

Effects of Storage Duration on Physicochemical and Antioxidant Properties of Tomato (*Lycopersicon esculentum* Mill.)

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Abstract

This study explored the physicochemical and nutritional changes associated with storage duration of fresh tomatoes. Fruits of the 'TY Megaton' and 'Yureka' tomato cultivars were harvested at the pink stage and stored at 12°C for 20 days. During storage, firmness, weight loss, skin color (Hunter L, a, b, a / b values), soluble solids content (SSC), titratable acidity (TA), pH, antioxidant contents (lycopene, ascorbic acid, and total phenolics) and antioxidant activity were evaluated. Firmness was above the minimum marketable limit and fresh weight loss was below maximum acceptable weight loss after 3 weeks of storage, and no deleterious effect on antioxidant contents or activities were observed. Significant differences in SSC, TA, and pH were seen between varieties, but not between fruits stored for different durations. In both varieties, Hunter a values increased more than five-fold after 8 days of storage; this correlated with a more than four-fold accumulation of lycopene after two weeks of storage. The antioxidant activity of tomatoes was highest at the beginning of the storage period, likely because of the effective DPPH - reducing power of ascorbic acid and total phenolics. Antioxidant activity increased after 12 days of storage because of increasing lycopene content. Hence, this study indicates that pink - stage tomatoes may be stored at 12°C for up to 3 weeks without affecting marketability or nutritional value.

Additional key words: antioxidant activity, ascorbic acid, lycopene, phenolics, storage period.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is a major horticultural crop with a worldwide production of 163.43 million tons and a value of US\$59.88 billion. In South Korea, 388.5 thousand tons of tomatoes with a value of US\$143.58 million were produced in 2013 (FAOSTAT, 2013). As one of the most widely consumed horticultural crops in the world, tomatoes make a significant contribution to human nutrition because they contain sugars, acids, vitamins, minerals, lycopene and other carotenoids, among other constituents (Simonne et al., 2006; Toor and Savage, 2006). Tomatoes are a rich source of antioxidants such as vitamin C, lycopene, phenolics, flavonoids and β - carotene, which contribute to their antioxidant or free radical - scavenging effects (Lenucci et al., 2006). Consumption of raw tomato



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and tomato - based products is associated with a reduced risk of cancer and cardiovascular diseases (Giovannucci et al., 2002). This protective effect is mainly attributed to valuable bioactive components with antioxidant properties (Borguini and Torres, 2009).

Tomatoes are climacteric fruits with a relatively short postharvest life in ambient conditions. As in other climacteric fruit, tomato ripening is highly dependent on ethylene action (Alexander and Grierson, 2002), which makes this fruit highly perishable. Inhibition of ethylene production delays fruit ripening and increases the shelf life for the consumer (Madhavi and Salunkhe, 1998). Variety, environmental effects, cultivation conditions, ripening stage, and postharvest storage all affect tomato composition (Anza et al., 2006). Temperature is the most important environmental factor to consider in the postharvest life of tomatoes because of its effects on the rates of biological processes (Mostofi and Toivonen, 2006). Low temperature is important for maintaining quality and extending the shelf life of fruits and vegetables after harvest. Postharvest recommendations indicate that tomatoes should be stored at 10°C or higher to avoid chilling injury (Roberts et al., 2002), and even 10°C may be detrimental to tomato flavor quality (Maul et al., 2000). A storage temperature of 10 - 13°C is recommended for pink - red to firm - red greenhouse - grown tomatoes (Alban, 1961).

Several studies have explored tomato storage and shelf life under various conditions, as well as the effects of different drying processes (Chang et al., 2006), and cooking processes such as boiling, baking, or frying (Sahlin et al., 2004) on the antioxidant properties of different varieties (George et al., 2004) and tomato fractions (Toor and Savage, 2005). However, information on the physicochemical changes and overall nutritional implications of storage duration on fresh tomato is not clear. The time between fruit harvesting and consumption might be up to several weeks, and during this period biochemical changes may affect tomatoes' nutritional value. Thus, an experiment was designed to study the variations in physicochemistry and antioxidant properties of fresh tomatoes during storage.

