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# Rootstock effect on yield, initial fruit quality, and lycopene content of 'Tasti Lee' tomatoes

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## Abstract

Tomatoes are a high-value crop commonly grown in high tunnel systems in the central United States. Grafting is an important tool for mitigation of soil borne disease pressure and abiotic stresses in tomato production and is used world-wide in protected growing systems such as high tunnels. ‘Tasti Lee’ is a high-quality tomato cultivar that is grown in the southeastern U.S. and has been bred for superior fresh-eating quality and enhanced lycopene content. Previous high tunnel trials in Kansas have shown that ‘Tasti-Lee’ significantly increases marketable yields when grafted to the vigorous rootstock ‘Maxifort.’ The objective of this trial was to investigate the yield and potential fruit quality impacts of ‘Tasti-Lee’ when grafting to five different roostocks and grown in a central U.S. high tunnel with little disease pressure. Due to the diverse impacts of grafting on fruit quality found in the literature, it is important to conduct localized rootstock trials and make conclusions on specific rootstock/scion combinations. ‘Tasti Lee’ tomatoes were grafted to ‘Maxifort,’ ‘DRO 141 TX,’ ‘Fortamino,’ ‘Estamino,’and ‘RST-04-106’ rootstocks and grown in a high tunnel system in Kansas in 2019. The experiment was arranged in a randomized complete block design. Total yield, marketable yield, and fruit size were assessed for the whole season on a per plant basis. Red ripe tomato fruit were used for assessing soluble solids content (SSC), titratable acidity (TA), lycopene content, and ascorbic acid content. Although the results were not statistically significant, all rootstocks increased the marketable fruit number and fruit size over the non-grafted control. ‘Maxifort, ‘Fortamino,’ and ‘Estamino’ were the best performing rootstocks. No differences in SSC, TA, lycopene content, or ascorbic acid were found due to grafting. Our results indicate that ‘Tasti-Lee’ could be a successful candidate for high-tunnel grafting systems in the central U.S.



## Keywords

Solanum lycopersicum, scion, soluble solids, carotenoids, ascorbic acid, grafting, fruit weight

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**Abstract**

Tomatoes (*Solanum lycopersicum)* are a high-value crop commonly grown in high tunnel systems in the central United States. Grafting is an important tool for mitigation of soil borne disease pressure and abiotic stresses in tomato production and is used world-wide in protected growing systems such as high tunnels. 'Tasti Lee' is a high-quality tomato cultivar that is grown in the southeastern U.S. and has been bred for superior fresh-eating quality and enhanced lycopene content. Previous high tunnel trials in Kansas have shown that 'Tasti-Lee' significantly increases marketable yields when grafted to the vigorous rootstock 'Maxifort.' The objective of this trial was to investigate the yield and potential fruit quality impacts of 'Tasti-Lee' when grafting to five different rootstocks and grown in a central U.S. high tunnel with little disease pressure. Due to the diverse impacts of grafting on fruit quality found in the literature, it is important to conduct localized rootstock trials and make conclusions on specific rootstock/scion combinations. 'Tasti Lee' tomatoes were grafted to 'Maxifort,' 'DRO 141 TX,' 'Fortamino,' 'Estamino,'and 'RST-04-106' rootstocks and grown in a high tunnel system in Kansas in 2019. The experiment was arranged in a randomized complete block design. Total yield, marketable yield, and fruit size were assessed for the whole season on a per plant basis. Red ripe tomato fruit were used for assessing soluble solids content (SSC), titratable acidity (TA), lycopene content, and ascorbic acid content. Although the results were not statistically significant, all rootstocks increased the marketable fruit number and fruit size over the non-grafted control. 'Maxifort, 'Fortamino,' and 'Estamino' were the best performing rootstocks. No differences in SSC, TA, lycopene content, or ascorbic acid were found due to grafting. Our results indicate that 'Tasti-Lee' could be a successful candidate for high-tunnel grafting systems in the central U.S.



