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Effect of ripening conditions on the physicochemical and antioxidant properties of tomato (*Lycopersicon esculentum* Mill.)

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Abstract This study was conducted to assess the physicochemical changes and overall nutritional implications of greenhouse-grown "TY Megaton" and "Yureka" tomato cultivars under on-vine and postharvest ripening conditions. In the first group, tomatoes were harvested from a vine at the breaker, pink, and red ripening stages and sampled immediately. The second group was harvested at the breaker stage and allowed to ripen under room conditions to the pink and red stages based on color values, similar to the vine-ripened samples. The results of the present study revealed that fresh weight loss was below the maximum acceptable weight loss and firmness was above the minimum limit of marketing after postharvest ripening to the pink and red stages; moreover, this process did not have any deleterious effect on the antioxidant properties or antioxidant activity of the tomatoes. Hence, the results clearly indicate that breaker-stage tomatoes can be postharvest-ripened under room conditions without affecting their marketability and nutritional components.

Keywords: antioxidant activity, ascorbic acid, lycopene, phenolics, storage period

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the major vegetable crops with a worldwide production of 163.43 million ton, valued at $59.88 billion. Its production in South Korea was 388.5 thousand ton in 2013, which was valued at $143.58 million (1). Tomatoes are widely consumed either in raw or processed form and significantly contribute in providing antioxidants in the diet. Tomatoes can provide antioxidants such as vitamin C, lycopene, phenolics, flavonoids, and β-carotene, which can contribute to their antioxidant or free radical scavenging effects (2). Regular intake of an adequate amount of fresh tomatoes or tomato products prevents the development of various types of cancers; strong evidence has been found for cancers of the lung, stomach, and prostate gland, and suggestive data were reported on their beneficial effects in cancers of the cervix, breast, oral cavity, pancreas, colorectum, and esophagus (3,4) as well as cardiovascular diseases (5). These protective effects of tomato are mainly attributed to its valuable bioactive components with antioxidant properties (6).

Several interrelated factors such as varietis, environmental effects, cultivation conditions, maturity stages, and postharvest storage conditions affect tomato composition (7). In the postharvest life of tomatoes, temperature is the most important environmental factor because it significantly affects the rates of biological processes (8). The ripening process in tomato fruit, as in other climacteric fruits, is highly dependent on ethylene action (9).

Tomatoes are highly perishable, and harvesting before the climacteric rise is considered as the best strategy to prolong its shelf-life and reduce the spoilage rate (10). As for most climacteric fruits, tomato crop is harvested at different maturity stages and can be ripened off of the plant (postharvest ripening); alternatively, can be harvested when the fruit has reached the fully matured stage (vine ripening). Most fresh-market tomatoes are harvested before they reach the table-ripening stage. Since vine-ripened tomatoes cannot stand the handling necessary to move them from the field to the consumer, the standard procedure is to harvest mature-green-stage tomatoes and ripen them in transit or at the destination (11). However, this practice may negatively affect the taste and nutritional quality as the fruits picked at the mature green stage or before turning red, although it is able to continue the ripening process, develop poor eating and nutritional traits when fully ripened (12). Therefore, in addition to primary factors, such as tomato-variety selection, proper plant nutrition, and growing conditions, the degree of ripeness during picking may contribute to postharvest physico-chemical changes and overall nutritional implications in tomatoes. The present study is designed with a hypothesis that harvesting tomatoes at the breaker stage could help withstand the handling activities and develop good nutritional quality after ripening. Hence, this study was conducted with the objective of evaluating the impact of on-vine and postharvest ripening on the physicochemical changes

and antioxidant properties of tomatoes.

Materials and Methods

Chemicals The chemicals used were of analytical grade. Gallic acid, Folin–Ciocalteu's phenol reagent, DPPH, and ascorbic acid were purchased from Sigma-Aldrich (St. Louis, MO, USA). Metaphosphoric acid, sodium hydroxide, sodium carbonate, butylated hydroxyanisole (BHA), methanol, ethanol, hexane, and acetone were obtained from DaeJung Chemicals, Korea.

