Tomato Irregular-ripening Symptom Development and Ripening of Silverleaf Whitefly-infested Dwarf Cherry Tomatoes

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ABSTRACT. Silverleaf whitefly (SLW) (*Bemisia argentifolii* Bellows and Perring) feeding was associated with development of tomato irregular ripening (TIR) symptoms. ‘Micro-Tom’, ‘Florida Basket’, ‘Florida Lanai’, and ‘Florida Petite’ dwarf cherry tomatoes (*Lycopersicon esculentum* Mill.) were infested with adult SLW to observe oviposition preference, plant tolerance, and TIR symptom development in two experiments. There was no oviposition preference among the cultivars in either of the trials. TIR fruit symptoms were expressed as longitudinal red streaks with yellow, green, pink, or red blotches externally and white tissue internally. External TIR symptoms at the pink stage of ripening ranged from 32% (‘Micro-Tom’) to 82% (‘Florida Basket’) in Expt. 1 and 44% (‘Micro-Tom’) to 93% (‘Florida Petite’) in Expt. 2. In Expt. 1, external TIR symptoms disappeared from 18% (‘Florida Lanai’) to 37% (‘Micro-Tom’) and, in Expt. 2, 16% (‘Micro-Tom’) to 39% (‘Florida Basket’) of the fruit during ripening. SLW-infested plants exhibited 82% (‘Florida Lanai’) to 99% (‘Florida Basket’) and 76% (‘Micro-Tom’) to 90% (‘Florida Petite’) of fruit with internal white tissue regardless of external symptoms in Expts. 1 and 2, respectively. Tomatoes with severe TIR symptoms rarely ripened to full red. Postharvest characteristics of ripening SLW-infested and control fruit were evaluated (Expts. 3 and 4). Generally, the SLW-infested fruit were lighter in color than the control fruit. The control fruit developed normal red color while the SLW-infested fruit developed a blotchy, streaky color that was overall more of an orange-red. SLW-infested fruit were firmer than the control fruit in both experiments. Ethylene production was higher in SLW-infested fruit. While the total soluble solids contents were not significantly different between the treatments, the SLW-infested fruit were more acidic than the control fruit. Each cultivar was susceptible to oviposition by SLW and induction of TIR symptoms. However, TIR symptom expression differed among the cultivars. Despite higher ethylene levels, the ripening process in the SLW-infested fruit appeared slower or may have been inhibited by factors induced by the SLW compared with the control fruit, which ripened normally.

In 1987, a new voracious whitefly was detected on tomatoes (*Lycopersicon esculentum* Mill.) grown in Florida and was identified as sweetpotato whitefly (SPW) (*Bemisia tabaci* Gennadius). Subsequently, it was described as a new species, the silverleaf whitefly (SLW) (*Bemisia argentifolii* Bellows and Perring). Shapiro (1996) indicated that the sudden change in the pest status of the insect was due to the immigration into the United States of a new biotype of *B. tabaci*, “B” biotype, and disappearance of the indigenous “A” biotype. Severe crop losses were attributed to *Bemisia* in southwestern Florida in Spring 1988 (Maynard and Cantliffe, 1989; Schuster et al., 1989) and in Spring 1989 in central Florida (Schuster et al., 1990).

SLW infestation of tomato plants is associated with a disorder known as tomato irregular ripening (TIR) (Maynard and Cantliffe,

1989; Schuster et al., 1990). The disorder is directly related to the feeding of the SLW and is also associated with high whitefly population (Maynard and Cantliffe, 1989; Schuster et al., 1989). Schuster et al. (1989) reported that Florida tomato growers lose an estimated \$25 million annually due to control costs and marketable fruit losses from SLW infestation.

The fruit is the only known part of the tomato plant affected by the whitefly-induced disorder. Externally, TIR appears as a distinct pattern of incomplete color development during ripening. Green fruit affected with TIR appear normal when harvested, but the symptom expression occurs during ripening. Red color develops as longitudinal streaks over the septa, with green and yellow in the intermediate areas over the locules. Internally, the affected tomato tissues develop white and yellow color during ripening (Maynard and Cantliffe, 1989; Schuster et al., 1990). External TIR symptoms can sometimes disappear or recover so that the fruit reach complete red color at the final stage of ripening (Maynard and Cantliffe, 1989; Powell and Stoffella, 1995a). Ethylene treatment, a common practice for ripening mature-green harvested tomatoes, does not appear to improve the red color development of

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affected tomatoes (Maynard and Cantliffe, 1989).

