Quality Comparison of Hydroponic Tomatoes (*Lycopersicon esculentum*) Ripened On and Off Vine

R. ARIAS, T.-C. LEE, D. SPECCA, AND H. JANES

ABSTRACT: There is a general belief that the quality of tomatoes ripened on vine is better than tomatoes ripened off the vine, influencing among other parameters, the price of this commodity. We compared the quality of hydroponic tomatoes ripened on and off vine by chemical, physical, and sensory evaluation to find what attributes are affected and to what extent. Lycopene, β-carotene, total and soluble solids, moisture content, ascorbic acid, acidity, pH, texture, and color were analyzed. Tomatoes ripened on vine had significantly more lycopene, β-carotene, soluble and total solids, higher a* and lower L*, and were firmer. However, a 100-judge panel rated only the color and overall liking of the vine-ripened tomatoes as more intense than the fruit ripened off vine. Therefore, the chemical and physical differences were mostly not large enough to influence the panelist's perception. The characterization of tomatoes ripened on and off vine may help to guide post-harvest handling and treatment and to improve the quality of tomatoes ripened off vine.

Key Words: tomatoes, *Lycopersicon esculentum* cv. Laura, ripening, quality, vine, hydroponics

Introduction

ONE OF THE MOST IMPORTANT CROPS AROUND THE WORLD IS the tomato — *Lycopersicon* species — with an annual production, as reported in 1994, of more than 20 million tons for processing tomatoes only (Schuch 1994). In the United States, the tomato is the 2nd most important vegetable crop in economic value, after the potato. It is among the 5 most popular vegetables in per capita use (Lucier 1997), contributing significantly to the overall nutrition of consumers (Schuch 1994; Thakur and others 1996).

Tomato quality depends on many factors such as cultivar, growing conditions, and ripening on or off the vine. Tomatoes are usually harvested at the mature green stage and ripened off the vine during transit to the final marketing place. There is a general belief that tomatoes ripened on the vine have better quality, mainly in terms of flavor, increasing the price of this commodity. Ripening off the vine reduces time to harvest, increases turnover, allows longer time for transportation and distribution, and increases shelf life. For this reason extensive studies have been conducted to compare the quality of tomatoes ripened on and off the vine. In addition, we have a special interest to address this issue, since the tomato was selected by the U.S. National Aeronautics and Space Administration (NASA) as a candidate crop to be grown on space stations, due to its distinguished psychological impact and nutritional and health benefits. Time to harvest is very critical to reduce consumables and increase tomato turnover in Advanced Life Support Systems (ALSS).

Ripening on and off the vine encompasses, but is not limited to, many factors such as light, temperature, relative humidity (RH), gas composition, maturity stage, cluster position, size of the fruit, and so forth. Several studies compared the quality of tomatoes ripened on and off vine under various conditions.

Bisogni and Armbruster (1973) compared the quality of field- and room-ripened tomatoes. The sensory evaluation conducted by a 10-judge panel showed that field-ripened tomatoes were sweeter and better in flavor and overall quality than room-ripened tomatoes. No differences were reported between pH, acidity, soluble solids, soluble solids/acidity ratio, or moisture content, and inconsistent results were obtained with ascorbic acid and reduced ascorbic acid of tomatoes ripened on and off vine.

Skok (1951) analyzed the quality of processed juice from tomatoes ripened on and off the vine. Field-grown tomatoes ripened on the vine and tomatoes ripened in stacked boxes at 22°C, without sunlight, were compared. Total solids, total sugars, lycopene content, and pH were the same for the tomatoes ripened on and off vine. Ascorbic acid was higher for the vine-ripened tomato juice compared to room-ripened tomato juice, and carotene was higher for the off-vine tomato juice. However, the author recognized that the decrease of ascorbic acid in the off-vine tomatoes was due to the lack of light exposure during ripening, and the carotene difference was due to the difference in ripeness stage of the tomatoes.

In 1953, Sayre and others found that lycopene, carotene, and color of green house tomatoes ripened on the vine and tomatoes ripened off the vine on a closed shelf to prevent sunlight were not significantly different.