Plant materials Tomatoes (*Lycopersicon esculentum* Mill.) of the "TY Megaton" (Asian line) and "Yureka" (European line) cultivars, which are commonly grown by the surrounding farmers, were grown in a greenhouse at the Kangwon province of South Korea in spring 2016. Harvesting was done from the third cluster of each plant, and the fruits at the tip of the cluster were not included in the experiment.

Color measurement Tomato fruits were harvested at three different ripening stages (breaker, pink, and full red) using the United States Department of Agriculture (USDA) tomato ripeness color-classification chart (13) and immediately transported to the Postharvest Laboratory after harvesting. Fruits were selected based on their uniformity and freedom from defects and blemishes. The color data for on-vine-ripened fruit samples (breaker, pink, and full red) were recorded immediately after harvesting. For the postharvest ripening experiment, tomatoes harvested at breaker stage were washed and allowed to be ripen with a daylight/dark cycle in a well-ventilated room at 20±2°C. Data were recorded at the pink and red ripening stages, corresponding to a*/b* values similar to those for vine-ripened samples (skin a*/b* value differing by no more than 0.1 units). Under both ripening conditions, each sample comprised of five fruits. The color of tomato fruits was measured using a Chroma Meter, model CR-400 (Minolta, Tokyo, Japan). Color variables were measured three times for each tomato near the mid-section, and the average was determined. Positive a* and b* values represent the degree of redness and yellowness, respectively (14).

Physicochemical changes

***Fresh weight loss and firmness*:** The fresh weight loss of tomato during the ripening period for the postharvest-ripened group was measured by subtracting the sample weight at the pink or red stage from its previous recorded weight at the breaker stage; the result was presented as the percentage (%) of weight loss compared with its initial weight. Tomato fruit firmness was measured using a Sun Rheo Meter Compac-100II (Sun Scientific Co. Ltd., Dobbs Ferry, NY, USA) with a maximum force of 10 kg and a 3-mm-diameter round stainless-steel probe with a flat end. The measurements were taken at the equatorial section of the fruit.

***Soluble solid content (SSC), titratable acidity (TA), and pH*:** SSC was measured for each sample fruit in five replications using an Atago DR-A1 digital refractometer (Atago Co. Ld., Tokyo, Japan) at 20°C and expressed as °Bx. Titratable acidity (TA) was determined by titrating diluted tomato juice (1 mL juice:19 ml distilled water) with 0.1 N NaOH up to a pH of 8.1 by using DL22 Food and Beverage Analyzer (Mettler Toledo, Columbus, OH, USA). The result was expressed as mg·100 g^{-1} of fresh tomato weight; pH was measured using a Mettler Toldo InLab® 413 pH meter.

Antioxidant components

***Lycopene content*:** Lycopene content was measured in triplicate by placing 0.5 g of each homogenized tomato sample a test tube; 5 mL of 0.05% (w/v) butylated hydroxyl toluene (BHT) in acetone, 5 mL of 95% (v/v) ethanol, and 10 mL of hexane were added to each test tube and centrifuged (5,871x*g* for 15 min). Then, 3 mL of deionized water was added to each test tube, and the samples were shaken for an additional 5 min. These test tubes were left at room temperature for 5 min without agitation to allow the separation of the hexane layer. The absorbance of the hexane (upper) layer was measured using a spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA) at 503 nm versus a blank of hexane solvent. The lycopene content of the samples was then expressed as mg/kg^{-1} of fresh weight according to the method reported by Fish *et al*. (15).

$$\text{Lycopene content (mg·kg}^{-1}\text{)} = A_{503} \times 0.0312.\ \text{kg}^{-1}\ \text{tissue}$$

***Ascorbic acid content*:** Vitamin C was analyzed using liquid chromatography on a reversed phase (RP) with ultraviolet (UV) detection according to a method described by Kim *et al*. (16). Briefly, 1 g of sample was mixed with 10 mL of 5% meta phosphoric acid (5 g/100 mL) and homogenized for 1 min. After the mixture was centrifuged (7,828x*g* for 10 min), the liquid layer of the extract was membrane-filtered (0.22 μm) and analyzed using a ZORBAX eclipse XDB-C18 (4.6 cm×250 mm, 5 μm, Agilent Technologies, Santa Clara, CA, USA) column and detector (UV-2075; Jasco, Tokyo, Japan) at 265 nm with a 20 μm injection of 100% MeOH:0.1M KH_2PO_4 (1:9 ratio) at 1 mL/min as the mobile phase. Ascorbic acid content was determined by comparing the sample readings with the standard curve and expressed as mg·100 g^{-1}.