**Keywords:** scion, soluble solids, carotenoids, ascorbic acid, grafting, fruit weight


**INTRODUCTION**

Vegetable grafting is a method of crop improvement that is used by growers worldwide to provide tolerance and maintain yields where soil-borne disease pressure is high (Lee et al., 2010; Singh et al., 2017). Grafting also provides tolerance to a number of abiotic stressors including high salinity ( Fernández-Garcí et al., 2004; Colla et al., 2010), high and low temperature stress (Rivero et al., 2003; Gao et al., 2006), and water-stress. Vigorous rootstocks are able to maintain or improve yields under these conditions due to more vigorous root systems, improved nutrient uptake and assimilation, and increased water use efficiency (Kumar et al., 2017; Singh et al., 2017). Therefore, selected vigorous rootstocks are widely used in intensive, protected culture systems such as high tunnels where one or more of these conditions may be present (Lee et al., 2010; Meyer et al., 2021). Tomato (*Solanum lycopersicum)* is one of the most economically and nutritionally important crops grown worldwide (Singh et al., 2017). Tomatoes are also the most commonly grafted vegetable (Kubota et al. 2008) and are a popular high-value crop for high tunnel production (Lang et al., 2020; Meyer at al., 2021).

The high-quality determinant cultivar 'Fla. 8153'--marketed as 'Tasti-Lee' by Bejo Seeds—is a product of the University of Florida breeding program. The fruit has a deep red interior color and high lycopene content due to the present crimson ($og^c$) gene (Scott et al., 2008). This fresh-market cultivar reliability produces firm, vine-ripe tomatoes that perform well in sensory and consumer panels (Scott et al., 2008; Cantliffe et al., 2009). In a previous high-tunnel grafting trial in Kansas, 'Tasti-Lee' grafted to 'Maxifort' resulted in a significant increase in marketable yields, indicating a compatible rootstock/scion combination (Loewen, 2018). Grafting incurs extra costs to growers, so the yields, marketability, and/or fruit quality must be enhanced to offset the added expenses (Djidonou et al., 2016; Meyer et al., 2021). "Tasti-Lee" offers central U.S. high tunnel growers a unique cultivar for marketing to consumers, but it is important to first understand potential fruit quality impacts due to grafting.

There are a wide-range of results in the literature on fruit quality impacts from grafting. This is likely due to the diverse rootstock-scion combinations as well as diverse environmental conditions and production systems. Components of tomato flavor and the accumulation of secondary metabolites in tomatoes can be impacted by genetics (Kuti and Konuru, 2005; Viskelis et al., 2008; Klee and Giovannoni, 2011) fruit maturity and harvesting practices (Gautier et al., 2008; Viskelis et al., 2008; Brajovic et al., 2012), environmental conditions (Brandt et al., 2006; Gautier et al., 2008) and genotype x environment interactions (Roselló et al., 2011; Panthee et al., 2012.).

Good tomato flavor is associated with high sugar and acid content (Djidonou et al., 2016) The ratio among sugars and acids is also important for perceived sweetness, tomato flavor, and consumer likeness (Baldwin et al., 1998). Soluble solid content (SSC) is a good indicator of tomato sugars, which typically consists of an even ratio between fructose and glucose (Georgelis et al., 2004). Grafting has previously been shown to decrease SSC (Pogonyi et al., 2005; Nicoletto et al., 2013; Schwarz et al., 2013) as well as have no effect on SSC (Khah et al., 2002; Djidonou et al., 2016). Similarly, reports of grafting have shown to increase titratable acidity (TA) (Flores et al., 2010; Turhan et al., 2011; Schwarz et al., 2013), decrease TA (Pogonyi et al., 2005) and not impact TA ( Khah et al., 2002; Di Gioia et al., 2010).

