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ALTERNATIVE METHODS TO MANAGE SILVERLEAF WHITEFLY [*BEMISIA TABACI* GENNADIUS (HEMIPTERA: ALEYRODIDAE)] IN ZUCCHINI (*CUCURBITA PEPO* L.)

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ABSTRACT

Whiteflies are the most detrimental insect pest for cucurbit crops in Georgia, USA. Plant growth and yield are severely reduced due to whitefly feeding and, more importantly, many plant viruses they vector. Chemical management of whiteflies has been ineffective. An integrated pest management (IPM) strategy is needed to reduce whitefly numbers to an acceptable level in cucurbit crops in Georgia. This study evaluated the impact of plastic mulch color, exclusionary row covers, particle clay, and organic insecticidal solutions (soap and neem oil) on plant growth, fruit yield, and whitefly index (WFindex) in zucchini squash (*Cucurbita pepo* L). The study was conducted during the fall of 2019 and 2020. Particle clay applications reduced zucchini foliar temperatures and WFindex and increased zucchini fruit yields. Black plastic mulch reduced fruit yield due to increased root zone temperature and did not impact whitefly numbers. Neem oil and soap decreased the WFindex but inconsistently affected fruit yield and quality. Our findings indicate that neem oil, soap, and particle clay may be part of an IPM program for whiteflies. However, further evaluations are needed in large plots and commercial fields to confirm the preliminary results of this study.

Key words: dish soap, neem oil, particle clay, plastic mulch, whitefly management

INTRODUCTION

Vegetables are the fourth largest commodity group grown in Georgia, assessed at $1.1 billion in farm gate value, with cucurbit vegetable crops accounting for $322 million in 2020 (Anonymous 2020). In Georgia, commercial production of zucchini (*Cucurbita pepo* L.) and other cucurbits is concentrated in the state's southern portion. Fall cucurbit crops are severely affected by whiteflies [*Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae)] and the viruses transmitted by them, including cucurbit chlorotic yellows virus (CCYV) (Kavalappara et al. 2021a, b), cucurbit leaf crumple virus (CuLCrV) (Larsen & Kmiecik 2010), and cucurbit yellow stunting disorder virus (CYSDV) (Gadhave et al. 2018). Whitefly populations decline in Georgia in the winter and start building up again when the weather gets warmer during the summer. Whitefly-transmitted (WFT) viruses are not reported to damage vegetables in the winter and the spring.

Viruses impact zucchini by reducing plant growth and fruit yield. Without host-plant resistance, current management practice relies heavily on chemical control targeting whiteflies, and this practice has minimal success and significantly increases production costs. Thus, the effects of alternative, nonchemical approaches to managing whiteflies and viruses need to be investigated to develop a successful IPM program. In southern Spain, strategies were evaluated for the control of silverleaf whitefly in zucchini, with integrated pest management providing the best suppressing effect (73%), followed by biological control (58%) and chemical control (44%) (Rodriguez et al. 2019).

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Plastic mulch color has been found to influence plant growth, fruit yield, and insect pest populations in horticultural crops (Greer & Dole 2003; Lamont 2005). Plastic mulches modify the crop's light and temperature microenvironment (Amare & Desta 2021; Sarkar et al. 2018) and improve plant vigor. The plastic mulch color influences the root-zone temperature under the film. Black mulches warm the soil more than white and silver mulches (Amare & Desta 2021; Díaz-Pérez & Batal 2002; Moreno et al. 2009). The ability of mulches to partially reflect the incoming radiation may influence insect behavior and has been used to manage insect vectors such as whiteflies (*Bemisia tabaci*) and thrips (*Frankliniella occidentalis*) (Greer & Dole 2003; LaTora et al. 2022). In fall tomatoes, plants on black mulch had higher root zone temperatures, an earlier appearance of tomato spotted wilt virus (TSWV) symptoms, and reduced vegetative growth and fruit yields compared to white mulch (Díaz-Pérez et al. 2007). Row and floating covers utilize nets to control insect landings by forming a physical barrier (Acharya et al. 2020; Antignus 2011; Ibarra-Jimenez et al. 2002; LaTora et al. 2022). Nets provide an alternative method for insect management by reducing the need for harmful pesticides (Licciardi et al. 2007).

