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Flesh quality and lycopene stability of fresh-cut watermelon

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Abstract

Red fleshed watermelons are an excellent source of the phytochemical lycopene. However, little is known about the stability of lycopene in cut watermelon. In this study, lycopene stability and other quality factors were evaluated in fresh-cut watermelon. Twenty melons each of a seeded (Summer Flavor 800) and a seedless (Sugar Shack) variety were cut into 5 cm cubes and placed in unvented polystyrene containers, sealed, and stored at 2 °C for 2, 7, or 10 days. At each storage interval, melons were evaluated for juice leakage, changes in carotenoid composition, color, soluble solids content (SSC), and titratable acidity. Headspace carbon dioxide and ethylene were monitored during storage intervals. Juice leakage after 10 days of storage averaged 13 and 11% for the seeded and seedless melons, respectively. Lycopene content decreased 6 and 11% after 7 days of storage for Summer Flavor 800 and Sugar Shack melons, respectively. β-Carotene and *cis* lycopene contents were 2 and 6 mg kg^{-1} for Summer Flavor 800 and Sugar Shack, respectively, and did not change with storage. After 10 days of storage, CIE L^* values increased while chroma values decreased, indicating a lightening in color and loss of color saturation in melon pieces. Symptoms of chilling injury, such as greatly increased juice leakage, or lesions on cubes, were not seen on the fresh-cut cut watermelon after 10 days storage at 2 °C. Puree pH increased and SSC decreased slightly after storage. Carbon dioxide levels increased and oxygen levels decreased linearly during storage, creating a modified atmosphere of 10 kPa each of CO_2 and O_2 after 10 days. Fresh-cut cut watermelon held for 7 or more days at 2 °C had a slight loss of SSC, color saturation, and lycopene, most likely caused by senescence.

Keywords: Carotenoid composition; Color; HPLC; Soluble solids; Titratable acidity; Modified atmosphere

1. Introduction

Red fleshed watermelons are a rich source of the phytochemical lycopene (Perkins-Veazie et al., 2001). This red carotenoid pigment may act as an antioxidant by quenching free radicals formed during normal metabolism and may deactivate DNA chain-breaking agents that are implicated in some cancers (Sies and Stahl, 1998). In numerous epidemiological studies, there are strong positive correlation between diets rich in lycopene-containing foods and protection against some cancers (Gann et al., 1999; DeSteffani et al., 2000). In a recent human clinical trial, lycopene from tomato sauce significantly reduced prostate cancer biomarkers in men with confirmed prostate cancer (Chen et al., 2001).

Currently, cut watermelon accounts for about 10% of all watermelon sales (National Watermelon

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Promotion Board, 2002). Fresh-cut watermelon is sold as quarters and halves with rind, or as cubes without rind. Quality degradation of fresh-cut watermelon has been described as loss of texture, color, and sweetness (Rushing et al., 2001). Lycopene content may be another quality attribute of watermelon, but no research has been conducted to quantify lycopene in fresh-cut watermelon. Extracted lycopene rapidly degrades when exposed to light, oxygen and high temperatures (Vogele, 1937; Brumann and Grimme, 1981), but lycopene may be quite stable when contained in a plant matrix, such as that of fresh-cut watermelon. Modified atmosphere storage was found to degrade β-carotene in fresh-cut peaches (Wright and Kader, 1997). Fresh-cut watermelon held in sealed storage can develop a modified atmosphere (MA) (Fonseca et al., 1999), but the effect of MA on color or lycopene content of watermelon is not known. The objective of this study was to determine how fresh-cut processing and modified atmosphere storage affect lycopene and other quality attributes in watermelon.

2. Materials and methods

Twenty freshly harvested ripe watermelons each of Summer Flavor 800 (seeded) (Abbott and Cobb, Trevose, PA) and Sugar Shack (seedless) (Sugar Creek Seed, Hinton, OK) were purchased from a commercial grower in southwestern Oklahoma. The melons were graded, sorted, and wiped with a damp cotton cloth by the grower as part of the routine handling procedure. Before cutting, melons were washed with sodium hypochlorite ($100\,ml\,l^{-1}$ active ingredient) and water rinse. Recommended sterile work conditions were maintained during preparation and cutting (about 4 h) and throughout the study (Rushing et al., 2001). Melons were cut longitudinally and heart and locular flesh portions were cut into 5 cm cubes. Cubes from each melon were randomly divided among 16 unvented rigid polyethylene storage containers (clamshells) (Delibox 16 oz., Genstar AD16, Rogers, MN) with snap tops. Boxes had 10–12 cubes each, weighed 300–330 g, and were held for 0, 2, 7 or 10 days at 2 °C. Watermelons were 13 °C when cut and preparation room was at 18 °C.