Lycopene is a strong antioxidant and the most abundant carotenoid found in tomatoes (Bramley, 2002). Tomatoes are one of the most significant sources of lycopene in the human diet due to their widespread consumption (Story et al., 2010). Observational and clinical studies have linked lycopene consumption to reduced risk and progression of prostate cancer (Giovannucci, 2005; Vaishampayan et al., 2007). There is also epidemiological evidence linking lycopene consumption to reduced breast cancer (Cui et al., 2008) and cardiovascular disease risk (Sesso et al., 2003). Ascorbic acid is another antioxidant found in high amounts in tomatoes and is associated with promoting human health (George et al., 2004). Similar to the organoleptic qualities, grafting has mixed effects on antioxidant content of tomato fruit (Davis et al., 2008; Rouphael et al., 2010). A study conducted in a Kansas high-tunnel system with no disease pressure, found that when 'BHN-589' was grafted to 'Maxifort', there was a significant increase in marketable yield and comparable antioxidant content to the non-grafted 'BHN-589' (Meyer et al., 2021) However, the rootstock 'RST-04-106' did not significantly increase yields over the non-grafted plants and the fruit had significantly higher antioxidant capacity (Meyer et al., 2021). This indicates that specific rootstocks/scion combinations and/or a rootstock's capacity to increase yield may also impact fruit quality. Due to conflicting rootstock performance and fruit quality outcomes in the literature, it is important to conduct localized rootstock trials with scions of interest (Kubota et al., 2008).

In the present experiment, five rootstocks that range in their typical yield performance in the absence of disease pressure were evaluated. 'Maxifort' is a well-studied vigorous F1 rootstock that has a proven ability to increase yields in midwestern high tunnels (Masterson et al., 2016; Loewen, 2018; Lang et al., 2020). 'RST-04-106' is recommended for bacterial wilt management in the southeast U.S. but has not improved yields compared to non-grafted plants in high tunnels with no disease pressure (Lang et al., 2020; Meyer et al., 2021). 'DRO141TX', 'Estamino', and 'Fortamino' are also vigorous F1 rootstocks that are promoted for offering good yields but are less studied. Lang et al. (2020) found that 'BHN 589' grafted to 'Estamino' and 'DRO141TX' resulted in comparable yields to 'Maxifort' in a central U.S. high tunnel. The objective of this study was to evaluate yield differences in the cultivar 'Tasti-Lee' when grafted to five different rootstocks and grown in a central U.S. high tunnel with little disease pressure. The second objective of this study was to determine if there is a rootstock effect on the organoleptic and nutritional content of this high-quality hybrid.

## MATERIALS AND METHODS

### Plant materials

All plant materials were propagated and grafted at the Olathe Horticulture Center in a Quonset-style greenhouse. 'Tasti-Lee' (Territorial Seed Company; Cottage Grove, OR) was used as the scion for all rootstock treatments and as the non-grafted control. The rootstocks evaluated were 'Maxifort' (Johnny's Selected Seeds; Winslow, ME), 'DRO141TX' (Johnny's Selected Seeds; Winslow, ME), 'RST-04-106-T' (NE Seed; East Hartford, CT) 'Fortamino' (Vitalis Organic Seeds; Salinas, CA), and 'Estamino' (Johnny's Selected Seeds; Winslow, ME). The seedlings were splice grafted and healed according to Rivard and Louws (2011).

High tunnel site and trial design

The high tunnel trial took place in a 9.1 x 19.5 m moveable high tunnel (Rimol Greenhouse Systems; Hooksett, NH) located at the Olathe Horticulture Center. The experiment was set up as a complete randomized block design. Four 16.5 m rows oriented north and south acted as the blocks and experimental replicates. Each row contained the six treatment plots: non-grafted 'Tasti-Lee' and 'Tasti-Lee' grafted to 'Maxifort', 'DRO141TX', 'RST-04-106-T', 'Fortamino', and 'Estamino.' On 24 June 2019 five replicate plants were planted in each plot with a 45.7 cm spacing between plants. A granular fertilizer (31-16-16) was applied at the time of transplanting at a rate of 22 kg/ha. Irrigation was applied through drip irrigation, weeds were managed with fabric mulch, and tomato plants were trained using a stake and weave system.

