1997). *Neoseiulus cucumeris* (Oudemans) and *A. swirskii* were most abundant in the bottom third of the canopy of greenhouse-grown sweet pepper (Fatnassi et al. 2015). However, the combined effects of plastic mulch and crop species on the density and distribution of *A. swirskii* have not been studied before. Therefore, based on previous research we wanted to determine: 1) how metalized UV-reflective and colored non-UV reflective plastic mulch treatments affect the density of *A. swirskii* in different field-grown vegetable crops, and 2) how crop species and mulch treatments affect within-plant distributions of *A. swirskii*.

Materials and Methods

Crops and Mulch for the Experiment

Experiments were conducted in the fall of 2015 and 2016. In 2015, 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) were tested. During that year, five mulch treatments: 1) metalized top and black bottom/silver on black ('Shine N' Ripe', 1.25 mil)), 2) metalized top and white bottom/silver on white ('Can-Shine'; 1 mil), 3) black on black (Can-GrowXSB, 0.6 mil), 4) black on white (Can-Grow XSB, 0.9 mil), 5) white on black (Can-Grow XSB, 0.9 mil), and 6) and bare soil with no mulch were evaluated for each crop.

Based on the 2015 results, when higher numbers of thrips were recorded on eggplant and cucumber than other crops, the 2016 experiment focused only on eggplant and cucumber. In 2016, the experiment included only the mulches with the highest and lowest thrips densities in 2015: white on black standard mulch, and silver on white and silver on black reflective mulches. The mulches were manufactured by Canslit Inc., Victoriaville, Quebec, Canada.

Experimental Site Preparation and Design

The studies were conducted in field research plots at the University of Florida, Tropical Research and Education Center (TREC), Homestead, Florida, USA. Raised soil beds, 91 cm wide and 15 cm high with 1.83 m between centers, were prepared. Before mulch installation, granular fertilizer (N-P-K: 6-12-12) (Loveland Products Inc., Greely, CO) was applied at 1,307 kg/ha in furrows, each 20 cm from and parallel to either side of the center of the bed. Plastic mulch and two drip tapes (Ro-Drip, Rivulis Irrigation Inc., San Diego, CA) were placed concurrently on the beds with a plastic mulch layer (Kennco micro-combo, Kenco Manufacturing Co Inc., Atoka, OK). Drip irrigation tape with emitters spaced at 30 cm intervals were placed on each side (7 cm from the center of the bed) of each bed.

In 2015, the experimental design was a randomized complete block with split plots. The experimental field was divided into three blocks (replicates). Each block consisted of six beds (main plots) each 54 m long, where each main plot was one mulch treatment and was divided into twelve 3.05 m long subplots (Fig. 1a). Crop species of each category was established in one-half of the main plot where *A. swirskii* was released. In the same way, the six crop species were set in the other half of each main plot, where no *A. swirskii* were released.

In 2016, the experimental design was similar to that of 2015; however, there were four replicates for each treatment, organized into four blocks. Each block was set up with the three mulch treatments as the main plots of 22.86 m long parallel beds. Each individual main plot consisted of four equal 4.57 m long subplots, one of each crop for the mite treatment and one of each crop for the no mite treatment (Fig. 1b).

In both years, crops/subplots were randomized within each plastic mulch treatment/main plot, and mulch treatments were randomized within each block. Within each main plot, there was a 1.52 m unplanted buffer area (Fig. 1a and b) between each subplot to minimize the dispersion of *A. swirskii* from one subplot to the next because crop canopy connectedness promotes dispersal of *A. swirskii* (Buitenhuis et al. 2010, Lopez et al. 2017). A 91 cm center to center spacing was maintained between main plots. Moreover, blocks were separated by 3.05 m of fallow soil, which was kept weed-free mechanically throughout the experiments to prevent the dispersal of *A. swirskii*; very few released *A. swirskii* left the plants by going to the ground (Lopez et al. 2017).

Crop Establishment

In 2015 on 13 November, greenhouse-grown, infestation-free 5-wk-old transplants of tomato, eggplant, and pepper were planted