Powell and Stoffella (1995a) reported that $\approx 34\%$ of mature-green harvested tomatoes from SLW-infested plants that developed external TIR symptoms during ripening had symptoms disappear by the time ripening had been completed. However, those fruit had a high percentage (71%) of internal TIR symptoms, especially white tissue. Furthermore, removing the tomatoes from the whitefly-infested field during fruit ripening did not appear to reduce TIR symptoms.

There are no known fresh-market tomato cultivars that are resistant to the SLW or the induction of TIR. Powell and Stoffella (1995b) evaluated nine commercially grown fresh-market tomato cultivars and all were susceptible to the induction of TIR. However, the severity of the external TIR symptoms may be a criterion for selecting a cultivar for fresh-market production.

The present objective was to evaluate the susceptibility to SLW oviposition and population development on the induction of external and internal TIR symptoms in four cultivars of dwarf cherry tomatoes under greenhouse conditions. Some postharvest quality characteristics of SLW-infested and uninfested dwarf cherry tomato fruit were also evaluated.

Materials and Methods

TIR symptom development of SLW-infested fruit

PLANT ESTABLISHMENT. The experiments were conducted during Summer 1995 (Expt. 1) (Entomology and Nematology Dept., Univ. of Florida, Gainesville) and during Fall 1995 (Expt. 2) (USDA-ARS, Horticultural Research Laboratory, Orlando, Fla.). Dwarf cherry tomatoes 'Micro-Tom', 'Florida Basket', 'Florida Petite', and 'Florida Lanai' seeds (donated by J.W. Scott, GREC, Bradenton, Fla.) were sown in seedling trays (72 cells/tray; $4 \times 4 \times 6$ cm) filled with Vergrow Transplant Mix A (V-J Growers Supply, Apopka, Fla.) containing Canadian sphagnum peat moss, coarse grade vermiculite, starter nutrient charge, and a wetting agent. The media in the trays were kept moist at all times. Seeds were germinated in a growth chamber with fluorescent light (14 h light and 10 h dark at 27°C).

After 17 d, the seedlings were transplanted into plastic pots (16 $\times$ 16 cm) filled with Vergrow Container Mix A (V-J Growers Supply), which contains Canadian sphagnum peat, coarse grade vermiculite, perlite, starter nutrients with major and minor essential elements, and a wetting agent. Seedlings were grown in a whitefly-free greenhouse (Entomology and Nematology Dept., Univ. of Florida, Gainesville). Temperatures in the greenhouses ranged from 24 to 37°C and relative humidity ranged from 55% to 100%. Manual watering was scheduled daily in Expt. 1, whereas drip irrigation was used for 5 min once a day for Expt. 2. The plants were fertilized with 20N-16P-8K ($2.5 \text{ g}\cdot\text{L}^{-1}$) weekly.

Fourteen days after transplanting, one plant from each of the four cultivars was randomly placed in each of nine screened (61 $\times$ 61 $\times$ 61 cm) cages. The cages were built with a wood frame and covered with a light-brown high-density polyethylene (52 $\times$ 52 mesh) fabric (LUMITE, Gainesville, Ga.). Plants were placed in the cages for 24 h before infestation.

WHITEFLY INFESTATION. Before the initial infestation, pots were watered heavily since the cages were not opened during whitefly exposure. About 50 pairs of SLW were released in the center of each cage. Whiteflies were obtained from a laboratory SLW colony maintained on cotton (*Gossypium hirsutum*) and collard (*Brassica oleracea*) plants (Entomology and Nematology Dept., Univ. of Florida, Gainesville). The whiteflies were allowed to infest the plants for 72 h. The experimental design was a random-

ized complete block with one plant of each cultivar per cage (four plants/cage), and the cages were replicated (blocked) nine times. Four or more plants from each cultivar were placed in a separate greenhouse (whitefly free) as controls. Control plants were watered and fertilized as previously described for each experiment.

