Yellow Squash and Zucchini Cultivar Selection for Resistance to Cucurbit Leaf Crumple Virus in the Southeastern United States

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ADDITIONAL INDEX WORDS. *Cucurbita pepo*, disease severity, fruit yield and quality, sweetpotato whitefly, weather conditions

SUMMARY. Large populations of sweetpotato whiteflies (*Bemisia tabaci*) have become more regular occurrences during the fall months in parts of the southeastern United States. Large populations of sweetpotato whiteflies have resulted in a significant increase in the incidence of sweetpotato whitefly-transmitted viruses, particularly the cucurbit leaf crumple virus (CuLCrV), which has the potential to cause complete yield loss of fall-planted yellow squash and zucchini (*Cucurbita pepo*). This study evaluated commercial cultivars of yellow squash and zucchini for resistance against CuLCrV and estimated the yield and fruit quality under environmental conditions during the fall growing season in the southeastern United States. A factorial experimental design was conducted with nine yellow squash and 11 zucchini cultivars during Fall 2017, Fall 2018, and Fall 2019 in Tifton, GA. In situ weather stations monitored the weather conditions during growing seasons, and yellow pest monitor cards monitored the sweetpotato whitefly populations in 2018 and 2019. During all growing seasons, yellow squash and zucchini plants were rated weekly for the severity of CuLCrV. Harvests were conducted 12 times during each season, and fruit were graded as fancy, medium, and culls. Rainfall distribution directly affected the sweetpotato whitefly populations during the production year. In 2018, frequent rainfall events created field conditions that reduced the sweetpotato whitefly populations compared with those during 2017 and 2019. The severity of CuLCrV negatively impacted both the yield and quality of fruit of yellow squash and zucchini, and no resistant commercial cultivars of yellow squash or zucchini were identified. Nonetheless, the yellow squash cultivars Lioness, Gold Prize, and Grand Prize, and the zucchini cultivars SV6009YG and SV0914YG had the highest yields when subjected to the highest sweetpotato whitefly populations during the study.

Sweetpotato whiteflies (*Bemisia tabaci*) have been reported in the southeastern United States

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since 1894. However, no economic impact on crops was associated with this pest until 1986, when significant infestations impacted ornamental plant nurseries in Florida (Price et al., 1987). Most recently, the sweetpotato whitefly population has increased in the southeastern United States during the fall months. This is particularly

notable in northwest Florida, southwest Georgia, and southeast Alabama, where the growing seasons of cucurbit vegetables [e.g., yellow squash and zucchini (*Cucurbita pepo*), cucumber (*Cucumis sativus*)] and agronomic crops [e.g., cotton (*Gossypium hirsutum*)] overlap during the year, allowing for the insect to disperse easily across crops. Consequently, vegetable growers have been challenged with sweetpotato whitefly-transmitted viruses, particularly the cucurbit leaf crumple virus (CuLCrV), which has caused significant yield losses of yellow squash and zucchini (*Cucurbita pepo*) crops (Akad et al., 2008; Coolong, 2017; Nyoike et al., 2008; Webb et al., 2017).

Georgia is a significant producer of yellow squash and zucchini in the United States (U.S. Department of Agriculture, 2019), with more than 7000 acres planted during the spring and fall seasons (Wolfe and Stubbs, 2018). When planted in the spring, yellow squash and zucchini have low to no damage from whiteflies because the insect populations are low. However, when yellow squash and zucchini are planted in the fall, there is an overwhelming increase in the sweetpotato whitefly populations and CuLCrV infection, resulting in significant yield losses (Gautam et al., 2020; Nyoike et al., 2008). Symptoms of CuLCrV exhibited by yellow squash and zucchini plants include severe foliar chlorosis, curling, stunting, and green streaking of the fruit, rendering them unmarketable (Webb et al., 2017). Between 2016 and 2017, growers in Georgia estimated losses of more than \$50 million, primarily because of disease outbreaks caused by whitefly-transmitted virus complex (Little, 2019).