In order to measure carbon dioxide (CO_2), oxygen (O_2), and ethylene levels inside the containers, a syringe outlet was created on the outside of each container with electrical tape covered with a silicone seal (ca. 1.5 cm). Carbon dioxide, O_2 and ethylene levels were monitored at 2 °C on days 1, 4, and 7 using 8 containers per day and prior to tissue analysis. A one ml sample of headspace was removed from designated containers with a sterile syringe and injected onto a gas chromatograph (Hewlett Packard 5890, Wilmington, DE) equipped with a thermal conductivity detector and a packed CTRI 3.1 m × 0.006 m glass and stainless steel column (Alltech Assoc., Deerfield, IL) with a helium flow of $60\,ml\,min^{-1}$ and oven, injector and detector temperatures at 35, 175, 100 °C, respectively, to measure CO_2 and O_2. Ethylene levels were determined by injecting a one ml headspace sample onto a gas chromatograph (Shimadzu, model 14A, Columbia, MD) equipped with a flame ionization detector and a 3.1 m × 0.003 m stainless steel column packed with activated alumina (Alltech Assoc., Deerfield, IL). The temperatures of the oven, injector, and detector were 125, 175, 150 °C, respectively. Background measurements of CO_2 and ethylene were made from the coolers and preparation room and subtracted from headspace values. Each container had approximately 200 ml of headspace, resulting in a weight to volume ratio of 1:0.7.

Colorimeter measurements were made at days 0 and 10 on eight random cubes per container replicate using a chromameter with an aperture of 8 mm diameter, D65 illuminant, and CIE $L^*a^*b^*$ color scale, (Minolta CR200, Ramsey, NJ). Calibrations were made using a white color tile ($L = 97.70$, $a = -0.48$, $b = 2.23$). Hue and chroma were calculated with the formulas ($\tan^{-1} b/a$) and $(a^2 + b^2)^{1/2}$, respectively (Gonnet, 1993).

Percent juice leakage was determined by weight after each storage interval, using the formula [(container + juice wt.) − (container wt.)/(container + fruit wt.) − (container wt.)] × 100%. Cubes were evaluated by researchers for chilling injury symptoms of flesh pitting, fading, or watersoaked appearance at each storage interval, and held at −80 °C until analyzed for soluble solids, pH, and lycopene.

For tissue analysis, composite samples of partially thawed melon (40 g) from each box were ground with mortar and pestle to reduce particle size and foaming, then homogenized (Brinkman Homogenizer, Westbury, NY) for about 1 min. Duplicates of 0.5 ml of

puree per sample were placed on a digital refractometer (Atago PR 100, Plainfield, NY) to determine percent soluble solids content (SSC). The pH was determined on duplicate samples by measuring the pH with a combination pH probe (Orion Research, Boston, MA) of 5 ml of puree per container mixed with 45 ml of double deionized water.

Two replicates of 2 g each were sub-sampled from the puree and extracted for total lycopene content using the method of Sadler et al. (1990). Briefly, this method consisted of extracting the tissue with a 2:1:1 mixture of hexane:acetone:ethanol and 0.1% BHT followed by spectrophotometric measurement at 503 nm (Perkins-Veazie et al., 2001). Concentration was determined using the extinction coefficient of 17.2×10^6 mol m^{-1} (Zechmeister et al., 1943). Standards of tomato lycopene (Sigma, St. Louis, MO) were used to validate lycopene peaks. High performance liquid chromatography (HPLC) elution profiles of carotenoids were determined from treatment subsamples using established techniques for extraction and HPLC quantification (Tonucci et al., 1995). Briefly, 25 g from five replicates per storage interval per cultivar of watermelon tissue were extracted using tetrahydrofuran, and partitioned into methylene chloride using salt water. Sample volume was reduced to about 45 ml using a rotary evaporator and waterbath set at 35 °C, then brought up to 50 ml volume with methylene chloride. Samples were filtered through a 0.45 μm PTFE filter and loaded onto an autosampler, then analyzed on a HPLC (Hewlett Packard 1100, Wilmington, DE) equipped with a diode array detector, with wavelength of 400–500 nm with 100 nm bandwidth. A Microsorb-MVC18 column, 25 cm length, 4.6 mm i.d. 5 μm spherical particles, (Varian Assoc., Walnut Creek, CA) and Brownlee C-18 guard column (3 cm length, 4.6 mm i.d.) (Perkin Elmer, Norwalk, CT) were used. Flow rate was set for 1 ml min^{-1} at a 25 °C column temperature. The gradient solvent method consisted of the following: 0–10 min, 85% acetonitile, 10% methanol, 2.5% methylene chloride, 2.5% hexane; the solvent ratio reached 45% acetonitrile, 10% methanol, 22.5% methylene chloride and 22.5% hexane at 45 min, then gradient was returned to original conditions by 60 min. Using an auto sampler, five injections of 20–100 μl were made per sample (Tonucci et al., 1995). Standards of tomato lycopene were used daily to validate lycopene and β-carotene peaks and to determine concentrations. The experiment was conducted as a completely randomized design over time. Data were analyzed using analysis of variance and mean separation was done by REGWQ (SAS Version 8.0, Cary, NC).