Materials and Methods

Chemicals

All chemicals used were of analytical grade. Folin–Ciocalteu's phenol reagent, 2,2 - diphenyl - 1 - picrylhydrazyl (DPPH), gallic acid and ascorbic acid were purchased from Sigma - Aldrich, Korea. Metaphosphoric acid and potassium dihydrogen phosphate were obtained from Yakuri Pure Chemicals, Kyoto, Japan. Sodium hydroxide, sodium carbonate, butylated hydroxyanisole, methanol, ethanol, hexane and acetone were obtained from DaeJung Chemicals, Korea.

Tomato Samples and Storage Conditions

Tomatoes (*Lycopersicon esculentum* Mill) cv. 'TY Megaton' and 'Yureka' were grown in a greenhouse in the Kangwon province of South Korea during Spring 2016. A USDA biological color chart (1991) was used to precisely select fruits of consistent maturity level and fruit color. Uniform - size fruits free from physical defects were harvested at the pink stage. Tomato fruits were washed and wiped dry and placed in a commercial plastic tomato box before being stored at 12°C for up to 20 days. Fruits were regularly inspected and data were collected at 4 - day intervals for the parameters considered (see below).

Physicochemical Changes

Fresh Weight Loss and Firmness

Tomatoes were weighed prior to storage, and weighed again at the end of the storage period. The post - storage weight was subtracted from the pre - storage weight, and fresh weight loss was presented as a percentage (%) of weight lost compared to the initial weight.

Tomato fruit firmness was measured using a Sun Rheo Meter Compac - 100II (Sun Scientific Co. Ltd., USA) with a maximum force of 10 kg and a 3 mm diameter round stainless steel probe with a flat end. Measurements were taken at the equator of the fruit

Color Changes

Hunter a (redness), b (yellowness), and L (brightness) values (McGuire, 1992) were determined using a CR - 400 chroma meter (Minolta, Japan). Color variables were measured three times from the sides of three tomatoes (near to the equatorial section), and the average determined.

Soluble Solids Content (SSC), Titratable Acidity (TA), and pH

Soluble solids content (SSC) was determined for each of five sample fruits using an Atago DR - A1 digital refractometer (Atago Co. Ltd., Japan) at 20°C, and expressed as °Brix.

Titrate acidity (TA) was obtained by titrating diluted tomato juice (1 ml juice: 19 ml distilled water) with 0.1 N NaOH up to pH 8.1 using a DL22 Food and Beverage Analyzer (Mettler Toledo Korea Ltd.). The result was expressed as mg of citric acid per 100 g of fresh tomato weight. A Mettler Toldo InLab 413 pH meter was used to measure pH.

Antioxidant Properties

Lycopene Content

Lycopene content of triplicate tomato samples was determined according to the method of Fish et al. (2002), with some modifications. Homogenized tomato samples (0.5 g of each) were placed into vials, to which was added 5 mL of 0.05% (w/v) butylated hydroxyl toluene (BHT) in acetone, 5 mL of 95% (v / v) ethanol, and 10.0 mL of hexane. Vials were then centrifuged (15 000 rpm for 15 min). Afterwards, 3 mL of deionized water was added to each vial, and the samples were shaken for another 5 min. Vials were left at room temperature for 5 min without agitation to allow phase separation. The absorbance of the hexane (upper) layer was measured with a spectrophotometer (Thermofisher Scientific, USA) at 503 nm versus a blank of hexane solvent. Lycopene content of samples was expressed as mg·kg⁻¹ of fresh weight.

Ascorbic Acid

Vitamin C was analyzed using reversed - phase liquid chromatography with UV detection, according to the method described by Kim et al. (2011). Briefly, 1 g of sample was mixed with 10 mL of 5% metaphosphoric acid and homogenized for 1 min. After centrifuging the mixture (20 000 rpm for 10 min), the liquid layer of extracts was membrane - filtered (0.22 µm) and analyzed using a ZORBAX Eclipse XDB - C18 (4.6 × 250 mm, 5 µm, Agilent, USA) column and detector (UV - 2075, Jasco, Japan) at 265 nm, with a 20 µL injection of MeOH: 0.1 M KH₂PO₄ (1:9 ratio) at 1 mL / min as the mobile phase.