During CuLCrV acquisition, there is a latent period that allows for

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
70.0532	oz/acre	g·ha ⁻¹	0.0143
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

insecticide sprays to suppress sweetpotato whitefly populations in the field. However, large populations and the CuLCrV persistent-circulative mode of transmission, in which whiteflies may remain viruliferous throughout their entire life cycle, result in the reduced efficacy of spray programs to minimize the impact of CuLCrV (Dutta et al., 2019). Furthermore, sweetpotato whitefly resistance to insecticides has been reported for more than 60 active ingredients (Mota-Sanchez and Wise, 2019), including organophosphates, carbamates, pyrethroids, insect growth regulators, pyriproxyfen, buprofezin, neonicotinoids, ketoenols, diamides, and pymetrozine (Horowitz et al., 2020). Therefore, integrated pest management practices comprise an essential alternative to spray programs and have shown satisfactory results managing this pest. For example, the use of reflective mulches has been reported to reduce sweetpotato whitefly populations in a variety of crops (Csizinszky et al., 1999; Kousik et al., 2015; Nyoiike et al., 2008; Polston and Lapidot, 2007; Simmons et al., 2010; Smith et al., 2000; Summers et al., 2004). In Georgia, 76% to 81% reductions in sweetpotato whitefly adults and nymphs were reported for tomato (*Solanum lycopersicum*) during a 3-year study using reflective silver mulch (Riley and Srinivasan, 2019). Additionally, biological controls (i.e., entomopathogenic fungi *Beauveria bassiana*, *Paecilomyces fumosoroseus*, and *Clonostachys rosea*) and organic insecticides have reportedly reduced sweetpotato whitefly populations (85% to 90%) in cucumber, cantaloupe (*Cucumis melo*), zucchini, and yellow squash (Anwar et al., 2018; Wraight et al., 2000).

The aforementioned studies reported that cultivar selection is a key step in the implementation of an integrated pest management strategy for sweetpotato whitefly populations and the virus complex transmitted by them. However, there are no reports of yellow squash and zucchini resistance to CuLCrV available for commercial cultivars to date. Therefore, this study evaluated commercial cultivars of yellow squash and zucchini for resistance to whiteflies and CuLCrV and estimated yield and fruit quality under the environmental conditions of the southeastern United States.

Materials and methods

Field experiments were conducted at the Tifton Vegetable Park at the University of Georgia, Tifton, GA (lat. 31°29'14"N, long. 83°31'10"W). The soil is characterized as a Tifton loamy sand series (2% slope) (U.S. Department of Agriculture, 1983). The climate in the region is classified as Cfa (humid subtropical climate) and is characterized by high temperatures with precipitation during the summer and cool dry periods during the winter (Köppen, 1931).

EXPERIMENTAL DESIGN AND CROP MANAGEMENT. Factorial experimental designs for nine yellow squash cultivars and 11 zucchini cultivars (Table 1) were separately arranged in a randomized complete block design ($r = 3$) during Fall 2017, Fall 2018, and Fall 2019. Seeds were directly planted on 18 Aug. 2017, 10 Aug. 2018, and 30 Aug. 2019, on 6-inch-tall raised beds spaced at 6 ft center-to-center with white-on-black totally impermeable film (TIF) plastic mulch (Vaporsafe RM, 60-inch; Raven Industries, Sioux

Falls, SD). A single row of plants was spaced 12 inches apart within rows on each bed for a population of 7260 plants/acre or 17,939 plants/ha. Within each bed, experimental plots comprised 10 plants. Adjacent plots within a bed were separated by a 5-ft buffer.

During all growing seasons, yellow squash and zucchini cultivars were sprayed weekly with 10 oz/acre flupyradifurone (Sivanto 200 SL; Bayer CropScience, Research Triangle Park, NC), 8 oz/acre fipronoxifen (Knack; Valent, Walnut Creek, CA), or 15 oz/acre cyantraniliprole (Exriel; DuPont, Wilmington, DE) to control sweetpotato whitefly. All other pest management practices used for disease control were performed according to the recommendations of the University of Georgia (Taylor, 2018). Fertilizer was applied weekly to supply 150 lb/acre of nitrogen using 7N-0P-5.8K (Big Bend Supply Co., Cairo, GA) via fertigation. Irrigation water was applied daily through drip irrigation tubing (12-inch emitter spacing, 0.5 gal/min per 100 ft at 10 psi; Chapin DLX; Jain USA, Haines City, FL) placed in the center of the bed. Irrigation events were applied to supply the historical crop evapotranspiration according to the methods of da Silva et al. (2019).