***Total phenolic content*:** Total phenolic content was quantified by slightly modifying a method described by Pataro *et al*. (17). Analyses were performed using spectrophotometric assays (Thermo Fisher Scientific) and Folin–Ciocalteu's phenol reagent (Sigma-Aldrich). Briefly, duplicates of a 2 g sample were extracted with 20 mL of 0.05% (v/v) aqueous HCl/methanol (10:90, v/v) and homogenized for 1 min using a homogenizer (Ultra Turrax® model T18 basic, IKA, Staufen, Germany) at 5,000 rpm; then, the homogenate was membrane-filtered (0.45 μm). The sample methanol extract (ME) (0.2 mL) was mixed with 2.6 mL of deionized water, 2 mL of 7% (w/v) Na_2CO_3, and 0.2 mL of Folin–Ciocalteu's phenol reagent. The absorbance of the reaction mixture was measured after incubation

for 90 min at room temperature. The measurement was performed at 750 nm against the blank sample containing the same mixture solution without the sample extract. Total phenolic content was quantified by comparing the sample readings with the standard curve and expressed as mg of gallic acid equivalents (GAE) per kg fresh weight of the sample.

Antioxidant activity The antioxidant activity was determined using a spectrophotometric assay (Thermo Fisher Scientific) and the DPPH method according to the procedure reported by Pataro *et al*. (17) with some modifications. The reagent solution of DPPH (Sigma-Aldrich) dissolved in methanol (0.1 mM) was used, and the absorbance of different treatments was determined at 515 nm using Kartell cuvettes, Italy. Methanol was used as a blank. First, a reagent solution comprising 3.9 mL of the methanol solution of DPPH was prepared, and the absorbance was immediately (t=0 min) recorded. This measurement was identified as "$t_{o,}$" and it refers to the reagent solution without the extracted sample. Subsequently, 2.5, 5, 10, and 20 mg·mL^{-1} samples of the ME solution of DPPH were prepared for each ripening condition. These samples were kept in the dark for 30 min at room temperature; then, their absorbance was measured. This measurement was identified as "$t_{30,}$" and it refers to the reagent solution containing the extracted sample. The percentage of the inhibition of the DPPH radical was calculated using the following equation:

$$\% \text{ reduced DPPH} = [(\text{absorbance } t_o - \text{absorbance } t_{30})/\text{absorbance } t_o] \times 100$$

Statistical analysis This study was conducted in a completely randomized design with nine replications for color; five replications for weight loss, firmness, SSC, TA, and pH; and in triplicate for all the other parameters. The values obtained for these parameters were analyzed via analysis of variance (ANOVA) at $p<0.05$ using the statistical analysis system (SAS) statistical software. The differences among the means were analyzed using ANOVA to determine whether the ripening conditions and varieties led to a significant difference in the physicochemical and antioxidant properties of tomatoes. When significant differences were detected, Duncan's multiple range test was performed to determine which particular means were significantly different ($p<0.05$).

Results and Discussion

Physicochemical changes

***Color changes*:** The color of the fruit is the most commonly used criteria to assess tomato quality. Therefore, both postharvest- and on-vine-ripened fruit colors were evaluated to ensure uniformity among the samples (Table 1). Hunter's L* values at the breaker and pink stages were not significantly different ($p<0.05$) for TY Megaton; however, all the stages were significantly different ($p<0.05$) for Yureka. Hunter's a* values increased progressively from the breaker to red stage, contrary to Hunter's L* values, which reduced progressively. The increase in the a* value is known to be directly associated with lycopene synthesis, whereas the a*/b* ratio has been reported to be a good indicator of lycopene content and, therefore, could be used to characterize the fresh-tomato ripeness stage (18,19). The pigmentation characteristics of tomato fruits are attributed to the transformation of chloroplasts to chromoplasts due to the synthesis of carotenoids, mainly lycopene and β-carotene (20).

