TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2016) 40: 475-488
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doi:10.3906/tar-1509-57

Impact of passive modified atmosphere packaging on physicochemical properties, bioactive compounds, and quality attributes of sweet pomegranates

Nurten SELÇUK, Mustafa ERKAN*
Department of Horticulture, Faculty of Agriculture, Akdeniz University, Antalya, Turkey

Received: 16.09.2015 • **Accepted/Published Online:** 24.02.2016 • **Final Version:** 14.06.2016

Abstract: The effects of two different types of modified atmosphere packaging (MAP) on the physicochemical properties, biochemical composition, and storage quality of sweet pomegranate variety Beynarı were investigated during long-term storage. Pomegranates were harvested at the commercial harvest stage and packed in two different commercial types of MAP (MAP1, sealed in packages made of Xtend® film; MAP2, sealed in bags made of ZOEPAC). Unpacked fruits stored in plastic boxes were used as the control. Following packaging treatments, all packed and unpacked fruit samples were stored at 6 ± 0.5 °C and 90 ± 5% relative humidity for 120 days, and they were removed from storage at 40-day intervals for different quality analyses. Furthermore, after each storage period, fruits were removed and kept at 20 °C for 3 days to simulate a period of shelf-life. During storage, O_2 levels decreased and CO_2 levels increased inside both packages, and a steady-state atmosphere (17.60–11.95 kPa O_2 and 4.40–5.00 kPa CO_2) was obtained at day 40 in cold storage. The MAPs significantly reduced weight loss and external physiological disorders, maintained visual quality, and prevented the decline of skin color, L^* (lightness), C^* (chroma), and h^o (hue angle) compared to control fruit. MAP2 was the most effective packaging in reducing weight loss both in cold storage and shelf-life conditions. Titratable acidity and total soluble solids decreased during storage and shelf-life, and no significant differences ($P > 0.05$) were observed between MAP1 and MAP2. Total phenolic and total anthocyanin contents and antioxidant activity increased slightly until the first 40 days of storage and then decreased during the rest of the storage, although ascorbic acid contents were gradually decreased. Ascorbic acid content was found to be the highest in the control fruit by the end of storage. Contents of organic acids were decreased in all treatments during storage, except for tartaric acid. Malic and tartaric acid contents were higher in control fruit compared to the MAP treatments. However, MAP2 treatment had higher citric acid contents than MAP1 and control fruit.

Key words: *Punica granatum* L., packaging, storage, quality, organic acids

1. Introduction

In recent years, the production and consumption of pomegranate fruit is increasing rapidly throughout the world, mainly due to greater awareness of its nutritive and medicinal attributes. Pomegranates are rich sources of polyphenols, including ellagitannins, gallotannins, ellagic acids, gallagic acids, catechins, anthocyanins, ferulic acids, and quercetins. These polyphenols exhibit various biological activities, such as eliminating free radicals, inhibiting oxidation and microbial growth, and decreasing the risk of cardio- and cerebrovascular diseases and some type of cancers (Mena et al., 2011).

Pomegranate fruit is grown in many different geographical regions, satisfying the nutritional and medicinal needs of populations of various countries (Holland et al., 2009). Turkey is one of the main pomegranate producers and exporters in the world and the production rate is increasing from year to year, mainly in its subtropical Mediterranean region (Ercisli et al., 2007). Although pomegranate is a nonclimacteric fruit it is subjected to continuous physiological and biochemical changes after harvest with severe problems during postharvest handling, storage, and marketing. Appearance, and especially skin and aril color, is an important quality factor for the marketing of pomegranates. Many factors affect appearance, including bruising, water loss, decay, and the development of physiological disorders during storage. In general, the major cause limiting the storage potential of pomegranates is the development of decay, which is often caused by the presence of fungal infection in the blossom end of the fruit at harvest (Hess-Pierce and Kader, 2003). Gray mold, caused by *Botrytis cinerea*, is the most economically important postharvest disease of pomegranates. This problem is aggravated at temperatures higher than 5 °C, which are recommended for pomegranates to avoid chilling injury (internal tissue

* Correspondence: erkan@akdeniz.edu.tr

browning). Thus, the minimum safe temperature for postharvest handling of pomegranates ranges between 5 and 8 °C, depending on varieties and production areas (Elyatem and Kader, 1984). For long-term storage, husk scald is another important factor limiting the commercial storage and marketing potential of the pomegranates, and this symptom appears as superficial skin browning initiating from the stem end of the fruit without affecting the internal tissues and spreading toward the blossom end as the severity increases. Moreover, husk scald increases the susceptibility of the fruit to decay.

Several postharvest conditions have been evaluated for long-term storage of pomegranates, including low-temperature storage (Ben-Arie and Or, 1986), intermittent warming (Artés et al., 1998), controlled atmosphere (CA) (Artés et al., 1996), and modified atmosphere (MA) storage (D'Aquino et al., 2010; Selcuk and Erkan, 2014, 2015). Among these procedures, the most successful method in reducing decay and physiological disorders is the use of CA storage, which with a combination of 5 kPa O_2 and 15 kPa CO_2 has been shown to extend the postharvest life of pomegranates for up to 5 months at 7 °C (Hess-Pierce and Kader, 2003). However, CA storage facilities are not always economical and available in many countries. The use of MA packaging (MAP), however, is a simple, economical, and effective method in delaying postharvest deterioration and maintaining the postharvest quality of pomegranates.

MAP technology has been successfully used to maintain postharvest quality and to prolong the storage period of many fruits and vegetables. By creating higher CO_2 and lower O_2 concentrations in the surrounding atmosphere of the commodities, decay, respiration rate, ethylene production, and enzymatic activity can be controlled, resulting in an increase in postharvest quality (Kader and Watkins, 2000; Caleb et al., 2012). MAP may also prevent weight loss and fruit shriveling by creating a higher relative humidity in the surrounding environment of the products (Zagory et al., 1989). MAP for pomegranates has been shown to reduce weight loss, shrinkage, scald development, and decay; delay senescence; and maintain postharvest fruit quality of pomegranates by several researchers (D'Aquino et al., 2010; Selcuk and Erkan, 2014, 2015).

There are many local cultivars exhibiting a wide range of sizes and sensory properties, including hard seeds, sweet, sour-sweet, or sour arils. Among the several pomegranate (*Punica granatum* L.) varieties grown in Turkey, the sweet variety Beynarı is the most common and is widely sought by consumers on the market due to its excellent sensory quality attributes and large fruit size with sweet and big light pink arils. The season of availability of this variety is usually short and lasts for only a few weeks, due partly to high demand and lack of innovative postharvest treatments to extend the shelf-life. Although MAP has been reported to prolong postharvest quality of different varieties of pomegranate fruit, no study has been conducted yet on the effect of MAP on Beynarı pomegranates. The objective of this study was to determine the effect of two different MAPs on extension of the storage life, quality attributes, antioxidant compounds, and storability of sweet Beynarı pomegranates.