MONITORING OF WEATHER CONDITIONS AND THE SWEETPOTATO WHITEFLY POPULATION. Rainfall and maximum and minimum air temperatures were recorded hourly using an automated weather station located in Tifton, GA, provided by the Georgia Automated Environmental Monitoring Network (University of Georgia Weather Network, 2019).

In 2018 and 2019, sweetpotato whitefly populations were monitored

Table 1. Zucchini and yellow squash cultivars used during the field experiments conducted during the growing seasons of 2017, 2018, and 2019.

Zucchini cultivar	Reported resistance	Yellow squash cultivar	Reported resistance
SV6009	Px, CMV, WMV, ZYMV	Lioness	PRSV, CMV, WMV, ZYMV
SV0914	Pcu, SLCV, CMV, WMV, ZYMV	Grand Prize	Px, PRSV, WMV, ZYMV
SV0474	Px, CMV, WMV, ZYMV	Gold Prize	WMV, ZYMV
Esteem	Px, PRSV, WMV, ZYMV	Conqueror III	PRSV, CMV, WMV, ZYMV
Payload	Px, PRSV, CMV, WMV, ZYMV	Enterprise	—
Respect	Px, PRSV, WMV, ZYMV	Lazor	ZYMV
Justice III	CMV, WMV, ZYMV	Gold Star	Px, CMV
Paycheck	Px, CMV, WMV, ZYMV	Cosmos	Px, PRSV, WMV, ZYMV
Spineless Beauty	—	Gentry	—
Spineless Perfection	Px, WMV, ZYMV		
Spineless King	Px, WMV, ZYMV		

Px = powdery mildew caused by *Podosphaera xanthii*; CMV = Cucumber mosaic virus; WMV = Watermelon mosaic virus; ZYMV = Zucchini yellow mosaic virus; Pcu = *Pseudoperonospora cubensis*; SLCV = Squash leaf curl virus; PRSV = Papaya ringspot virus.

Fig. 1. Disease score criteria used for cucurbit leaf crumple virus (CuLCrV) in yellow squash and zucchini. Scales: 1 = no visible symptoms; 2 = $\leq 50\%$ of plants showing leaves with minimal curling symptoms and early chlorosis; 3 = $>50\%$ of plants showing leaves with minimal curling and early chlorosis; 4 = $\leq 50\%$ of plants showing leaves with severe curling, yellowing, or stunting; and 5 = $>50\%$ of plants showing severe curling, yellowing, or stunting.

weekly using yellow pest monitor cards (3- × 5-inch sensor; BASF, Research Triangle Park, NC) during the entire year. Yellow pest monitor cards were installed 15 cm above the ground and vertically oriented. The numbers of whiteflies were counted in the center 12 inches² of each card.

MONITORING OF CuLCrV DURING GROWING SEASONS. During all growing seasons, yellow squash and zucchini plants were rated weekly for the severity of CuLCrV starting at first harvest (9 Sept. 2017, 11 Sept. 2018, and 22 Sept. 2019). The CuLCrV monitoring was conducted over 4 consecutive weeks. During each screening, an overall score was assigned to each plot of both trials using the severity ratings for CuLCrV (Fig. 1) as follows: 1 = no visible symptoms; 2 = $\leq 50\%$ of plants showing leaves with minimal curling symptoms and early chlorosis; 3 = $>50\%$ of plants showing leaves with minimal curling and early chlorosis; 4 = $\leq 50\%$ of plants showing leaves with severe curling, yellowing, or stunting; and 5 = $>50\%$ of plants showing severe curling, yellowing, or stunting.

To confirm the CuLCrV symptoms on yellow squash and zucchini, leaf samples ($n = 3$ samples per replicate per cultivar) were tested using a real-time polymerase chain reaction assay specific for CuLCrV (Gautam et al., 2020). DNA samples that tested positive for CuLCrV were included as a positive control. Water was added instead of DNA in negative controls.

YELLOW SQUASH AND ZUCCHINI HARVEST. Yellow squash and zucchini plants were harvested three times weekly starting on 9 Sept. 2017, 11 Sept. 2018, and 22 Sept. 2019.