***Weight loss and firmness*:** The percentage weight loss during postharvest ripening at 20±2°C from the breaker stage to the postharvest-ripened pink and red stages of TY Megaton was 1.23 and 1.90%, respectively. Similarly, the weight loss in Yureka was 0.77 and 1.76% to attain the postharvest pink and red stages, respectively (Fig. 1). The maximum acceptable weight loss before a tomato becomes unsaleable has been reported to range from 6 to 7% (21). In this study, the weight loss values of tomatoes during ripening for both the cultivars were found to be lower than those suggested by Nunes (21). Considering the significant difference ($p<0.05$) in weight loss in the present study, it could be concluded that the response of tomato cultivars to water loss varies markedly.

Firmness was reduced significantly ($p<0.05$) as ripening proceeded in both varieties during both on-vine and postharvest ripening (Fig. 1); moreover, the firmness value was above the minimum firmness

Table 1. Hunter's L*, a*, b*, and a*/b* color values for TY Megaton and Yureka tomato cultivars under vine- and postharvest-ripening conditions

Parameters	Cultivar	Ripening conditions				
		Breaker	Vine pink	Postharvest pink	Vine red	Postharvest red
L*	TY Megaton	$50.57\pm0.72_a^{A1)}$	$50.59\pm0.67_a^{A}$	$50.79\pm0.44_a^{A}$	$45.39\pm0.65_b^{A}$	$44.95\pm0.20_b^{A}$
	Yureka	$51.49\pm0.55_a^{B}$	$50.79\pm1.24_a^{A}$	$50.99\pm1.31_a^{A}$	$48.62\pm0.57_b^{B}$	$47.82\pm0.37_b^{B}$
a*	TY Megaton	$6.02\pm1.35_a^{A}$	$2.48\pm3.50_b^{A}$	$2.67\pm1.58_b^{A}$	$12.97\pm0.70_c^{A}$	$13.17\pm0.44_c^{A}$
	Yureka	$6.65\pm0.73_a^{A}$	$0.98\pm0.58_b^{B}$	$1.14\pm1.11_b^{B}$	$10.2\pm1.97_c^{A}$	$10.6\pm1.55_c^{B}$
b*	TY Megaton	$16.77\pm1.68_a^{A}$	$16.38\pm1.39_a^{A}$	$16.58\pm1.13_a^{A}$	$12.76\pm0.75_b^{A}$	$11.96\pm0.49_b^{A}$
	Yureka	$19.98\pm0.38_a^{B}$	$19.73\pm1.74_a^{B}$	$18.75\pm1.14_b^{B}$	$17.43\pm0.74_c^{B}$	$16.83\pm0.60_c^{B}$
a*/b*	TY Megaton	$-0.28\pm0.06_a^{A}$	$0.16\pm0.22_b^{A}$	$0.16\pm0.10_b^{A}$	$1.02\pm0.04_c^{A}$	$1.10\pm0.05_c^{A}$
	Yureka	$-0.33\pm0.03_a^{B}$	$0.06\pm0.06_b^{B}$	$0.06\pm0.06_b^{B}$	$0.59\pm0.11_c^{B}$	$0.63\pm0.08_c^{B}$

[1)]For each value, mean±standard deviation was determined in nine replicates; Values with different upper-case letters within the same column are significantly different ($p<0.05$), whereas the means with different lower-case letters within the same row are significantly different ($p<0.05$).