2. Materials and methods

2.1. Fruit samples

Beynarı is a popular sweet Turkish variety (*Punica granatum* L.) and typically grown on the subtropical Mediterranean coast of Turkey. The harvest time of the fruit extends from mid-October to mid-November. This cultivar is late-season, ripening with delicious sweet and large light pink arils. The arils represent 50% of the whole fruit and contain an average moisture content of 75%. Pomegranates for this experiment were harvested in mid-October by hand at the commercial maturity stage (size 350–400 g, total soluble solids 15.56%, total titratable acidity 0.50%) from a commercial orchard in Antalya, Turkey. On the same day, harvested fruits were immediately transported by a ventilated truck to the postharvest laboratory of the Department of Horticultural Science and stored at 6 °C for 120 days in a cold storage unit of Akdeniz University. Samples were selected for uniformity in size, shape, and color. Fruits with signs of mechanical damage, sunburn, cracks, cuts and bruises, disease, and pest damage were discarded.

2.2. Fruit packaging and storage

The fruit were randomly divided into three lots and each lot was given one of the following three treatments: 1) control fruits were stored in open plastic boxes; 2) MAP1 fruits were sealed in packages made of Xtend® film XF.A12 (65 cm in length × 55 cm in width, Code: 815-PG3, Patent No.: 6190710, StePac Co., Antalya, Turkey); 3) MAP2 fruits were sealed in bags made of ZOEPAC (65 cm in lengthy × 70 cm in width, Patent No.: 203563, Serpak Co., Antalya, Turkey).

After sorting, fruits were placed in totally opened plastic boxes (40 cm × 60 cm × 14 cm) (18 fruits per box) and packed in two different MA bags. The fruits were stored at 6 ± 0.5 °C and 90 ± 5% relative humidity (RH) for up to 120 days. After 40, 80, and 120 days of storage, 36 fruits from each experimental unit were transferred to an evaluation room; while 18 of the pomegranates (6 fruits per replication) were analyzed immediately for quality assessment, the rest of the pomegranates (18 fruits) were evaluated after having been kept for 3 days at 20 °C under shelf-life (SL) conditions.

2.3. CO_2 and O_2 levels inside MAPs

Changes in CO_2 and O_2 levels inside the packages were monitored during each evaluation period using an O_2 and CO_2 gas analyzer (Servomex Oxygen Analyzer 570A, Servomex Ltd., UK and Bühler CO_2 analyzer IR-3000, Bühler Technologies, Germany). The measurements were taken from 2 different sides of each package. A total of 6 measurements were made for 3 packages for each treatment. The results were reported as O_2 and CO_2 kPa.

2.4. Physicochemical analyses

2.4.1. Weight loss and visual quality assessments

Samples of 36 fruits (18 fruits for storage and 18 fruits for shelf-life condition) per packaging treatment were evaluated for physical and chemical attributes at harvest and at the end of both storage and SL periods. At harvest, individually numbered fruits were weighed, and at the end each of storage period and subsequent SL periods three replicates were weighed again and weight loss was determined and expressed as percent loss from initial weight. The overall visual quality was conducted on the base of a 5-point hedonic scale, where: 1 = very poor; 2 = poor (limit of marketability); 3 = good; 4 = very good; 5 = excellent (Selcuk and Erkan, 2015).

2.4.2. Skin surface color

External skin color (three different measurements at three equidistant points on the equatorial region of each individual fruit) was measured on 18 fruits from each replicate using a chromameter (CR 200, Minolta, USA), which provided CIE L^*, a^*, and b^* values. Negative a^* values indicate green and higher positive a^* values indicate a red color. Higher positive b^* values indicate a more yellow skin color and negative b^* indicate a blue color. These values were then used to calculate hue degree, where 0° = red-purple, 90° = yellow, 180° = bluish green, and 270° = blue, and chroma, which indicates the intensity or color saturation (Selcuk and Erkan, 2015).

2.4.3. Titratable acidity and total soluble solids

Arils were extracted by hand and squeezed with cheesecloth and the juice obtained was analyzed for titratable acidity (TA) and total soluble solids (TSS). TA was determined by titrating 2 mL of fruit juice in 38 mL of distilled water with 0.1 N NaOH to an end point of pH 8.1 and expressed as g/100 g of citric acid. TSS was measured by a digital refractometer (Model Number REF121, Atago, China) and expressed as %.

2.5. Total phenolics, total anthocyanin content, and determination of antioxidant activity using DPPH assay

To prepare the fruit extracts, 5-g samples of arils from each replicate were extracted twice with 10 mL of 80% acetone containing 0.2% formic acid using a homogenizer (Heidolph Silent Crusher M Homogenizer P/N-595-06000-00, Germany) for 2 min and then centrifuged at 20,000 × *g* for 20 min at 4 °C. The supernatants were combined to make a final volume of 25 mL for analysis, stored at –20 °C, and then used for analysis of total phenolics, total anthocyanins, and antioxidant activity.

The total phenolics content was measured using the method described by Spanos and Wrolstad (1990). For this purpose, 100 µL of the sample extract, 900 µL of Nanopure water, and 5 mL of 0.2 N Folin–Ciocalteu reagent were added to a 15-mL volumetric flask. The contents were mixed and allowed to stand for 5 min at room temperature. Next, 4 mL of saturated sodium carbonate (75 g L^{-1}) was added. Solutions were mixed and allowed to stand at room temperature for 2 h. The absorbance of the final solution was recorded with a spectrophotometer (Analytic Jena UV-Vis L 40, Germany) at 765 nm with respect to the blank solution (80% aqueous acetone). The results were expressed as milligram of gallic acid equivalent per 100 grams of fresh weight (mg GAE 100 g^{-1} fw).

Total anthocyanin content in pomegranate extracts was measured using the pH differential method (Fuleki and Francis, 1968). The absorbance was measured spectrophotometrically at 510 and 700 nm in buffers at pH 1.0 and 4.5, using $A = [(A_{510} - A_{700})_{pH\ 1.0} - (A_{510} - A_{700})_{pH\ 4.5}]$. The results were expressed as milligram of cyanidin-3-glucoside equivalent per 100 grams of fresh weight (mg Cya 3 100 g^{-1} fw).