WHITEFLY SAMPLING AND COUNT. At the end of the 72-h infestation (17 d after transplanting), the plants were removed from the cages for leaf sampling. Four terminal leaflets at mid-canopy were collected from each plant and placed in plastic bags. Sampling was performed with care so as not to damage the plants since these same plants were later grown to maturity for fruit samples. The leaves were refrigerated overnight at 4°C until SLW counts were made. Eggs were counted on the upper and lower leaf surfaces under $15\times$ magnification, and leaf area was measured with a leaf area meter (LI-3000A; LI-COR, Lincoln, Nebr.).

After leaf sampling, the plants were rearranged in a randomized complete-block experimental design on the greenhouse bench without the cages. The remaining SLW eggs and adults on the leaves from the initial infestation were allowed to continue infesting the tomato plants for ≈ 7 weeks. Watering and fertilization were also maintained as previously described. Before the first harvest (5 weeks after transplanting), a second set of tomato leaf samples was collected as previously described for eggs, nymphs, red-eyed nymphs, and pupal exuviae counts. The counts were made under $15\times$ magnification on 2-cm^2 disks cut from the center of the leaflets.

RIPENING OF SLW-INFESTED FRUIT. Tomato fruit were harvested every other day from breaker to pink stage and stored at 20°C . Fruit harvest was continued as long as there were fruit on a plant. Fruit color development was monitored daily for development of external TIR symptoms, which included external streakiness and blotchiness. The fruit were marked to indicate TIR incidence as the symptoms appeared. At the full red stage, external TIR symptoms were graded as 0 = no symptoms and 1 = blotches and streaks with regard to symptom disappearance and blossom-end star formation. The fruit were then sliced in half to rate the internal TIR symptoms as 0 = no symptoms and 1 = white endocarp.

Percentage of fruit with external and internal TIR, external TIR disappearance, and star formation were calculated. Percentage data were transformed using arcsine square root before conducting an analysis of variance (ANOVA). All of the measured variables were subjected to ANOVA using SAS (SAS Institute, Cary, N.C.). Genotype means were separated by the Waller-Duncan multiple k ratio comparison at $P < 0.05$.

Fruit quality measurements of SLW-infested fruit

PLANT ESTABLISHMENT. 'Florida Petite' dwarf cherry tomato seeds (donated by Florida Foundation Seed Producers Inc., Greenwood, Fla.) were sown in trays (72 cells/tray; $4 \times 4 \times 6$ cm) filled with Vergrow Transplant Mix A. The media in the trays was kept moist at all times. Seeds were germinated in a growth chamber with fluorescent light (14 h light and 10 h dark at 27°C).

After 15 days, the germinated seedlings were transplanted into plastic pots (16 $\times$ 16 cm) filled with Vergrow Container Mix A. Seedlings were grown in a whitefly-free condition in the growth chamber. Temperature in the chamber ranged from 24 to 37°C and relative humidity from 55% to 100%. Manual watering was scheduled daily, and the plants were fertilized with 20N-16P-8K ($2.5 \text{ g}\cdot\text{L}^{-1}$) once a week.

WHITEFLY INFESTATION. Three weeks after transplanting, 20 plants were moved into a greenhouse (Entomology and Nematology Dept., Univ. of Florida, Gainesville). These plants were naturally infested with an existing colony of SLW on tomato plants in the greenhouse. To confirm that a substantial infestation oc-

cured, populations were monitored by turning over two to three leaves and counting the adult SLW before each harvest. SLW populations ranged from 100 to 400 adults per two to three leaflets. Fruit were harvested at the breaker stage and stored at 20 °C.

CONTROL PLANTS. Another 20 tomato plants from the growth chamber were moved into a whitefly-free greenhouse (Environmental Horticulture Dept., Univ. of Florida, Gainesville). These plants were treated with imidacloprid (0.04 g a.i./plant) (Admire 2F; Bayer, Kansas City, Mo.) in 25 mL of water per plant as a soil drench when the plants were initially moved into the greenhouse, followed by a second treatment 3 weeks later. Watering and fertilization were scheduled as previously described. Fruit were harvested at the breaker stage and stored at 20 °C.

