Effect of Time After Harvest on Stem Scar Water Absorption in Tomato

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Abstract. Fresh market tomatoes (*Solanum lycopersicum* L.) handled through dump tanks and flumes at packinghouses can absorb water via stem scar tissues. This water uptake can lead to internalization of various hazardous bacteria, including *Erwinia carotovora* (Jones), the causal agent of bacterial soft rot. Studies were conducted to determine if the interval between harvest and water immersion affected water uptake for 'Florida 47' and 'Sebring', cultivars with high and low water uptake, respectively. Fruit were held for 2, 8, 14, and 26 hours after harvest for the fall season and 2, 4, 6, 8, and 14 hours for the following spring season before water immersion. Mature green fruit were weighed, submerged in water for 2 min and then reweighed to determine water uptake. During the submergence, air pressure was applied such that the fruit were exposed to a static water-head equivalent to 1.3 m. In the fall season 'Sebring' fruit absorbed significantly less water than 'Florida 47' fruit at 8 and 26 hours after harvest. In the spring season fruit of 'Sebring' absorbed significantly less water than 'Florida 47' at all times after harvest, confirming results of previous studies. In the fall season, the time interval between harvest and treatment did not affect water uptake for either cultivar. By contrast, in the spring season fruit absorbed significantly greater amounts of water at 2 hours as compared with 4, 6, 8, and 14 hours after harvest, whereas similar amounts of water were absorbed at 4–14 hours after harvest. Therefore, to minimize the tendency of fruit to absorb water, packinghouse managers should hold freshly harvested fruit for at least 4 hours before immersing them in the dump tank.

Bacterial soft rot, commonly incited by *Erwinia carotovora* (Jones), causes significant losses each year in many types of fresh produce, most frequently under warm, moist conditions. The disease is often found in fresh market tomatoes (*Solanum lycopersicum* L. formerly *Lycopersicon esculentum* Mill) (see Peralta et al., 2006) that can be inoculated by water absorption through the stem scar when the fruit are immersed in the water of a packinghouse dump tank. Processed tomatoes do not typically develop this disease because they are not stored. This pathogen cannot penetrate the intact epidermis of the fruit (Showalter and Bartz, 1979). Internal infections often give rise to the most severe form of the disease where initial symptoms are hidden by outer wall tissues until the fruit collapses releasing large volumes of infectious fluids. Sometimes, internal infections

can occur through holes in the blossom-end scar or wounds.

The two pressure imbalances on tomato surfaces that produce an absorption of water are somewhat controlled by a) limiting the period of exposure of fruit to the water, b) warming the water above the pulp temperature of the fruit, c) limiting the unloading speeds so that fruit float in a single layer, and d) avoiding direct impact of water streams on fruit surfaces during unloading from gondolas or bins. Additionally, in some packinghouses field bins are shaded under ambient conditions and not unloaded until the day after harvest, which leads to lower fruit temperatures and dryer stem scars. Keeping fruit shaded after harvest is helpful because it reduces sun-induced fruit warming, which reduces the demand for water heating and cooler fruit are less prone to water uptake than warm fruit (Bartz, 1999).

Soft rot bacteria can also inoculate fruit prior, during, or after harvest. Insect injuries in combination with high moisture in the plant canopies can lead to fruit decay in the field. If the plant canopies contain free moisture from rainfall, dew, or guttation at

the time of harvest, bacteria that become suspended in the moisture are spread to harvest-related wounds or the stem scar. At the packinghouse, fruit can become inoculated by contamination with fruit that carry the bacteria. Additionally, the pathogen and other hazardous microorganisms can accumulate in the dump tank water.

To prevent fruit from becoming inoculated in the dump tank, packinghouse operators chlorinate the water. This reduces the amount of live bacteria in the water, which often prevents the development of bacterial soft rot in healthy fruit. It is recommended that the free chlorine level remain between 150 and 200 ppm at pH 6.5–7.5 for maximum efficacy (Bartz et al., 2002). It is often difficult for commercial packinghouses to have the correct amount of chlorine in the dump tank water because as organic matter (stems, leaves, fruit, and soil) enters the dump tank, the concentration of free chlorine decreases. Moreover, chlorination of the water does not disinfect fruit that are already inoculated with the pathogen (Bartz et al., 2002).