The antioxidant activity of the samples was analyzed by using the DPPH assay according to the procedures of Maisuthisakul et al. (2007). First, 100 µL of the diluted sample extract (prepared at 5 different concentrations providing 10%–90% inhibition for the DPPH radical) was added into 4 mL of freshly prepared DPPH (2,2-diphenyl-1-picrylhydrazyl radical) solutions (6×10^{-5} M in MeOH). The mixtures were shaken and kept in the dark at room temperature for 30 min. Absorbance values of the final solutions were recorded at 515 nm using a spectrophotometer (Analytic Jena UV-Vis L 40) with respect to a control solution (80% MeOH instead of extract in DPPH solution). The antioxidant activity of the samples was expressed as percentage inhibition of the DPPH radical which was calculated by using the following equation:

$$I\ (\%) = [(A_c - A_s) / A_c] \times 100,$$

where I is the inhibition percentage and A_c and A_s are the absorbance values of the control and test samples, respectively.

The sample extract concentration providing 50% inhibition (EC_{50}) of the DPPH radical was calculated by plotting the concentration versus inhibition percentage (%). Using the same procedure, the EC_{50} value of Trolox solution was also determined to compare antioxidant activity of the samples. Antioxidant activity of samples was also expressed as Trolox equivalent antioxidant capacity (TEAC).

2.6. Extraction and HPLC analysis of ascorbic acid and organic acids

An Agilent 1100 series HPLC system integrated with an autosampler (G1313A), including temperature control for the column (G1316A), a degasser system (G1379A), a quaternary gradient pump (G1311A), a photodiode-array detector (G1315B), a refractive index detector (1200 series), and a software package for system control and data acquisition (Agilent Chemstation software), was used for analyses.

Ascorbic acid was extracted from the pomegranate arils following a modified method of Karhan et al. (2004). Fruits were homogenized for 1 min at medium speed in a blender. The homogenate (25 g) was added to 75 mL of 6% metaphosphoric acid with a homogenizer (Heidolph Silent Crusher M Homogenizer P/N-595-06000-00) at medium speed for 1 min. Extracts were centrifuged at 20,000 × *g* for 15 min at 4 °C and the supernatant was collected into a 100-mL volumetric flask. One milliliter of the extract was filtered through a membrane filter (0.45 µm, Macherey Nagel, Germany) and 20 µL of sample was used for HPLC analysis of ascorbic acid. Extracts were analyzed using a liquid chromatograph equipped with a diode array detector monitoring at 254 nm. Separations were achieved on a Luna C18 (2) column (4.6 × 150 mm, 5 µm) fitted with a guard column (4 × 3.0 mm, 5 µm) of the same material (Phenomenex, USA). HPLC elution was carried out at 30 °C using 20 mM KH_2PO_4 (pH 3.0)/acetonitrile (95:5) as the mobile phase at a flow rate of 0.7 mL min^{-1}. Results were expressed as mg ascorbic acid 100 g^{-1} fw.

For organic acids, 25 g of pomegranate arils was weighed and homogenized at medium speed for 5 min with 25 mL of deionized water and then shaken for 30 min. The homogenates were centrifuged at 20,000 × *g* for 20 min at 30 °C and the supernatant was collected into a 50-mL volumetric flask. One milliliter of the extract was filtered through a membrane filter (0.45 µm, Macherey Nagel, Germany) and 20 µL of sample was used for HPLC analysis of organic acids (citric, malic, succinic, tartaric, and oxalic) (Selcuk and Erkan, 2015).

Organic acids were analyzed isocratically with a Rezex ROA-Organic Acid H+ (8%) (8 µm, 300 × 7.8 mm I.D., Phenomenex) column. HPLC elution was carried out at 55 °C using 0.005 N sulfuric acid as the mobile phase at a flow rate of 0.5 mL min^{-1}. Organic acids were identified and quantified using a UV detector with wavelength set at 210 nm and by comparison of retention times and peak areas with standard solutions of known organic acids. The contents were expressed as mg 100 g^{-1} fw.

Authentic standard compounds were purchased from Merck KGaA (Germany) and Sigma-Aldrich (Chimie SARL, France). For ascorbic acid and organic acid quantification, external standard calibration curves were determined for the identified components. Five injections were made for each calibration level. For the linear regression of the curves of external calibration standards, r^2 values were between 0.995 and 0.999.

2.7. Statistical analysis

The experimental design was a completely randomized factorial design. Groups of three replicates of 36 fruits per treatment for the cold storage and SL periods were established. The data were analyzed using the Statistical Analysis System software program, version 9.0 (SAS Inst., Cary, NC, USA) by ANOVA and treatment means were statistically compared using Duncan's multiple range test ($P \leq 0.05$).

3. Results and discussion

3.1. O_2 and CO_2 levels inside the MAPs

The changes in O_2 and CO_2 levels in MAP1 and MAP2 during storage are shown in the Figure. As expected, the levels of O_2 inside the packages decreased, and CO_2 levels increased during storage due to the continuous process of respiration after harvest. An equilibrium-modified atmosphere (steady state) was attained within the packaging after 40 days of storage. The O_2 and CO_2 levels at 120 days of storage were 17.60 kPa and 4.40 kPa for MAP1 and 12.00 kPa and 5.00 kPa for MAP2, respectively. MAP1 maintained similar CO_2 levels to that of MAP2. However, there was a relatively lower O_2 level in MAP2 compared to MAP1 during 120 days of storage. The differences in the O_2 levels between the MAP systems can be explained by the differences in their O_2 and CO_2 permeabilities. In general, the O_2 levels inside the tested packaging materials were similar to those reported for other pomegranates (cultivars Hicrannar and Hicaznar) in MAPs constructed with patented films (Selcuk and Erkan, 2014, 2015). Similar results have been reported for Mollar de Elche sweet pomegranates (Artés et al., 2000). Pomegranate fruit

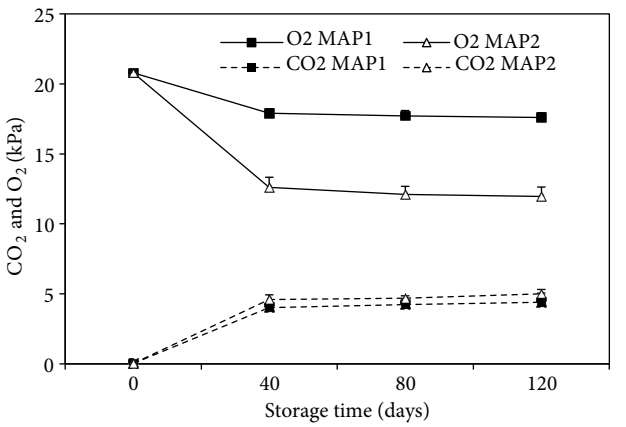

Figure. Changes in CO_2 and O_2 levels inside MAPs during storage at 6 °C.

is a nonclimacteric fruit, with a relatively low respiration rate that declines with time after harvest, and it produces trace amounts of ethylene (Erkan and Kader, 2011). Artés et al. (1998) recommended a controlled atmosphere of 5 kPa O_2 + 0 kPa to 5 kPa CO_2 storage at 5 °C with RH above 95% during the storage of the Mollar cultivar to minimize decay, weight loss, and chilling injuries. In contrast, Hess-Pierce and Kader (2003) reported that the optimal controlled atmosphere condition for the pomegranate cultivar Wonderful was 5 kPa O_2 + 15 kPa CO_2 at 7.5 °C.