Particle film technology (chemically inert particles of kaolin clay) (Glenn & Puterka 2002) is an effective nonchemical method to control several insects in numerous crops (De Smedt et al. 2015; Hidayat et al. 2013; Sharma et al. 2015). Additionally, particle clay alleviates high light and temperature stresses in horticultural crops (Gharaghani et al. 2018; Glenn & Puterka 2002). Biological pest management is used in organic and conventional systems (Baker et al. 2020). Biological approaches include biopesticides, biological control, pheromones, and biostimulants. Neem oil has been used as a pesticide for centuries. It is increasingly popular as an organic pesticide due to its low toxicity to humans and beneficial organisms. Neem oil extracted from the neem tree (*Azadirachta indica* Juss.) contains over 100 biologically active compounds (Campos et al. 2016). Neem oil inhibits the aphid (*Myzus persicae*) transmission of potato virus Y to sweet pepper (*Capsicum annuum* L.) by interfering with virus acquisition (Lowery et al. 1997). In *Acacia* seedlings, neem seed oil at 0.5% effectively controlled babul whitefly (*Acaudaleyrodes rachipora*) (Sundararaj et al. 1996). Foliar applications of neem oil reduced colonization, oviposition, and egg hatch and increased the mortality of immature stages of silverleaf whitefly in tomatoes (*Lycopersicon esculentum* Mill.) (Kumar et al. 2005). Detergents and soaps cause mortality of *Bemisia tabaci* nymphs in zucchini squash, tomato, and cucumber. (Butler et al. 1993).

The present study aimed to evaluate the effects of IPM strategies on zucchini whitefly control, plant growth, and fruit yield. The IPM strategies included plastic mulch color, row covers, particle clay, and organic insecticidal solutions (soap and neem oil).

MATERIALS AND METHODS

Experimental site, design, and treatments

The study was carried out at the Horticulture Farm, University of Georgia, Tifton Campus (31.446 N and 83.477 W, and an altitude of 116 m) in the fall of 2019 and 2020. The soil is loamy sand and has a pH of 6.5. A historical annual mean air temperature of 18.9 °C and precipitation of 1208 mm (www.georgiaweather.net/). In 2019 (23 Aug. to 15 Oct.), average air temperatures were 33.5 °C (maximal), 26.8 °C (mean), and 20.1 °C (minimal), and cumulative rainfall was 85 mm. In 2020 (12 Aug. to 6 Oct.), average air temperatures were 30.0 °C (maximal), 25.1 (mean), and 20.2 °C (minimal), and cumulative rainfall was 221 mm. Weather data were collected from a University of Georgia nearby (< 300 m) weather station (University of Georgia Weather Network).

Zucchini 'Spineless Beauty F1' (Harris Seeds, Rochester, NY) was direct-seeded on two rows per bed formed on 1.8-m centers, 30 cm between plants within the row and 36 cm between rows. Beds were covered with 1.52 m wide and 25 μm thick low-density polyethylene plastic mulch. A single drip tape (John Deere Ro-Drip, 40) with 20.3-cm emitter spacing and 1.0 $L \cdot h^{-1}$ emitter flow was placed 5 cm deep in the bed center. Irrigation water was applied when cumulative crop evapotranspiration was 12 mm (ca. 2–3 days). The plot size was a 4-m long bed (26 plants per plot).

The number of whiteflies per leaf was estimated visually as a whitefly index (WFindex) using the following scale: 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750). The WFindex was evaluated on the abaxial side of three randomly selected mature leaves per plot during the early morning when whiteflies had little activity. The WFindex determinations were based on five evaluations made twice weekly, starting 30 days after seeding. Plants were monitored weekly for symptoms of viral diseases.

Three trials were conducted in the fall of 2019 and one in the fall of 2020, using similar production practices to evaluate various approaches to managing whiteflies. All treatments were replicated four times and arranged in a randomized complete block design.

Plastic mulch color and row cover (Trial #1)

Zucchini was planted on 23 Aug. 2019. The row cover was installed immediately after planting and removed on 24 Sep. 2019. There were four treatments [two plastic mulches (white and black) and two row-cover treatments (with or without row cover)]. Plastic mulches were from Berry Plastics (Evansville, IN). The mulches were made from low-density polyethylene, 1.52 m wide, 25 μm thick, with a slick surface. The row cover was white (3 m wide, 18.7 $g \cdot m^{-2}$, and 95% light transmission; AgroFabric Pro19; Seven Springs Farm Supply, Check, VA) and was laid in the field immediately after planting.

Plastic mulches and particle clay (Trial #2)

Zucchini was planted on 26 Aug. 2019. There were six treatment combinations [3 plastic mulches (black, gray-on-black, and white-on-black) × 2 kaolin particle clay treatments (treated and untreated)]. The plastic mulch (gray-on-black) was from Pliant (Chesterbrook, PA) and had the same parameters as the others. The kaolin particle clay [‘Surround® WP’ (Novasource, Phoenix, AZ)] was applied on 4, 12, and 17 Sept. 2019 at 112 $kg \cdot ha^{-1}$. Leaf temperature and mulch film temperature were measured (3 readings per plot) with an infrared thermometer at 1400 HR on 4 Oct. 2019.

