Producing a Grafted and a Non-Grafted Tomato Plant from the Same Seedling

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SUMMARY. Growing grafted hybrid tomato (*Solanum lycopersicum*) cultivars in greenhouse operations is gaining popularity worldwide. The costs of producing grafted plants remain a deterrent to the smaller producer. After removing plant tops to use as scions for grafting tomato plants, the stumps that have well-developed root systems and cotyledon leaves are usually discarded with the root media and containers. If productive plants can be produced from sprouts on the stumps, they can be used as non-grafted hybrids at the same farm or sold to other growers for income to defray part of the grafting costs. A 2-year greenhouse study examined the effects of three propagation methods and three tomato cultivars on plant yield and related traits. Seedling, grafted, and stump sprout plants of the hybrid cultivars Geronimo, Quest, and Starbuck were used in this study. Plants grafted on 'Maxifort' rootstock had greater stem diameter ($P < 0.0001$) below the first and third clusters than the seedling or stump sprout plants. The seedling plants had greater stem diameter than stump sprout plants below both clusters. During the first 3 weeks of harvest, seedling plants produced greater yields ($P < 0.0001$) than grafted or stump sprout plants and the differences were cultivar related. 'Quest' was the only cultivar that produced similar yields (2.8 vs. 2.3 lb) as a seedling or a grafted plant during the first 3 weeks of harvest. Tomato plants propagated by all three methods produced similar yields and fruit weight in the remaining 16 weeks of harvest. Cultivars had no significant effect on yield during the first 3 weeks of harvest ($P > 0.05$), but their yields were significantly different during the remaining 16 weeks of harvest ($P < 0.0001$). The apparent reason for yield advantages of the seedling plants during the first 3 weeks of harvest was the uninterrupted growth during the seedling stage. Propagation method had no specific influence on fruit quality attributes. On the bases of this study, producing productive tomato plants from stump sprouts is a feasible cultural technique that can reduce losses associated with plants used in grafting. It also allows the repeated use of the soilless media and the seedling containers. The produced plants can generate substantial income for businesses that graft a significant number of tomato seedlings. For this cultural method to work, grafting should be timed to allow the stump sprout plants to grow for at least 5 weeks before planting in the grow bags. This practice is normally followed in producing transplants from seeds.

Grafting tomato plants is an old cultural technique that has been practiced since the early 1900s in Japan, South Korea, and other Asian and Middle Eastern countries (Kubota et al., 2008). The use of grafted plants was not common in North America up until late in the last century except in home gardens and by small organic tomato growers in the southern United States (King et al., 2008). Surveys conducted in 2006

showed the number of grafted seedlings in North America was over 40 million indicating a change of this trend (Jung et al., 2005; Kubota et al., 2008). Tomato growers want to grow grafted plants to control soil-borne diseases, increase yield, and improve plant adaptation to less than optimum environmental conditions (Bletsos et al., 2003; Giles, 2011; King et al., 2008; Louws et al., 2010; Schwarz et al., 2010).

Producing grafted tomato plants is costly because of intensive labor input for propagation, optimizing the

environmental conditions for healing the graft, longer periods needed for producing the transplants, and the additional costs of the rootstock (Rivard et al., 2010). The high costs often discourage potential growers even with the additional benefits of increased yield and reduction of pest control costs. Production of double-stemmed grafted plants was suggested to reduce the expenses needed to purchase the grafted plants (Jung et al., 2005). Semiautomated or fully automated grafting robots were also invented to minimize labor cost for grafting vegetables (Kurata, 1994).

The practice of grafting tomato plants leads to discarding the stumps of the scion cultivar after removing the tops for grafting (Snyder, 2011). In most cases, the stumps are the remains of costly hybrid cultivars that were planted in multicell trays filled with commercial soilless mixtures (Rivard et al., 2010). The stumps have well-developed root systems that supported the scion plants for ≈ 3 weeks before cutting the tops for grafting (Black et al., 2003). If productive plants can be generated on the stumps, they can be used at the same farm or sold to other growers as non-grafted hybrids for returns that can defray part of the grafting costs.