3. Results and discussion

During storage, headspace CO_2 levels increased while O_2 levels decreased in containers (Fig. 1). No differences were found between watermelon cultivars in CO_2 production. Both oxygen and carbon dioxide levels reached about 10 kPa after 10 days of storage, creating a modified atmosphere. Fonseca et al. (1999) reported that CO_2 levels ranged from 0.51 to 3.8 kPa for fresh-cut cut stored watermelon, depending on container used (polypropylene cup-and-lid boxes versus polystyrene clamshell containers). These researchers reported that the containers were not sealed tightly and were not leak-proof. In our study, the polyethylene containers had a tight snap closure that prevented liquid leakage, although they were not airtight. We did not detect any off-odors after any storage period and the O_2 levels were not below the 3 kPa range considered necessary for anaerbiosis (Kader, 1986).

The ethylene concentration in all containers was extremely low (approximately 0.06:l l^{-1}) and was not different between cultivars or among days of storage. Uncut fresh or stored watermelons normally produce ethylene at very low rates (1.7 nl kg^{-1} s^{-1} at 18 °C) (Elkashif et al., 1989). High levels of CO_2 (>5 kPa) reduce tissue ethylene generation (Kader, 1986), and CO_2 may have built up rapidly enough in the containers with fresh-cut cut watermelon to preclude additional ethylene generation.

The amount of juice leakage was 13% for Summer Flavor 800 and 11% for Sugar Shack cubes after 2 days of storage and did not change significantly over storage interval (data not shown). Since Summer Flavor 800 is a seeded melon, the greater juice leakage compared to Sugar Shack may have been due to the increased tissue degradation associated with seed cavities. Juice leakage is not a desirable characteristic in fresh-cut cut watermelons, as the juice gives the tissue a water-soaked appearance, and provides an excellent medium for microbial growth (Cartaxo and Sargent, 1997).

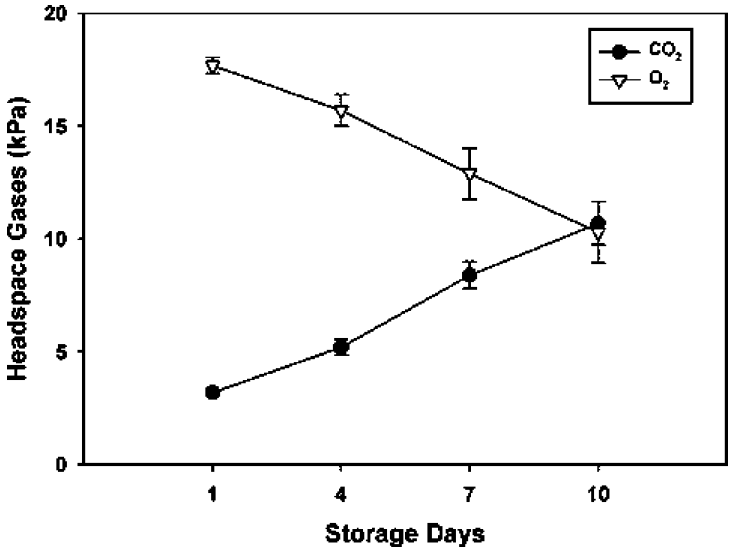

Fig. 1. Changes in carbon dioxide and oxygen headspace environments of cut watermelon stored in polystyrene containers for 2, 7 or 10 days at 2 °C. Bars above and below the lines indicate standard error bars.