Organic insecticidal solutions (Trial #3)

Zucchini was planted on 30 Aug. 2019. Plants were grown on low-density white-on-black polyethylene plastic mulch. There were three treatments which were liquid dish soap [2% (Dawn dish soap, Procter and Gamble)], neem oil [1% (Georgia Organic Solutions, Blakely, GA)], and the control (water). Soap, neem oil, and the control were applied on 18 Sep. 2019. This trial was repeated in the fall of 2020 (planted on 12 Aug.). Treatments (soap, neem oil, and water) were applied on 21 and 28 Aug. and 8 Sep. 2020.

Fruits were harvested (10 plants per plot) and graded as marketable and nonmarketable according to the standards of the United States Department of Agriculture (Anonymous 2016). Nonmarketable fruit included discoloration, mechanical injury, and damage caused by insects and diseases.

Statistical analysis

Except for the whitefly index, data were analyzed using the General Linear Model from SAS (ver. 9.4, SAS Inst., Cary, NC). Means comparisons were performed using Tukey’s test ($P < 0.05$). The WFindex was analyzed using a logistic regression model for the ordinal response variable. Treatment effects were tested by comparing the odds of whitefly index values in different treatment groups. Instead of mean comparisons, odds ratios were used to detect the differences between groups of treatments. A significant difference in the WFindex between treatments was concluded when the 95% confidence interval of the odds ratio did not include 1. The analysis was performed by LOGISTIC SAS procedure.

RESULTS

In Trial #1, plastic mulch color did not affect the fresh plant weight (FW), WFindex, marketable fruit number, marketable fruit weight, and individual fruit weight (Table 1). Plants kept under row cover showed reduced whiteflies index. Plants under row cover had 4.87 times higher odds of displaying a small number of whiteflies than uncovered plants, where the confidence interval of the odds ratio was (2.04, 11.65) (Table 1A). However, when the small or medium numbers of whiteflies are compared to the high numbers of whiteflies, the odds of plants under the row cover were 2.18 times higher than those uncovered. This result is nonsignificant when considering its 95% confidence interval (0.61, 7.82). The equivalent statement is that row cover significantly reduced the odds of having medium or high numbers of whiteflies but not the odds of only having high numbers of whiteflies. Therefore, the effect of row cover on the WFindex depends on the values of the WFindex.

In Trial #2, plastic mulch color did not affect plant FW and individual fruit weight (Table 2). Marketable fruit number and weight were highest in plants on gray mulch and lowest in black mulch. Particle clay reduced the WFindex (Table 1A) and increased the marketable fruit number and total weight (Table 2). Leaf temperature and mulch film surface temperature were similar among plastic film mulches. However, applying particle clay reduced leaf and mulch film surface temperatures.

In Trial #3 (2019), plant FW and fruit weight were unaffected by insecticidal solutions (Table 3). The WFindex was reduced on plants treated with neem oil and soap. Marketable fruit number and yield were highest with neem oil and lowest with the control. In 2020, insecticidal treatments did not affect plant FW, marketable fruit number and yield, and individual fruit weight (Table 4). We did not observe any foliar symptoms associated with virus diseases in both years of the study.

Table 1. Effect of plastic mulch color and row cover on plant growth, leaf whitefly index (WFindex), and zucchini fruit yield (Trial #1). Values are means ± SE, fall of 2019

Treatment	Plant fresh wt (g)	Whitefly index[1]	Marketable (1000 per ha)	Marketable (t per ha)	Fruit wt (g per fruit)
			Mulch		
Black	328 ± 34	3.0	101.3 ± 9.1	21.6 ± 2.6	208.0 ± 26.5
White	336 ± 36	3.2	131.8 ± 13.5	28.4 ± 3.3	216.8 ± 12.3
			Row cover		
Covered	333 ± 32	1.8 b[2]	135.4 ± 11.0	28.1 ± 3.7	201.3 ± 12.9
Uncovered	331 ± 37	4.3 a	108.6 ± 11.5	24.6 ± 1.9	236.0 ± 24.0
			Significance		
Mulch (M)	0.882	0.972	0.180	0.298	0.845
Row cover (C)	0.971	<0.002	0.094	0.360	0.218
M × C	0.667	0.994	0.829	0.820	0.706

[1]WFindex (per leaf): 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750)