The objectives of this study were to evaluate the effects of propagating three tomato cultivars as seedling, grafted, and stump sprout plants on yield and related traits and to determine if the outcome is cultivar related.

Materials and methods

Studies were conducted in 2010 and 2011 in a 30 $\times$ 96-ft double-polyethylene greenhouse used to grow 600 tomato plants in 300 polyethylene bags, at Louisiana State University Agricultural Center in Bossier City. In every study, tomato plants were grown in 5-gal upright grow bags filled to 2 inches from the top with perlite, using a run to waste production system in which nutrient runoff was not recycled (Snyder,

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1

2001). The perlite in each bag was disinfected and used for the duration of the study (Hanna, 2010).

Seeds from the hybrid tomato cultivars Geronimo, Quest, and Starbuck were planted around the third week of November in plastic trays with 38 cells. Each cell measured 2.2 inches in diameter and 2.5 inches in depth (Growing System, Milwaukee, WI). The trays were filled with soilless mix (Pro-Mix BX; Premier Horticulture, Quakertown, PA), and the seedlings were grown for 5 weeks before planting in the grow bags. Additional seedlings from all cultivars and the rootstock 'Maxifort' were grown in the seedling trays for 3 weeks (Leonardi and Romano, 2004) before grafting in early December. All three cultivars were grafted using the tube grafting technique described by McAvoy (2005). The 3-week-old 'Maxifort' seedlings were cut at an angle below the cotyledon leaves and the tops were discarded. 'Geronimo', 'Quest', and 'Starbuck' seedlings of the same age were cut at similar angle above the cotyledon leaves and the tops (scions) were grafted onto the rootstock bottoms. The graft union was held by a silicon tube (Bato Plastics, Zevenbergen, The Netherlands) that holds the scion and rootstock together in firm contact. Each silicon tube has a slit that allows the tube to fall off as the graft union heals and expands in diameter (Black et al., 2003; Kubota et al., 2008). The grafted plants were protected from direct sun light in high humidity tunnels for 7–10 d and gradually acclimated to normal growing conditions for another 5–10 d before planting in the grow bags. The remaining stumps of all three cultivars were kept under the same growing conditions of the transplants from seeds to generate sprouts (new plants) from the auxiliary buds at the cotyledon leaves. One sprout was allowed to grow per stump for 2–3 weeks before transplanting in the grow bags.

All seedling, grafted, and stump sprout plants were transplanted into the grow bags $\approx$ 5 weeks following sowing. Two transplants planted at a 3-inch depth to cover the root ball and spaced 7 inches apart in each grow bag. Using the V-shape method, plants were spaced 17 inches apart within the row and rows were spaced 3 ft apart at the overhead supporting wire. The greenhouse had 10 rows of plants with north/south orientation. Other cultural

practices consisted of standard recommendations for growing greenhouse tomatoes for fresh market production in Louisiana and Mississippi (Hanna, 2003; Snyder, 2001).

The experiment was a 3×3 factorial of propagation methods (seedling, grafted, and stump sprout plants) and cultivars (Geronimo, Quest, and Starbuck) in a randomized complete block design with three replications (plots) of eight plants. Stem diameter of all plants per plot was measured below the first and third fruit cluster using a caliper (Fraction+; Central Tools and Instruments, New York). Three to five ripe fruit having similar color and size were selected from each plot at midharvest in early May for fruit analysis. Fruit were placed in a food processor (Waring Commercial, Atlanta) after slicing to small wedges. The food processor was operated at high speed until all fruit tissue reached a liquid form (Morgan, 2001). About 0.3 mL of the mixed solution was placed onto the surface of a digital refractometer (Pal-1; Atago, Tokyo) and soluble solids concentration was recorded. Fruit potassium and sodium contents were determined using a Cardy ion meter (Horiba Instruments, Irvine, CA). Fruit pH was determined using a pH meter (IQ Scientific Instruments, San Diego).

