HortScience 45(3):466–468. 2010.

Color Changes and Antioxidant Content of Vine and Postharvest-ripened Tomato Fruits

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Additional index words. tomato, antioxidants, color, postharvest

***Abstract*. Tomato fruit ripening is a complex, genetically programmed process that culminates in dramatic changes in texture, color, flavor, and aroma of the fruit flesh. The characteristic pigmentation of red ripe tomato fruit is the result of the de novo synthesis of carotenoids, mainly lycopene and β-carotene, which are associated with the change in fruit color from green to red as chloroplasts are transformed to chromoplasts. The aim of this study was to examine the effect of ripening conditions on color development and antioxidant content. Detached tomato fruit stored at 15 and 30 °C and vine-ripened fruits were studied to characterize the ripening process by Hue (°) index (CIELab color system), which is strongly influenced by the circumstances of ripening. Total polyphenols, ascorbic acid, and lycopene content of tomato fruits were analyzed at the end of the experiment. Changes in the color of fruit stored at 15 °C and vine-ripened fruit showed significantly higher a* compared with fruit stored at 30 °C. Storage temperature influenced positively ascorbic acid and negatively lycopene content, whereas total polyphenols did not show differences among the different ripening conditions.**

Tomato is a significant food crop with more than 126 million tons harvested in the world in 2007 (FAOSTAT Crop Production Tomato, 2008) and characterized by high consumption, year-round availability, and significant health benefits. It contains high levels of antioxidants (Abushita et al., 2000), which are important in the prevention of many cancer types and cardiovascular diseases (Takeoka et al., 2001). Color is one of the most important quality components of tomato fruits. The amount of predominant carotenoid lycopene, which causes red coloration of fruits, is characterized well by a* parameter. β-carotene is an orange colorant of fruits, in which the parameter is measurable by b* in the CIELab color system (Sacks and Francis, 2001). The ripening process of tomatoes is well characterized by the color evolution of fruit surface (Hertog et al., 2007). Chlorophyll breaks down and carotenoids, mostly lycopene, accumulate during ripening (Brandt et al., 2006).

There is a general belief that the quality of vine-ripened tomatoes is better than that of fruit ripened off the vine. Analytically, vine-ripened tomatoes contain more lycopene, β-carotene, soluble and total solids, and had higher a* and lower L* values, but sensory evaluation did not necessarily justify this generalization (Arias et al., 2000). The aim of the present study was to compare the process of on-vine or postharvest ripening of tomatoes with regard to the effect of storage temperature on fruit color evolution and antioxidant content.

Materials and Methods

Round-type, indeterminate tomato cultivar Lemance F_1 (average fruit mass 110 to 130 g) grown under optimal greenhouse conditions (22/18 °C) was investigated in 2006. Fruit samples from turning maturity stages according to Yamaguchi (1983) were chosen randomly in four repetitions, four fruits in each repetition, for measuring the ripening process on the plant and in postharvest dark storage at 15 and 30 °C.

Color measurements were performed at three points in the equatorial region of the tomatoes by a Sheen Micromatch Plus tristimulus colorimeter (Sheen Instruments Ltd., Kingston-Upon-Thames, U.K.) applying the CIELab color system. The L*, a*, b* values, received directly, were used to calculate the hue:

$$\text{Hue}(^\circ) = \tan^{-1}(b^* a^{*-1}), \text{ if } a^* > 0 \text{ and}$$
$$\text{Hue}(^\circ) = 180 + \tan^{-1}(b^* a^{*-1}), \text{ if } a^* < 0.$$

The total soluble solids expressed as °Brix was examined with a refractometer (AST Model 1230; Atago Co. Ltd., Tokyo, Japan) according to the Hungarian Standard (MSZ EN 12143, 1998).

Acid content of fruits was determined according to a Hungarian Standard and expressed as mg citric acid in 100 g fresh weight (MSZ EN 750, 1998).