A randomized complete block experimental design was used with each treatment. The fruit quality measurements were replicated seven times for Expt. 3 and eight times for Expt. 4 (one fruit per replicate) for fruit color, firmness, and total soluble solid content. In addition, fruit for titratable acidity and pH measurements were harvested separately at the mature-green stage and only analyzed once and represented fruit of SLW-infested and uninfested control regardless of TIR symptoms.

ETHYLENE MEASUREMENT. Seven turning stage tomato fruit from each treatment were placed in 66-mL sealed jars for 3 h at 20 °C for the ethylene measurement. After 3 h, two 0.5-mL headspace gas samples were withdrawn from each jar. Samples were analyzed on a photoionization gas chromatograph (Photovac 10A10; Photovac Inc., Ontario, Canada), equipped with a 76.3 × 0.3-mm 60/80 mesh activated alumina column. Ethylene measurements were obtained every 24 h for 10 d and were expressed as $\mu\text{L C}_2\text{H}_4/\text{kg/h}$.

FRUIT COLOR DETERMINATIONS. Fruit color was measured at areas with red color development on the shoulder and near the blossom end of each fruit. Color measurements on each fruit were made with a reflectance colorimeter (Chroma Meter CR-200; Minolta Corp., Ramsey, N.J.). Measurements were made using the $L^*a^*b^*$ color system, where L^* indicates lightness on a scale of 0 = black to 100 = white; a^* indicates green (–) to red (+) axis, and b^* indicates blue (–) to yellow (+). The hue was calculated from the a^* and b^* values as follows: $\text{hue} = \arctan(a/b) \times 180/3.1416$, representing the actual color. Chroma was calculated as follows: $\text{chroma} = \text{square root}(a^2 + b^2)$, representing the intensity of the color. Hue is a measure of the particular shade of color, while chroma indicates the color's intensity or purity and reflects the departure of a color from gray for a given hue (Francis, 1980; McGuire, 1992). Repeated color measurements at the same locations on each fruit were obtained daily for 10 d.

TIR SYMPTOM DEVELOPMENT. Initially, SLW-infested fruit were marked as the fruit developed external TIR symptoms (streaks or blotches). On the final (tenth) day of each experiment, the fruit

were evaluated for external TIR symptoms again and blossom end star formation. The fruit were then sliced in half to observe any internal white tissue development. Symptom severity for external TIR was graded as 0 = no symptoms, 1 = slight blotches and streaks, and 2 = distinct blotches and streaks. Symptom severity for internal TIR was graded as 0 = no symptoms, 1 = pink endocarp, and 2 = white endocarp.

FRUIT FIRMNESS MEASUREMENTS. At the final (tenth) day of each experiment, fruit firmness was measured using an IFAS deformation tester (Gull, 1987). Firmness was measured by applying 1 kg of mass onto the blossom end of each fruit for 5 s and expressed as millimeters.

TOTAL SOLUBLE SOLIDS. Total soluble solids (TSS) measurements were made with a hand-held temperature-compensated refractometer (model 10431; AO Instrument, Buffalo, N.Y.). The juice extract from each fruit was squeezed manually (≥ 2 drops) onto the refractometer. The TSS measurements were taken on the last (tenth) day of the experiments.

TITRATABLE ACIDITY AND pH. At the full-red stage, a composite sample of tomato fruit was randomly obtained from each treatment. SLW-infested fruit included those with and without external TIR symptoms. Fruit from each treatment were divided into seven replications of eight fruit each. The fruit from each replicate were homogenized separately at high speed with a homogenizer (Polytron; Brinkman Instrument Inc., Westbury, N.Y.) for 1 min. The homogenate was centrifuged with a centrifuge (model J2-21; Beckman, Palo Alto, Calif.), at 7840 g , for 15 min. Supernatant pH was determined with a pH meter (model M140; Corning Medical and Scientific, Essex, England). A 6-mL aliquot of the supernatant was diluted to 50 mL with deionized water. Titratable acidity was determined by titrating the solution with an automatic system (models 395, 380, 381, and 385; Fisher Scientific, Pittsburgh) to pH 8.1 with 0.1 N NaOH. Percent titratable acidity was calculated as percentage of citric acid = $[\text{mL base} \times \text{base normality} (0.1 \text{ mEq/mL}) \times \text{Eq mass of acid} (64.04 \text{ mg/Eq})] / [\text{sample mass (mg)}] \times 100$. Fruit analyzed for titratable acidity and pH were from a different harvest than fruit used in Expts. 3 and 4.