Harvest was initiated in early March and ended in mid-July. Fruit was harvested at the pink ripening stage twice per week for 19 weeks. Small-size fruit and fruit with blossom-end rot and other defects were removed (negligible number because most were removed during cluster pruning), and the remainder graded according to U.S. Department of Agriculture standards (USDA, 1997). Marketable yield was determined by weighing fruit graded medium or larger during the first 3 weeks and during the remaining 16 weeks of harvest to reflect the effects of the early growth interruption of grafted and stump sprout plants on yield.

Data were analyzed as a randomized complete block design with three replications, using the PROC MIXED procedure of SAS (version 9.2; SAS Institute, Cary, NC). Blocks (replications) nested within years were considered random, and propagation methods and cultivars were considered fixed. Levels of significance of the main effects and interactions in the analysis of variance table were determined

with the F test. Mean separation of the main effects and interactions was conducted using the DIFF option of the least square means.

Results and discussion

Data are presented as the average of 2 years because by-year interaction effects on evaluated traits were not significant. Propagation methods and cultivars had significant effects on stem diameter below the first and third cluster, but their interaction effect was not significant (Table 1). The grafted plants produced greater stem diameter than the seedling plants or the stump sprout plants below both clusters. Previous reports indicated that the rootstocks and scions interact, to produce vigorous root system that enhances water and mineral uptake, leading to stronger grafted plants (Lee, 1994; White, 1963). Stump sprout plants produced the smallest stem diameter below both clusters as a result of late growth. The presence of the cotyledon leaves and a well-developed root system on the stumps did not accelerate sprouts growth to achieve similar stem diameter to the seedling plants. 'Geronimo' produced plants with greater stem diameter than any of the other two cultivars below both clusters (Table 1).

Propagation method had significant effects on tomato marketable yield during the first 3 weeks of harvest, but had no effects on the marketable yield during the remaining 16 weeks of harvest. Plants propagated by all three methods produced fruit with similar weight (Table 2). Cultivars had no significant effect on marketable yield during the first 3 weeks of harvest, but marketable yields and fruit weight were significantly different during the remaining 16 weeks of harvest. After the first 3 weeks of harvest, 'Geronimo' produced significantly greater yields than 'Quest' or 'Starbuck'. This is similar to previous studies where 'Geronimo' produced greater marketable yields than 'Quest' (Hanna, 2009). Propagation method $\times$ cultivar interaction for yield was significant during the first 3 weeks of harvest (Table 2). Regardless of the cultivar, seedling plants produced significantly greater marketable yields than stump sprout plants during the first 3 weeks of harvest (Table 3). Seedling plants also produced significantly greater marketable yields than grafted plants during the same period except 'Quest' (Table 3).

Table 1. Analysis of variance and mean separation by least square means of tomato stem diameter below first and third clusters in 2010 and 2011 as related to treatment effect in a 30 × 96-ft (9.1 × 29.3-m) greenhouse at Louisiana State University Agricultural Center, Bossier City.

Treatment	Avg stem diam over 2 years (inches) ^z	
	Below first cluster	Below third cluster
Propagation method		
Grafted	0.57 a ^y	0.63 a
Seedling	0.54 b	0.62 b
Stump sprout	0.39 c	0.59 c
Cultivar		
Geronimo	0.51 a	0.63 a
Quest	0.50 b	0.60 b
Starbuck	0.49 b	0.61 b
	<i>P</i> > <i>F</i>	
Propagation method (M)	<0.0001	<0.0001
Cultivar (C)	0.0004	<0.0001
M × C	0.6710	0.0779

^z1 inch = 2.54 cm.

^yFor each propagation method and cultivar, means within columns followed by the same letter are not significantly different at *P* ≤ 0.05 by least square means.

Table 2. Mean separation by least square means and analysis of variance for tomato marketable yield and fruit weight in 2010 and 2011 as related to treatment effect in a 30 × 96-ft (9.1 × 29.3-m) greenhouse at Louisiana State University Agricultural Center, Bossier City.