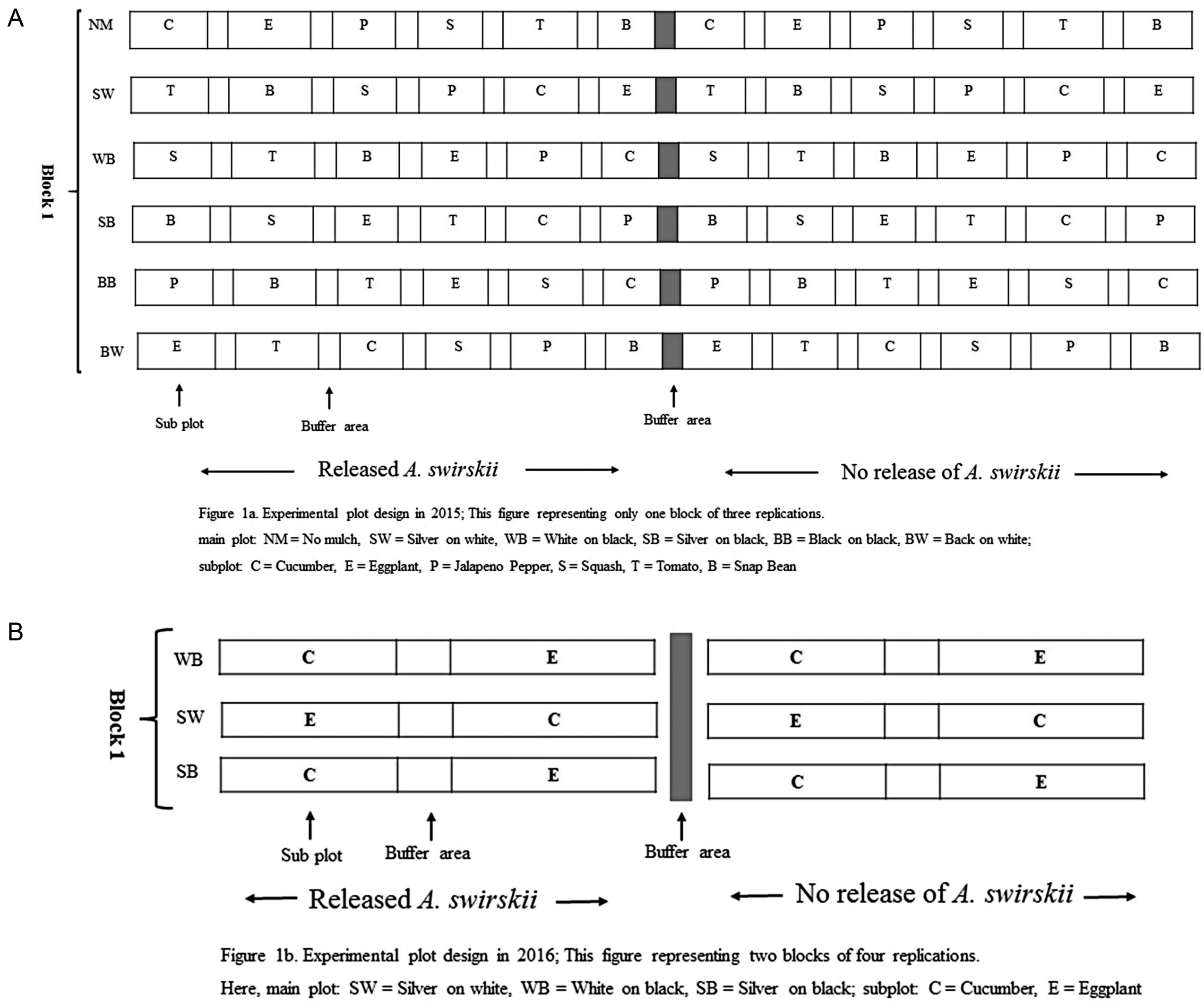

Fig. 1. (a) Experimental plot design in 2015 showing only one block of three replications. Main plot: NM = No mulch, SW = Silver on white, WB = White on black, SB = Silver on black, BB = Black on black, BW = Back on white; subplot: C = Cucumber, E = Eggplant, P = Jalapeno Pepper, S = Squash, T = Tomato, B = Snap Bean. **b.** Experimental plot design in 2016 showing only one block of four replications. Here, main plot: SW = Silver on white, WB = White on black, SB = Silver on black; subplot: C = Cucumber, E = Eggplant, P = Jalapeno Pepper, S = Squash, T = Tomato, B = Snap Bean.

manually in beds with a spacing of 45, 45, and 31 cm, respectively. For crops grown from seed, two seeds of squash, three seeds of cucumber, and three seeds of snap bean were directly seeded per hole (4 cm diameter, 2 cm deep) in the subplots with a spacing of 31, 31, and 15 cm, respectively. Following germination, squash and cucumber were thinned to one plant and snap bean to two plants per hole. In 2016, on 8 November, cucumber was manually seeded, and greenhouse-grown, infestation-free transplants of eggplant were planted on 12 November, one day after the germination of cucumber.

Crop Maintenance

In 2015 and 2016, after transplanting, starter fertilizer (20-20-20: N-P-K, Diamond R Fertilizer Inc. Ft. Pierce, FL) solution (20 g/3.78 liters of water) was applied to deliver 30–40 ml as a drench at the base of each transplant using a backpack sprayer without a nozzle tip. Throughout the experiment, irrigation (drip system) and additional fertilizer (N-P-K: 3-0-10; Helena Chemical Co., Alachua, FL) were applied following the recommended standard practices for vegetable production in Florida (Dittmar et al. 2015). Lepidopteran insects, including melonworms, *Diaphania hyalinata* (L.) and pickleworms, *Diaphania nitidalis* (Stoll), were controlled with 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.), each applied to the foliage at 2.24 kg/ha twice each year in a biweekly rotation. Bacterial and fungal pathogens were controlled with 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 (1.68 kg/ha, Dithane DF, Dow Agro Sciences, Zionsville, IN) in a weekly rotation. In 2015, crop maintenance using the above-mentioned products was continued until 25 d before releasing *A. swirskii*. However, because *A. swirskii* were released early in 2016, applications of the products, as mentioned above, continued that year after releasing *A. swirskii*, although applications were halted within 3 d after releasing the predator.