Total Phenolics

Total phenolics content was quantified using a slightly modified version of the method described by Pataro et al. (2015). Briefly, 2 g of each tomato sample (in duplicate) was extracted with 20 mL of 0.05% (v/v) aqueous HCl/methanol (10:90, v/v) using a homogenizer (Ultra Turrax T18 Basic, IKA, Germany) at speed 5 for 1 min, and the homogenate was membrane-filtered (0.45 µm). The sample extract (0.2 mL) was mixed with 2.6 mL of deionized water, 2 mL of 7% (w/v) Na₂CO₃, and 0.2 mL of Folin - Ciocalteu's phenol reagent. After incubating at room temperature for 90 min, a spectrophotometer (ThermoFisher Scientific, USA) was used to measure the absorbance of the reaction mixture at 750 nm against a blank sample containing the same mixture solution without the sample extract. Total phenolics content was expressed as mg of gallic acid equivalents (GAE) per kg fresh weight of sample.

Antioxidant Activity

Using duplicates of the same extracts used to quantify total phenolic content analyses, antioxidant activity was measured by spectrophotometric assay (ThermoFisher Scientific, USA) and the DPPH method reported by Pataro et al. (2015), with some modifications. First, cuvettes (Kartell, Italy) containing 3.9 mL of DPPH dissolved in methanol (0.1 mM) were prepared, and the absorbance at 515 nm was read immediately ($t_0 = 0$ min). Methanol was used to determine the absorbance of auto zero and the blank. Subsequently, 800 µL of each tomato extract was mixed with 3.2 mL of methanol-DPPH solution and kept in the dark for 30 min (t_{30}) at room temperature before measuring their absorbance. The percentage of DPPH inhibition was calculated as follows:

$$\% \text{ reduced DPPH} = [(\text{absorbance } t_0 - \text{absorbance } t_{30}) \div \text{absorbance } t_0] \times 100$$

Statistical Analysis

A completely randomized study design was used, with nine replicates for color, five for weight loss, firmness, SSC, TA and pH, and three for all other parameters. Parameter measurements were analyzed by analysis of variance (ANOVA) at $p < 0.05$ using SAS (SAS / STAT® 9.1, SAS Institute Inc., Cary, NC, USA) statistical software. Differences between mean values were analyzed by one-way ANOVA to determine whether storage duration and variety caused significant differences in the physicochemical and antioxidant properties of tomatoes. Duncan's multiple range test was used to determine which particular means were significantly different ($p < 0.05$).

Results and Discussion

Physicochemical Changes

Weight Loss and Firmness

In both tomato varieties, percentage weight loss increased significantly ($p < 0.05$) with increasing storage period (Fig. 1). After 20 days of storage the weight loss was 2.86% and 2.38% for 'Yureka' and 'TY Megaton', respectively. According to Nunes (2008), the maximum acceptable weight loss before a tomato becomes unsellable is 6 - 7% (Nunes, 2008); in this study, weight loss for both cultivars was within the acceptable weight loss range. This may be because the tomatoes used in