[2] Within column and main factor, means followed by the same letter are not significantly different based on Tukey's test at 95% confidence

Table 1A. Effect of row cover on whitefly index (WFindex) odds ratio estimates and Wald confidence intervals in zucchini grown with row cover or uncovered, fall of 2019

Odds ratio	Estimate	95% confidence interval	
WFindex 2: With cover vs. Uncovered	4.874	2.040	11.650
WFindex 3: With cover vs. Uncovered	2.181	0.608	7.819

[1]WFindex (per leaf): 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750)

Table 2. Effect of plastic mulch color and particle clay applications on plant growth, leaf whiteflies index (WFindex), and marketable fruit yield in zucchini (Trial #2). Values are means ± SE, fall of 2019

Treatment	Plant fresh wt (g)	WFindex	Marketable (1000 per ha)	Marketable (t per ha)	Fruit wt (g)	Leaf temperature (°C)	Mulch surface temperature (°C)
Mulch							
Black	521 ± 46	2.64[1]	52.6 ± 2.9 b[2]	11.9 ± 0.9 b	227 ± 11.9	36.9 ± 1.7	45.5 ± 2.6
Gray	509 ± 33	2.75	68.7 ± 5.0 a	16.4 ± 1.6 a	237 ± 11.4	36.2 ± 1.4	46.6 ± 3.1
White	462 ± 23	2.63	68.6 ± 5.9 a	14.9 ± 1.5 ab	217 ± 12.6	36.8 ± 1.2	46.8 ± 1.3
Particle clay							
Untreated	488 ± 28	2.90 a[3]	58.0 ± 4.0 b	13.0 ± 1.1 b	225 ± 10.5	39.6 ± 0.9 a	51.0 ± 1.4 a
Treated	509 ± 32	2.44 b	67.2 ± 4.2 a	15.4 ± 1.2 a	228 ± 9.3	33.7 ± 0.7 b	41.5 ± 1.2 b
Significance							
Mulch (M)	0.508	0.708	0.007	0.018	0.468	0.737	0.798
Particle clay (C)	0.613	<0.0001	0.032	0.035	0.645	0.0002	<0.0001
M × C	0.990	0.079	0.335	0.069	0.092	0.865	0.188

[1]WFindex (per leaf): 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750)

[2]Within column and main factor, all means except means of WFindex followed by the same letter are not significantly different based on Tukey's test at 95% confidence

[3]Plants treated with particle clay had 59.77 times higher odds of showing fewer whiteflies than untreated plants, where the 95% Wald confidence interval of the odds ratio was (11.42, 312.82)

Table 3. Effect of organic insecticidal solutions on plant growth, whitefly index (WFindex), and zucchini fruit yield (Trial #3). Values are means ± SE, fall of 2019

Treatment	Plant fresh wt (g)	WFindex[1]	Marketable (1000 per ha)	Marketable (t per ha)	Fruit wt (g per fruit)
Neem oil	624 ± 74	2.7 ± b[2]	46.6 ± 3.9 a[3]	9.3 ± 1.0 a	199 ± 10.4
Soap	631 ± 44	2.5 ± c	34.1 ± 6.1 ab	6.0 ± 1.3 ab	181 ± 7.1
Control (water)	569 ± 49	3.7 ± a	20.6 ± 5.7 b	3.8 ± 1.2 b	175 ± 22.1
P	0.693	<0.0001	0.023	0.024	0.517

[1]WFindex (per leaf): 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750)

[2]Plants treated with neem oil had 604.14 times higher odds of showing fewer whiteflies than plants treated with water, where the 95% Wald confidence interval of the odds ratio was (30.73, >999.99). Plants treated with soap had over 999.99 times higher odds of showing fewer whiteflies than with water, where the 95% Wald confidence interval of the odds ratio was (122.31, >999.99). When comparing neem oil and soap, plants treated with soap had 7.03 times higher odds of showing fewer whiteflies than plants treated with neem oil. However, the confidence interval (1.07, 46.22) barely excluded 1

[3]Within column, all means except means of WFindex followed by the same letter are not significantly different based on Tukey's test at 95% confidence

Table 4. Effect of organic insecticidal solutions on plant growth, whiteflies index (WFindex), and zucchini fruit yield (Trial #3). Values are means ± SE, fall of 2020

Treatment	Plant fresh wt (g)	WFindex[1]	Marketable (1000 per ha)	Marketable (t per ha)	Fruit wt (g per fruit)
Neem oil	777	2.7 b[2]	102 ± 2	16.6 ± 1.0	162 ± 9
Soap	717	2.6 b	105 ± 6	16.8 ± 1.4	158 ± 7
Control (water)	602	4.1 a	108 ± 8	17.0 ± 1.2	159 ± 6
P	0.283	<0.0001	0.850	0.959	0.804