3.2. Weight loss and visual quality

Weight loss gives direct information about the storage quality of pomegranates, which is crucial and valuable, due to the fact that every loss in weight leads to an economic loss for storage operators. In general, the weight loss of the fruits progressively increased with storage time, but compared with control fruit, the weight loss of packaged pomegranates was significantly reduced. The weight loss of control fruit reached 11.77% while those of fruits packaged in MAP1 and MAP2 were only 4.47% and 1.43%, respectively, after 120 days, which indicated that MAP2 was fairly effective in preventing weight loss (Table 1). The increase in weight loss continued in relation to the duration of the SL period. At SL conditions, the control fruit lost 13.73% of its weight, while those treated with MAP1 and MAP2 lost 4.91% and 1.52% of their initial weight, respectively, after 120 + 3 SL days (Table 2). The weight loss in pomegranates is mainly caused by water transpiration and CO_2 loss during respiration. High porosity of the fruit peel, which permits free water vapor movement of pomegranates, makes them susceptible to rapid water loss, resulting in shriveling and desiccation. Shriveling symptoms in pomegranates are noticeable only when weight loss exceeds 5% or more of the initial weight (Elyatem and Kader, 1984). In this study, both MAPs significantly reduced the water and weight loss of pomegranates during the 120 days of storage and SL period, and the lowest weight loss was obtained from the MAP2 treatment. It could be assumed that the packaging materials established a microenvironment with high

Table 1. Weight loss, visual quality, and L^*, C^*, and h° values of Beynarı pomegranates during storage at 6 °C.

Testing index	Treatments	Storage time			
		Day 0	Day 40	Day 80	Day 120
Weight loss (%)	Control	-	5.47c	8.32b	11.77a[a]
	MAP1	-	2.08f	3.19e	4.47d
	MAP2	-	0.97g	1.21fg	1.43fg
Visual quality[b] (index number)	Control	5.00a	4.00bc	3.33c	2.33d
	MAP1	5.00a	5.00a	4.00bc	3.33c
	MAP2	5.00a	5.00a	4.33ab	3.67bc
L^*	Control	73.30a	66.43c	65.85cd	63.89d
	MAP1	73.30a	68.92b	68.20bc	67.66bc
	MAP2	73.30a	68.98b	68.27bc	68.18bc
C^*	Control	42.93a	38.14bcd	37.21cd	36.84d
	MAP1	42.93a	39.10b	38.66b	38.47bc
	MAP2	42.93a	39.13b	38.72b	38.66b
h^o	Control	92.93a	83.38c	76.37d	73.70e
	MAP1	92.93a	86.89b	81.35c	77.03d
	MAP2	92.93a	86.54b	81.74c	78.22d

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

[b] The visual quality was assessed on the basis of a 5-point hedonic scale, where: 1 = very poor; 2 = poor (limit of marketability); 3 = good; 4 = very good; 5 = excellent.

Table 2. Weight loss, visual quality, and L^*, C^*, and h^o values of Beynarı pomegranates after storage at 6 °C plus 3 days at 20 °C.

Testing index	Treatments	Storage time			
		Day 0	Day 40 + 3 SL	Day 80 + 3 SL	Day 120 + 3 SL
Weight loss (%)	Control	-	7.53c	10.63b	13.73a[a]
	MAP1	-	2.62f	3.67e	4.91d
	MAP2	-	1.06g	1.31g	1.52g
Visual quality[b] (index number)	Control	5.00a	3.67bc	3.00c	1.67d
	MAP1	5.00a	4.33ab	3.67bc	3.00c
	MAP2	5.00a	4.33ab	3.67bc	3.00c
L^*	Control	73.30a	68.85b	64.77c	63.62c
	MAP1	73.30a	73.01a	72.44a	68.85b
	MAP2	73.30a	72.01a	71.40ab	68.81b
C^*	Control	42.93a	37.86bcd	36.57cd	36.30d
	MAP1	42.93a	38.83b	38.78b	38.03bc
	MAP2	42.93a	38.68b	38.62b	38.51b
h^o	Control	92.93a	81.98c	78.04d	71.36e
	MAP1	92.93a	84.31c	82.36c	77.29d
	MAP2	92.93a	88.44b	83.39c	78.35d

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.
[b] The visual quality was assessed on the basis of a 5-point hedonic scale, where: 1 = very poor; 2 = poor (limit of marketability); 3 = good; 4 = very good; 5 = excellent.

relative humidity and low O_2 and high CO_2 levels. All these factors help to slow down the respiration and transpiration rates, thereby limiting weight loss. These results are in agreement with previous research reporting on quality of MA-packed pomegranates (D'Aquino et al., 2010; Selcuk and Erkan, 2014, 2015).

The visual quality of pomegranates is often the first of many quality attributes judged by the consumer and is, therefore, extremely important in overall product acceptance by consumer. Many factors affect visual quality, including bruising, water loss, decay, and the development of physiological disorders such as husk scald during storage. In this study the overall visual quality, reflecting the acceptance or rejection of the product from the consumer's point of view, was monitored, observing a reduction in visual quality of pomegranates with storage time in all treatments during the entire storage period (Tables 1 and 2). A significant difference in visual quality was found between control and MAP-treated fruit during the storage and SL periods. After 120 days of storage, control fruits were scored at the limit of marketability (score = 2.33), while those treated with MAP1 and MAP2 were scored as good (score = 3.33 and 3.67, respectively). However, after 120 + 3 SL days of storage, control fruits were rejected (score = 1.67), while those treated with MAP1 and MAP2 were still scored as good (score = 3.00). In the control group visual quality was strongly affected by weight loss, which leads to shriveling and browning of the skin. This is in agreement with the previous finding of D'Aquino et al. (2010) that the skin of the control fruit, which experienced excessive transpiration, lost its natural color, shriveled, and finally hardened. Selcuk and Erkan (2014, 2015) reported that visual appearance in pomegranates was strongly affected by weight loss, decay, skin shriveling, and browning during cold storage, and MAP reduced these quality losses. Decay incidence was not observed in pomegranates subjected to control or MAP treatments during the entire storage period. In contrast to our findings, Artés et al. (1998) observed visible decay occurrence in Mollar de Elche sweet pomegranate fruit