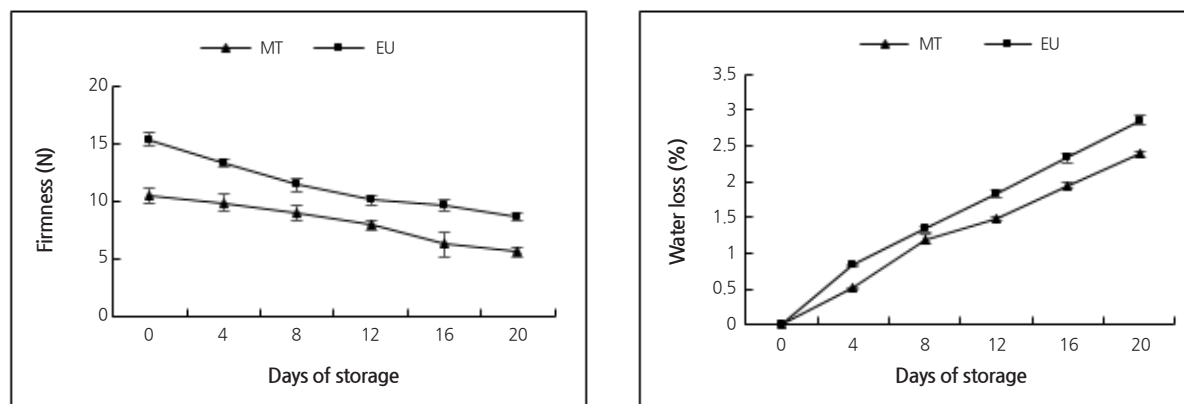


Fig. 1. Changes in firmness and water loss of 'TY Megaton' (MT) and 'Yureka' (EU) tomato cultivars, as affected by storage duration at 12°C. Vertical bars represent standard error of the means (n = 5).

this study were stored at the recommended temperature of 12°C (Alban, 1961), and relative humidity was managed at 85 ± 5%. In the present study, significantly different weight loss was observed between the two cultivars, suggested that these cultivars vary in amount of water loss.

In both varieties, firmness reduced significantly ($p < 0.05$) with increasing storage duration (Fig. 1), but in both cases remained above the minimum limits of marketable firmness suggested by Batu (2004), at 1.45 N for retail, and 1.28 N for home consumption. In this study, firmness after 20 days of storage was 5.8 N and 8.7 N for 'TY Megaton' and 'Yureka', respectively.

SSC, TA, and pH

Analysis of variance (ANOVA) revealed significant differences ($p < 0.05$) between tomato cultivars in terms of their biochemical characteristics. The maximum SSC (5.64 °Brix) for 'TY Megaton' was recorded on day 12, and for 'Yureka' (5.32 °Brix) was recorded on day 16, but there was no significant difference ($p > 0.05$) between the number of storage days (Table 1). Previous studies likewise reported no significant differences between tomato cultivars stored at room temperature for 14 days (Wills and Ku, 2002).

Table 1. Changes in color of 'TY Megaton' and 'Yureka' tomato cultivars, as affected by storage duration at 12°C.

Parameters	Variety	Storage days					
		0	4	8	12	16	20
L*	TY Megaton	50.52 ± 0.62 ^a	46.75 ± 1.18 ^b	44.49 ± 1.54 ^c	44.80 ± 1.70 ^c	43.79 ± 1.80 ^d	43.67 ± 1.23 ^d
	Yureka	50.63 ± 0.98 ^a	45.64 ± 0.49 ^b	45.66 ± 1.54 ^b	45.42 ± 0.56 ^b	45.33 ± 0.73 ^b	44.80 ± 0.48 ^b
a*	TY Megaton	2.06 ± 0.89 ^a	7.97 ± 0.72 ^a	11.40 ± 1.21 ^c	14.62 ± 1.48 ^d	15.24 ± 2.87 ^e	13.62 ± 1.25 ^a
	Yureka	1.26 ± 1.05 ^a	9.43 ± 3.16 ^b	12.53 ± 1.53 ^b	13.28 ± 1.50 ^b	12.65 ± 0.73 ^b	9.89 ± 1.17 ^b
b*	TY Megaton	16.22 ± 1.27 ^a	14.08 ± 0.59 ^a	13.11 ± 0.50 ^c	13.12 ± 0.95 ^c	12.94 ± 0.61 ^c	12.37 ± 0.43 ^d
	Yureka	19.77 ± 1.74 ^b	16.99 ± 0.45 ^b	16.94 ± 0.69 ^b	16.15 ± 0.75 ^c	16.02 ± 0.77 ^c	13.75 ± 1.24 ^b
a*/b*	TY Megaton	0.13 ± 0.06 ^a	0.57 ± 0.06 ^a	0.87 ± 0.09 ^c	1.12 ± 0.13 ^d	1.18 ± 0.22 ^d	1.10 ± 0.10 ^{dc}
	Yureka	0.06 ± 0.05 ^b	0.55 ± 0.18 ^a	0.74 ± 0.07 ^c	0.82 ± 0.09 ^b	0.79 ± 0.04 ^b	0.72 ± 0.04 ^{dc}

Values with different upper case letters within the same column, and means with different lower case letters within the same row are significantly different ($p < 0.05$). For each value, mean ± standard deviation was determined from nine replicates

Titrateable acidity (TA) gradually decreased with increasing storage duration; a minimum acidity of $0.61 \text{ mg} \cdot 100\text{g}^{-1}$ was recorded in 'Yureka' after 20 days of storage, while for 'TY Megaton', maximum acidity ($0.85 \text{ mg} \cdot 100\text{g}^{-1}$) was at day 0 (Table 1). Reduction in acidity during storage might be associated with the conversion of organic acids into sugars and their derivatives, or their utilization in respiration (Rai et al., 2012).