Fruit was harvested once weekly from 26 July to 1 Oct. Marketable and unmarketable fruit were counted and weighed separately. Marketability was determined as being free from large cracks, pest damage, fruit rot, and/or blossom end rot. Fruit smaller than 3.8 cm were considered unmarketable. All marketable fruit was further sorted by size: small, medium, large, and jumbo before being counted and weighed. On the last harvest day, all fruit larger than 5 cm was harvested, counted, and weighed.

### Tomato sampling and initial quality analysis

On 1 October, 5 mature red tomato fruits from each treatment were transported to the postharvest physiology lab in Olathe, KS for quality analysis. To ensure the mature red maturity standard was met, external color data was collected on each fruit, by taking two measurements at opposite 45-degree angles on the blossom end with a A5 Chroma-Meter (Minolta CR-400; Minolta Co. Ltd., Osaka, Japan). Quartered tomatoes from each replication were blended and 20 g of puree was centrifuged and the supernatant was used for determination of titratable acidity and total soluble solids. Approximately 2 g of the blended tissue was homogenized with 20 mL of 6% metaphosphoric acid (Fisher Scientific, Hampton, NH, USA) with 2N acetic acid solution and frozen at -20 °C until analysis of ascorbic acid. An automated titrator (862 Food/Beverage Compact titrosampler, Metrohm, Herisau, Switzerland) was used for measuring titratable acidity. Total soluble solids were measured as °Brix with a temperature compensating refractometer (AR200 digital refractometer, Reichert, Depew NY, USA. The remaining tomato quarters were frozen at -20°C until they were used for lycopene analysis.

Ascorbic acid extraction and analysis

Determination of ascorbic acid (AsA) was based on the method by Klimczak and Gliszczynska-wiglo (2015). The previously frozen samples were thawed, vortexed, and centrifuged. The supernatant was further diluted with 6% metaphosphoric acid/2N acetic acid solution (1 supernatant: 4 solution) and filtered through a 1 mL 96-well 0.22 µm filter plate (AcroPrep; Pall Co., Port Washington, NY) into a 2 mL 96-well plate (SKU: 186002482, Waters Co., Milford, MA, USA). Samples were analyzed on a Waters Aquity UPLC (Waters Co., Milford, MA, USA) equipped with a photodiode array detector (PDA). 5 µL from each well was injected in triplicate and separated with an Acquity BEH C18 column (Waters Co., Milford, MA, USA). The mobile phases consisted of 5 mM potassium phosphate monobasic ($KH_2PO_4$), pH 2.65 with 0.1% of formic acid (mobile phase A) and methanol with 0.1% of formic acid (mobile phase B). The solvent management was a linear gradient starting with 5% A, with an increase to 15% A over 1 min, and then to 35% A over 1 min, and a return to the initial conditions over the next 4 min. The flow rate was 0.2 mL/min. Quantification of AsA was based the chromatogram recorded at 245nm with the PDA detector and an external analytical grade ascorbic acid standard curve ranging from 2.5-5 µg/mL Fisher Scientific, Hampton, NH, USA. Ascorbic acid content is reported as mg AsA/100g FW.

Lycopene extraction and analysis

Spectrophotometric determination of lycopene was measured based on the method by Nagata and Yamashita (1992). Under dark conditions, frozen tissue from each replication was blended (Oster #6694, Wood Dale, IL). Approximately 1 g of blended tissue was vortexed for 1 min with 16 mL acetone:hexane (2:3) in a 50 mL test tube. The samples were frozen at (-20 °C) for 1 h to allow for phase separation. An aliquot of 250 µl from the upper phase was pipetted into a 96-well microplate in triplicate for each replication (Costar #3364, corning, Tewksbury, MA). Absorbance was measured at 663, 645, 505, and 453 nm on a spectrophotometer (Synergy H1, BioTek Instruments, Inc. Winooski, VT). Lycopene content was calculated with the following equation: (mg/100 mL) = $-0.0458A_{663} + 0.204A_{645} + 0.372A_{505} - 0.0806A_{453}$ and expressed as µg/g dry weight (DW).