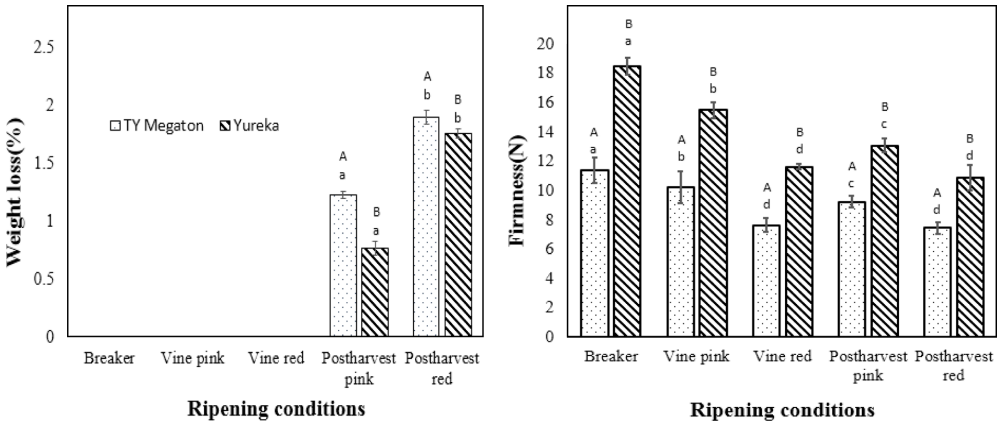

Fig. 1. Weight loss and firmness of TY Megaton and Yureka tomato cultivars under vine- and postharvest-ripening conditions. The bars with different upper-case letters indicate a significant difference (p<0.05) between cultivars, whereas the bars with different lower-case letters indicate a significant difference (p<0.05) between the ripening conditions. The vertical bars represent the standard error of the means (n=5).

limit suggested for marketing. Firmness for the postharvest-ripened red stage was 7.43 and 10.83 N for TY Megaton and Yureka, respectively. Two possible minimum firmness limits suggested by Batu (22) for tomato fruits at the point of retail marketing and at home were 1.45 and 1.28 N, respectively.

***SSC, TA, and pH*:** ANOVA showed significant differences (p<0.05) between cultivars in terms of SSC, TA, and pH. The SSC of tomato fruits at each ripening stage (breaker, pink, and red) at the harvest and at postharvest (pink and red) stages is presented in Table 2. Fruits at the mature breaker stage exhibited the lowest amount of SSC, i.e., 5.56 and 5.10% for TY Megaton and Yureka, respectively. Conversely, vine-ripened tomatoes exhibited the highest SSC, i.e., 6.30 and 5.56% for TY Megaton and Yureka, respectively. The SSC at the breaker stages was significantly lower than that at the vine-ripened and postharvest-ripened pink and red stages. Vine-ripened tomatoes exhibited a 13.30 and 9.02% higher SSC than the fruits picked at the breaker stage for TY Megaton and Yureka, respectively.

The titrable acidity gradually decreased as the ripening stage proceeded. The minimum acidity (0.51 mg·100 g^{-1}) was recorded in Yureka at the postharvest-ripened red stage, whereas TY Megaton exhibited the maximum acidity (1.00 mg·100 g^{-1}) at the breaker stage (Table 2). The conversion of organic acid into sugar and their derivatives or their utilization in respiration might be the reason for the reduction in acidity during ripening (23). The range of pH in the present study varied from 4.63 to 5.08 in TY Megaton and from 5.24 to 5.75 in Yureka (Table 2). There was an inverse relationship between TA and pH; as the ripening stage proceeded, there was an increasing trend of pH in both cultivars. A high pH content in tomato fruit juice was recorded in the vine-ripened red stage for both cultivars. Rai *et al*. (23) studied four cultivars of tomato and found that the pH varied from 3.43 to 4.63.

Antioxidant components

***Lycopene*:** The results of present study revealed that the lycopene content of both cultivars significantly (p<0.05) increased as the ripening stage proceeded. At breaker stage, the lycopene content of TY Megaton and Yureka was 5.27 and 5.15 mg·kg^{-1}, respectively. The lycopene contents of Yureka and TY Megaton reached their peaks (21.52 and 20.44 mg·kg^{-1}, respectively) at the postharvest red stage (Table 3). Helyes *et al*. (24) reported the lycopene contents of 16 different tomato varieties in Hungary, and the results varied significantly, i.e., from 39.3 to 171 mg·kg^{-1}; they reported that varieties and ripening stages were important determinants of the lycopene content. Brandt *et al*. (25) also reported lycopene contents ranging from 0.1 to 59 mg·kg^{-1} at different maturity stages with an increasing trend as the maturity proceeded; moreover, they clearly showed the variations in the lycopene contents at the breaker, pink, and red maturity stages. In the present study, lycopene accumulation increased as the ripening stage proceeded. It has been reported by different authors that chlorophyll breaks down whereas carotenoids, mostly lycopene, accumulate during ripening (19,25,26). Lycopene begins to accumulate after the breaker stage, and at the ripened red stage, lycopene comprises 95% of all colored carotenoids and 73% of the total carotenoids (26). It is considered that carotenoids with their antioxidant properties possibly offer protection against some forms of cancer (27).