The pH varied from 4.52 to 4.97 in 'TY Megaton' and from 5.53 to 5.69 in 'Yureka' (Table 1). The pH of both cultivars increased with increasing storage duration. The maximum pH content of tomato fruit juice was recorded after 20 days of storage in both cultivars. Rai et al. (2012) studied four cultivars of tomato and found variations in pH from 3.43 to 4.63.

Color Changes

Skin and flesh color is one of the most important quality factors affecting tomato appearance (Brandt et al., 2006). Color is measured using a chroma meter and evaluated against the Hunter a, b, L scale, where more negative a represents increasing greenness and more positive a represents increasing redness; more negative b indicates increasing blueness and more positive b indicates increasing yellowness; and L (on a scale of 0 - 100) indicates darkness to brightness. In tomato, color development is characterized by lower L values readings, and a change from negative to positive a values (Shewfelt et al., 1988). Increasing redness is desirable in most tomato cultivars, hence Hunter a values are best for evaluating the maturation process based on color.

In the present study, Hunter a values of both cultivars were significantly different ($p < 0.05$) throughout the storage period. The highest values (+15.4) and (+13.8) were recorded on day 16 for 'TY Megaton' and on day 12 for 'Yureka', respectively (Table 2). The a/b ratios were significantly different and follow the same trend as Hunter a values for both cultivars (Table 2). The highest ratios - 1.18 and 0.82 - were obtained on day 16 for 'TY Megaton' and on day 12 for 'Yureka', respectively.

In the present study, increasing a value was shown to be directly associated with lycopene synthesis, and hence increasing lycopene content. The a/b ratio is a good indicator of lycopene content and, therefore, can be used to characterize fresh tomato ripeness stage (Arias et al., 2000; Helyes et al., 2006).

Hunter L values reduced slightly during storage, irrespective of cultivar (Table 2).

Antioxidant Properties

Lycopene

The lycopene content of both cultivars increased significantly ($p < 0.05$) after harvest and throughout the storage period. The initial lycopene content of 'TY Megaton' and 'Yureka' was 5.43 and $4.00 \text{ mg} \cdot \text{kg}^{-1}$, respectively. The lycopene content of 'Yureka' reached its peak ($23.88 \text{ mg} \cdot \text{kg}^{-1}$) on day 20, and 'TY Megaton' ($22.05 \text{ mg} \cdot \text{kg}^{-1}$) on day 16 (Table 3). Lycopene synthesis increased with increasing storage duration. In 'TY Megaton', storage for more than 16 days after harvest led to a decrease in the total lycopene content, while in 'Yureka' it increased for up to 20 days. As George et al. (2004) proposed, this might be due to the nature of the cultivar.

The present study revealed high correlation ($r^2 = 0.92$) between tomato color (Hunter a value) and lycopene content (Table 4). Lycopene content increases significantly as tomato fruits mature from the green stage to the red stage (Dumas et al., 2003; Brandt et al., 2006; Helyes et al., 2006). Lycopene begins to accumulate after the breaker stage, and by the ripe - red stage, lycopene comprises 95% of all colored carotenoids and 73% of the total carotenoids (Dumas et al., 2003). The

Table 2. Changes in soluble solids content, titratable acid and pH of 'TY Megaton' and 'Yureka' tomato cultivars, as affected by storage duration at 12°C.