Picha (1986) investigated the effect of harvest maturity on the composition of tomatoes. He used cherry tomatoes and other larger tomato varieties, grown in the field and ripened on the vine and in a chamber at 23°C and 75% RH, under cool white light. Sugar content of the cherry tomatoes was less for the off-vine than for the vine-ripened tomatoes. However, no difference was found in the sugar content of the larger varieties. Citric acid content was similar for on and off vine, and malic acid was the same for the larger tomatoes ripened on and off vine but less for the vine-ripened cherry varieties.

Pantos and Markakis (1973) found that the ascorbic acid content of field-grown, vine-ripened tomatoes was higher than the ascorbic acid content of tomatoes ripened off the vine in cabinets.

Scott and Kramer (1949) compared field-grown, vine-ripe tomatoes and tomatoes ripened in a room, in darkness and at different temperatures, finding that ascorbic acid of ripened-off-

vine tomatoes was lower than the vine-ripened tomatoes.

Fryer and others (1954) acknowledged that the ascorbic acid content is affected by, among other factors, the cluster position of the tomatoes, being higher for the higher clusters, which receive more sunlight. Ascorbic acid content of greenhouse tomatoes was higher for the upper-cluster tomatoes and was affected by season; but no difference was found on the ascorbic acid content of field-grown tomatoes from different clusters. Since the same ascorbic acid was developed in the tomatoes regardless of the cluster position in the field-grown tomatoes, the authors concluded that it might be due to the abundant nutrients and sunlight in the field.

House and others (1929) monitored the changes of vitamin A, B, and C in tomatoes ripened on and off vine and ethylene treated. Vitamins A and B were similar for all tomato treatments, while vine-ripened tomatoes had the highest amount of Vitamin C.

Watada and others (1976) found that ascorbic acid was the same for tomatoes ripened on- and off-vine, while β-carotene was higher for vine-ripened tomatoes. Tomatoes ripened off the vine were held at 21°C .

The studies cited above have compared the quality of tomatoes ripened on and off the vine. However, most of them have failed to match the same environmental conditions under which the tomatoes were ripened. Tomatoes grown in the field are subjected to rainfall, sunlight, season, soil nutrients, temperature fluctuations, and pests, among other variances that will affect the quality of the tomatoes. When these tomatoes are harvested to be ripened off the vine, the conditions in the field and in a laboratory shelf, box, bag, or chambers are quite different. The same criteria have to be considered for vine-ripe, greenhouse tomatoes when compared to tomatoes ripened off the vine in a shelf or bag.

Our objective was to compare the quality of 1 variety of tomatoes ripened on and off the vine under the same light, temperature, RH, pressure, gas composition, air flow, maturity stage, and cluster position in a green house. We matched the conditions of both ripening methods, using tomatoes grown in a controlled greenhouse, in such a way that the only difference between these conditions was that some tomatoes were attached to the plant, while others were not. The tomatoes ripened side by side, at the same height, shading, temperature, air flow, humidity, and gas composition in the surrounding air.

The quality of these tomatoes was determined by measuring lycopene, β-carotene, firmness, color (L*, a*. b*), total and soluble solids, ascorbic acid, acidity, pH and by sensory evaluation performed by a panel of 100 members. The judges evaluated firmness, color, sweetness, acidity, overall flavor, and overall liking of tomatoes ripened on and off the vine.

Results and Discussion

LYCOPENE PRODUCTION IN TOMATOES IS AFFECTED BY SEVERAL factors, such as environment, variety, and ripeness stage. We maintained the same ambient conditions for the tomatoes ripening on and off the vine to avoid any variation that may bias the results. We found that the lycopene content of vine-ripened tomatoes was higher, 6.63 mg/100 g, than in the detached tomatoes, 5.00 mg/100 g.

A small, although significant, increase of β-carotene in vine-ripened tomatoes was found. β-carotene content of the on- and off-vine tomatoes was 0.18 and 0.13 mg/100 g, respectively. Watada and others (1976) also observed lower β-carotene levels in detached tomatoes. Skok (1951) also reported a difference in the β-carotene content for these treatments, finding a higher concentration in detached tomatoes; however, he acknowledged that this increase was due to the differences in ripeness stages of the samples, since the detached tomatoes were over ripe. Since the temperature and ripeness stage was the same for the tomatoes, there must be some other factors affecting the development of lycopene and β-carotene in tomatoes ripened on and off the vine.