Harvests were conducted 12 times during each season and fruit were graded as fancy (US no. 1), medium, and cull fruit according to the U.S. Department of Agriculture grade standards (U.S. Department of Agriculture, 2016). For both yellow squash and zucchini, fruit classified as fancy had an average weight of 158 g and average length of 15 cm, whereas fruit classified as medium had an average weight of 294 g and average length of 20 cm. Fruit was culled (unmarketable) because of shape, virus symptoms, and poor color.

STATISTICAL ANALYSIS. Statistical analyses were performed using the software JMP Pro 15.0 (SAS Institute, Cary, NC). For each crop, the severity of CuLCrV was analyzed using cultivar, sampling time, year, and their interactions as fixed effects, whereas sampling time was treated as a repeated measurement. The total yield and yield of fancy, medium, and cull fruit of yellow squash and zucchini were analyzed using cultivar, year, and their interaction as fixed effects. During all analyses, when the F value of the analysis of variance was significant, multiple mean comparisons were performed using Tukey's test with a P value of 0.05. Additionally, the severity of CuLCrV at first harvest was correlated with yellow squash and zucchini yields of total fancy, medium, and cull fruit. Correlations were considered significant at a P value of 0.05, and the Pearson coefficient was selected to determine the strength of the correlation.

Results

WEATHER CONDITIONS AND SWEETPOTATO WHITEFLY POPULATIONS. Sweetpotato whitefly populations in

2018 and 2019 were negligible from January to June; they increased during July, August, and September, and they started to decline from October to December (Fig. 2). Sweetpotato whitefly populations comprised an average of 130 whitefly adults/trap on 21 Sept. 2018, and an average of 637 whitefly adults/trap on 20 Sept. 2019. During the yellow squash and zucchini growing seasons, sweetpotato whitefly trap counts were, on average, 25, 98, 76, and 23 whitefly adults/trap in 2018, and 86, 450, 258, and 170 whitefly adults/trap in 2019, during planting, vegetative growth, flowering, and fruiting/harvest stages, respectively.

Daily maximum and minimum air temperatures varied more during 2017 and 2019 than during 2018 (Fig. 3); however, daily maximum and minimum air temperatures during all study years were within the optimum range for sweetpotato whitefly development (15 to 35 °C). The average daily air temperature for all years was 26 °C.

Rainfall accumulations during each season were 229, 380, and 58 mm in 2017, 2018, and 2019, respectively. The frequency of rainfall events seemed to affect sweetpotato whitefly populations more than the total volume of rainfall. In 2017, there were few scattered heavy rainfall events (Fig. 3), which led to extremely high levels of sweetpotato whitefly adults observed in the field (data not recorded). In 2018, rainfall occurred almost daily, early in the season (Fig. 2). Consequently, sweetpotato whitefly populations were the lowest in 2018 (Fig. 2). In 2019, there were scattered rain events during the study

Fig. 2. Sweetpotato whitefly population per trap (no. of adult whiteflies/12 inches²) in 2018 and 2019, in Tifton, GA. 1 inch = 2.54 cm.

period (Fig. 3), which may have resulted in higher sweetpotato whitefly populations (Fig. 2).

EFFECTS OF CuLCrV ON YELLOW SQUASH AND ZUCCHINI. Year, sampling time, and cultivar did not significantly interact to affect CuLCrV severity in yellow squash. However, the main effect of year and cultivar significantly affected CuLCrV severity in yellow squash (Fig. 4). The mean severity of CuLCrV was highest in 2017 (4.3),

followed by 2019 (3.2) and 2018 (0.1). Cultivars Cosmos (2.8) and Gold Star (2.8) had the highest CuLCrV severity ratings; however, their severity ratings were not significantly different from those of cultivars Conqueror III (2.6), Enterprise (2.5), Gentry (2.7), and Lazor (2.5). The cultivar Lioness (2.1) had the lowest CuLCrV severity.

Similar to yellow squash, significant interactions were not observed

among years, sampling time, and cultivar for CuLCrV severity in zucchini. However, the main effects of year and cultivar were significant for CuLCrV severity (Fig. 5). The CuLCrV severity ratings were highest in 2017 and 2019. There were no visible CuLCrV symptoms observed in zucchini in 2018. For the main effect of cultivar, ‘Paycheck’ (1.9) had the highest severity rating for CuLCrV, whereas ‘Justice III’ (1.3) had the lowest severity rating. The severity rating of ‘Paycheck’ was not significantly different from those of ‘Spineless Beauty’ (1.8), ‘Spineless King’ (1.7), ‘Spineless Perfection’ (1.8), and ‘SV0474YG’ (1.7).