Source and Maintenance of *A. swirskii*

Amblyseius swirskii mites were supplied by Koppert Biological Systems Inc., Howell, Mississippi, USA. Upon arrival, mites in vermiculite with bran were stored in a growth chamber maintained at

11 ± 1°C, 60 ± 5 % RH, with a 12:12 h L: D period and released 24–48 h after arrival.

Prerelease Sampling and *A. swirskii* Application

Prerelease visual sampling was conducted to ascertain that melon thrips larvae, prey for *A. swirskii*, were present on all crops. In 2015, prerelease leaf sampling was done on 25 December, 24 h before the release of *A. swirskii*. Sampling was performed by randomly inspecting five fully expanded leaves, one leaf/plant, in each subplot using a handheld magnifying glass (10×).

Ten to fifteen mites (11 ± 0.54, mean ± SEM, n = 10) were released on each plant's broader leaves at the middle stratum by placing ca. 0.10 g (0. 10 ± 0.003, mean ± SEM, n = 10) of bran containing *A. swirskii* with a forceps (Specimen-10-Forceps, Bioquip products, Inc., CA, USA) having a flat tip. The amount of bran and the number of *A. swirskii* in the bran were determined by collecting bran from vermiculite 10 times and counting *A. swirskii* under a stereomicroscope at a 20× magnification. In each release, the number of mites per plant was 45 ± 5, which was accomplished by four releases over two consecutive days for each crop. In the first release period, *A. swirskii* were applied on all crops 49 d after planting (DAP) on 26–27 December 2015. A second release was performed 4 wk after the first release (77 DAP, 25–26 January 2016), with the same number of *A. swirskii* and application methods as described for the first release. The second release was made only on Jalapeño pepper and eggplants because cucumber, snap bean, and squash had reached senescence. Tomato was excluded from the second release because *A. swirskii* did not establish on tomato as confirmed from the first release. *Amblyseius swirskii* were released in the morning (08:00 EST) and afternoon (17:00 EST) to avoid high solar intensity. Releasing *A. swirskii* during periods of heavy rains and high wind was also avoided.

In 2016, the release method and numbers of *A. swirskii* released were generally the same as in 2015. An exception was that in 2015, *A. swirskii* were released early in the season when the population of melon thrips was low. Prerelease visual sampling was conducted following the method as described for 2015. *Amblyseius swirskii* were released on 27 November 2016 when the number of melon thrips adults was 0–5/plant. The first release of *A. swirskii* was done 15 d after germination of cucumber and transplanting of eggplant. The second release was done 18 d after the first release (33 DAP).

Evaluation Method for *A. swirskii* Density

In 2015, density of mites in different crops and mulches was determined 2 wk after the first release. Five fully expanded leaves were randomly sampled from the middle third of five plants in each subplot. Leaf samples from each sub-plot were placed in a 1-liter plastic cup marked with plastic mulch and crop type and replication number. All samples were transported to the TREC vegetable IPM laboratory and processed following methods described by Seal and Baranowski (1992). Afterward, numbers of *A. swirskii* mites and melon thrips in the samples were counted using a stereomicroscope (Leica MZ6, Leica Microsystems Inc., Buffalo Grove, IL) at a 20× magnification. Adult and immature (protonymph and deutonymph) *A. swirskii* present in each sample were counted together. Mite population in each mulch and crop were sampled only from the first release of *A. swirskii*.

In 2016, mite densities in different mulches and crops were determined three times. The first evaluation was done 2 wk after the first release by sampling five fully expanded leaves; one leaf/plant from five randomly selected plants in each subplot. The second and third evaluations were done at 10 d and 20 d, respectively, after the second release at 33 DAP. In the second release, an assessment was done by sampling four fully expanded leaves from each subplot. Sample processing and *Thrips palmi* and *A. swirskii* recording methods were the same as followed in 2015. In 2016, on the first sampling date at 14 DAR (day after release), the number of eggs of *A. swirskii* was recorded by direct inspection of collected leaves under the stereomicroscope.

Evaluation Method for Within-plant Distribution of *A. swirskii*

In 2015, within-plant distribution of *A. swirskii* was evaluated only on eggplant and 'Jalapeno' peppers, 6 d after the second release (DAR) at 77 DAP. Five plants were randomly selected from each subplot of each mulch treatments for sampling mites and thrips using leaf samples. Before collecting leaf samples, plants were divided into three equal strata—bottom, middle, and top/upper based on visual estimation. Leaves were sampled from the third node near the bottom, fifth or sixth node in the middle, and second node below the plant apex. One leaf was collected from each of the three strata (top, middle, and bottom) of a plant in each *A. swirskii* treated sub-plot.