Juice leakage in fresh-cut cut watermelon can increase as a result of cube size, storage temperature, or modified atmosphere. Fonseca et al. (1999) found that cubes of length <1.9 cm had more juice leakage due to cut surface injury, while cubes >4 cm in length had more juice loss from compression. Sargent (1998) found that fresh-cut cut watermelon cubes held at 1 °C had 50% more leakage than those held at 3 °C, and concluded that this difference was due to chilling injury. Cartaxo and Sargent (1997) reported that juice leakage increased from 10 to 20% in fresh-cut watermelon stored 5 days at 3 °C under actively maintained atmospheres of O_2, 3 kPa, plus CO_2, 5–20 kPa, compared to that stored in an ambient environment. The percent leakage found in our study was similar to that reported by Fonseca et al. (1999) for non-compartmentalized Sangria watermelon cubes. In our study, juice leakage did not increase as CO_2 increased and O_2 decreased, perhaps because a high CO_2 environment was not continuous during storage. The relatively small amount of juice leakage may also indicate that fresh-cut watermelon are not chilling sensitive at 2 °C. Weight loss was less than 0.05% for both cultivars and did not increase with storage interval, as boxes were unvented and all juice was contained.

Soluble solids content declined slightly after 2 days for Sugar Shack and after 7 days of storage for Summer Flavor 800 melons (Table 1). Loss in SSC during storage is common in both uncut and fresh-cut cut produce and has been previously reported in uncut watermelon (Chisholm and Picha, 1986). The pH increased slightly after 2 days storage for Sugar Shack and after 7 days storage for Summer Flavor 800 (Table 1).

Table 1
Quality factors of percent soluble solids concentration, titratable acidity, and pH of fresh-cut Summer Flavor 800 and Sugar Shack watermelon held for 0, 2, 7, or 10 days at 2 °C[a]

Cultivar	Days in storage	Soluble solids content (%)	pH
Summer Flavor 800	0	12.2 a	5.84 c
	2	12.0 a	5.92 b
	7	11.6 b	5.97 a
	10	11.6 b	6.02 a
Sugar Shack	0	11.9 a	5.74 c
	2	11.4 b	5.90 b
	7	11.4 b	5.91 ab
	10	11.4 b	5.96 ab

[a] Mean separation within cultivar by Ryan–Einot–Gabriel–Welsch Q (REGW-Q). Means within a column followed by the same letters are not significantly different.

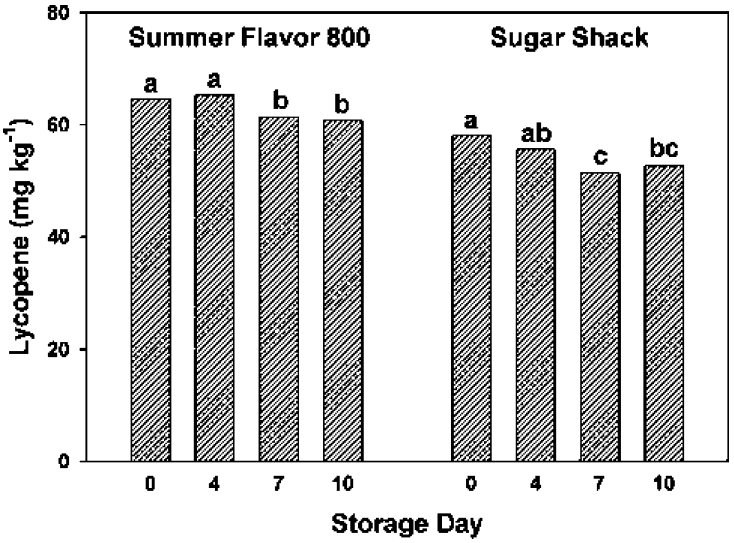

Fig. 2. Changes in lycopene composition of cut watermelon during storage for 2, 7, or 10 days at 2 °C. Mean separation within a cultivar by REGWQ.

These trends were similar to those seen by Chisholm and Picha (1986) and Cartaxo and Sargent (1997).