YELLOW SQUASH AND ZUCCHINI YIELD AND FRUIT QUALITY. There was a significant interaction between year and cultivar for the yield of fancy, medium, and cull fruit of yellow squash (Table 2). The yield of fancy yellow squash fruit was higher during 2018 than during 2017 and 2019, regardless of cultivar (Table 3). In 2017, the fancy fruit yield was the greatest for cultivars Lioness (3790 kg·ha⁻¹) and Grand Prize (3487 kg·ha⁻¹). Cultivar Gentry (30,078 kg·ha⁻¹) had the highest yield of fancy fruit in 2018, whereas cultivars Gold Prize (2684 kg·ha⁻¹), Grand Prize (1554 kg·ha⁻¹), and Gold Star (1018 kg·ha⁻¹) had the highest yield of fancy in 2019. The yield of medium

Fig. 3. Weather conditions during 2017, 2018, and 2019, including maximum and minimum air temperatures (°C) and rainfall events (mm). Data recorded at 1-h intervals and retrieved from the Georgia Automated Environmental Monitoring Network at Tifton. Yellow squash and zucchini were planted on 8 Aug. 2017, 10 Aug. 2018, and 30 Aug. 2019, and harvested three times weekly for a total of 12 harvests starting on 9 Sept. 2017, 11 Sept. 2018, and 22 Sept. 2019. (1.8 × °C) + 32 = °F; 1 mm = 0.0394 inch.

Fig. 4. The severity of cucurbit leaf crumple virus (CuLCrV) per year, the week after the first harvesting, and among cultivars during the yellow squash development during 2017, 2018, and 2019. Severity scales: 1 = no visible symptoms; 2 = $\leq 50\%$ of plants showing leaves with minimal curling symptoms and early chlorosis; 3 = $>50\%$ of plants showing leaves with minimal curling and early chlorosis; 4 = $\leq 50\%$ of plants showing leaves with severe curling, yellowing, or stunting; and 5 = $>50\%$ of plants showing severe curling, yellowing, or stunting. Values followed by the same letters within each graphic indicate no significant difference ($P < 0.05$) according to the Tukey-Kramer adjustment.

fruit was higher in 2018 and 2019 than in 2017 for all cultivars, except for Cosmos, which had the highest yield of medium fruit only in 2018. The cultivar had no effect on the yield of medium fruit in 2017 and 2018, whereas cultivar Gold Star ($1283 \text{ kg} \cdot \text{ha}^{-1}$) had the highest yield of medium fruit in 2019. Yellow squash grown in 2018 had the highest yield of cull fruit; however, then number of cull

fruit in 2017 was significantly higher than that in 2018. The lowest yield of cull fruit was measured in 2019; this might have been expected because the 2019 study year had the lowest total yield. The overall average numbers of cull fruit in 2017, 2018, and 2019 represented 89%, 46%, and 26% of total yields, respectively.

Similar to yellow squash, zucchini fancy, medium, and cull yields were

affected by a significant interaction between year and cultivar (Table 3). The yield of fancy zucchini fruit was not significantly different among years for all cultivars, except for Respect, which had a lower yield of fancy fruit in 2019 compared with 2018, and except for SV6009, which had a lower yield in 2019 compared with 2018 and 2017. In 2017, the cultivar SV6009 ($15,793 \text{ kg} \cdot \text{ha}^{-1}$) had the highest yield

Fig. 5. The severity of cucurbit leaf crumple virus (CuLCrV) per year, the week after harvesting, and among cultivars during zucchini development during 2017, 2018, and 2019. Severity scales: 1 = no visible symptoms; 2 = $\leq 50\%$ of plants showing leaves with minimal curling symptoms and early chlorosis; 3 = $>50\%$ of plants showing leaves with minimal curling and early chlorosis; 4 = $\leq 50\%$ of plants showing leaves with severe curling, yellowing, or stunting; and 5 = $>50\%$ of plants showing severe curling, yellowing, or stunting. Values followed by the same letters within each graphic indicate no significant difference ($P < 0.05$) according to the Tukey-Kramer adjustment.