***Ascorbic acid*:** The analysis of ascorbic acid showed significant variation (p<0.05) under different ripening conditions for both cultivars. In the present study, vitamin C concentration ranged from 20.35 to 29.09 mg·100 g^{-1}. The maximum vitamin C content was recorded at the breaker stage for both TY Megaton (29.09 mg·100 g^{-1}) and Yureka (27.54 mg·100 g^{-1}). Sharma *et al*. (28) reported ascorbic acid contents ranging from 11.21 to 53.29 mg·100 g^{-1} in tomato genotypes. In the present study, the ascorbic acid content of tomato decreased gradually as ripening proceeded, and the minimum values of 20.35 and 21.95 mg·100 g^{-1} were recorded for TY Megaton and Yureka, respectively, at the vine-ripened red stage (Table 3). In agreement with this study, Abushita *et al*. (29) described the changes that

Table 2. SSC, TA, and pH levels of TY Megaton and Yureka tomato cultivars under vine- and postharvest-ripening conditions

Parameter	Cultivar	Ripening conditions				
		Breaker	Vine-pink	Postharvest Pink	Vine-red	Postharvest red
SSC (°Bx)	TY Megaton	$5.56\pm0.11_{a}^{A}$ [1)]	$5.78\pm0.29_{a}^{A}$	$5.64\pm0.25_{a}^{A}$	$6.30\pm0.22_{b}^{A}$	$5.68\pm0.12_{a}^{A}$
	Yureka	$5.10\pm0.24_{a}^{B}$	$5.16\pm0.18_{a}^{B}$	$5.16\pm0.17_{a}^{B}$	$5.56\pm0.29_{b}^{B}$	$5.52\pm0.48_{b}^{B}$
TA ($mg\cdot100\ g^{-1}$)	TY Megaton	$1.00\pm0.03_{a}^{A}$	$0.85\pm0.05_{b}^{A}$	$0.82\pm0.03_{b}^{A}$	$0.82\pm0.07_{b}^{A}$	$0.80\pm0.06_{b}^{A}$
	Yureka	$0.76\pm0.06_{a}^{B}$	$0.69\pm0.10_{a}^{B}$	$0.58\pm0.07_{b}^{B}$	$0.62\pm0.09_{b}^{B}$	$0.51\pm0.01_{b}^{B}$
pH	TY Megaton	$4.73\pm0.15_{a}^{A}$	$4.85\pm0.06_{ab}^{A}$	$4.63\pm0.19_{a}^{A}$	$5.08\pm0.10_{b}^{A}$	$5.02\pm0.62_{b}^{A}$
	Yureka	$5.24\pm0.10_{a}^{B}$	$5.64\pm0.09_{b}^{B}$	$5.52\pm0.12_{b}^{B}$	$5.75\pm0.09_{b}^{B}$	$5.73\pm0.28_{b}^{B}$

[1)]For each value, mean±standard deviation was determined in five replicates; Values with different upper-case letters within the same column are significantly different (p<0.05), whereas the means with different lower-case letters within the same row are significantly different (p<0.05).

Table 3. Lycopene, ascorbic acid, total phenolic contents and DPPH inhibition of TY Megaton and Yureka tomato cultivars under vine- and postharvest-ripening conditions