Table 1—Comparison of the analysis of Laura tomatoes ripened on and off the vine under the same environmental conditions. The results show the mean and the confidence interval.

Analysis	On	Off	Difference, %	
Lycopene, mg/100 g	6.63 (0.9)	5.00 (0.6)	32.51	*
β-carotene, mg/100 g	0.18 (0.01)	0.13 (0.01)	32.66	**
Soluble solids, EBrix	5.50 (0.01)	5.00 (0.01)	10.00	**
Total solids, %	5.88 (0.09)	5.46 (0.05)	7.61	**
Ascorbic acid, mg/100 g	20.17 (0.40)	20.09 (0.37)	0.42	
Color,				
L*	40.1 (0.3)	41.0 (0.4)	2.30	**
a*	23.3 (0.4)	22.0 (0.5)	6.16	**
b*	23.1 (0.5)	24.0 (0.4)	3.90	**
a*/b*	1.0 (0.01)	0.9 (0.01)	11.05	**
Firmness, N/mm	2.30 (0.02)	1.99 (0.02)	15.57	**
pH	4.29 (0.01)	4.23 (0.01)	1.48	
Acidity, g/100 g citric acid	0.639 (0.02)	0.637 (0.02)	0.18	

In last column: * $P < 0.05$, ** $P < 0.01$

The soluble solids were higher for the tomatoes ripened on the vine by 10% (Table 1). The principal substrates of the respiration process are simple sugars, like glucose and fructose (Kader 1987), and the rise of the respiration rate may result in a loss of soluble solids. The loss of soluble solids may be due to the depletion of substrates utilized from the fruit ripening off vine; since there is no supply of substrates from the mother plant, as in the on-vine tomatoes. Therefore, the soluble solids are lower. Picha (1986) also found higher soluble solids in vine-ripened cherry tomatoes.

The total solids of the vine-ripened tomatoes were higher by 7.6% than for the off-vine tomatoes. This may be the effect of the substrate consumption from the food reserves of the off-vine fruits to maintain their physiological functions and/or higher solids accumulation in the on-vine fruit.

Some studies reported the same ascorbic acid content for on- and off-vine tomatoes (Watada 1987; Watada and others 1976; Bisogni and Armbruster 1973; Fryer and others 1954; Skok 1951), while others reported that the attached tomatoes developed more vitamin C (House and others 1929; Scott and Kramer 1949; Fryer and others 1954; Pantos and Markakis 1973). We found that the ascorbic acid content of the tomatoes ripened on and off the vine was not statistically different (Table 1).

Vine-ripened tomatoes had higher a* and a*/b* ratio and lower L* and b* values. This indicates more red color for vine-ripened tomatoes, which were also darker than tomatoes ripened off the vine. The objective color measurements correlated with the sensory evaluation of color, which showed more intense redness for the tomatoes ripened on the vine. Skok (1951) also found that vine-ripened tomatoes develop more red color than off-vine tomatoes.

The firmness of the tomatoes ripened on the vine was significantly higher, by 15.5%, than the firmness of the tomatoes ripened off the vine. The difference in firmness may be explained by the physiological changes after the harvesting of the tomatoes. Phan (1987) suggested that when tomatoes are harvested, the fruit continues loosing water due to transpiration and respiration; because there is no more water supply from the mother plant, there is a consequent loss of turgidity.

Acidity and pH of the tomatoes ripened on and off the vine were not significantly different. Skok (1951) and Bisogni and

Armbruster (1973) also studied the pH of tomatoes ripened on and off the vine and reported no significant differences between the treatments. Other authors (Bisogni and Armbruster 1973; Picha 1986) reported the same results.