Table 2. Effect of the interaction between yellow squash cultivar and year on the yield of fancy, medium, and cull fruit in Tifton, GA.

Yellow squash cultivar	Yr		
	2017	2018	2019
Yield (kg·ha ⁻¹) ^z			
Fancy fruit			
Conqueror III	855 bc ^y B ^x	19,322 b A	274 b B
Cosmos	0 c B	18,288 b A	0 b B
Enterprise	570 bc B	14,443 b A	169 b B
Gentry	0 c B	30,078 a A	571 b B
Gold Prize	960 b B	16,521 b A	2,684 a B
Gold Star	95 c B	19,370 b A	1,018 a B
Grand Prize	3,487 a B	13,530 b A	1,554 a B
Lazor	475 bc B	19,718 b A	329 b B
Lioness	3,790 a B	11,542 b A	493 b B
Medium fruit			
Conqueror III	0 a B	1,628 a A	188 b A
Cosmos	0 a B	2,291 a A	0 b B
Enterprise	0 a B	446 a A	256 b A
Gentry	0 a B	1,254 a A	256 b A
Gold Prize	0 a B	868 a A	250 b A
Gold Star	0 a B	1,519 a A	1,283 a A
Grand Prize	0 a B	109 a A	438 ab A
Lazor	0 a B	217 a A	313 ab A
Lioness	0 a B	1,145 a A	63 b A
Cull fruit			
Conqueror III	9,495 bc B	21,007 a A	164 a C
Cosmos	7,596 c B	15,070 ab A	0 a C
Enterprise	9,970 abc A	16,848 a A	169 a B
Gentry	4,505 c B	17,112 a A	452 a C
Gold Prize	9,157 bc A	15,382 ab A	1,808 a B
Gold Star	3,527 c AB	8,925 b A	224 a B
Grand Prize	9,437 bc B	21,007 a A	359 a C
Lazor	16,101 a A	14,285 ab A	329 a B
Lioness	12,723 ab A	15,677 ab A	55 a B

^z1 kg·ha⁻¹ = 0.8922 lb/acre.

^yWithin a column, values followed by the same lowercase letter indicate no significant difference ($P \leq 0.05$) between cultivars according to the Tukey-Kramer adjustment.

^xWithin a row, values followed by the same uppercase letter indicate no significant difference ($P \leq 0.05$) between years according to the Tukey-Kramer adjustment.

of fancy fruit, whereas cultivar Spineless King (4093 kg·ha⁻¹) had the lowest. There were no significant differences among any other cultivars for yields of fancy fruit in 2017. In 2018, the yield of fancy fruit was not different among cultivars. In 2019, cultivar SV0914 (11,789 kg·ha⁻¹) had the highest yield of fancy fruit, whereas ‘Justice III’ (3071 kg·ha⁻¹), ‘Respect’ (2629 kg·ha⁻¹), and ‘Spineless King’ (1986 kg·ha⁻¹) had the lowest yields of fancy fruit. The yield of medium fruit was higher in 2018 and 2019 than in 2017 for all cultivars. In 2017 and 2018, there were no significant differences among cultivars for yields of medium fruit. In 2019, the cultivar Spineless King (7342 kg·ha⁻¹) had a significantly greater yield of medium fruit than cultivars Spineless

Beauty, Esteem, and Justice III. In general, the yield of zucchini cull fruit was significantly greater in 2017 and 2018 than in 2019, except for cultivars Esteem, Respect, Spineless Beauty, and SV0474, which had no significant difference in yield of cull fruit across years. In 2017, cultivar Paycheck (13,685 kg·ha⁻¹) had the highest yield of cull fruit, and cultivar Esteem (6735 kg·ha⁻¹) the lowest. In 2018 and 2019, there were no significant differences in cull fruit among cultivars. The highest yield of cull fruit was measured in 2017.

EFFECTS OF CuLCrV ON YIELD AND FRUIT QUALITY. The effect of CuLCrV on yellow squash and zucchini total yield and fruit quality are correlated in Figs. 6 and 7. The yellow

squash total yield and yield of fancy, medium, and cull fruit significantly decreased with an increase in yellow squash CuLCrV severity (Fig. 6). Although the zucchini total yield and yield of fancy fruit were significantly and negatively correlated with CuLCrV severity (Fig. 7), there were no significant correlations between the yields of medium and cull fruit with CuLCrV severity for zucchini (Fig. 7).