Summer Flavor 800 watermelons were significantly higher in lycopene content than Sugar Shack regardless of storage interval (Fig. 2). Total lycopene content did not change significantly in either cultivar stored for 2 days at 2 °C (Fig. 2), but was reduced after 7 days of storage (6 and 11% total lycopene loss for Summer Flavor 800 and Sugar Shack, respectively). No further significant losses occurred after 10 days of storage. One to three tentatively identified *cis* lycopene peaks and one *trans* lycopene peak were identified in all samples (Fig. 3). No lycopene isomerization was found in fresh-cut watermelon; lycopene *cis* isomers contributed 5% and *trans* isomer contributed 95% of total lycopene content. β-carotene levels did not change in samples during storage and averaged 2 mg kg^{-1}. The average lycopene concentration in these melons is higher and the β-carotene slightly lower than that reported for watermelon in the USDA Carotenoid Database (49 and 3 mg kg^{-1}, respectively) (Holden et al., 1999). However, the lycopene content in watermelon can vary among cultivars, production sources and seasons (Perkins-Veazie et al., 2001).

The color values L^* and chroma changed during storage in fresh-cut watermelon of both cultivars (Table 2). L^* values increased during storage, indicating lightening in color, while chroma values decreased, indicating a loss in color saturation for stored melon cubes. The red color, measured as change in a^*, decreased slightly between 0 and 10 days storage. Hue, a ratio of a^* to b^*, only decreased by 1–2% during storage. A similar loss in color was reported for fresh-cut watermelons stored for 10 days at 2 or 3 °C, respectively (Fonseca et al., 1999; Cartaxo and Sargent, 1997). The slight loss of color in watermelon cubes seen in our study most likely resulted from oxidation and senescence processes. Sugar Shack had slightly higher L* values than Summer Flavor 800 indicating a lighter color, and during cutting, Sugar

Table 2
Color changes of L^*, a^*, b^*, chroma, and hue in Summer Flavor 800 (seeded) and Sugar Shack (seedless) watermelons held for 10 days at 2 °C

Cultivar	Days in storage	L	a^*	b^*	Hue	Chroma
Summer Flavor 800	0	37.2a[a]	26.9a	13.6a	26.7a	30.2a
	10	38.9b	24.6b	12.1b	26.1a	27.5b
Sugar Shack	0	40.4a	25.6a	13.5a	27.6a	29.0a
	10	41.4b	24.9b	12.9b	27.4a	28.0b

[a] Mean separation within cultivar by REGWQ. Means within a column followed by the same letters are not significantly different.