**Statistical analysis**

All data was analyzed using SAS software (SAS Studio 3.8, SAS Institute, Cary, NC) The yield parameters were averaged for the total season for each replicate plot and expressed on a per plant basis. Each yield and quality parameter were subject to PROC MIXED with rootstock treatment as a fixed effect, the blocking effect in the RANDOM statement and option DDRM=KR in the MODEL statement. Mean separation was carried out using Fischer's LSD at $P<0.05$ for yield parameters and Tukey's HSD $P<0.05$ for fruit quality parameters.

**RESULTS**

The marketable yield, total yield, and percent marketability results can be seen in Table 1. There were not significant impacts on total or marketable fruit yields due to grafting. The total fruit size from the non-grafted plants was significantly smaller as compared to all of the rootstock treatments (Table 1). The percentage of jumbo-sized fruit was higher in all of the grafted plants, with the greatest percentages observed in the rootstocks 'DRO-141-TX', 'Maxifort' and 'Estamino' (Figure 1). The fruit quality results can be seen in Table 2. Titratable acidity, TSS, TSS:TA ratio, lycopene content, and AsA content were comparable across all rootstock treatments and the non-grafted control. The values obtained for TSS ranged from 4.2 to 4.5°Brix and the TA ranged from 0.272 to

0.299 % citric acid. Lycopene content ranged from 17.07 to 24.33 (μg/g FW) and AsA ranged from 21.90 to 28.78 (mg/100g FW) among the treatments.

Table 1. Tomato fruit yield of grafted and non-grafted 'Tasti Lee' tomatoes from a high tunnel trial in Olathe, KS in 2019.

| | Marketable Fruit Yield | | | Total Yield | | | % Marketability | |
|---|---|---|---|---|---|---|---|---|
| Treatment[1] | Weight (kg/plant) | Number (fruit/ plant) | Fruit size (g)[3] | Weight (kg/ plant) | Number (fruit/ plant) | Fruit size (g) | Weight | Number |
| Nongrafted | 1.91 a[2] | 12.05 a | 158 a | 3.24 a | 20.85 a | 155.40 b | 58.9 a | 58 a |
| RST-04-106 | 2.49 a | 14.65 a | 171 a | 3.75 a | 22.35 a | 168.60 a | 65.7 a | 64.8 a |
| DRO141TX | 2.11 a | 11.9 a | 177.13 a | 3.83 a | 21.75 a | 175.45 a | 55.8 a | 55.2 a |
| Fortamino | 3.10 a | 17.85 a | 177.13 a | 4.78 a | 28.35 a | 167.87 a | 64.4 a | 63.3 a |
| Estamino | 2.55 a | 14.47 a | 177.13 a | 3.93 a | 22.65 a | 173.42 a | 65.1 a | 63.9 a |
| Maxifort | 2.51 a | 14.1 a | 178.72 a | 3.96 a | 22.66 a | 175.45 a | 62.4 a | 61.2 a |
| LSD (α=0.05) | ns | ns | ns | ns | ns | 12.13 | ns | ns |

[1]The experiment design was a randomized complete block design with 4 rows (blocks) in one high tunnel. Each rootstock treatment consisted of 5 plants.
[2]Means followed by the same letter are not significant according to Fisher's LSD (α=0.05).
[3]Average fruit size was determined by dividing the number of fruits by the fruit weight