In 2016, within-plant distributions of *A. swirskii* were determined in eggplant and cucumbers 23 DAR at 33 DAP. For eggplant, methods of dividing plant strata and selection of plant nodes for leaf sampling were the same as in 2015. However, for vining cucumber plants, the foliage within 25.4 cm from the base (bottom stratum), within 15.24 cm from the apex (top stratum), and the section between the bottom and top strata (middle stratum) were sampled. Four plants were randomly selected from each subplot of three mulch treatments for sampling. In both years, leaf samples were processed and the numbers of *A. swirskii* mites and melon thrips in the samples were counted following methods described for density evaluation of *A. swirskii*.

Statistical Analyses

All data were subjected to square root transformation before statistical analyses to meet the assumption of normality. Data were analyzed using mixed model analysis of variance (ANOVA) with mulch and crop type as fixed variables and replications as random variables for each year (PROC GLIMMIX model, SAS version 9.3, SAS Institute Inc., Cary, NC; SAS Institute Inc. 2013). In the PROC GLIMMIX model, the method of Kenward-Roger's was used to determine the degrees of freedom. For adults, immatures, eggs and total counts of *A. swirskii* in each mulch and crop, differences among means were determined by Tukey's Honestly Significant Difference (HSD) procedure using SAS Statistical Software in SAS (SAS Institute, Inc.). All the data were analyzed at the 5% significance level. PROC CORR in SAS was done to determine relationships between *A. swirskii* in different plant strata with those of melon thrips larvae. Untransformed means and standard errors are presented in the tables and figure.

Results

Crop and Mulch Effects on the Density of *A. swirskii*

In 2015, there was no significant interaction between crop and mulch treatments for the number of *A. swirskii* (P > 0.05; Table 1). Mulch type had no significant impact on the population density of *A. swirskii*. However, crop species had a significant effect on the density of *A. swirskii* (Table 1). The total number (adults and immatures) of *A. swirskii* was highest in eggplant and cucumber followed by squash, Jalapeno pepper, and snap beans. There were

Table 1. Analysis of variance (ANOVA) table of effects of crop species and mulch treatment on the number of *A. swirskii* in 2015 and 2016

Year	Release times	Evaluation	Effect	Adult df*	Adult F	Adult P	Immature df*	Immature F	Immature P	Egg df*	Egg F	Egg P	Total df*	Total F	Total P
2015	49 DAP	14 DAR	Crop	--	--	--	--	--	--	--	--	--	5, 10	6.29	0.007
			Mulch	--	--	--	--	--	--	--	--	--	5, 60	0.81	0.55
			Crop × Mulch	--	--	--	--	--	--	--	--	--	25, 60	1.14	0.33
2016	15 DAP	14 DAR	Crop	1, 18	0.42	0.52	1, 18	1.04	0.32	1,9	14.06	0.005	1, 9	2.61	0.14
			Mulch	2, 18	3.04	0.07	2, 18	0.41	0.67	2, 6	1.04	0.41	2, 9	1.01	0.40
			Crop × Mulch	2, 18	0.40	0.67	2, 18	0.09	0.91	2, 9	0.48	0.63	2, 9	0.16	0.85
2016	33 DAP	10 DAR	Crop	1, 9	66.14	<0.0001	1, 9	79.73	<0.0001	--	--	--	1, 9	90.08	< 0.0001
			Mulch	2, 9	0.14	0.87	2, 9	0.44	0.66	--	--	--	2, 9	0.14	0.87
			Crop × Mulch	2, 9	0.06	0.95	2, 9	2.68	0.12	--	--	--	2, 9	1.80	0.22
2016	33 DAP	20 DAR	Crop	1, 9	50.37	< 0.0001	1, 15	4.30	0.06	--	--	--	1, 15	15.05	0.001
			Mulch	2, 6	0.35	0.72	2, 15	0.42	0.67	--	--	--	2, 15	0.45	0.65
			Crop × Mulch	2, 9	0.45	0.65	2, 25	0.42	0.67	--	--	--	2, 25	0.50	0.62

DAP (Days after planting), DAR (Days after release).

*Numerator and denominator of df, Immature (larva + protonymph + deutonymph), Total (adult + immature).