Parameters	Variety	Storage days					
		0	4	8	12	16	20
SSC (°Brix)	TY Megaton	5.40 ± 0.10 ^A	5.40 ± 0.12 ^A	5.46 ± 0.11 ^A	5.64 ± 0.09 ^A	5.58 ± 0.4 ^A	5.62 ± 0.13 ^A
	Yureka	5.16 ± 0.18 ^B	5.26 ± 0.32 ^B	5.28 ± 0.16 ^B	5.24 ± 0.15 ^B	5.32 ± 0.29 ^B	5.26 ± 0.30 ^B
TA (mg·100g ⁻¹)	TY Megaton	0.85 ± 0.05 ^A	0.82 ± 0.04 ^A	0.82 ± 0.05 ^A	0.80 ± 0.01 ^A	0.83 ± 0.04 ^A	0.78 ± 0.04 ^A
	Yureka	0.71 ± 0.09 ^B	0.72 ± 0.03 ^B	0.62 ± 0.09 ^B	0.64 ± 0.02 ^B	0.62 ± 0.01 ^B	0.61 ± 0.06 ^B
pH	TY Megaton	4.52 ± 0.52 ^A	4.58 ± 0.59 ^A	4.69 ± 0.27 ^A	4.65 ± 0.18 ^A	4.88 ± 0.26 ^A	4.97 ± 0.14 ^A
	Yureka	5.53 ± 0.19 ^B	5.59 ± 0.06 ^B	5.65 ± 0.09 ^B	5.63 ± 0.24 ^B	5.60 ± 0.25 ^B	5.69 ± 0.24 ^B

Values with different upper case letters within the same column, and means with different lower case letters within the same row are significantly different ($p < 0.05$). For each value, mean ± standard deviation was determined from five replicates.

Table 3. Changes in lycopene content, ascorbic acid, total phenolics, and DPPH scavenging power of 'TY Megaton' and 'Yureka' tomato cultivars, as affected by storage duration at 12°C.

Parameters	Variety	Storage days					
		0	4	8	12	16	20
Lycopene (mg·kg ⁻¹)	TY Megaton	5.43 ± 0.03 ^A	10.66 ± 0.03 ^A	12.84 ± 0.13 ^A	17.77 ± 0.07 ^A	22.05 ± 0.03 ^A	16.84 ± 0.02 ^A
	Yureka	4.00 ± 0.15 ^B	10.49 ± 0.10 ^A	15.98 ± 0.08 ^B	21.71 ± 0.05 ^B	21.51 ± 0.17 ^A	23.88 ± 0.12 ^B
Ascorbic acid (mg·100g ⁻¹)	TY Megaton	31.32 ± 0.25 ^A	25.89 ± 0.32 ^B	24.48 ± 0.67 ^C	23.29 ± 0.41 ^A	22.89 ± 0.34 ^A	21.01 ± 1.78 ^C
	Yureka	30.16 ± 0.23 ^B	29.72 ± 1.02 ^B	24.77 ± 0.71 ^B	23.34 ± 0.55 ^C	22.98 ± 0.18 ^A	22.95 ± 0.49 ^B
Total phenolics (mg GAE·kg ⁻¹)	TY Megaton	231.30 ± 3.12 ^A	220.04 ± 14.7 ^B	245.12 ± 11.39 ^E	233.08 ± 5.34 ^A	238.18 ± 5.8 ^A	237.42 ± 6.3 ^A
	Yureka	262.67 ± 11.5 ^B	266.37 ± 13.6 ^B	279.13 ± 5.45 ^B	276.46 ± 0.97 ^B	268.05 ± 2.5 ^B	263.76 ± 8.4 ^B
DPPH inhibition (%) ^Z	TY Megaton	91.04 ± 0.72 ^A	91.72 ± 0.42 ^A	91.44 ± 0.21 ^A	93.63 ± 0.80 ^A	94.69 ± 0.65 ^A	91.4 ± 0.98 ^A
	Yureka	0.57 ± 0.51 ^B	90.58 ± 0.22 ^B	90.61 ± 0.80 ^B	92.24 ± 0.54 ^B	93.06 ± 0.79 ^B	93.07 ± 0.54 ^B

Values with different upper case letters within the same column, and means with different lower case letters within the same row are significantly different ($p < 0.05$).

^ZAll data were detected at 20 mg/ml methanol extracts from tomatoes.

For each value, mean ± standard deviation was determined from three replicates.

Table 4. Correlation coefficients of the main parameters considered.