Ascorbic acid content was measured according to a Hungarian Standard (MSZ EN 14130, 2003). The compound was quantified by Reverse Phase (RP) high-performance liquid chromatography (HPLC) on a Lichrosper 100 RP18 end-capped column (Merck Kft., Budapest, Hungary) (5 μm, 250 × 4.0 mm) using potassium-dihydrogenphosphate/N-cetyl-N,N,N-trimethyl-ammonium-bromide in methanol (92/8 v/v) as a mobile phase and ultraviolet detection at 265 nm. The characteristics of the determination are as follows: column temperature 35 °C, flow rate 0.7 mL·min^{-1}, volume of injection 80 μL, and running time 14 min. The HPLC system used for ascorbic acid analysis consisted of Perkin Elmer Co. (Norwalk, CT) Series 200 equipment with a Series 200 high-precision pump combined with a Series 200 Autosampler, a Series 200 HPLC Photo Diode Array Detector, and an IRIS Spectral Processing System.

Carbohydrate content was measured after an acidic hydrolysis with HCl at 65 °C during 5 min by the classical Schoorl method (COMMISSION DIRECTIVE 79/796/EEC, 1979).

Total polyphenols were analyzed with the Folin-Denis method according to the AOAC official protocol 952.03 (AOAC, 1990).

Lycopene was extracted from the tomato juice with a mixture of n-hexane, methanol, and acetone (2:1:1) containing BHT. Optical density of the hexane extract was measured at 502 nm by a Perkin Elmer Lambda 3B ultraviolet spectrophotometer (Perkin Elmer Co.) (Sadler et al., 1990). Lycopene concentrations were calculated by applying the molecular extinction coefficient of 158500 (Merck&Co., 1989). All parameters measured are referred to fresh weight of fruits.

The results were expressed as the average ± SD at $P = 0.05$. The statistical analysis was carried out by the Student t test using the Statistica 9 software (Statsoft Inc., Tulsa, OK).

Results and Discussion

Figure 1 shows the evolution of CIELab color parameter a* and b*, which represents well-colorful carotenoid content of tomato fruits. However, the evolution of the red fruit color (a*) was more rapid at 30 °C than at 15 °C or on the vine. Color changes in fruit stored at 15 °C and developed on the vine were different from those at 30 °C because lycopene, which is the main source of the red color of tomato, is not synthesized above 30 °C. In this temperature range, only β-carotene is produced, which has a ceiling temperature of 38 °C (Brandt et al., 2006).

CIELab a*/b* or Hue index is the most commonly used parameter to indicate the color development of ripening tomato fruit. Table 1 shows CIELab color parameters of

Received for publication 25 Nov. 2009. Accepted for publication 28 Jan. 2010.
This study was partially funded by TECH-09-A3-2009-0230, USOK2009 project.
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vine and postharvest ripened tomato fruits at the end of the ripening process. The Hue value of fruit stored at 30 °C was significantly higher (less red) than of those ripened at 15 °C or on the vine.

Figure 2 shows the evolution of the Hue value of tomatoes during ripening. Temperature and the method of ripening greatly affect the ripening processes of tomatoes. Hertog et al. (2007) reported similar temperature effects in their study on color changes of detached tomatoes at different constant temperatures.

Soluble solids (°Brix), reducing sugars, titratable acidity, ascorbic acid, total polyphenols, and lycopene content were also evaluated (Table 2). For soluble solids (°Brix) and reducing sugars, only slight differences could be ascribed to ripening conditions. Total polyphenol content did not differ among treatments and ranged between 28 and 32 mg/100 g, which are acceptable in greenhouse-grown tomatoes. Fruits stored at 15 °C had the lowest ascorbic acid content (14.2 mg/100 g). In fruit stored at 30 °C and in vine-ripened fruit, it was 15.2 and 17.5 mg/100 g, respectively. Hence, a significant difference between on- and off-vine ripened tomatoes has been established. Higher temperature seems to be favorable for ascorbic acid synthesis. In addition, solar exposure is probably required for further ascorbic acid accumulation, but this was ambiguous during a longer ripening process (Wold et al., 2004). Riga et al. (2008) have studied vine-ripened tomato and established that temperature had a stronger influence on tomato antioxidants than photosynthetically active radiation. Growers could obtain tomatoes of similar color by postharvest ripening than that provided on the vine by natural sunlight.