To reduce or avoid bacterial soft rot, growers can produce fruit that resist stem scar water uptake. Cultivars, such as Solar Set, Sunny, Horizon, and Equinox, have significantly less tendency for water uptake as compared with certain other popular cultivars (Scott et al., 1985, 1989, 1995). More recently 'Sebring' was shown to have low stem scar water uptake while 'Florida 47' had higher water uptake (Bartz and Scott, 2005). If the fruit are free of wounds and have not internalized inocula, then development of soft rot is unlikely. Bartz and Showalter (1981) presented evidence suggesting that when the pedicel was removed from the fruit right before water immersion, the fruit absorbed significantly higher amounts of water than fruit that were destemmed 2 d earlier. It was not known how long within 2 d it took the stem scars to dry out to absorb significantly less water. Fresh stem scars may be water-congested, particularly in the vascular tissues, and would easily absorb water. It is suggested that old stem scars absorb less water because they become congested with air as time elapses after harvest. This air does not allow water to move into the tissues easily. The objective of this study was to determine if different delay periods between harvest and water handling steps affected the tendency of tomato fruit to absorb water and if this effect was similar for cultivars that differed in the potential for water uptake. This information may help packinghouse managers determine how long to hold fruit before immersing them into the dump tank.

Materials and Methods

Fall 2005. Seeds of tomato hybrids 'Florida 47' and 'Sebring' were sown in an inert medium, Black Beauty spent coal (Reed Minerals Div., Highland, IN), on 19 Aug. 2005 to have seedlings at the same growth stage. The seedlings were transplanted

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on 26 Aug. into Speedling trays (3.8 cm³ cell size; Speedling, Sun City, FL) in the greenhouse. The plants were transplanted to field beds on 20 Sept. in a completely randomized block design with three blocks and 10 plants per plot. The soil in the field was Myakka, Haplaquents, and St. Johns sandy soil. The beds were raised 25 cm high, 71 cm wide at the top, and 81 cm wide at the base. Plants were spaced 46 cm apart within plots that were 92 cm apart in rows with 152 cm between rows. The beds had been fumigated with 67% methyl bromide: 33% chloropicrin at 197 kg·ha⁻¹. Granular fertilizer with a total of 293 kg·ha⁻¹ of nitrogen and 486 kg·ha⁻¹ of potassium placed in two bands was applied on top of the beds 20 cm away from the plants, and the beds were covered with white plastic mulch. The plants were staked and tied and irrigated by seepage ditches adjacent to three experimental beds. Plants were sprayed with pesticides as needed throughout the season according to Olson et al. (2005–2006).

Fruit of various sizes were harvested on 16 Dec. at the mature green stage. The fruit for all blocks and harvest times were harvested between 8:10 and 8:30 AM with sunrise at 7:14 AM. After 12 fruit were harvested from each block and harvest time, they were brought into a laboratory held at 22 °C with 46% relative humidity and split into four groups that were immersed in water at time intervals of 2, 8, 14 and 26 h after harvest. Before water immersion, fruit were stored with the stem scars upright. For each time interval, fruit were split into three subsets so that each experimental unit (fruit for each harvest time interval, block and cultivar) had three samples. The fruit were then wiped off with a towel and labeled with a permanent marker with the block number, cultivar identification number, subset, and time treatment. Each subset of fruit was weighed on a scale to find the initial weight. After each subset of four fruit was weighed, ≈36 fruit, which consisted of randomly selected fruit from each cultivar and block, were put into a 22.8 L pressure cooker with a 30.5 cm depth. The water was at 30 °C, and the fruit were at room temperature (22 °C). The fruit were pressurized with compressed air for 2 min at 11,921.3 Pa of pressure under 1–1.3 m water head pressure to simulate the pressure changes the fruit experience when entering the dump tank. All of the fruit were immersed in 15 cm of water by placing a steel plate and 0.95-kg weight over the top layer of fruit. The water in the pressure cooker was changed, and a second set of 36 fruit was treated. After treatment the fruit were then dried with towels and separated into their respective groups of four. After all of the fruit had been dried, each subset was reweighed to determine the weight gain by subtracting the weight before immersion from the weight after immersion. The percentage water uptake was transformed by the arc-sine square-root method, where the percent weight increase = weight increase/initial weight × 100, which was transformed by the square

root of (0.5 + percent weight increase). The data were analyzed using analysis of variance to test the differences between cultivars generated by SAS (SAS Institute, 1997). Tukey's W procedure was used, and standard errors were calculated to test the differences between the cultivars and time intervals. The least-square means procedure was used to test the effects of fruit weight on water uptake (Ott and Longnecker, 2004).