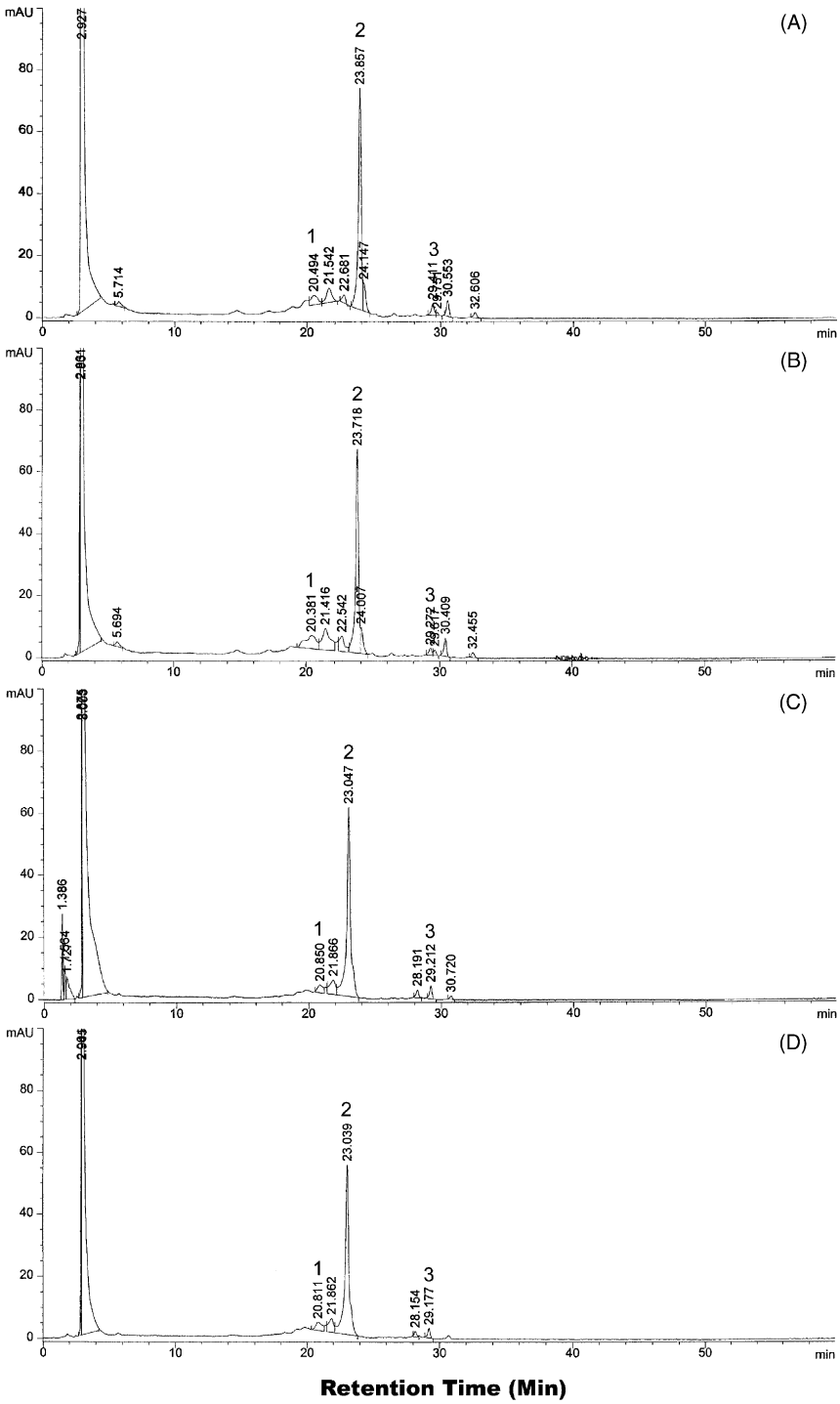

Fig. 3. HPLC chromatographs of Summer Flavor 800 (A and B) and Sugar Shack (C and D) watermelons cut and stored in polystyrene containers before (A and C) and after 7 days of storage at 2 °C (B and D). Numbered carotenoids peaks in chromatographs are as listed. (1) *cis* lycopene isomers; (2) *trans* lycopene; (3) *trans* β-carotene.

Shack was judged to be slightly less ripe than Summer Flavor 800 by color and SSC. Although chroma, a*, and lycopene values declined significantly for both cultivars during storage, these components were not correlated (data not shown). Lycopene levels and L* values were negatively correlated, although the linear relationship was weak ($P = 0.001$, $R^2 = -0.258$). The lack of predictive power using reflectance tristimulus colorimetry to determine lycopene content in watermelon flesh has been previously reported and is thought to be due to lack of instrument sensitivity (Perkins-Veazie et al., 2001). Although we were unable to obtain a scanning colorimeter to measure absorbency in this study, other studies with watermelon puree indicate that absorbence at 560 nm, with a haze correction at 700 nm, accurately predicts lycopene content (Davis et al., 2003).

Lycopene loss may have occurred from cutting, juice leakage, or high CO_2. Chilling injury can decrease the pigment content of flesh in uncut watermelons, but we did not find symptoms of chilling injury on the fresh-cut watermelon flesh, such as pitting, excessive juice leakage, or water-soaked lesions. Fresh-cut processing was reported to increase enzyme-catalyzed color reactions and enhance oxidation of exposed tissues (Huxsoll et al., 1989). Fresh-cut grated carrots lost 20–40% of initial β-carotene levels after storage for 8 days at 5 °C (Hägg et al., 1994). Controlled atmosphere storage, with carbon dioxide environments >12 kPa, increased β-carotene degradation in fresh-sliced stored peaches (Wright and Kader, 1997). Conversely, a low O_2 environment slowed carotenoid loss, chlorophyll degradation in breaker stage tomatoes (Goodenough and Thomas, 1981; Nakhasi et al., 1991).

The results from this study indicate that cutting and storing watermelon resulted in slight loss of color saturation and lycopene. The losses did not appear until after 7 days of storage and therefore were not directly due to the cutting process itself. Melon pieces stored in the polyethylene containers at a weight:volume ratio of 1 to 0.7 developed a slight modified atmosphere after 7 days storage. Tissue senescence or the modified atmosphere conditions created during storage may have caused slight degradation of lycopene and color. We did not determine if the modified atmosphere affected the flavor or prevented the development of microorganisms on the fruit.

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