All measured variables were subjected to analysis of variance (ANOVA) using SAS (SAS Institute) and treatment effects were determined by F test at $P = 0.01$ and 0.05 .

Results and Discussion

TIR symptom development of SLW-infested fruit

OVIPOSITION OF SLW IN DWARF CHERRY TOMATO. All four cultivars of dwarf cherry tomatoes were susceptible to oviposition by SLW in Expts. 1 and 2. Although the same number of adult SLW were released in both trials, there was a greater oviposition rate

Table 1. Population levels of silverleaf whitefly in dwarf cherry tomatoes 5 weeks after initial infestation.²

Expt.	Cultivar	N	Egg	Nymph	Redeveloping nymph	Exuviae
			(no./cm ² leaflet)			
1	Micro-Tom	5	36.7 ab ³	76.5 a	4.1	1.6 b
	Florida Basket	5	36.3 ab	22.7 b	4.8	7.7 a
	Florida Petite	5	59.5 a	27.8 b	7.8	8.9 a
	Florida Lanai	5	22.4 b	32.4 b	10.4	7.9 a
2	Micro-Tom	20	21.1 b ³	38.8	4.7 b	8.2 ab
	Florida Basket	20	36.7 a	36.1	5.7 b	5.4 bc
	Florida Petite	20	29.3 ab	41.0	8.1 a	11.2 a
	Florida Lanai	20	22.2 b	30.1	5.0 b	3.3 c

²No./cm² = total no. upper and lower (four) leaflets/total area upper and lower (four) leaflets. All values were transformed using square root (no./cm² + 0.1).

³Mean separation by Waller-Duncan multiple range test at $P < 0.05$.

after the whiteflies were released in the cages in Expt. 1 than Expt. 2. However, under heavy (Expt. 1) and low (Expt. 2) initial whitefly oviposition, SLW exhibited no significant oviposition preference among the four cultivars (data not shown). No foliar symptoms from adult SLW feeding were observed on the leaves after the 72-h infestation period. Most of the eggs were located on the lower surface of the leaves (data not shown).

Five weeks after transplanting, leaf samples had several developmental stages of the SLW. 'Florida Basket', 'Florida Petite', and 'Florida Lanai' had lower counts of nymphs but significantly greater survival of immatures to adult stage (based on exuviae count) than 'Micro-Tom' (Expt. 1) (Table 1). However, numbers of red-eyed nymphs in Expt. 1 did not differ significantly among the cultivars (Table 1). Nymph counts in Expt. 2 were also not significantly different among the cultivars (Table 1). However, in Expt. 2, 'Florida Petite' had significantly more red-eyed nymphs than the other cultivars (Table 1).

SLW adults and nymphs did not appear to induce any physiological disorder at the feeding sites on the leaves, but may have indirectly caused secondary effects of interveinal chlorotic and necrotic spots on the leaves observed at later stages of growth. The chlorotic and necrotic tissue may have been due to nutrient depletion or toxin produced by the SLW feeding or its symbiotic microorganisms. The honeydew excreted by the SLW onto the lower leaves and fruit became a medium for sooty mold, which appeared as a dark layer on the leaves and fruit. The sooty mold may affect plant photosynthesis and transpiration rates, thereby contributing to the development of TIR symptoms. Egg, nymph, and exuviae counts were higher on the lower than upper leaf surface in both samples in Expts. 1 and 2 (data not shown).

FRUIT EXTERNAL TIR SYMPTOMS. Dwarf cherry tomatoes at the mature-green or early breaker stages did not exhibit TIR symptoms, except for slight yellow color around the stem scar or shoulder, or the development of star breaker at the blossom end of the fruit. Occasionally, color development was observed to begin from the shoulder instead of the blossom end. Initially, the external TIR symptoms appeared as faint longitudinal red streaks over the septa, beginning from the blossom end and extending to the stem scar of the fruit. The remaining fruit surface usually appeared green, but sometimes blotches of red or yellow, or both developed as the fruit ripened (Fig. 1).