Treatment	Avg tomato yield over 2 years (lb/plant) ^z		
	First 3 wk ^y	Next 16 wk ^x	Avg fruit wt (oz) ^w
Propagation method			
Grafted		26.5 a ^y	8.0 a
Seedling		25.5 a	7.8 a
Stump sprout		25.5 a	7.9 a
Cultivar			
Geronimo		29.2 a	8.2 a
Quest		23.3 b	7.5 b
Starbuck		25.1 b	8.0 a
		<i>P</i> > <i>F</i>	
Propagation method (M)	<0.0001	0.4182	0.3461
Cultivar (C)	0.0783	<0.0001	<0.0001
M × C	0.0059	0.2285	0.3582

^z1 lb = 0.4536 kg.

^yMarketable yield of fruit graded medium or larger in the first 3 weeks of the harvest season (March to July).

^xMarketable yield of fruit graded medium or larger during the remaining 16 weeks of the harvest season.

^w1 oz = 28.3495 g.

^yFor each propagation method and cultivar, means within columns followed by the same letter are not significantly different at *P* ≤ 0.05 by least square means.

Table 3. Interaction effects of propagation methods and tomato cultivars on marketable yield during the first 3 weeks of harvest in a 30 × 96-ft (9.1 × 29.3-m) greenhouse in 2010 and 2011 at Louisiana State University Agricultural Center, Bossier City.

Cultivar	Avg marketable yield over 2 years (lb/plant) ^z		
	Propagation method		
	Grafted	Seedling	Stump sprout
Geronimo	2.2 A b ^y	3.1 A B a	0.1 B c
Quest	2.3 A a	2.8 B a	0.8 A b
Starbuck	2.5 A b	3.6 A a	0.3 B c

^z1 lb = 0.4536 kg.

^yFor each cultivar, means within columns followed by the same upper case letter are not significantly different at *P* ≤ 0.05 by least square means. For each propagation method, means within rows followed by the same lower case letter are not significantly different at *P* ≤ 0.05 by least square means.

These differences indicate that the un-interrupted growth of the seedling plants for 5 weeks before planting in the grow bags contributed to greater yields during the first 3 weeks of harvest and the differences were cultivar related. The less productivity of stump sprout plants during the first 3 weeks of harvest can be explained by the fact that they were 3 weeks late in growth than the seedling plants. Previous work indicates that greenhouse tomato seedlings should be grown for at least 5 weeks before transplanting into the grow bags (Hanna, 2009). Regardless of the fast growth of the grafted plants, they were less productive during the first 3 weeks of harvest than the seedling plants except 'Quest'. The rapid vegetative growth of the grafted plants resulted in greater stem diameter below the first and third clusters than the seedling plants but not greater yields during the first 3 weeks or the remaining 16 weeks of harvest. Plants were grafted 3 weeks after planting the seeds and the grafted plants went through a period of healing before resuming normal growth. During that time, the seedling plants continued normal growth without interruption. The delayed re-growth of grafted plants may have contributed to their lack of yield advantage even though vegetative growth was faster.

Fruit analysis indicated that stump sprout plants produced fruit with higher sodium content and soluble solid concentrations than grafted plants. 'Quest' produced fruit with higher sodium contents than the other two cultivars. 'Starbuck' produced fruit with higher soluble solids concentration than 'Geronimo' but similar to 'Quest' (Table 4). Davis et al. (2008) indicated that grafting can affect various quality aspects of vegetables. Although propagation methods and cultivars had no significant effects on fruit potassium content, their interactions were significant (Table 4). Interaction effects indicated that 'Geronimo' and 'Starbuck' propagated by all three methods and all cultivars propagated by the seedling method produced fruit with similar potassium content (Table 5). In general, fruit analysis was not suggestive of specific quality associated with any propagation method. Previous work indicated that understanding the impact of grafting on vegetable fruit quality is far from being completed (Rouphael et al., 2010).