Fruit samples revealed considerable treatment-specific differences (more than 50%) in lycopene content. For the red color parameters, storage at 30 °C resulted in the lowest lycopene content (2.1 mg/100 g) and vine-ripened tomatoes contained the highest concentration (4.5 mg/100 g). Initially, lycopene synthesis was accelerated at 30 °C and during the first 5 d, the red coloration was more rapid in fruit of this treatment. Nevertheless, the optimal temperature for lycopene synthesis is 16 to 22 °C, whereas the ceiling temperature is 30 to 32 °C (Dumas et al., 2003), so at the end of the ripening process, fruits stored at 15 °C and vine-ripe contained statistically higher lycopene content. This agrees with the finding of Helyes et al. (2007) that found the fruit surface temperature has a dominant role in lycopene synthesis in tomatoes.

Results of our study have implications for improvement of tomato for lycopene and red coloration. In conclusion, tomato fruits subjected to elevated air temperatures increased orange colorants (β-carotene) and decreased the content of lycopene in the tomato fruits.

The mechanism of on-vine and detached tomato fruit ripening appears to be different and requires more study to accurately describe these differences.

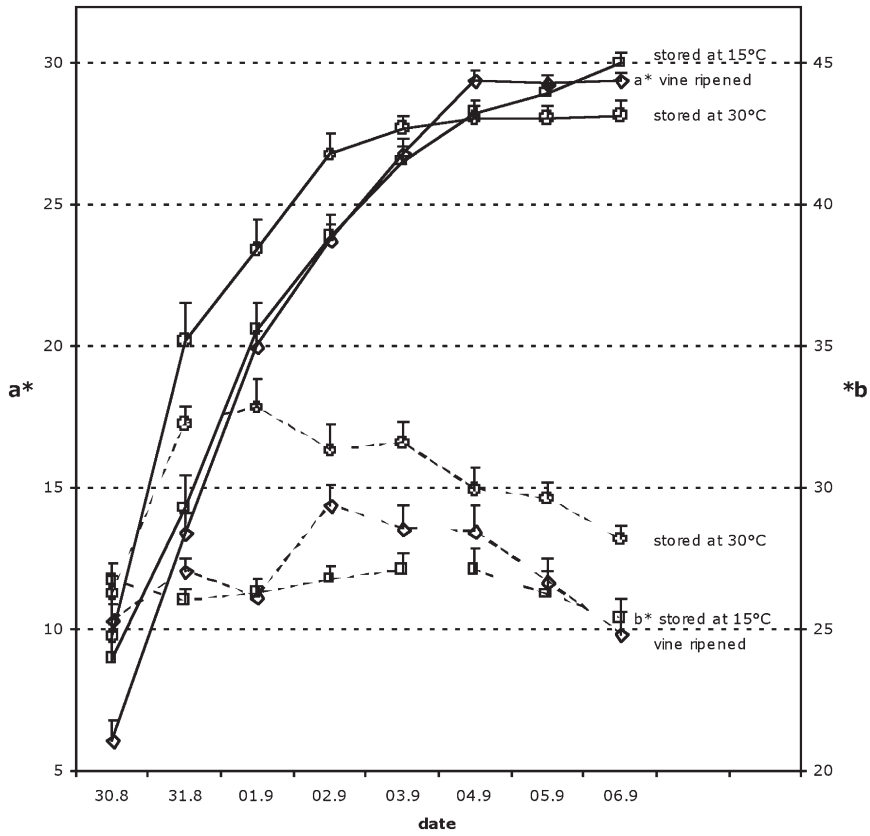

Fig. 1. Evolution of CIELab color parameters (a*, b*) of tomato fruits during the ripening period. Vertical bars represent the significant differences at $P = 0.05$ (n = 16).