stored at 5 °C after 12 weeks of storage. Similarly, Selcuk and Erkan (2014) observed visible decay occurrence in Hicrannar sweet pomegranates stored at 6 °C after 60 days of storage. D'Aquino et al. (2010) observed that there were no significant differences in decay incidence between wrapped and control pomegranates after 6 and 12 weeks of storage, while after an additional SL period of 7 days at 20 °C, wrapped fruit had significantly higher decay levels than control fruit. Differences in decay incidence and severity in pomegranates could be due to the level of infection by pathogens at harvest, since the fruits were not treated with postharvest fungicides before storage. It may also be related to preharvest temperatures, fruit maturity, and cultural practices (Elyatem and Kader, 1984).

3.3. Skin color

Skin color is an important quality parameter for marketing of pomegranates. Color values are presented as lightness (L^*), hue angle ($h°$), and chroma (C^*) by conversion from a^* and b^*. The $h°$ values indicate how green (180) or yellow (90) a fruit is, and C^* describes the vividness to dullness of the color. The L^* values significantly decreased with storage time compared to the freshly harvested fruit (73.30). During the cold storage, a significant decline in L^* (darker fruit) was observed in control fruit, probably because of surface moisture loss, which could be responsible for the observed darker color (Selcuk and Erkan, 2015). However, MAP1- and MAP2-treated fruits showed significantly higher L^* (brighter) values. Similarly, the decrease in L^* was higher in control fruit than in MAP1 and MAP2 treatments after 120 + 3 SL days of storage period.

The initial C^* value was 42.93 in pomegranates. The C^* values were significantly decreased to 36.84, 38.47, and 38.66 in control, MAP1, and MAP2 treatments, respectively, at the end of 120 days of storage (Table 1). Similar to the cold storage period, C^* values decreased significantly ($P \leq 0.05$) during the SL period. The decreases in C^* values were delayed by the use of MAPs, without significant differences between MAP1 and MAP2 (Table 2). Both groups of MAP-treated fruit had higher C^* values than control fruit, indicating an increase in browning of the affected area caused by scald.

The initial $h°$ value of pomegranates was 92.93. Although $h°$ values of both control and MAP-treated fruits decreased significantly throughout the storage and SL periods, the use of MAPs significantly reduced the loss of $h°$ values in pomegranates. Beynarı pomegranates have a green skin color, and the main pigment contributing to the color is the chlorophyll. The $h°$ values were lower for the control fruit than for the MAP1- and MAP2-treated fruit at 120 days of storage and 120 + 3 SL days of storage period. This means that the decrease in green color and increase in brownish color were higher in control fruit than in MAP1- and MAP2-treated fruit at the end of storage, and this behavior was also observed after the SL period.

Both the MAP1- and MAP2-treated fruit had higher L^*, C^*, and $h°$ values than control fruit at the end of storage, indicating a retention of the initial green color that may be due to slow rate of respiration and limited water loss and/or limited chlorophyll degradation, which is responsible for the green color. Retention of the green color due to limited chlorophyll degradation in fruits and vegetables can also be initiated by the elevated CO_2 and/or depleted O_2 in package concentrations and the establishment of a steady-state microenvironment inside the package. Our results confirmed that MAP treatments had better fruit color maintenance throughout the storage duration and our findings are in agreement with previous studies (D'Aquino et al., 2010; Selcuk and Erkan, 2014, 2015). Contrary to our results, Nanda et al. (2001) reported slight changes in the color of cultivar Ganesh stored over a 12-week duration and there were no significant differences in fruit color at 8 °C, 15 °C, and 25 °C.

3.4. Titratable acidity and total soluble solids

TA and TSS are important determinants of fruit taste and consumer acceptability. At harvest, the TA was 0.50 g/100 g citric acid, and it decreased significantly with storage time in all treatments during storage and SL conditions (Tables 3 and 4). However, no significant differences among treatments were found, with a range of 0.33 to 0.35 g/100 g of citric acid during 120 days of storage. A similar reduction was also observed during the SL periods, and no significant differences among treatments were found, with a range of 0.31 to 0.33 g/100 g citric acid after 120 + 3 SL days of storage at 20 °C (Table 4). Pomegranate fruit is classified as a nonclimacteric fruit and maturation and ripening occur on the plant prior to harvest; fruits harvested before ripening do not continue ripening after harvest in storage and are of inferior eating quality (Elyatem and Kader, 1984). Furthermore, pomegranate fruits do not have starch or other carbohydrates to provide energy for respiration, and they use acids and sugars for this process.

The taste of pomegranate is determined mainly by juice TSS and the ratio between TSS and TA. The TSS contents in all treatments decreased significantly during cold storage and SL periods compared to the respective initial values (15.56%) (Tables 3 and 4). However, no significant differences in TSS content were observed between control and MAP-treated fruits in both cold storage and SL conditions. This observed reduction could mostly be explained by the degradation of sugars with prolonged storage period in pomegranates (Fawole and Opara, 2013).

Accordingly, previous reports have shown that in pomegranates, the use of MAPs with high CO_2 and low O_2 atmospheres has a slight or no effect on the evolution of these chemical parameters (Artés et al., 2000; D'Aquino

Table 3. Titratable acidity, total soluble solids, total phenolic content, total anthocyanin content, and antioxidant activity of Beynarı pomegranates during storage at 6 °C.