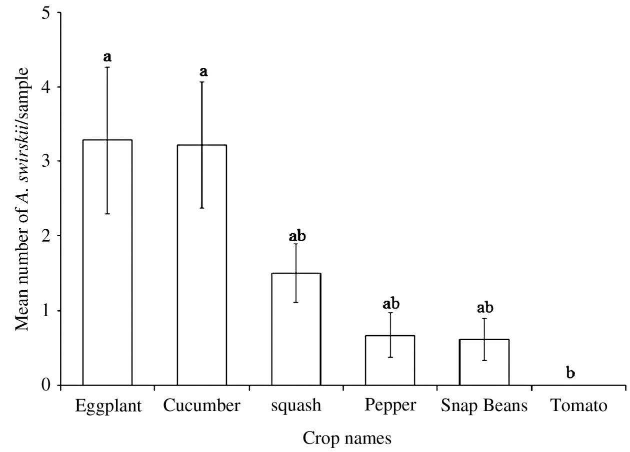

Fig. 2. Mean ± SE number of *A. swirskii* in different crop species in 2015. (Mulch treatments were pooled because there was not significant interaction between mulch and crop species according to a two-way ANOVA ($P > 0.05$, Tukey's HSD test). Bars with the different letters differ significantly at $P \leq 0.05$ according to Tukey's HSD test. Sampling conducted at 49 DAP (Days after planting) and 14 DAR (Days after release). Mean number of *A. swirskii* in each sample (adult + immature + egg), Immature (larva + protonymph + deutonymph).

no *A. swirskii* adults or immatures on tomato (Fig. 2). There were no statistical differences in the mean number of *A. swirskii* among mulch treatments (Table 3).

In 2016, sampling at 15 d after the first release (DAR) demonstrated that, except for the number of eggs, there was no significant effect of crop or mulch treatments on the number of *A. swirskii*. The mean number of *A. swirskii* adults, immatures, and the total number of mites were statistically similar in cucumber and eggplant and among mulch treatments (Tables 2 and 3). The second release of *A. swirskii* at 33 DAP evaluated 10 DAR, showed a significant effect of crop species on the density of *A. swirskii* (Table 1). The mean number of *A. swirskii* adults, immatures and the total number of mites were significantly higher in eggplant than in cucumber (Tables 1 and 2). There were no significant effects of mulch treatments or mulch and crop treatments combined (Tables 1 and 3) on the number of mites. The differences among crop species and mulch and the significance of the interaction between crop and mulch were similar at 20 DAR to observations at 10 DAR (Tables 1–3).

Crop and Mulch Effects on the Within-plant Distribution of *A. swirskii*

In both 2015 and 2016, stratum within the crop canopy had a significant effect on the distribution of *A. swirskii* (Table 4). In 2015, there was no significant interaction between crop and stratum, however a significant interaction was observed in 2016 for the number of adults and the total number of *A. swirskii* (Table 4). There was a significant interaction between mulch treatment and stratum in 2015; however, in 2016, there was no significant interaction (Table 4). Each year, in each crop and mulch treatment, the average numbers of *A. swirskii* were significantly higher in the bottom stratum than the middle stratum. The fewest *A. swirskii* were observed in the top stratum (Tables 5–7). In each year, the number of *A. swirskii* were positively correlated with the number of melon thrips larvae in each stratum (2015: Pearson correlation coefficients, $r = 0.40$, $P < 0.0001$; 2016: Pearson correlation coefficients, $r = 0.35$, $P < 0.0023$).

Table 2. Mean ± SE number of *A. swirskii* in different crop species in 2016

Release times	Evaluation	Crops	Mite's stage			
			Adult	Immature	Egg	Total
15 DAP	14 DAR	Cucumber	8.33 ± 1.01az	4.41 ± 0.87a	5.00 ± 1.07a	17.75 ± 2.48a
		Eggplant	7.50 ± 1.10a	3.25 ± 0.76a	2.17 ± 0.04b	12.92 ± 1.80a
33 DAP	10 DAR	Cucumber	5.08 ± 0.84bz	13.50 ± 1.37b	----	18.58 ± 2.07b
		Eggplant	12.08 ± 1.18a	37.08 ± 3.91a	-----	49.17 ± 4.60a
33 DAP	20 DAR	Cucumber	5.75 ± 1.81bz	15.67 ± 4.46a	-----	20.08 ± 5.80b
		Eggplant	21.58 ± 3.47a	24.75 ± 3.40a	-----	46.33 ± 5.86a

Mulch treatments were pooled because there was not significant interaction between mulch and crop species according to a two-way ANOVA ($P > 0.05$). [z]Means in the same column for each date with different letters are significantly different at $P \leq 0.05$ according to aTukey's HSD test. DAP (Days after planting), DAR (Days after release). Immature (larva + protonymph + deutonymph), Total (adult + immature + egg).

Table 3. Effect of mulch treatment on mean ± SE number of *A. swirskii* in 2015 and 2016