Parameters	Firmness	Hunter a	Lycopene	Ascorbic acid	Total phenolics	DPPH inhibition (%)
Firmness	1	-0.68***	-0.75***	0.69***	-0.32***	-0.37***
Hunter a		1	0.92***	-0.88***	0.33***	0.61***
Lycopene			1	-0.95***	0.37***	0.52***
Ascorbic acid				1	-0.49***	-0.53***
Total phenolics					1	0.10 ^{ns}
DPPH inhibition (%)						1

ns and *** indicate non-significant and significant differences at $p < 0.001$, respectively

antioxidant properties of carotenoids may offer protection against some forms of cancer (Opiyo and Ying, 2005).

Ascorbic Acid

In both cultivars, significant ($p < 0.05$) variation in ascorbic acid content was observed throughout the storage period. The concentration of vitamin C ranged from 21.01 to 31.32 mg·100g⁻¹. The maximum vitamin C content was recorded at 0 day

for both 'TY Megaton' (31.32 mg·100g⁻¹) and 'Yureka' (30.16 mg·100g⁻¹). Sharma et al. (1996) reported variation in ascorbic acid content ranging from 11.21 to 53.29 mg·100g⁻¹ in tomato genotypes. In the present study, the ascorbic acid content of tomato decreased gradually during storage. Minimum values of 21.01 mg·100g⁻¹ and 22.95 mg·100g⁻¹ were recorded for 'TY Megaton' and 'Yureka', respectively (Table 3). Rai et al. (2012) reported a similar decreasing trend in tomatoes stored under ambient conditions.

Total Phenolics

Significant differences ($p < 0.05$) in total phenolics content were observed between varieties and between storage durations (Table 3). Maximum values of 245.12 mg GAE·kg⁻¹ and 279.13 mg GAE·kg⁻¹ were recorded on day 8 for 'TY Megaton' and 'Yureka', respectively. In both cultivars, no significant differences ($p > 0.05$) in total phenolics content were observed between 0 and 20 days of storage, indicating that storage period has no effect on the overall antioxidant content of tomatoes. The range of total phenolics contents found in the present study concurs with results reported by Park et al. (2016).

Antioxidant Activity

There was a significant difference ($p < 0.05$) in the DPPH radical - scavenging activity of tomatoes during the storage period. Irrespective of cultivar, the recorded DPPH radical - scavenging activity was highest after 12 days of storage, when lycopene accumulation was also highest. In fact, a positive correlation ($r^2 = 0.52$) between DPPH radical - scavenging activity and lycopene accumulation was found (Table 3, 4).

Lycopene is a highly effective antioxidant with the highest singlet oxygen - quenching rate of all carotenoids tested in biological systems (Rao et al., 2012). Fruits and vegetables, especially tomatoes, are good dietary sources of lycopene. Increased consumption of tomatoes and tomato products is associated with a decreased risk of prostate cancer; it is assumed that this is related to the antioxidant properties of lycopene (Etminan et al., 2004, Giovannucci et al., 2002). In the present study, a negative correlation ($r^2 = - 0.49$) was found between ascorbic acid and total phenolics contents; this could be explained by a gradual reduction in ascorbic acid during pink - stage tomato storage, meanwhile total phenolics increased, reached its maximum level on day 8, and decreased thereafter.

The results of the present study reveal that, after 3 weeks of storage, firmness was above the minimum marketable limit and fresh weight loss was below maximum acceptable weight loss after 3 weeks of storage. Storage for up to 3 weeks also had no deleterious effect on lycopene, ascorbic acid or total phenolics content, or on the antioxidant activities of these compounds. Significant differences between varieties were observed in terms of SSC, TA and pH, but the number of days of storage made no significant difference. Hunter *a* values increased more than five - fold after 8 days of storage, which was correlated with a more than four - fold accumulation of lycopene observed after two weeks of storage in both varieties. These findings suggest that the antioxidant activity of tomatoes was high, even at the beginning of the storage period; this might be explained by the effective DPPH - reducing power of ascorbic acid and total phenolics. In line with increasing lycopene content, antioxidant activity also increased after 12 days of storage. Hence, we conclude that pink - stage tomatoes may be stored for up to 3 weeks at 12°C without affecting marketability or nutritional value.

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