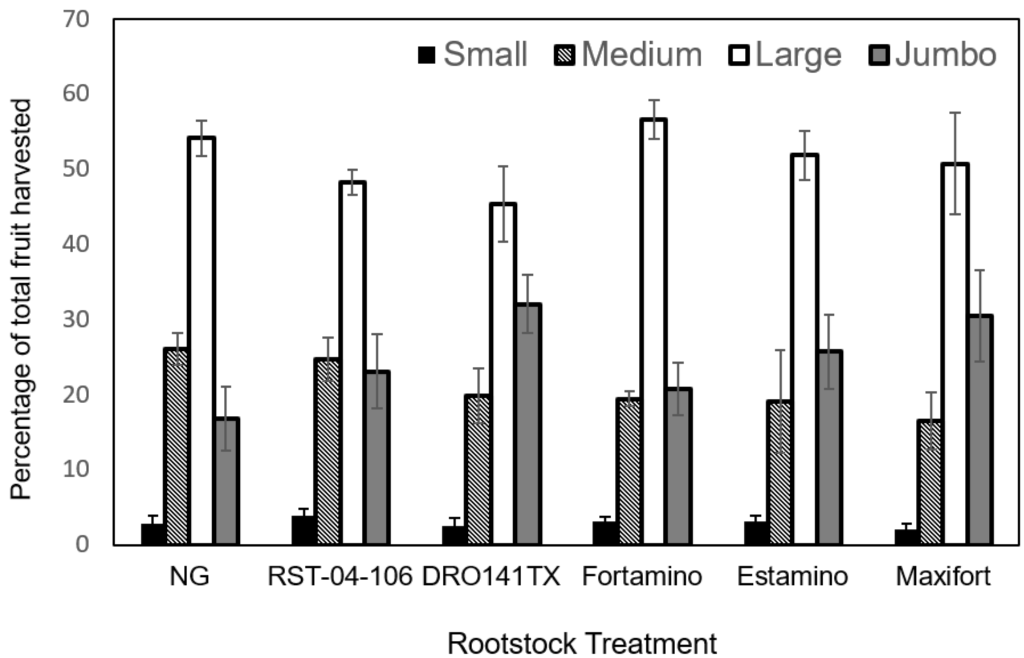


Figure 1. Percent distribution of fruit sizes of (small, medium, large, jumbo) harvested from non-grafted 'Tasti-Lee' and 'Tasti-Lee' grafted to 'RST-04-106,' 'DRO141TX,' 'Fortamino,' 'Estamino,' and 'Maxifort.'

Table 2. Tomato fruit organoleptic quality and nutritional content of grafted and non-grafted 'Tasti-Lee' tomatoes grown in a high tunnel in Olathe, KS in 2019. Fruit was harvest at mature red and analyzed on the day of harvest.

| Treatment[1] | TA (% citric acid) | TSS (°Brix) | SSC:TA ratio | Lycopene (µg/g FW) | AsA (mg/100g FW) |
|---|---|---|---|---|---|
| Nongrafted | 0.272 a[2] | 4.3 a | 16.2 a | 20.92 a | 26.70 a |
| RST-04-106 | 0.275 a | 4.5 a | 16.4 a | 17.07 a | 27.64 a |
| DRO141TX | 0.290 a | 4.3 a | 15.3 a | 18.66 a | 28.78 a |
| Fortamino | 0.299 a | 4.4 a | 15.0 a | 17.36 a | 24.50 a |
| Estamino | 0.262 a | 4.2 a | 16.0 a | 21.17 a | 25.52 a |
| Maxifort | 0.298 a | 4.3 a | 14.3 a | 24.33 a | 21.90 a |
| | ns | ns | ns | ns | ns |

[1]The experiment design was a randomized complete block design with 4 rows (blocks) in one high tunnel. Each rootstock treatment consisted of 5 plants per plot and 5 fruit from each plot were homogenized for fruit quality measurements.
[2]Means followed by the same letter are not significantly different according to Tukey's HSD (α=*0.05)*.

**DISCUSSION**

Yield and fruit quality parameters were compared among non-grafted 'Tasti-Lee' and 'Tasti-Lee' grafted to five different rootstocks. Although it was not statistically significant, all rootstocks increased the marketable fruit weight over the non-grafted plants by a range of 10% to 62%. The lack of statistical significance in the present experiment is likely due to a wide variance within treatment groups and relatively small sample size (one season). 'Maxifort', 'Fortamino' and 'Estamino' performed best in this trial and would be the best candidates for improving marketable yields of 'Tasti-Lee'. 'RST-04-106' had the lowest total yield (kg/plant) of the five rootstocks tested and 'DRO141TX' had lower percent marketability than the non-grafted control (Table 1). These results are consistent with Loewen (2018) where grafting to 'Maxifort' increased the marketable yields of 'Tasti-Lee' by 60%.