Year	Release times	Evaluation	Mulch	Mite's stage			
				Adult	Immature	Egg	Total
2015	49 DAP	14 DAR	SB	-- -- --	-- -- --	-- -- --	1.28 ± 0.39[z]
			SW	-- -- --	-- -- --	-- -- --	1.72 ± 0.85
			WB	-- -- --	-- -- --	-- -- --	1.33 ± 0.46
			BW	-- -- --	-- -- --	-- -- --	1.06 ± 0.55
			BB	-- -- --	-- -- --	-- -- --	1.44 ± 0.46
			NM	-- -- --	-- -- --	-- -- --	2.44 ± 0.95
2016	15 DAP	14 DAR	SB	5.88 ± 0.85	4.50 ± 1.27	3.00 ± 1.20	13.38 ± 2.71
			SW	7.75 ± 0.86	3.13 ± 0.83	3.13 ± 0.92	14.00 ± 2.31
			WB	10.12 ± 1.61	3.88 ± 0.92	4.63 ± 1.24	18.63 ± 3.10
2016	33 DAP	10 DAR	SB	7.88 ± 1.66	27.38 ± 5.72	-- -- --	35.25 ± 7.08
			SW	8.50 ± 1.90	27.13 ± 7.25	-- -- --	35.63 ± 8.98
			WB	9.38 ± 1.91	21.38 ± 3.39		30.75 ± 5.24
2016	33 DAP	20 DAR	SB	14.88 ± 4.68	24.50 ± 6.42	-- -- --	39.38 ± 9.90
			SW	11.50 ± 3.85	18.63 ± 5.16	-- -- --	30.13 ± 8.78
			WB	14.63 ± 5.02	17.50 ± 3.35	-- -- --	32.13 ± 6.68

Crop species were pooled because there was not significant interaction between mulch and crop species according to a two-way ANOVA ($P > 0.05$). [z]For each date, there was no significant differences in the mean number of *A. swirskii* among different mulch treatments according to Tukey's HSD test ($P > 0.05$). DAP (Days after planting), DAR (Days after release). Silver on black (SB), Silver on white (SW), White on black (WB) Black on white (BW), Black on black (BB), and No mulch (NM). Immature (larva + protonymph + deutonymph), Total (adult + immature + egg).

Table 4. ANOVA assessing the effects of crop and mulch on the distribution of *A. swirskii* in different strata of host plants in 2015 and 2016

Year	Release times	Effect	Mite's stage						
				Adult		Immature		Total	
			df*	*F*	*P*	*F*	*P*	*F*	*P*
2015	77 DAP	Stratum	2, 48	--	--	--	--	28.28	< 0.0001
		Mulch × Stratum	10, 48	--	--	--	--	2.81	0.008
		Crop × Stratum	2, 48	--	--	--	--	2.65	0.08
		Mulch × Crop × Stratum	10, 48	--	--	--	--	2.25	0.03
2016		Stratum	2, 51	54.44	<0.0001	68	<0.0001	77.92	<0.0001
	33 DAP	Mulch × Stratum	4, 51	1.94	0.12	0.43	0.78	0.33	0.85
		Crop × Stratum	2, 51	8.03	0.0009	1.13	0.33	3.73	0.03
		Mulch × Crop × Stratum	4, 51	0.68	0.61	1.63	0.18	1.43	0.23

DAP (Days after planting),

*Numerator and denominator of df,Immature (larva + protonymph + deutonymph),Total (adult + immature).

Discussion

Mulch treatment did not affect the density of *A. swirskii*. *Amblyseius swirskii*, which are typically found on the undersides of the leaves (Messelink 2005, Ohtsuka and Osakabe 2009) and in the lower and middle strata of the plant canopy (Fatnassi et al. 2015, Razzak 2018). We anticipated that crops grown on metalized UV reflective mulch would have fewer *A. swirskii* compared to those grown on colored plastic mulch and bare ground. Nottingham and Kuhar (2016)

Table 5. Mean ± SE number of *A. swirskii* in different strata, crop species pooled, 2015

Stratum	Mites per sample SW WB BW BB NM					
	SB	SW	WB	BW	BB	NM
T	0.0 ± 0.0b[z]	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0b
M	0.0 ± 0.0 b	0.17 ± 0.17a	0.33 ± 0.21a	0.0 ± 0.0 b	0.33 ± 0.21b	0.17 ± 0.17ab
B	1.50 ± 0.72a	0.33 ± 0.33a	0.17 ± 0.17a	1.50 ± 0.43a	1.33 ± 0.76a	0.67 ± 0.33a
F, P	10.75; 0.0001	0.64; 0.52	1.22; 0.30	17.17; < 0.0001	8.50; 0.0007	3.75; 0.03

[z]Means in the same column with different letters are significantly different for each mulch treatments at $P \leq 0.05$ according to Tukey's HSD test. For each mulch, df = 2, 48. Number of *A. swirskii* (adult + larva + protonymph + deutonymph); Silver on black (SB), Silver on white (SW), White on black (WB) Black on white (BW), Black on black (BB), and Nomulch (NM); T (Top), M (Middle), and B (Bottom).