The panelists rated the color and overall liking of the tomatoes ripened on the vine as higher (Table 2). The sensory evaluation of field vine-ripened and chamber off-vine tomatoes preformed by Bisogni and Armbruster (1973) showed more sweetness for the on-vine tomatoes, although they did not find any difference in the soluble solids content of the on- and off-vine tomatoes. We found a 10% increase of soluble solids in the on-vine tomatoes over the off-vine tomatoes. However, the judges found no difference in the sweetness and overall flavor of the tomatoes. Perhaps the increase of soluble solids of the vine-ripened tomatoes was not big enough to influence tomato flavor perception by the panel. Despite the popular perception of tasteless off-vine tomatoes, there was no difference in the sweetness, acidity, and overall flavor of the tomatoes ripened on and off the vine. Firmness was also not significantly different between the treatments. Since the panel rated the tomatoes ripened on the vine as higher in overall liking, color must be a very important parameter when evaluating the overall acceptance of tomatoes.

Table 2—Sensory evaluation of tomatoes ripened on and off the vine. The table shows the average and confidence interval of the results.

Attribute	On	Off	Difference, %	
Color	10.52 (0.7)	8.80 (0.8)	19.31	**
Firmness	9.54 (0.9)	8.94 (0.8)	6.71	
Acidity	6.60 (0.9)	5.95 (0.7)	11.09	
Sweetness	6.72 (0.9)	6.32 (0.8)	6.48	
Overall flavor	8.74 (0.8)	7.69 (0.8)	13.65	
Overall liking	10.11 (0.7)	8.22 (0.8)	22.87	**

** $P < 0.01$

Conclusions

THE TOMATOES RIPENED ON THE VINE WERE MORE RED AND darker than the off-vine tomatoes. The a*/b* ratio, which is indicative of the red color development in tomatoes, was also higher for the vine-ripened tomatoes. The lycopene content, β-carotene, soluble solids, total solids, and firmness were also higher for the vine-ripened tomatoes. The panel rated the vine-ripened tomatoes as more intense in red color and overall liking.

Materials and Methods

LAURA TOMATOES (*LYCOPERSICON ESCULENTUM* MILL CV. Laura) were grown in the Burlington County Research and Demonstration Greenhouse (Florence, N.J., U.S.A.) under a flood hydroponic system. The seeds were raised in a 3 in rock wool cube and transferred to a production bench on day 35, when they were placed on a rayon polyester material at a spacing of 12 x 12 in. All plants were topped at a height of 36 in, and the side shoots were pruned regularly.

Several working benches were selected from the middle of the row. All the tomatoes were planted the same day. Mature green tomatoes from the 2nd cluster were tagged, and half of them were harvested, while the other half remained on the vine.

The harvested tomatoes were placed next to the clusters with tagged tomatoes, so they would be exposed to the same environmental conditions, such as temperature and temperature fluctuations, light intensity and shading, air flow, RH, and gas composition.

Tomatoes on and off the vine were allowed to ripen for the same amount of time and, when they reached an intense red color, were harvested and brought immediately to our laboratory for analysis. Some tomatoes ripened off the vine were left for more time to see if they ripened more, but they did not. After a few days, they became very soft. The tomatoes were washed with distilled water and dried thoroughly before any analysis was performed.

The texture of the tomato is very often measured as firmness (Adegoroye and others 1989). We developed a rapid, easy, and sensitive method for the measurement of firmness in tomato, using a spherical probe. Furthermore, with this method the tomato is subjected to minimal physical damage, so further analysis can be done and correlated for the same fruit. Texture analysis was achieved by measuring the firmness in compression of the tomato fruits using a TA.XT2 Texture analyzer (Stable Micro Systems, Surrey, England) around the equatorial area of the tomato with a 1/2 inch diameter spherical probe (Texture Technologies, Scarsdale, N.Y., U.S.A.). The tomatoes were half immersed in a container with wet sand (Holt 1970) to prevent slipperiness of the fruit during measurements. Compression was applied for 5 mm on the equatorial area of the tomato, at a speed of 1 mm/sec, and firmness was calculated dividing force by distance. Color measurements were performed on the surface of the tomatoes, around the equatorial region. The color was measured at least 11 times in each tomato. A Minolta Chroma Meter CR-200 (Minolta Camera Co. Ltd., Osaka, Japan) tristimulus color analyzer, consisting of a 8-mm dia measuring area and a diffuse illumination/ 0° viewing was utilized. The chroma meter was 1st calibrated with a white tile and checked for recalibration in between measurements, although no adjustments were necessary. Readings are reported using the L*, a*, b* system. Seventeen tomatoes ripened on the vine and 17 tomatoes ripened off vine were used. The color and firmness were measured in the whole tomato and then the tomatoes were homogenized individually for chemical and physical analysis.