The appearance of external TIR symptoms was observed in all the cultivars, but at different rates and severities. 'Florida Basket', 'Florida Petite', and 'Florida Lanai' had significantly higher incidence of external TIR at the pink stage than 'Micro-Tom' in both experiments (Table 2). 'Micro-Tom' consistently had a significantly lower incidence of external TIR symptoms than the

other cultivars. This observation may have been due to the extremely small size of fruit from stressed SLW-infested 'Micro-Tom' plants in which color development could not be clearly observed. The external TIR symptom expression reported here corroborates the results on fresh-market tomato reported by Maynard and Cantliffe (1989) and Schuster et al. (1990).

SYMPTOM DISAPPEARANCE. External TIR symptoms sometimes disappeared between the pink and the full-red stage during ripening and the fruit would appear normal. Symptom disappearance occurred in all cultivars and ranged from 18% to 37% and 16% to 39% in Expts. 1 and 2, respectively (Table 2). While symptom disappearance was not significantly different among the cultivars in Expt. 1, 'Florida Petite' and 'Florida Basket' had significantly higher numbers of fruit that ripened normally after exhibiting external symptoms at the pink stage as compared to 'Micro-Tom' and 'Florida Lanai' in Expt. 2 (Table 2). Powell and Stoffella (1995a) also observed the disappearance of external TIR symptoms in commercial fresh-market tomatoes.

Control fruit (from whitefly-free plants) from each cultivar ripened more evenly from the blossom end to the shoulder than fruit from SLW-infested plants. Occasionally, a few of the control fruit exhibited sun scald or yellow shoulder at the stem scar, and mild blotchiness, but almost never streakiness (data not shown). According to Picha (1987a), yellow shoulder and blotchy ripening may be nutritionally related disorders in tomato.

At high levels of infestation, SLW may feed on the developing fruit. These fruit exhibited white spots at the full red stage. Under a dissecting microscope (15× magnification), puncture wounds were observed in the center of the white spots, possibly from the feeding of the SLW at the green stage. The puncture wounds enlarged as the fruit size increased. No white spots with puncture wounds were observed in control fruit.

STAR FORMATION. The incidence of star formation at the blossom end of fruit ranged from 62% to 95% in Expt. 1 and 7% to 59% in Expt. 2. The star was initiated at the blossom end, developed longitudinally, and was concentrated around the lower half of the fruit (Fig. 2). The star was usually yellow or golden in color, but sometimes appeared only as a thin cross or lines at the blossom end. 'Florida Lanai' consistently exhibited a high incidence of star formation in Expts. 1 and 2 (Table 2). Golden star was more pronounced in 'Florida Lanai', and the other cultivars exhibited more lines at the blossom end (data not shown).

Control fruit also exhibited a thin line type star at the blossom end in certain cultivars, but none exhibited the golden star phenomenon (data not shown). We agree with Schuster et al. (1990) that the golden star may be related to the TIR disorder. In addition, the thin lines or cross reported here may not be associated with the TIR disorder.

Table 2. Tomato irregular ripening (TIR) symptom development and disappearance in dwarf cherry tomatoes infested with silverleaf whitefly.²

Expt.	Cultivar	Fruit (no.)	Pink stage	External TIR symptoms (%)			Internal TIR symptoms ² (%)
				Full-red	Symptom stagedisappearance ²	Star formation	
1	Micro-Tom	97	32 c ³	14 b	18	75 bc	86 bc
	Florida Basket	181	82 a	52 a	30	90 ab	99 a
	Florida Petite	137	71 ab	34 ab	37	62 c	90 b
	Florida Lanai	106	67 b	44 a	23	95 a	82 c
2	Micro-Tom	390	44 c	37 c	16 c	20 b	76 b
	Florida Basket	425	77 b	43 bc	39 a	7 c	86 a
	Florida Petite	373	93 a	52 b	35 a	22 b	90 a
	Florida Lanai	296	90 a	67 a	22 b	59 a	86 a

²Percentage of fruit with external TIR symptoms that disappeared at full red stage.

³Mean separation by Waller/Duncan's multiple range test at $P < 0.05$.