Parameters	Cultivar	Ripening conditions				
		Breaker	Vine pink	Postharvest pink	Vine red	Postharvest red
Lycopene ($mg\cdot kg^{-1}$)	TY Megaton	$5.27\pm0.92_{a}^{A}$ [1)]	$14.41\pm1.05_{b}^{A}$	$14.90\pm0.88_{b}^{A}$	$19.60\pm0.73_{c}^{A}$	$20.44\pm0.45_{c}^{A}$
	Yureka	$5.15\pm0.43_{a}^{A}$	$14.28\pm0.60_{b}^{A}$	$16.25\pm1.28_{d}^{B}$	$20.26\pm1.28_{c}^{B}$	$21.52\pm0.82_{c}^{B}$
Ascorbic acid ($mg\cdot100\ g^{-1}$)	TY Megaton	$29.09\pm1.80_{a}^{A}$	$23.31\pm0.89_{b}^{A}$	$22.40\pm0.99_{b}^{A}$	$20.35\pm0.84_{c}^{A}$	$23.17\pm0.97_{b}^{A}$
	Yureka	$27.54\pm0.85_{a}^{B}$	$23.89\pm1.45_{b}^{A}$	$22.14\pm1.14_{c}^{A}$	$21.95\pm0.62_{c}^{A}$	$22.81\pm0.91_{c}^{A}$
Total phenolics ($mg\ GAE\cdot100\ g^{-1}$)	TY Megaton	$228.66\pm2.77_{a}^{A}$	$214.43\pm11.73_{b}^{A}$	$218.75\pm6.59_{ab}^{A}$	$209.57\pm9.38_{b}^{A}$	$211.04\pm12.75_{b}^{A}$
	Yureka	$244.91\pm8.10_{a}^{B}$	$239.06\pm8.07_{a}^{B}$	$239.07\pm6.12_{a}^{B}$	$234.90\pm4.19_{a}^{B}$	$232.04\pm13.71_{b}^{B}$
DPPH inhibition (%)[Z2)]						
2.5 $mg\cdot mL^{-1}$	TY Megaton	$75.87\pm0.80_{a}^{A}$	$83.17\pm1.54_{b}^{A}$	$83.30\pm0.87_{bc}^{A}$	$83.51\pm1.08_{bc}^{A}$	$84.58\pm0.94_{c}^{A}$
	Yureka	$75.59\pm0.81_{a}^{A}$	$83.35\pm1.10_{b}^{A}$	$83.41\pm1.89_{bc}^{A}$	$83.47\pm1.15_{bc}^{A}$	$84.92\pm1.04_{c}^{A}$
5 $mg\cdot mL^{-1}$	TY Megaton	$79.80\pm0.76_{a}^{A}$	$86.80\pm0.62_{b}^{A}$	$86.55\pm0.52_{b}^{A}$	$87.07\pm1.74_{bc}^{A}$	$88.68\pm0.50_{c}^{A}$
	Yureka	$79.53\pm1.57_{a}^{A}$	$87.51\pm0.57_{b}^{A}$	$86.68\pm1.42_{b}^{A}$	$87.56\pm0.85_{bc}^{A}$	$88.27\pm1.10_{c}^{A}$
10 $mg\cdot mL^{-1}$	TY Megaton	$89.08\pm0.69_{a}^{A}$	$91.15\pm0.71_{b}^{A}$	$90.94\pm0.47_{b}^{A}$	$91.06\pm0.52_{b}^{A}$	$91.55\pm0.44_{b}^{A}$
	Yureka	$88.42\pm1.83_{a}^{B}$	$90.53\pm0.72_{b}^{B}$	$90.60\pm0.78_{b}^{A}$	$90.77\pm0.44_{b}^{A}$	$90.79\pm0.57_{b}^{A}$
20 $mg\cdot mL^{-1}$	TY Megaton	$93.80\pm1.15_{a}^{A}$	$93.77\pm0.39_{a}^{A}$	$93.59\pm0.24_{a}^{A}$	$94.88\pm0.43_{b}^{A}$	$94.62\pm0.65_{b}^{A}$
	Yureka	$92.72\pm0.09_{a}^{B}$	$93.01\pm0.57_{a}^{B}$	$92.42\pm0.35_{a}^{B}$	$93.78\pm0.08_{b}^{B}$	$93.83\pm0.63_{b}^{B}$

[1)]For each value, mean±standard deviation was determined in triplicate; Values with different upper-case letters within the same column are significantly different (p<0.05), whereas the means with different lower-case letters within the same row are significantly different (p<0.05).
[2)Z]The data are detected at different concentrations of MEs from tomatoes.

occurred in the vitamin C content of "Floriset" tomato cultivar with the dynamics of ripening by harvesting at green, breaker, pink, and red stages. They reported that the maximum concentration of ascorbic acid was estimated from the breaker stage; however, as the ripening stage advanced, there was a decrease in the ascorbic acid content possibly due to its antioxidant function because ripening cells absorb high amounts of oxygen for a high rate of respiration. Gould (30) recommended varieties for processing in order to obtain ascorbic acid in excess of 20 mg/100 g; TY Megaton and Yureka could be those potential varieties for processing and could be used in breeding programs to improve nutritional values owing to their high ascorbic acid content.