Testing index	Treatments	Storage time			
		Day 0	Day 40	Day 80	Day 120
TA (g/100 g citric acid)	Control	0.50a	0.43c	0.39d	0.33e[a]
	MAP1	0.50a	0.46b	0.40d	0.34e
	MAP2	0.50a	0.45b	0.39d	0.35e
TSS (%)	Control	15.56a	15.30ab	15.02bc	14.83cd
	MAP1	15.56a	15.08bc	14.78cd	14.39d
	MAP2	15.56a	15.08bc	14.80cd	14.46d
Total phenolic contents (mg GAE 100 g^{-1} fw)	Control	162.6a	169.7a	162.5a	157.5ab
	MAP1	162.6a	168.8a	144.4b	141.9b
	MAP2	162.6a	168.7a	144.7b	142.2b
Total anthocyanin contents (mg Cya 3 100 g^{-1} fw)	Control	1.32c	2.36a	2.22a	1.98ab
	MAP1	1.32c	2.40a	2.01ab	1.57bc
	MAP2	1.32c	2.16a	2.04ab	1.59bc
Ascorbic acid contents (mg 100 g^{-1} fw)	Control	2.22a	1.48b	1.08c	0.51d
	MAP1	2.22a	1.27bc	0.55d	0.14e
	MAP2	2.22a	1.09c	0.57d	0.13e
EC_{50} values[b] (mg fw mg^{-1} DPPH)	Control	62.97cd	60.37d	61.23cd	70.32abc
	MAP1	62.97cd	61.22cd	68.33ad	76.85a
	MAP2	62.97cd	61.36cd	66.57bcd	74.33ab

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.
[b] EC_{50} of Trolox was determined as 0.12 ± 0.01 mg mg^{-1} DPPH. TA, titratable acidity; TSS, total soluble solids.

et al., 2010; Selcuk and Erkan, 2015). Similarly, storage of pomegranates in 2–5 kPa O_2 and 10–15 kPa CO_2 had no adverse effect on TA, TSS, and flavor (Hess-Pierce and Kader, 2003). On the contrary, Ghafir et al. (2010) reported significant increases in TSS content in pomegranate fruit during prolonged storage.

3.5. Total phenolic, total anthocyanin, and ascorbic acid contents and antioxidant activity

Phenolic compounds have been reported as the major antioxidant components in pomegranates. These antioxidant compounds have been widely reported to have beneficial effects on the maintenance of health and the prevention of cancer and cardiovascular diseases (Koyama et al., 2010). In general, total phenolic contents of pomegranates increased slightly until 40 days of storage. Thereafter, the total phenolics content of all treatments declined during the rest of the storage in all the treatments (Table 3). The total phenolics content of control fruit was higher than in MAP treatments at 80 days of storage, which indicated that MAP causes the inhibition of total phenolics content. This increase was also observed in the control fruit until 40 + 3 SL days of storage, while total phenolics decreased in MAPs treatments during the SL period (Table 4). The total phenolics content of control fruit was higher than in MAP treatments at 40 + 3 SL days of storage. Cisneros-Zevallos (2003) reported that the accumulation of bioactive compounds, such as phenolics, is related to different postharvest abiotic stresses, such as cold storage and atmospheric conditions. These increases were delayed in pomegranates stored under MAP conditions, as shown in our previous papers (Selcuk and Erkan, 2014, 2015). Earlier studies in strawberries and pomegranate arils

Table 4. Titratable acidity, total soluble solids, total phenolic content, total anthocyanin content, and antioxidant activity of Beynarı pomegranates after storage at 6 °C plus 3 days at 20 °C.

Testing index	Treatments	Storage time			
		Day 0	Day 40 + 3 SL	Day 80 + 3 SL	Day 120 + 3 SL
TA (g/100 g citric acid)	Control	0.50a	0.44c	0.36def	0.33efg[a]
	MAP1	0.50a	0.49ab	0.37de	0.32fg
	MAP2	0.50a	0.45bc	0.38d	0.31g
TSS (%)	Control	15.56a	15.46ab	14.98c	14.58d
	MAP1	15.56a	15.45ab	15.10c	14.34d
	MAP2	15.56a	15.26abc	14.97c	14.43d
Total phenolic contents (mg GAE 100 g^{-1} fw)	Control	162.6ab	177.6a	158.1b	154.8b
	MAP1	162.6ab	154.1b	149.3b	149.2b
	MAP2	162.6ab	151.5b	149.8b	147.7b
Total anthocyanin contents (mg Cya 3 100 g^{-1} fw)	Control	1.32d	2.12ab	2.21a	2.04abc
	MAP1	1.32d	2.09abc	1.63bcd	1.55cd
	MAP2	1.32d	1.69ad	1.49d	1,39d
Ascorbic acid contents (mg 100 g^{-1} fw)	Control	2.22a	1.28b	0.84c	0.31d
	MAP1	2.22a	1.21bc	0.21d	0.14d
	MAP2	2.22a	1.26b	0.24d	0.15d
EC_{50} values[b] (mg fw mg^{-1} DPPH)	Control	62.97cd	60.88d	65.78bcd	73.40ab
	MAP1	62.97cd	67.54ad	71.37abc	75.27a
	MAP2	62.97cd	67.71ad	69.34ad	75.86a

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.
[b] EC_{50} of Trolox was determined as 0.12 ± 0.01 mg mg^{-1} DPPH. TA, titratable acidity; TSS, total soluble solids.

showed that elevating CO_2 partial pressures in storage usually resulted in the prevention of significant increases in the levels of polyphenols (Gil et al., 1997; Holcroft et al., 1998).

Beynarı pomegranates contained small amounts of anthocyanins (1.32 mg Cya 3 100 g^{-1} fw) at harvest (Table 3). The total anthocyanin content in all pomegranates exhibited a significant increase during the first 40 days, reaching a maximum accumulation, and then decreased for all the treatments during cold storage, and these values were relatively higher than the harvest value. The total anthocyanin content of control fruit increased until 80 + 3 SL days of storage, and then declined during the rest of the storage. This increase was also observed for MAP treatments until 40 + 3 SL days, and after this time a decrease was observed (Table 4). Control fruit had higher total anthocyanin contents than the fruit stored in MAP1 or MAP2 during cold storage and SL periods (Tables 3 and 4). It is already known that anthocyanin synthesis continues after harvest and also in low-temperatures storage. Synthesis of anthocyanin pigments in fruits during storage at low temperatures has been reported in pomegranates (Ben-Arie et al., 1984). Furthermore, anthocyanin synthesis and/or degradation might have been affected by CO_2 and O_2 levels. This is correlated with the activity of the anthocyanin biosynthetic pathway enzymes (Holcroft et al., 1998; Miguel et al., 2004). In agreement with our results, Artés et al. (2000) observed an increase in total anthocyanin content stored in perforated polypropylene film and control fruit at 5 °C. However, at the end of the SL period, all treatments suffered a decrease in total anthocyanin content. Similar changes in anthocyanin content were observed in pomegranates, with an initial increase followed by a decrease in content during storage (Miguel et al., 2004; Selcuk and Erkan, 2014). However, D'Aquino et al. (2010) found that the content

of total anthocyanins did not change in control fruit, but progressively declined in wrapped pomegranates, especially during the SL period.