INTERNAL TIR SYMPTOMS. The internal white tissue symptom of TIR occurred in the pericarp tissue surrounding each of the locules, primarily in the endocarp of the SLW-infested fruit (Fig. 3). Some fruit also exhibited small circles or patches of white tissue randomly dispersed within the pericarp area, possibly associated with low SLW infestation. The white tissue induced by SLW also appeared to have a firm and dry texture. Under a dissecting microscope (15× magnification), the cellular contents of the cells in the white tissue appeared yellow. 'Florida Basket' had significantly higher incidence of white tissue than the other cultivars in Expt. 1 (Table 2). 'Florida Petite', 'Florida Basket', and 'Florida Lanai' each had significantly higher incidences of white tissue than 'Micro-Tom' in Expt. 2 (Table 2).

The internal white tissue at the pink stage was observed at a higher incidence—82% to 99% and 76% to 90%—than the external TIR symptoms, which ranged from 32% to 71% and 44% to 93% in Expts. 1 and 2, respectively (Table 2). Fully red, overripe, and soft tomato fruit from SLW-infested plants still exhibited white tissue, especially in the form of white patches. Perhaps the white tissue, once formed in the fruit, never disappears in SLW-infested fruit. This has also been observed in commercially grown tomatoes (P. Stoffella, personal communication).

Most control fruit at the full-red stage exhibited two distinct layers in the pericarp area. The exocarp was redder than the

endocarp, which appeared pink or lighter, but never as white as in infested fruit. Perhaps the light pink tissue in the inner pericarp is a normal characteristic of certain cultivars of tomato.

Tomato irregular ripening, expressed externally and internally, was associated with SLW feeding. 'Micro-Tom', 'Florida Basket', 'Florida Petite', and 'Florida Lanai' were all susceptible to SLW oviposition and feeding and to the development of TIR symptoms. No relationship could be shown between the TIR symptom expression and the SLW population for these cultivars because only an initial egg and nymph count was performed during the entire harvest period. The best indication of SLW infestation in tomato was the internal white tissue in the pericarp and locule area, followed by the external red streaks on the surface of the fruit. The development of a golden star at the blossom end is another criterion to consider, but it was not consistently associated with SLW infestation. External TIR symptom disappearance among the cultivars was low and occurred too late in the color development to affect the marketability of the fruit. The high incidence of external and internal TIR symptoms in the cultivars evaluated in these experiments would have caused drastic losses in yield and quality for commercial fresh-market cherry tomatoes.

Ripening of SLW-infested fruit.

ETHYLENE PRODUCTION. Ethylene production declined during

Fig. 1. Developmental stages of external tomato irregular ripening symptoms (left to right) in silverleaf whitefly-infested dwarf cherry tomatoes.

Fig. 2. Star formation (left) in silverleaf whitefly-infested and uninfested control (right) dwarf cherry tomatoes.

Fig. 3. Internal tomato irregular ripening symptoms in silverleaf whitefly-infested dwarf cherry tomatoes.

Table 3. Mean tomato irregular ripening symptom expression, total soluble solids (TSS) deformation (firmness), titratable acids, and pH in silverleaf whitefly infested and uninfested control fruit.

Expt.	Treatment	N	TIR symptoms			TSS (°Brix)	Deformation (mm) ^w	Titratable	
			External ^c	Star formation ^b	Internal ^a			acidity (%)	pH
3	Control	7	0.00	0.00	0.00	3.74	26.8	---	---
	SLW-infested	7	0.87	0.87	1.71	3.93	21.6	---	---
	Significance		NS	**	**	NS	*		
4	Control	8	0.14	0.14	0.57	3.86	24.0	1.29	3.92
	SLW-infested	8	1.50	0.63	2.00	3.96	14.6	1.79	3.84
	Significance		**	*	**	NS	**	**	**

^aExternal TIR symptom rating scale: 0 = no symptoms, 1 = slight blotch, and 2 = distinct streaks and blotch.

^bStar formation rating scale: 0 = no symptoms and 1 = star formation.

^cInternal white tissue rating scale: 0 = no symptoms, 1 = pink endocarp, and 2 = white endocarp.

^wA 1-kg weight was applied at the blossom end of the fruit for 5 s (mm/5 s.).