Spring 2006. 'Florida 47' and 'Sebring' tomato seeds were sown on 6 Feb. 2006. The seedlings were transplanted on 20 Feb. into Speedling trays in the greenhouse. The plants were transplanted in the field on 20 Mar., and plants were reset as needed on 23, 27, and 28 Mar. Plants were grown in raised beds with a mixture of Myakka and Melabar sandy soil that was covered with sliver plastic mulch. The plants were fertilized with a total of 169 kg·ha⁻¹ of nitrogen, 37 kg·ha⁻¹ of phosphorus, and 210 kg·ha⁻¹ of potassium throughout the season through drip irrigation. The fruit were harvested on 22 June, with sunrise at 6:34 AM, and then tested as described for water uptake at 2, 4, 6, 8, and 14 h after harvest.

Results

Water uptake was significantly affected by the cultivar and time intervals for both seasons (Table 1). Both cultivar and time had a higher significance during the spring season. There was not a significant interaction between cultivar and harvest interval for both seasons, indicating that both cultivars reacted in the same way to the harvest intervals. The average amounts of water uptake during the fall for 'Florida 47' and 'Sebring' were 2.22 g (range, 0.53–7.87 g) and 0.35 g (range, 0.00–1.37), respectively. The average amounts of water uptake for the spring season for 'Florida 47' and 'Sebring' were 1.15 g (range, 0.4–2.3 g) and 0.17 g (range, 0.07–0.60 g), respectively. The range includes data taken from all time intervals.

The average amount of water absorbed by 'Florida 47' was significantly greater than 'Sebring' for both seasons (Table 2). During the fall season, 'Florida 47' fruit absorbed significantly more water than did 'Sebring' fruit at 8 and 26 h but not at 2 or 14 h, which was due to a high amount of variation at the 2- and 14-h time intervals. During the spring season, 'Florida 47' fruit absorbed significantly greater amounts of water than did 'Sebring' at all time intervals. The amount

of water absorbed by the fruit was significantly affected by fruit weight where large fruit absorbed greater amounts of water than small fruit for 'Florida 47' during both seasons and for 'Sebring' during the spring season (data not shown).

During the fall season, neither 'Florida 47' nor 'Sebring' fruit absorbed significantly different amounts of water at any time interval but both had their highest values at the 2-h interval (Fig. 1). Standard errors were greatest at 2 h for both cultivars, and this largely prevented the detection of significant differences. Water uptake decreased by 31% and 7% between the 2- and 8-h time interval for 'Florida 47' and 'Sebring', respectively, during the fall season. 'Florida 47' and 'Sebring' fruit did absorb significantly more water at 2 h as compared with 4, 8, 14, and 26 h after harvest during the spring season (Fig. 2). 'Florida 47' fruit absorbed slightly larger amounts of water at 14 h after harvest during the spring season. Water uptake decreased by 55% and 27% between the 2- and 4-h interval for 'Florida 47' and 'Sebring', respectively, during the spring season.

Discussion

In a previous study Bartz and Scott (2005) found that 'Sebring' absorbed significantly less water than 'Florida 47'. In this study 'Sebring' had significantly less water uptake than 'Florida 47' overall and at most time intervals over both seasons. In the two instances where the amount of water absorbed by 'Florida 47' and 'Sebring' was not significantly different, the variation was high and standard errors overlapped at these points. The reason that 'Sebring' absorbed less water is not known, but anatomical studies might provide some clues. It is possible that there are differences in the cells or tissues that make up the stem scar region of the fruit. These differences may be due to the size of the vascular bundles in the stem scars or in the cell and intercellular space sizes of the tissue surrounding the vascular bundles in the stem scar. Because 'Sebring' absorbs less water than 'Florida 47', it is less likely to be infected during postharvest handling. One way to decrease the amount of infection of bacterial soft rot is to use cultivars that resist water uptake.

Even though the water uptake values were not significantly different for either cultivar

Table 1. Analysis of variance for tomato water uptake for 'Florida 47' and 'Sebring' immersed in water at various time intervals after harvest at the Gulf Coast Research and Education Center (Wimauma, FL) in Fall 2005 and Spring 2006.