Table 6. Mean ± SE number of *A. swirskii* in different strata, crop species pooled, 2016

Mulch	Stratum	*F*; *P*	Mite's stage		
			Adult	Immature	Total
	T		1.50 ± 0.50b[z]	3.13 ± 0.74b	4.63 ± 1.16b
SB	M		14.88 ± 4.68a	24.50 ± 6.42a	39.38 ± 9.90a
	B		23.13 ± 5.63a	36.25 ± 8.07a	59.38 ± 13.62a
		F; *P*	31.85; < 0.0001	27.71; < 0.0001	30.54; < 0.0001
SW	T		1.75 ± 0.49b	3.88 ± 1.09c	5.63 ± 1.39c
	M		11.50 ± 3.85a	18.63 ± 5.16b	30.13 ± 8.78b
	B		16.25 ± 4.26a	38.25 ± 5.99a	54.50 ± 9.39a
		F; *P*	17.88; < 0.0001	21.86; < 0.0001	25.26; < 0.0001
WB	T		3.50 ± 0.66b	3.25 ± 0.82c	6.75 ± 0.88c
	M		13.88 ± 5.24a	17.50 ± 3.35b	31.38 ± 6.57b
	B		13.50 ± 2.71a	42.88 ± 10.37a	56.38 ± 12.38a
		F; *P*	8.58; 0.0006	25.28; < 0.0001	22.78; < 0.0001

[z]Means in the same column for each mulch with different letters are significantly different for each mulch treatments at $P \leq 0.05$ according to Tukey's HSD test. For each mulch and stage, df = 2, 51.Immature (larva + protonymph + deutonymph),Total (adult + immature); Silver on black (SB), Silver on white (SW), White on black (WB) Black on white (BW), Black on black (BB), and No mulch (NM); T (Top), M (Middle), and B (Bottom).

Table 7. Mean ± SE number of *A.swirskii*in different strata of cucumber and eggplant in 2016

Crop	Stratum	*F*; *P*	Mite's stage		
			Adult	Immature	Total
Cucumber	Top		1.92 ± 0.61c[z]	3.25 ± 0.77c	5.17 ± 0.99c
	Middle		5.25 ± 1.85b	15.67 ± 4.46b	20.92 ± 5.65b
	Bottom		11.0 ± 2.28a	36.17 ± 8.0a	47.17 ± 9.82a
		F; *P*	14.83; < 0.0001	29.37; < 0.0001	29.36; < 0.0001
Eggplant	Top		2.58 ± 0.38b	3.58 ± 0.67c	6.17 ± 0.9b
	Middle		21.58 ± 3.47a	24.75 ± 3.40b	46.33 ± 5.86a
	Bottom		24.25 ± 3.75a	42.08 ± 4.92a	66.33 ± 8.30a
		F; *P*	47.64; < 0.0001	39.76; < 0.0001	52.29; < 0.0001

[z]Means within the same column for each crop followed by the same letter are not significantly different at $P \leq 0.05$ according to Tukey's HSD test. For each crop and stage, df = 2, 51. Immature (larva + protonymph + deutonymph),Total (adult + immature).

reported that in field plots of bean in Blacksburg, VA, USA, reflected short-wave length (400-700 nm) light was higher over reflective metalized plastic mulch than white plastic or black plastic mulch or bare soil. However, in that experiment, temperature and humidity were similar in all treatments. Based on their findings, we assume that a similar level of temperature and humidity contributed to the success of *A. swirskii* in different mulch treatments. This assumption could be substantiated by further testing of these mulch types with reflectivity measurements in south Florida's agro- ecosystem. Moreover, numerous laboratory studies revealed the deleterious effect of UV-B on egg production, hatching, and survivability of immature and adult phytophagous and predatory mites (Ohtsuka and Osakabe 2009; Koveos et al. 2017). However, in many cases, laboratory studies may not translate into the natural environment. In the laboratory, organisms are exposed to specific doses of UV continuously for a particular period, not the case in the natural environment. Moreover, mites tend to evade areas of high UV radiation (Legarrea et al. 2010), inhabiting the underside of leaves as well as domatia of the leaves (Ohtsuka and Osakabe 2009, Suzuki et al. 2009), and hiding in different plant parts (Onzo et al. 2010). The photoreactivation system of the cuticular carotenoids of phytophagous and predatory mites are reported to aid in UV-B tolerance (Fukaya et al. 2013, Koveos et al. 2017).

In the present study, *A. swirskii* established on all crops except tomato. Paspati (2019) also reported that *A. swirskii* did not establish on tomato plants. Tomato may not be a preferable host to *A. swirskii*, or it might be due to the absence of a sufficient number of prey (melon thrips). Tomato was the least preferable host to melon thrips and few melon thrips larvae were observed in tomato leaf samples (Razzak et al. 2019). Among the six vegetable crops in this study, tomato leaves had the highest number of glandular trichomes per unit area (Razzak et al. 2019). Higher densities of glandular trichomes impede the movement of spider mites and *A. swirskii*, which is an indicator of the repellence property of tomato (Maluf et al. 2007, van Houten et al. 2013). However, additional studies are warranted to make a definitive statement on the establishment efficiency of *A. swirskii* on tomato.