NS, *, ** Nonsignificant or significant mean values between treatments at $P < 0.05$ or 0.01 , respectively, by F test.

10 d storage at 20 °C in SLW-infested and control fruit (data not shown). Ethylene production by SLW-infested fruit was ≈ 2 -fold higher than control fruit on the first day after harvest in the first experiment and was higher during the last 3 d of storage in both experiments. The pattern of ethylene production observed suggests that the fruit were at or past the climacteric peak at the time of harvest despite the fact that their external color was mostly green. The higher initial levels of ethylene in the SLW-infested fruit may have been related to stress associated with the insect feeding activity (Martin et al., 1988). Stress is known to result in elevated ethylene production in tomato and other plants (Autio and Bramlage, 1986; Larrigaudiere et al., 1990; MacLeod et al., 1976).

FRUIT FIRMNESS. Control fruit were consistently softer than SLW-infested fruit in both experiments (Table 3). Although the difference between firmness of the control and SLW-infested fruit was $\approx 19\%$ in Expt. 3, the SLW-infested fruit in Expt. 4, which exhibited more severe TIR symptoms, were 39% firmer than the control fruit. The differences in firmness measurements of the SLW-infested and control fruit may also have been due to SLW population density.

TOTAL SOLUBLE SOLIDS. Although the SLW-infested fruit had slightly higher °Brix measurements than the control fruit in both experiments (Table 3), the total soluble solids contents were not significantly different between treatments.

PERCENT TITRATABLE ACIDITY. The major organic acids in tomato are citric acid and malic acid at ≈ 0.6 to 0.7 and 0.2% by fresh mass, respectively for cherry tomato (Picha, 1987b), but malic acid levels are reduced as the fruit ripen due to its use as a respiratory substrate during the climacteric (Hobson and Grierson, 1993). The predominant acid in the fruit at the full-red stage is citric acid. Percent titratable acidity was significantly higher in the SLW-infested fruit than the control fruit (Table 3), perhaps due to the advanced ripeness of the control fruit. The pH values were significantly higher in the control fruit than in the SLW-infested fruit (Table 3), i.e., the SLW-infested fruit were more acidic than control fruit.

EXTERNAL AND INTERNAL TIR SYMPTOMS AND FRUIT COLOR. External TIR symptoms were very slight in fruit from SLW-infested plants in Expt. 3 (Table 3). However, the internal TIR symptoms (white endocarp) were significantly different between the treatments. Star formation at the blossom end occurred more in the SLW-infested fruit than in uninfested control fruit (Table 3). In Expt. 4, the external and internal TIR symptoms and more star formation occurred on the SLW-infested fruit than on the uninfested control fruit (Table 3). Overall, the SLW-infested fruit in Expt. 4

exhibited higher incidence of external and internal TIR symptoms than Expt. 3.

External TIR symptom disappearance was higher in Expt. 3 than Expt. 4, and SLW population density at the time of fruit development may have had an affect on the amount of TIR symptom disappearance in the fruit. In addition, perhaps the location of the fruit on the plant and the density of SLW on the leaves near the fruit of the same plant may have influenced the intensity or the disappearance of TIR symptoms.

Color measurements of control and SLW-infested fruit indicated that the red areas of SLW-infested fruit were lighter (higher L*), with a similar to more orange-red hue than the control fruit (data not shown). The chroma or color intensity of SLW-infested fruit was greater than the control fruit in Expt. 1. However, there was no difference in chroma between the treatments in Expt. 2. In contrast to control fruit, which changed directly from green to a uniform red, the SLW-infested fruit developed yellow areas (streaks) that eventually became orange-red to red.

Conclusions

Ethylene production in the SLW-infested fruit was generally higher than the control fruit. SLW-infested fruit were nonuniform, lighter, and more orange-red than control fruit. Total soluble solids contents were not significantly different between the treatments. The SLW-infested fruit were firmer and more acidic than the control fruit. External and internal TIR symptoms were generally high in the SLW-infested fruit, whereas the control fruit did not exhibit any distinct TIR symptoms and ripened normally to the full-red stage. These results suggest that the ripening process was slower or inhibited in certain fruit locations of the SLW-infested fruit, whereas the control fruit ripened normally.

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