Source	Fall 2005				Spring 2006			
	DF	SS	MS	F value	DF	SS	MS	F value
Model	7	0.1576	0.0225	4.13**	9	0.1709	0.0190	25.42***
Error	16	0.0871	0.0054		20	0.0149	0.0007	
Cultivar	1	0.0817	0.0817	15.00**	1	0.1333	0.1333	178.57***
Time	3	0.0611	0.0204	3.74*	4	0.0332	0.0083	11.12***
Cultivar × time	3	0.0148	0.0049	0.91	4	0.0043	0.0011	0.26

***Significant differences at $P \leq 0.05$, 0.001, and 0.0001, respectively.

Table 2. Comparison of water uptake for fruit of 'Florida 47' and 'Sebring' overall and at four time intervals over two seasons at the Gulf Coast Research and Education Center (Wimauma, FL) in Fall 2005 and Spring 2006.

Season	Hours after harvest	Wt increase (%) ^z	
		Florida 47	Sebring
Fall 2005	2	0.48 a ^y	0.14 a
	8	0.15 a	0.01 b
	14	0.15 a	0.06 a
	26	0.26 a	0.02 b
	Average	0.26 a	0.06 b
Spring 2006	2	0.42 a	0.11 b
	4	0.23 a	0.03 b
	6	0.22 a	0.02 b
	8	0.20 a	0.02 b
	14	0.22 a	0.02 b
	Average	0.26 a	0.04 b

^z(Weight increase/initial weight) × 100.

^ySignificant differences for two cultivars at each time interval determined by Tukey's *W* Procedure at $P \leq 0.05$ using the percentages transformed by the arc-sine square-root method.

during the fall season due to high variability, the amount of water absorbed tended to be greater at 2 h as compared with the other time intervals (Fig. 1). Fresh, water-congested stem scars may be more prone to environmental variation than air-congested stem scars. The higher variability in this study may have been due to the position of the fruit in the pressure cooker where the fruit on the bottom had more pressure applied to them, so they could have absorbed more water. Although water uptake differences were not significant in the fall, it appeared that water congestion of the stem scars dissipated between 2 and 8 h after harvest. Thus, in the spring we wanted to further explore this time interval. In the spring season the amount of water absorbed at 2 h was significantly greater than at 4, 6, 8, and 14 h after harvest for 'Florida 47' and 'Sebring'. Bartz and Showalter (1981) had found that when fruit were held for 2 d before immersing them in water, the stem scars became congested with air and water could not move through the stem scar. Our results suggest the stem scars dried out by 4 h after harvest, which suggests that fruit should be held for at least 4 h before immersion in the dump tank.

However, conditions at the packinghouse are different from those used in our study. In this study, the harvested fruit were placed on trays with the stem scar facing up and stored on the laboratory bench with low relative humidity (46%). The fruit were in a single layer, so all of the stem scars were directly exposed to air, therefore drying out at the same rate. In a commercial setting, fruit are harvested into buckets and then dumped into a gondola or bin to a depth up to 1.5 m. Because the tomatoes at the top of the container may dry out faster than those in the middle of the container, the fruit may need to be held longer than 4 h to dry out their stem scars and significantly reduce water uptake. The relative humidity is much lower in the laboratory than in a gondola or bin full of

Fig. 1. Effect of time interval after harvest on fruit stem scar water uptake for two cultivars at the Gulf Coast Research and Education Center (Wimauma, FL) in Fall 2005. ^aMeans within cultivar were not significantly different by Tukey's *W* procedure at $P \leq 0.05$ using the percentages transformed by the arc-sine square-root method.

Fig. 2. Effect of time interval after harvest on fruit stem scar water uptake for two cultivars at the Gulf Coast Research and Education Center (Wimauma, FL) in Spring 2006. ^aMeans within cultivar not followed by the same letter are significantly different by Tukey's *W* procedure at $P \leq 0.05$ using the percentages transformed by the arc-sine square-root method.

tomatoes, so the stem scars would remain water-congested rather than becoming air-congested. The wetness of the fruit at harvest could also play a significant role here. Growers generally harvest only when all fruit in the field are dry and delay harvest after a rain event, but this is not always possible. Fruit on the outside of the vine might be dry while fruit within the canopy might still be wet in some instances. Symptoms usually

appear on the fruit during storage, and the load can be rejected by the receiver even if only a small percentage of fruit are infected. Although an exact recommendation cannot be made, it can be recommended that they choose a cultivar with less water uptake and hold fruit at least 4 h before immersion in the dump tank, especially when environmental conditions favor the pathogen growth in the field.

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