The carotenoids were extracted from the homogenized samples with a mixture of hexane, acetone, and ethanol (5:2.5:2.5) (Fisher Scientific, Springfield, N.J., U.S.A.) under stirring for 10 min. Water was added to help the phase separation with stirring for 15 min. Then the mixture was filtered and the polar and nonpolar layers were separated (Sadler and Dezman 1990). An aliquot of the nonpolar phase was filtered through a 0.45 Φm nylon filter membrane (Fisher Scientific, Springfield, N.J., U.S.A.) and injected into the high-performance liquid chromatographer (HPLC).

The analyses, separation, and quantification of lycopene (ψ-ψ carotene) and β-carotene were accomplished by HPLC using a C30 column (YMC, Wilmington, N.C., U.S.A.), in a mobile phase of methyl alcohol (Fisher Scientific, Pittsburgh, Pa., U.S.A.) and methyl ter-butyl ether (Sigma Chemical, St. Louis, Mo., U.S.A.) in a ratio of 3:7 (Emenhiser and others 1995). The lycopene and β-carotene standards used were 90-95% pure (Sigma Chemical Company, St. Louis, Mo., U.S.A.). The solvents were filtered using a 0.45 Φm nylon filter membrane (Fisher Scientific, Springfield, N.J., U.S.A.) and degassed with helium. All solvents were HPLC grade.

The HPLC system consisted of a Waters 600 E System Controller, Waters 991 Photodiode Array Detector, Waters U 6 K Injector System and a Waters 600 Multi-solvent Delivery Sys-

tem (Millipore, Milford, Mass., U.S.A.).

For the analysis of moisture and total solids, an aliquot of the sample was dried at 70°C in a Fisher Isotemp 282A vacuum oven (Fisher Scientific, Pittsburgh, Pa., U.S.A.) until constant weight.

The soluble solids were determined and reported as Brix, by refractometry (Buret and others 1983) using a Leica Brix scale refractometer (Leica Inc., Buffalo, N.Y., U.S.A.).

Acidity was determined by a titratable method, the homogenized sample was mixed with distilled water and titrated with 0.1 N NaOH solution to pH 8.1 ± 0.05 using a pH meter. The results are reported as % citric acid (Thakur and others 1996).

Ascorbic acid was determined using the DIC procedure -2,6-Dichloroindophenol- (AOAC 1990).

The pH was measured in the homogenized sample with an Orion EA 940 pH-meter (Orion Research Inc. Boston, Mass., U.S.A.) at 25°C.

Sensory evaluation of the hydroponic tomatoes determined the textural, flavor, color, and overall acceptability of the fruits, using a quantitative descriptive analysis. The panel was formed by 100 members. The members were Rutgers University students. Most of them had previous experience as judges in sensory evaluation. Tomato quarters were presented at room temperature to the panel, and the judges evaluated the intensity of the attribute, in a score sheet with a 15-cm scale line. Intensity of the attribute was determined by measuring the distance from the zero point to the intensity mark placed by the judge (Heintz and Kader 1983). The following attributes were evaluated: color, firmness, acidity, sweetness, overall flavor, and overall liking.

References

Adegoroye A, Jolliffe P, Tung M. 1989. Textural characteristics of tomato fruits (Lycopersicon esculentum) affected by sunscald. J. Sci. Food Agric. 49:95-102.

[AOAC]. Association of Official Analytical Chemists. 1990. Official methods of analysis. 15th edition. Washington, D.C.: Association of Official Analytical Chemists. p 1058-1059.

Bisogni C, Armbruster G. 1973. Quality comparison of room ripened and field ripened tomato fruits. J. Food Sci. 41:333-338.

Buret M, Gormely R, Roucoux P. 1983. Analysis of tomato fruit: effect of frozen storage on composition values –an inter laboratory study. J. Sci. Food Agric. 34:755-760.

Emenhiser C, Sander LC, Schwartz SJ. 1995. Capability of a polymeric C_{30} stationary phase to resolve *cis-trans* carotenoid isomers in reversed-phase liquid chromatography. J. Chromatogr. 707:205-216.