Table 4. Analysis of variance and mean separation by least square means for tomato fruit potassium, sodium, pH, and soluble solid concentration as related to three propagation methods and three cultivars planted in a 30 × 96-ft (9.1 × 29.3-m) greenhouse in 2010 and 2011 at Louisiana State University Agricultural Center, Bossier City.

Treatment	Tomato fruit analyses ^z			
	Potassium (ppm) ^y	Sodium (ppm)	pH	Soluble solids concn (%)
Propagation method				
Grafted		30.6 b ^x	4.52 a	5.32 b
Seedling		39.3 a	4.51 a	5.56 ab
Stump's sprout		39.5 a	4.52 a	5.75 a
Cultivar				
Geronimo		34.9 b	4.53 a	5.38 b
Quest		39.8 a	4.49 a	5.53 a
Starbuck		34.6 b	4.52 a	5.71 a
		<i>P</i> > <i>F</i>		
Propagation method (M)	0.1240	<0.0001	0.8033	0.0265
Cultivar (C)	0.1175	0.0184	0.3247	0.1135
M × C	0.0305	0.1789	0.3247	0.1983

^zTomato fruit samples were collected at midharvest season (early May) and data were presented as an average of 2 years.

^y1 ppm = 1 mg·L⁻¹.

^xFor each propagation method and cultivar, means within columns followed by the same letter are not significantly different at *P* ≤ 0.05 by least square mean.

Table 5. Interaction effects of propagation method and tomato cultivar on fruit potassium content in a 30 × 96-ft (9.1 × 29.3-m) greenhouse in 2010 and 2011 at Louisiana State University Agricultural Center, Bossier City.

Cultivar	Avg fruit potassium over 2 years (ppm) ^z		
	Propagation method		
	Grafted plants	Seedling plants	Stump sprout plants
Geronimo	1900 B a ^y	1867 A a	1883 A B a
Quest	2050 A a	1967 A a	1833 B b
Starbuck	1917 B a	1917 A a	1950 A a

^z1 ppm = 1 mg·L⁻¹.

^yFor each cultivar, means within columns followed by the same upper case letter are not significantly different at *P* ≤ 0.05 by least square means. For each propagation method, means within rows followed by the same lower case letter are not significantly different at *P* ≤ 0.05 by least square means.

Conclusions

Using grafted tomato plants is gaining popularity in North American greenhouse tomato operations. Plant tops of good hybrid cultivars are used as scions to produce the grafted plants leaving the stumps to be discarded. In most cases, the stumps are left with the cotyledon leaves and a root system that supported the scions before grafting. Producing grafted plants from hybrid tomato cultivars is costly. The expenses include the price of seeds, labor wages, root media, seedling containers, feeding nutrients, and costs to optimize the growing conditions for a longer seedling stage.

This study indicates that producing productive plants from the stump sprouts is feasible and can be used to defray parts of the costs to produce the grafted plants. Both plants grown from

the stump sprouts and the seeds produced statistically similar yields after the first 3 weeks of harvest. The most apparent reason for reduced early season yield of the stump sprout plants was the late growth. A simple remedy for that is to allow the stump sprout plants to grow for 5 weeks after initiation before transplanting in the grow bags or sold commercially.

The botanical components for producing plants from the stump sprouts are similar to those for producing plants from seeds. The stumps are left with the root system and the cotyledon leaves, both are essential components for producing plants from seeds. This technique should eliminate wasting a valuable part of a good hybrid tomato cultivar and allow for the repeated use of the seedling containers filled with valuable potting

mixtures. The grafting process should be timed to allow both the grafted and stump sprout plants to grow for at least 5 weeks before planting in the grow bags or sold commercially. Surveys conducted in 2006 revealed that the number of grafted seedlings in North America exceeded 40 million resulting in similar number of discarded stumps. Tomato plants produced from the stumps can be sold at market prices to generate substantial income for graft-producing businesses.

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