***Total phenolic content*:** Significant differences (p<0.05) were observed in the total phenolic contents between varieties and among various ripening conditions (Table 3). The maximum values of 228.66 and 244.91 mg $GAE\cdot kg^{-1}$ were recorded at the breaker stage for TY Megaton and Yureka, respectively. In both cultivars, a reducing trend was observed as the ripening stage proceeded; the lowest values of 209.57 and 232.04 mg $GAE\cdot kg^{-1}$ were recorded at the vine-ripened and postharvest-ripened red stages for TY Megaton and Yureka, respectively. The range of total phenolic contents obtained in the present study is in agreement with the result reported by Park *et al*. (31). George *et al*. (32) also reported phenolic contents ranging from 92 to 220 $mg\cdot kg^{-1}$ in the pulp of cherry tomato cultivars. The antioxidative properties of polyphenolics in different plant extracts have been reported, and there was a suggestion on the possible protective roles of polyphenolic compounds in reducing the risk of cardiovascular diseases in humans (33).

Antioxidant activity There was a significant difference (p<0.05) in the DPPH radical scavenging of tomatoes under different ripening conditions. A high DPPH radical scavenging percentage irrespective of cultivars and concentrations (MEs of fresh tomatoes) was recorded for red-stage (both on-vine- and postharvest-ripened) tomatoes, in which lycopene accumulation was high. There was no significant difference (p<0.05) the in DPPH radical scavenging percentage

between on-vine-ripened and postharvest-ripened pink- and red-stage tomatoes for both cultivars; this indicates that the ripening condition has no effect on the antioxidant activity of tomatoes. The MEs from fresh tomatoes showed an excellent DPPH scavenging ranging from 89.08 to 94.88% at a concentration higher than 10 mg·mL^{-1}; this is in agreement with the results of Chang *et al*. (34), who reported scavenging effects ranging from 87.7 to 99.7% at a concentration higher than 4 mg·mL^{-1}. In this study, the trends of DPPH radical scavenging follow the same trends as lycopene accumulation (Table 3). In agreement with the present results, lycopene was reported to be a highly effective antioxidant owing to its ability to act as a free radical scavenger and its highest singlet oxygen-quenching rate among all the carotenoids tested from biological systems (35). Some medical research studies have reported that fruits and vegetables, especially tomato, are good sources of lycopene. Giovannucci *et al*. (3,4) reported that an increased consumption of tomatoes and tomato products is associated with a decreased risk of a variety of cancer, and their assumptions were related to the antioxidant properties of lycopene.

In conclusion, the results of the present study revealed that fresh weight loss was below the maximum acceptable weight loss and that firmness was above the minimum limit of marketing after postharvest ripening at the pink and red stages; this does not have any deleterious effect on the antioxidant components (lycopene, ascorbic acid, and total phenolics) or antioxidant activity. A higher pH content was observed in the vine-ripened red stage for both cultivars, and vine-ripened tomatoes had higher SSC than fruits picked at breaker stage. In both the on-vine- and postharvest-ripened tomatoes of the two cultivars, more than four-fold accumulation of lycopene was observed when the breaker stage tomatoes ripened to the red stage. The antioxidant activity also increased as the ripening stage proceeded irrespective of the ripening conditions for both varieties, followed by an increasing trend of lycopene content. The present findings show that the antioxidant activity of tomatoes was high even at the breaker stage at a concentration higher than 10 mg·mL^{-1}; this could be due to the effective DPPH reducing power of ascorbic acid and total phenolics. Hence, the results of the present study clearly indicate that breaker-stage tomatoes can be postharvest-ripened under room conditions without affecting their marketability and nutritional components.

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