[1]WFindex (per leaf): 1 – no whiteflies, 2 – small number of whiteflies (< 250), 3 – medium number of whiteflies (250–500), 4 – high number of whiteflies (500–750), and 5 – extremely high number of whiteflies (> 750)

[2]Plants treated with neem oil had 135.69 times higher odds of showing fewer whiteflies than plants treated with water (95% Wald confidence interval of the odds ratio was 11.98, >999.99). Plants treated with soap had over 181.74 times higher odds of showing fewer whiteflies than plants treated with water (95% Wald confidence interval of the odds ratio was 15.54, >999.99). When comparing neem oil to soap, the odds of showing fewer whiteflies were not significant; the odds ratio was 0.75 [confidence interval (0.20, 2.84)]

DISCUSSION

Plastic mulch color

Plastic mulch color had no effects on plant FW or WFindex and had an inconsistent impact on fruit yield. While in Trial #1, there were no significant effects of plastic mulch color on fruit yield, in Trial #2, marketable fruit number and yield were reduced on black plastic mulch by 23% and 20%, respectively, compared to white mulch. The reduced fruit yields are probably because of supraoptimal root-zone temperature conditions under black mulch during the fall season in Georgia, as previously reported for tomatoes (Díaz-Pérez & Batal 2002) and other crops. Plastic mulch color did not affect the WFindex, suggesting that root-zone temperature did not influence whiteflies.

Row cover

The WFindex was reduced in plants that had been covered. The low presence of whiteflies did not increase plant FW or fruit yield. Plants under row cover may have enhanced plant growth and reduced low insect populations (Acharya et al. 2020). However, the effect of row cover on the enclosed environment depends on net composition, covering method, and season. During the summer, a cover composed of polyethylene terephthalate increased the air temperature (Hamasaki 2013).

Particle clay

The benefits of particle clay are inconsistent in the literature. In the present study, particle clay reduced the WFindex. Our findings agree with studies showing that particle clay controls several insects (De Smedt et al. 2015; Glenn & Puterka 2002; Hidayat et al. 2013). Our results showed that particle clay decreased leaf and mulch surface temperatures. The diminished leaf temperature resulted from the reduced infrared radiation captured by leaves covered with particle clay. Under the high ambient temperature conditions, the decreased leaf temperature may have improved fruit growth, leading to increased fruit yields. Particle clay increased marketable fruit number and yield but did not impact plant fresh weight. In bell and jalapeno peppers (*Capsicum annum* L.), particle clay did not affect leaf gas exchange, the incidences of Phytophthora blight (*Phytophthora capsici*) and *Pythium* spp., and fruit yields (Russo & Díaz-Pérez 2005).

Organic insecticidal treatments

Neem oil and soap decreased the WFindex in both 2019 and 2020. This reduction in whitefly populations explains the increased zucchini fruit number and yield in 2019. In 2020, however, there were no differences in fruit number and yield among insecticidal treatments. The impact of whiteflies and viral diseases on zucchini may vary yearly due to interactions with environmental factors (personal observation). Neem oil is efficacious for thrips (Thysanoptera) control in mango (*Mangifera indica* L.) and can be used in combination with imidacloprid (Aliakbarpour et al. 2011). In corn, neem extract was as effective as fipronil in controlling *Diabrotica speciosa* larvae (Boiça et al. 2017). As part of the IPM program that included chemical pesticides, neem oil effectively controlled pests and increased tomato fruit yields (Boiça et al. 2007). In zucchini and tomato leaves, detergents caused more than 85% mortality of sweet potato whitefly compared to water (Butler et al. 1993). Detergents, soaps, neem oil, and other plant-derived oils applied on the undersurface of leaves provided adequate control of whitefly on cotton (*Gossypium*) (Puri et al. 1994).

CONCLUSIONS

Particle clay applications reduced leaf temperatures and WFindex and increased zucchini fruit yields. Further studies on particle clay as a tool for the management of whiteflies and for improving plant health are needed. Black plastic mulch reduced fruit yields and thus is not recommended for fall zucchini production in South Georgia. Neem oil and soap reduced the population of whiteflies. Therefore, neem oil, soaps, and particle clay may be part of IPM programs for whiteflies. Further evaluations in large plots and commercial fields may be necessary to investigate the benefits of these alternate tools.

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Disclosure statement

The authors report that there are no competing interests to declare.

Data availability statement

All the data are included in the manuscript.

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