Fryer H, Ascham L, Cardwell A, Frazier J. 1954. Relation between stage of maturity and ascorbic acid content of tomatoes. J. Am. Soc. Hort. Sci.. 64:365-371.

Heintz C, Kader A. 1983. Procedures for the sensory evaluation of horticultural crops. HortScience 18(1):18-22.

House M, Nelson P, Haber E. 1929. The vitamin A, B and C content of artificially versus naturally ripened tomatoes. J. Biol. Chem. 81(3):495-504.

Holt CB. 1970. Measurement of tomato firmness with a Universal Testing Machine, J. Texture Studies 1:491-501.

Kader A. 1987. Respiration and gas exchange of vegetables. In: Weichmann J, editor. Postharvest physiology of vegetables. New York: Marcel Dekker Inc. p 25-43.

Lucier GS. 1997. In vegetables and specialties situation and outlook. Washington, D.C.: U.S. Dept. of Agriculture. Economic Research Service.

Pantos C, Markakis P. 1973. Ascorbic acid content of artificially ripened tomatoes. J. Food Sci. 38(3):550.

Phan C-T. 1987. Biochemical and physiological changes during the harvest period. In: Weichmann J, editor. Postharvest physiology of vegetables. New York: Marcel Dekker Inc. p 9-22.

Picha D. 1986. Effect of harvest maturity on the final fruit composition of cherry and large-fruited tomato cultivars. J. Amer. Soc. Hort. Sci. 111(5):723-727.

Sadler G, Dezman D. 1990. Rapid extraction of lycopene and β-carotene from reconstituted tomato paste and pink grapefruit homogenates. J. Food Sci. 55(5):1460-1461.

Sayre C, Robinson W, Wishnetsky T. 1953. Effect of temperature on the color, lycopene, and carotene content of detached and of vine-ripened tomatoes. J. Am. Soc. Hort. Sci. 61:381-387.

Schuch W. 1994. Improving tomato quality through biotechnology. Food Technol. 11:18-83.

Scott L, Kramer A. 1949. The effect of storage upon the ascorbic acid content of tomatoes harvested at different stages of maturity. J. Am. Soc. Hort. Sci. 54:277-280.

Skok J. 1951. Quality of artificially ripened tomatoes for canning purposes. Food Res. 16:147-153.

Thakur B, Singh R, Nelson P. 1996. Quality attributes of processed tomato products: A review. Food Reviews International 12(3):375-401.

Thakur B, Singh R, Tieman D, Handa A. 1996. Tomato product quality from transgenic fruits with reduced pectin methylesterase. J. Food Sci. 61(1): 85-87,108.

Watada A. 1987. Vitamins. In: Weichmann J, editor. Postharvest physiology of vegetables. New York: Marcel Dekker Inc. p 455-485.

Watada A, Aulenbach B, Worthington J. 1976. Vitamins A and C in ripe tomatoes as affected by stage of ripeness at harvest and by supplementary ethylene. J. Food Sci. 41:856-858.

MS 19990846 received 8/30/99; revised 2/18/00; accepted 3/30/00.

This research was supported by NJ-NSCORT(New Jersey-NASA Specialized Center of Research and Training), and their support is greatly appreciated. The authors also would like to thank Dr. Beverly Tepper and Ms. Natalia Ulrich (Food Science Dept. Rutgers University), Dr. Dmitriy Zasypkin (Food Science Dept. Rutgers University, NJ-NSCORT), and Dr. Logan Logendra (Plant Science Dept. Rutgers University, NJ-NSCORT) for their help and support.

Authors Arias and Lee are with the Department of Food Science, the Center for Advanced Food Technology, and the NJ-NSCORT (New Jersey-NASA Specialized Center of Research and Training), Rutgers, The State University of New Jersey. Author Specca is with the Burlington County Research and Demonstration Greenhouse. Author Janes is with NJ-NSCORT and the Department of Plant Science at Rutgers, The State University of New Jersey and with the Burlington County Research and Demonstration Greenhouse. Address inquiries to Tung-Ching Lee 65 Dudley Road, New Brunswick, NJ 08901-8520 (E-mail: lee@aesop.rutgers.edu).