Table 1. CIELab color parameters of vine and postharvest ripened tomato (cv. Lemance F_1) fruits at the end of the ripening process (n = 4; ± SD).

	L*[z]	a*	b*	Hue
Vine-ripened	41.2 ± 0.78[a]	29.4 ± 0.52[a]	24.9 ± 1.62[a]	40.0 ± 1.74[a]
Storage (15 °C)	43.1 ± 1.06[b]	30.0 ± 0.76[a]	25.4 ± 1.48[a]	40.1 ± 1.70[a]
Storage (30 °C)	44.0 ± 0.94[b]	28.2 ± 0.92[b]	28.2 ± 1.02[b]	45.0 ± 1.24[b]

[z]Data in the same column bearing the same superscript letter are not significant at $P = 0.05$.

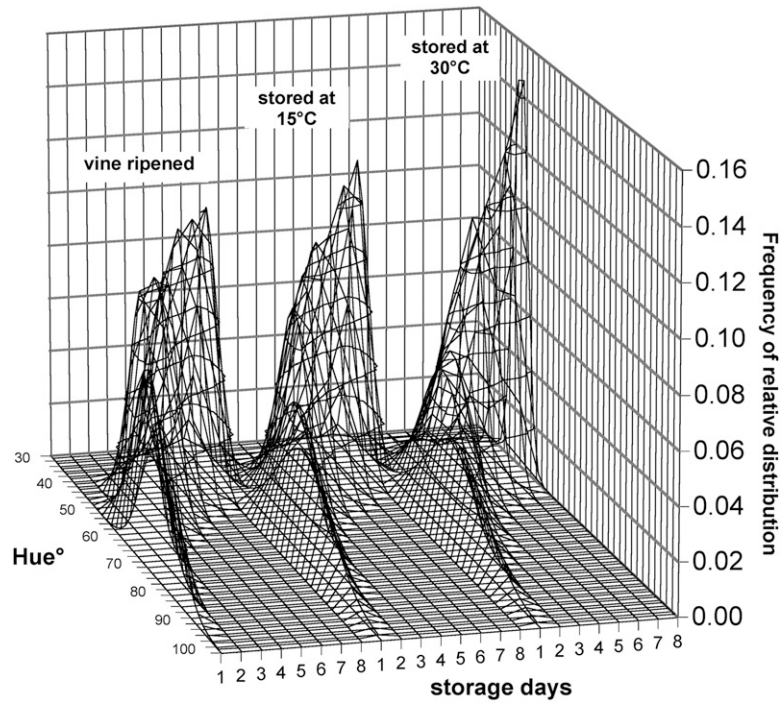

Fig. 2. Frequency distribution of Hue color parameter during the ripening process of vine and postharvest ripened tomato fruits.

Table 2. Components of vine and postharvest ripened tomato (cv. Lemance F_1) fruits at the end of the ripening process (n = 4; ± SD).

	°Brix[z,y]	Sugars (%)	Organic acids (‰)	Ascorbic acid (mg/100 g)	Total polyphenols (mg/100 g)	Lycopene (mg/100 g)
Vine-ripened	4.3 ± 0.15	2.3 ± 0.35	4.0 ± 0.47	17.5 ± 2.19[a]	29.4 ± 2.12	4.5 ± 1.40[a]
Storage (15 °C)	4.5 ± 0.09	2.3 ± 0.20	4.1 ± 0.10	14.2 ± 1.48[b]	31.5 ± 3.22	3.9 ± 0.70[a]
Storage (30 °C)	4.4 ± 0.06	2.1 ± 0.17	4.2 ± 0.19	15.2 ± 3.07[a]	27.7 ± 1.68	2.1 ± 0.64[b]

[z]Data in the same column bearing the same superscript letter are not significant at $P = 0.05$.
[y]Data were recorded on a fresh weight basis.

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