Ascorbic acid has an important role as a phytochemical, due to its functionality as an antioxidant besides its vitamin C activity (Saxena et al., 2009). The initial ascorbic acid content of pomegranates was found to be 2.22 mg 100 g^{-1} fw and it decreased significantly in all treatments during storage and SL periods (Tables 3 and 4). Control fruit had higher ascorbic acid contents than the fruit stored in MAP1 or MAP2 during storage and SL periods (Tables 3 and 4). Lower ascorbic acid retention in MAP-treated fruit might be due to delayed biosynthesis or fast degradation of ascorbic acid. The effect of elevated CO_2 on ascorbic acid content varies among commodities and is dependent on CO_2 levels, storage temperatures, and durations. Generally, high CO_2 levels in the storage atmosphere cause a degradation of ascorbic acid (Lee and Kader, 2000). These results in the present study were in agreement with the earlier report of MAP of pomegranates in similar packaging materials (Selcuk and Erkan, 2015). Artés et al. (1996) investigated different controlled atmosphere conditions in pomegranate cultivar Mollar, and a decrease in ascorbic acid of pomegranates in all treatments during SL was reported. Arendse et al. (2014) and O'Grady et al. (2014) also reported a decrease in ascorbic acid content of pomegranates at different storage temperatures and an extended storage period. On the contrary, Sayyari et al. (2010) found an increase in ascorbic content in Mollar de Elche pomegranates treated with different oxalic acid concentrations (2, 4, and 6 mM). Miguel et al. (2006) also observed a significant increase in ascorbic acid concentration in Mollar de Elche and Assaria fruits stored at 5 °C for 4 months.

Phenolics, anthocyanins, and ascorbic acid are the main compounds responsible for antioxidant activity in pomegranate (Gil et al., 2000). The EC_{50} parameter was widely used by different authors to measure the antioxidant power (Brand-Williams et al., 1995; Vinson et al., 1995), and according to them, the lower EC_{50} reflects higher antioxidant power. In the present study, EC_{50} values decreased slightly during the first 40 days of storage and then increased in all treatments (Tables 3). This decrease was also observed for control fruit during the SL period until 40 + 3 SL days, and after this time it increased (Tables 4). However, no significant difference in the EC_{50} values was found between control and MAP-treated pomegranates at the end of storage and SL conditions (Tables 3 and 4). Individual phenolic components such as ellagic acid derivatives and hydrolysable tannins as well as anthocyanins have been implicated in the antioxidant capacity of pomegranate fruit (Gil et al., 2000; Shwartz et al., 2009; Fawole and Opara, 2013). In the present study, we observed changes in total phenolics compatible with the trends observed in the antioxidant capacity exhibited by the fruit during storage. Our findings are in agreement with Ayhan and Eştürk (2009), who reported an increase in antioxidant activity in pomegranate arils until the 9th day of storage and then a decrease under passive and active MAPs with low or no O_2. López-Rubira et al. (2005) investigated the SL and overall quality of minimally processed pomegranate arils under MAP and treated with UV-C. The authors observed that arils stored at 5 °C for 13 or 15 days showed no significant changes in anthocyanin as well as antioxidant activity. Arendse et al. (2014) also reported that the radical scavenging activity (RSA) of pomegranates declined in all storage regimes with storage time. Between 2 and 3 months of storage, RSA declined by over 56% in fruit stored at 5 °C, 7.5 °C, and 10 °C. Furthermore, RSA levels in fruit stored at 7.5 °C declined significantly to the lowest levels (78%) after 5 months of storage. On the contrary, Gil et al. (1996) investigated the influence of MAPs of perforated polypropylene and oriented polypropylene (40 μm) on the anthocyanin of minimally processed pomegranates (Mollar de Elche) stored at 8, 4, and 1 °C for 7 days. At the end of the SL period, total anthocyanins had decreased in the samples stored at 8 and 4 °C, whereas significant increases were observed in arils stored at 1 °C under MAP.

3.6. Organic acid contents

Organic acids, including citric, malic, oxalic, acetic, fumaric, tartaric, ascorbic, quinic, and succinic acids in pomegranate juice, are important components that contribute to flavor attributes and largely affect taste characteristics and organoleptic quality (Melgarejo et al., 2000). The amounts and types of organic acids differ among pomegranate cultivars, cultural practices, and regional climate and soil characteristics (Poyrazoğlu et al., 2002). Our results showed that malic acid is the main organic acid in Beynarı pomegranate arils (the content at harvest being 640.96 mg 100 g^{-1} fw), and oxalic and citric acids are the second predominant organic acids in pomegranates (247.26 and 169.94 mg 100 g^{-1} fw, respectively), with low concentrations of succinic and tartaric acid also recorded (69.37 and 8.94 mg 100 g^{-1} fw, respectively) (Table 5), as reported previously in other sweet pomegranate cultivars (Mirdehghan et al., 2007). In Turkish pomegranate citric, malic, and oxalic acids were the three major organic acids (Poyrazoğlu et al., 2002).

A general trend of a decrease in malic acid content was observed as the storage time increased for all treatments. This decrease was also observed for all samples during SL conditions. Control fruit had higher malic acid contents than the fruit stored in MAP1 or MAP2 during storage. At the end of 120 days of storage, the malic acid content recorded was the highest for the control fruit (448.13 mg

Table 5. Organic acids contents of Beynarı pomegranates during storage at 6 °C.

Organic acids	Treatments	Storage time			
		Day 0	Day 40	Day 80	Day 120
Malic acid (mg 100 g^{-1} fw)	Control	640.96a	562.52b	514.84bc	448.13cd[a]
	MAP1	640.96a	523.13b	448.35cd	377.27e
	MAP2	640.96a	496.68bc	391.45de	293.86f
Oxalic acid (mg 100 g^{-1} fw)	Control	247.26a	191.77b	168.99c	132.14de
	MAP1	247.26a	202.01b	148.68cd	112.92e
	MAP2	247.26a	196.65b	169.43c	138.17d
Citric acid (mg 100 g^{-1} fw)	Control	169.94a	141.18b	126.41bc	110.36c
	MAP1	169.94a	138.06b	127.97bc	85.55d
	MAP2	169.94a	142.43b	135.55bc	122.72bc
Succinic acid (mg 100 g^{-1} fw)	Control	69.37a	52.76abc	43.59bc	36.09c
	MAP1	69.37a	64.59a	58.88ab	42.96bc
	MAP2	69.37a	51.80abc	42.64bc	33.77c
Tartaric acid (mg 100 g^{-1} fw)	Control	8.94d	9.87cd	13.88b	18.09a
	MAP1	8.94d	9.65cd	10.16cd	12.34bc
	MAP2	8.94d	9.39d	9.73cd	14.94b

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

100 g^{-1} fw) and the lowest for the MAP2 fruit (293.86 mg 100 g^{-1} fw) (Table 5). A similar pattern was observed during the SL conditions. At the end of the SL period, malic acid content of the control fruit was the highest (447.74 mg 100 g^{-1} fw), and that of the fruit stored in MAP2 was the lowest (319.04 mg 100 g^{-1} fw) (Table 6).