In this study, the highest number of *A. swirskii* was found in eggplant followed by cucumber. Squash, snap beans, and Jalapeno pepper did not differ in preference for *A. swirskii*. A higher number of non-glandular trichomes and domatia are attributed to providing a competitive advantage in prey searching, feeding, mating, oviposition, and hiding of phytoseiid predators. Leaves with domatia had more diverse and higher densities of a phytoseiid species relative to leaves without domatia (O'Dowd and Willson 1991; Walter and O'Dowd 1992a, 1992b). Domatia also offer refuge and protection from top predators, biotic, and abiotic stress (Schmidt 2014, Ghazy et al. 2016). The number of eggs, immatures, and adults of phytoseiid predators *Kampimodromus aberrans* and *A. swirskii* have been positively correlated with the trichome and domatia densities (Barret and Kreiter 1995, Kreiter et al. 2002, Avery et al. 2014). Razzak et al. (2019) found that trichome densities were similar in eggplant, cucumber and squash. However, in eggplant, each trichome has six radiating bars (stellar shaped trichome), which created a denser structure and might have provided more benefit respective to predation and escape from biotic and abiotic stress. Razzak et al. (2019) also reported that the prey (*T. palmi*) densities are higher in eggplant than in cucumber. Higher prey densities could be another driving factor in the preference for eggplant over cucumber. Volatile organic compounds emitted by plants infested with the pest species act as a cue for arthropod predators and parasitoids to attack their prey (Margolies et al. 1997, Sabelis et al. 2007, Arimura et al. 2009). It is not clear why cucumber was preferable to squash, although the trichome densities were similar in both crops. Further study is needed to elucidate the host preference of *A. swirskii* more thoroughly.

In this study, a higher number of *A. swirskii* was found in the bottom stratum followed by the middle stratum of each crop within each mulch treatment. The uppermost stratum had the fewest number of *A. swirskii*. The top stratum was comprised of smaller leaves and exposed to direct sunlight, which might contribute to leaf area with a nonpreferable amount of moisture to *A. swirskii* compared to the other strata. The number of prey larvae was also less in the top stratum. Weintraub et al. (2004) observed that a phytoseiid predator, *Neoseiulus cucumeris*, remained mostly in the plant's bottom and middle sections. Fatnassi et al. (2015) also reported a higher number of *A. swirskii* and *N. cucumeris* in the bottom and middle strata of greenhouse-grown sweet pepper because of higher humidity from a higher transpiration rate compared with the top stratum. They conducted their study in the absence of prey. The present study showed that the number of *A. swirskii* was positively correlated with the number of *T. palmi* larvae, which agrees with the findings of Castineirus et al. (1997).

Overall, there were no significant effects of plastic mulch treatment, either UV reflective or non-UV reflective mulch, on within-plant distributions of *A. swirskii*. We presumed that UV- reflection could impact the within-plant distribution. Onzo et al. (2010) reported that during daytime, predatory mites, *Typhlodromalus aripo*, hide in different parts of cassava plants to protect them from the harmful effects of solar UV. Moreover, specific details of biological and behavioral attributes of *A. swirskii* discussed in the first section of this discussion would probably explain why there were no impacts of reflectivity from different plastic mulches on the within-plant distribution. Our study is the first report on the impact of different plastic mulch treatments on the within-plant distribution of *A. swirskii* in different field-grown vegetable crops.

Implications

Our experiments demonstrated that UV reflection from metalized plastic mulches was not harmful to the establishment of *A. swirskii*, suggesting that the UV reflective mulch could be integrated with this predatory mite to manage various arthropod pests (thrips, whiteflies, aphids, phytophagous mites) infesting several vegetable crop species. However, further release experiments of *A. swirskii* should be conducted with reflective mulches consisting different grades of metallic infusion and reflectivity to make a definitive conclusion. Moreover, reflectivity from different mulches should be measured in the early season when crops do not cover the mulched area and in the late season when the crop canopy shades most of the mulched area. Multi-functionality is an important component of a strong IPM strategy. In another experiment, Razzak et al. (2019) found that compared to colored plastic mulch and bare plots, reflective mulch significantly reduced the number of *T. palmi* in the six vegetable crops tested in the present study. We also assessed plant growth and yield of all these six vegetable crops (unpublished), which were greater with metalized reflective mulch than the other plastic mulches or plots with no mulch. There are numerous reports indicating the effectiveness of metalized mulches in suppressing weed and disease pressure (Lamont 1993, Stapleton and Summers 2002, Summers et al. 2010), and controlling other vegetable and horticultural pests, such as whiteflies, aphids, and leafhoppers. Therefore, metalized mulch combined with the release of a phytoseiid predator could be an important tool in an IPM program for vegetable crops.

An important component of IPM also involves proper sampling and monitoring of pest species as well as the released predator. Therefore, information regarding host preference and within-plant distribution of *A. swirskii* will help growers with proper sampling for pests and can help improve pest management by releasing *A. swirskii*. Our study was conducted over 2 yr in relatively small field plots. Further larger-scale studies involving measurements of reflectivity, careful monitoring of pest and predators, as well as microclimate, and assessment of the cost–benefit ratio are warranted prior to making specific recommendations to growers.

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