Discussion

Weather conditions impacted sweetpotato whitefly populations during the 3 years when they were studied. Our results are supported by the literature, in which there is a generally positive correlation between sweetpotato whitefly populations and daily air

Table 3. Effect of the interaction between zucchini cultivar and year on the yield of fancy fruit, medium fruit, and cull fruit in Tifton, GA.

Zucchini cultivar	Yr		
	2017	2018	2019
Yield (kg·ha ⁻¹) ^z			
Fancy fruit			
Esteem	10,456 ab ^y A ^x	12,744 a A	4,916 ab A
Justice III	9,970 ab A	9,073 a A	3,071 b A
Paycheck	14,521 ab A	8,688 a A	5,916 ab A
Payload	10,339 ab A	16,257 a A	6,532 ab A
Respect	10,328 ab AB	15,667 a A	2,629 b B
Spineless Beauty	8,021 ab A	9,864 a A	6,878 ab A
Spineless King	4,093 b A	8,545 a A	1,986 b A
Spineless Perfection	6,457 ab A	9,709 a A	8,986 ab A
SV0474	8,118 ab A	17,905 a A	9,078 ab A
SV0914	11,254 ab A	15,761 a A	11,789 a A
SV6009	15,793 a A	15,785 a A	5,876 ab B
Medium fruit			
Esteem	310 a B	3,750 a A	4,184 c A
Justice III	136 a B	3,813 a A	3,484 c A
Paycheck	0 a B	3,255 a A	4,820 abc A
Payload	136 a B	3,219 a A	5,353 ab A
Respect	0 a B	3,255 a A	5,133 abc A
Spineless Beauty	229 a B	4,449 a A	3,416 c A
Spineless King	0 a C	2,496 a B	7,342 a A
Spineless Perfection	109 a B	3,445 a A	2,696 c A
SV0474	0 a B	5,426 a A	1,916 c A
SV0914	362 a B	4,967 a A	3,063 c A
SV6009	434 a B	4,530 a A	3,109 c A
Cull fruit			
Esteem	6,735 b A	5,412 a A	2,397 a A
Justice III	10,777 ab A	6,791 a A	656 a B
Paycheck	13,685 a A	6,093 a B	3,451 a B
Payload	12,699 ab A	6,636 a AB	3,145 a B
Respect	8,777 ab A	5,127 a A	3,177 a A
Spineless Beauty	7,629 ab A	4,895 a A	2,273 a A
Spineless King	10,571 ab A	7,691 a A	2,217 a B
Spineless Perfection	7,881 ab A	7,121 a A	355 a B
SV0474	7,219 ab A	5,154 a A	3,197 a A
SV0914	9,956 ab A	8,461 a A	466 a B
SV6009	10,033 ab A	6,100 a AB	2,041 a B

^z1 kg·ha⁻¹ = 0.8922 lb/acre.

^yWithin a column, values followed by the same lowercase letter indicate no significant difference ($P \leq 0.05$) between cultivars according to the Tukey-Kramer adjustment.

^xWithin a row, values followed by the same uppercase letter indicate no significant difference ($P \leq 0.05$) between years according to the Tukey-Kramer adjustment.

temperatures, and a negative correlation between sweetpotato whitefly populations and rainfall distribution (Hagen et al., 2008; Rafiq et al., 2008; Thriveni, 2019; Yadav et al., 2015). Although temperatures during all years were ideal for sweetpotato whitefly development, the few rainfall events during the early stages of yellow squash and zucchini development in 2017 and 2019 created optimum environmental conditions for sweetpotato whitefly reproduction (Yadav et al., 2015). In contrast, the frequent rainfall

events in 2018 negatively impacted the sweetpotato whitefly populations during the same period.