The rootstock impact on fruit size observed in this trial is consistent with other reports of tomatoes increasing in fruit size when grafted to vigorous rootstocks (Pogonyi et al., 2005; Turhan et al., 2011;Djidonou et al., 2016, 2020). Previous literature has found there is a negative correlation between fruit weight and SSC or sugar content due to a dilution effect (Georgelis et al., 2004; Zörb et al., 2020). In the present experiment, this increase in fruit size did not significantly impact TSS content. Djidonou et al. (2016) also found no significant decrease in SSC in the larger-sized 'Florida 47' fruit grafted to 'Beaufort' and 'Multifort'. Turhan et al. (2011) saw significant decreases in TSS in among three different commercial cultivars grafted to the vigorous rootstocks 'Beaufort' and 'Arnold'. Similarly, Pogonyi et al. (2005) also found significant decreases in °Brix when the cultivar 'Lemance' was grafted to 'Beaufort.' The authors concluded this was due to a significant increase in fruit size and fruit number. This increase in fruit size could be positive for growers, as it can increase total yields (Djidonou et al., 2016).

The average SSC from this experiment (4.3°Brix) is lower than results from multiple seasons of outdoor production in of 'Tasti Lee' in Florida where SSC ranged from 4.98 to 5.5 (Scott et al., 2008). TA was also lower in the present experiment than what is reported in Scott et al. (2008), where it ranged from 0.37 to 0.39 % citric acid for 'Tasti-Lee'. However, SSC from this high tunnel trial was higher than that reported for nongrafted 'Tasti-Lee' tomatoes grown hydroponically in a greenhouse in Florida, where the average over two harvest days of red-ripe tomatoes was 2.7°Brix (Cantliffe et al., 2009). TA was similar among this trial and Cantliffe et al. (2009). These results indicate that production systems and environmental conditions can alter organoleptic quality of 'Tasti-Lee' tomatoes.

Our results show that grafting did not impact the lycopene or AsA content of 'Tasti-Lee' tomatoes. This is consistent with Djidonou et al. (2016) who saw no impact on lycopene content among grafted and non-grafted 'Florida 47'. Other studies have also found no impact on lycopene content due to grafting (Khah et al., 2002; Turhan et al., 2011), while others have reported increases in specific rootstock or scion combinations or under stress conditions (Fernández-Garcí et al., 2004; Brajovic et al., 2012; Schwarz et al., 2013). One of the more consistent trends in the literature is a rootstock-mediated reduction is AsA in tomato fruit (Di Gioia et al., 2010; Turhan et al., 2011 Djidonou et al., 2016.; Mauro et al., 2020). Suggested mechanisms of fruit AsA reduction from grafting include the redistribution or accumulation of the compound in other parts of the plant due to more vigorous vegetative growth ( Wadano et al., 1999; Vrcek et al., 2011). However, Mauro et al. (2020) found a reduced AsA in fruit grafted to low-vigor *S. pimpinellifolium* rootstocks. The authors suggest that there was dilution effect because the grafted fruit had higher water content (Mauro et al., 2020). We did not see this same trend with 'Tasti-Lee' grafted to five different rootstocks.

**CONCLUSION**

Although only one season of data is reported here, our results indicate that the high-quality cultivar 'Tasti-Lee' can be grafted to vigorous rootstocks without impairing organoleptic or nutritional quality. The best-performing rootstocks in this central U.S. high tunnel trial were

'Maxifort', 'Fortamino,' and 'Estamino,' which increased the average fruit size and fruit number over the non-grafted 'Tasti-Lee.' This cultivar could be a unique option for fresh-market growers in the central U.S.

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