Cultivar selection would be the first step of an integrated pest management strategy for the management of CuLCrV in yellow squash and zucchini. Although there were differences in yield among cultivars, CuLCrV symptoms were recorded for all yellow squash and zucchini cultivars evaluated. This suggests that resistance to CuLCrV in commercial yellow squash and zucchini are not available, particularly among the

cultivars screened during this study. For yellow squash, the cultivar Lioness had the lowest severity rating of CuLCrV, whereas cultivars Cosmos and Gold Star had the highest CuLCrV severity ratings. For zucchini, the cultivar Justice III had the lowest CuLCrV severity rating, whereas cultivar Paycheck the highest. The better performance of broad virus resistance packages to protect yields is commonly discussed for cultivar selection in an integrated pest management practice (Schultheis and Walters, 1998; Sikora et al., 2008).

Fig. 6. Correlation between the severity of cucurbit leaf crumple virus (CuLCrV) and yield (kg·ha⁻¹) of fancy (A), yield of medium (B), yield of cull fruit (C), and total yield (D) during the 2017, 2018, and 2019 yellow squash seasons in Tifton, GA. 1 kg·ha⁻¹ = 0.8922 lb/acre.

However, our results indicated that there is no consistent difference in virus resistance among the materials evaluated, thereby indicating that a broad virus resistance package does not necessarily guarantee resistance to all viruses.

Total yield and fruit quality for both crops were directly negatively correlated with CuLCrV severity, and similar results for yellow squash and zucchini have been previously reported (Adkins et al., 2011; Akad et al., 2008; Costa et al., 1994; McAvoy, 2017; Sikora et al., 2008; Webb et al., 2017). During our study, a CuLCrV severity rating higher than 3 led to very low yields, regardless of the crop. There was a stronger negative correlation among CuLCrV and total yield and quality parameters of yellow squash compared with that of zucchini, suggesting that yellow squash is more sensitive to

sweetpotato whitefly and/or sweetpotato whitefly-transmitted viruses than zucchini. Particularly, the yellow squash cultivar Gentry had the highest yields when the sweetpotato whitefly populations were lower (i.e., 2018), but the yields were lower than those of other cultivars under high sweetpotato whitefly pressure (i.e., 2017 and 2019) when cultivars Lioness, Gold Prize, and Grand Prize had the highest yields. Similarly, zucchini cultivars SV6009 and SV0914 performed better than other cultivars under high sweetpotato whitefly populations (i.e., 2017 and 2019), but there was no significant difference among zucchini cultivars for yield when the sweetpotato whitefly pressure was low (i.e., 2018). These results corroborate those of Coolong (2017) and Rowell et al. (2002), who stated that yellow squash and zucchini cultivars with low

or no virus resistance could achieve the same level of productivity and fruit quality in a disease-free environment.

Conclusions

Sweetpotato whitefly and sweetpotato whitefly-transmitted virus complex, particularly CuLCrV, have become a major problem for yellow squash and zucchini production areas in the southeastern United States. Cultivar selection is the first step of the integrated pest management practice to minimize the impact of whiteflies on these crops; however, no available study has evaluated the resistance of commercial yellow squash and zucchini cultivars to CuLCrV. The present study evaluated commercial cultivars of yellow squash and zucchini for resistance to sweetpotato whitefly and against CuLCrV to determine yield and fruit quality under environmental

Fig. 7. Correlation between the severity of cucurbit leaf crumple virus (CuLCrV) and yield (kg·ha⁻¹) of fancy (A), yield of medium (B), yield of cull fruit (C), and total yield (D) during the 2017, 2018, and 2019 zucchini seasons in Tifton, GA. 1 kg·ha⁻¹ = 0.8922 lb/acre.

conditions of the southeastern United States. The sweetpotato whitefly population varied across years and was negatively correlated with the incidence of rainfall. The severity of CuLCrV negatively impacted the yield and quality of fruit of yellow squash and zucchini, and no resistant cultivar of yellow squash or zucchini was identified. Yellow squash cultivars Lioness, Gold Prize and Grand Prize, and zucchini cultivars SV6009 and SV0914 had the best yields under the highest sweetpotato whitefly population evaluated. In addition to cultivar recommendations, the information generated during this study can be useful for yield and loss estimates under different sweetpotato whitefly populations. Future studies should focus on evaluating alternative crop management practices (e.g., the effect of planting date to

account for the impact of weather variability on the interaction between sweetpotato whitefly and crop development) that could be incorporated in integrated pest management for sweetpotato whitefly and sweetpotato whitefly-transmitted viruses.

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