Oxalic acid content decreased significantly with storage time in all treatments during cold storage and SL conditions. Oxalic acid content of pomegranates stored in MAP2 (138.17 mg 100 g^{-1} fw) was higher than that of control fruit (132.14 mg 100 g^{-1} fw) and MAP1 fruit (112.92 mg 100 g^{-1} fw) after 120 days of storage (Table 5). A similar pattern was also observed during the SL conditions (Table 6).

Citric acid content decreased in all treatments during the cold storage and SL conditions. The pomegranates stored in MAP2 (122.72 mg 100 g^{-1} fw) had higher citric acid contents than the control fruit (110.36 mg 100 g^{-1} fw) and MAP1 fruit (85.55 mg 100 g^{-1} fw) after 120 days of storage. A similar pattern was observed during the SL conditions and pomegranates stored in MAP2 maintained higher values of citric acid content compared to the control and MAP1 fruit.

Succinic acid of all samples decreased significantly in all treatments throughout storage. After 120 days of storage, the highest succinic acid was obtained from the pomegranates stored in MAP1 (42.96 mg 100 g^{-1} fw), while the lowest was obtained from the control fruit (36.09 mg 100 g^{-1} fw) and MAP2 fruit (33.77 mg 100 g^{-1} fw) (Table 5). A similar pattern was also observed during the SL conditions (Table 6).

On the contrary, a significant increase in tartaric acid contents was observed during cold storage and SL conditions for all pomegranates. After 120 days of cold storage, tartaric acid content was higher in control fruit (18.09 mg 100 g^{-1} fw) compared to the MAP2 (14.94 mg 100 g^{-1} fw) and MAP1 (12.34 mg 100 g^{-1} fw) treatments (Table 5). A similar pattern was also observed during the SL conditions (Table 6).

In this experiment, there was a significant decrease in organic acid contents of pomegranates during cold storage and SL conditions. Similarly, Selcuk and Erkan (2015) found a decrease in organic acid contents of Hicaznar pomegranates at 6 °C for 210 days and no significant differences among the treatments except for tartaric acid. Ustun et al. (2012) also found a decrease in malic and citric

Table 6. Organic acids contents of Beynarı pomegranates after storage at 6 °C plus 3 days at 20 °C.

Organic acids	Treatments	Storage time			
		Day 0	Day 40 + 3 SL	Day 80 + 3 SL	Day 120 + 3 SL
Malic acid (mg 100 g^{-1} fw)	Control	640.96a	530.99b	509.36b	447.74c[a]
	MAP1	640.96a	481.06bc	444.35c	367.64de
	MAP2	640.96a	522.48b	420.34cd	319.04e
Oxalic acid (mg 100 g^{-1} fw)	Control	247.26a	199.72b	166.32b	141.21d
	MAP1	247.26a	167.36b	139.85d	118.81d
	MAP2	247.26a	184.99b	150.16d	130.56d
Citric acid (mg 100 g^{-1} fw)	Control	169.94a	130.48b	112.56bcd	92.96de
	MAP1	169.94a	126.34bc	98.36cde	76.03e
	MAP2	169.94a	133.56b	124.94bc	115.24bcd
Succinic acid (mg 100 g^{-1} fw)	Control	69.37a	52.79bcd	42.42def	33.33fg
	MAP1	69.37a	57.80abc	48.50cde	40.21efg
	MAP2	69.37a	62.47ab	41.53def	29.95g
Tartaric acid (mg 100 g^{-1} fw)	Control	8.94e	11.12cde	14.11b	21.79a
	MAP1	8.94e	11.97bcd	12.32bcd	12.99bcd
	MAP2	8.94e	10.42de	11.02cde	13.82bc

[a] Values within a column with different letters are significantly different at $P \leq 0.05$ according to Duncan's multiple range test. SL, shelf-life.

acid contents and an increase in tartaric acid contents of grapes packaged in MAP during storage. However, in this research the authors found that these treatments did not significantly affect changes in citric acid contents, whereas tartaric acid contents of grapes packaged in PPE or ZOEPAC bags with or without Antimold® sachets were higher than those packaged in PPE or ZOEPAC bags with a SO_2 pad after 2 and 3 months of storage. However, Valero et al. (2006) found a significant reduction in levels of tartaric acid and other organic acids in Autumn Royal grapes packaged in nonperforated oriented PP bags at 1 °C for 56 days and no significant differences between treated and control berries in oxalic, citric, and fumaric acids contents. The accumulation of tartaric acid could be due to its chemical characteristics, since it is difficult to metabolize because of its tendency to form salts that are not easily degraded by any known enzymes (Philip and Kuykendall, 1973; Esteban et al., 1999). Sayyari et al. (2011) reported that all organic acids decreased in control fruit during storage, while in acetyl salicylic acid (at three concentrations: 0.1, 0.5, and 1.0 mM)-treated pomegranates only a significant decrease in malic acid was found, although the diminution was lower than that observed in controls at 2 °C for 84 days. On the contrary, Miguel et al. (2006) found an increase in organic acid contents of Mollar pomegranates from the beginning of the assay up to 2 months of cold storage, independent of treatment (covered with low-density polyethylene film, treated with calcium, or control fruits), and then it decreased. Organic acids usually accumulate at the early stages of fruit development and decrease during the fruit ripening and storage due to use as respiratory substrates in the mature fruit (Tang et al., 2010).

3.7. Conclusions

The results of this study showed that weight loss and visual appearance are the major postharvest problems affecting the quality of sweet Beynarı pomegranates during long-term storage. The MAPs maintained the visual quality of the fruits, prevented fruit shriveling and browning, and consequently inhibited skin color changes. A gradual decrease in TA and TSS in all fruits was observed over time both in cold storage and SL periods. The total phenolics content of control fruit was higher than in MAP treatments during cold storage. The total anthocyanin content of control fruit was higher than on MAP treatments during the SL period. Ascorbic

acid content decreased significantly in all treatments during storage and SL periods. However, the storage of pomegranates in MAP2 provided better conservation of citric acid contents. Our results suggest that the storage life of Beynarı pomegranates can be extended up to 120 days when packed in MAP without serious loss in weight or by decay at 6 ± 0.5 °C and 90 ± 5% RH. This finding may be conveniently exploited at the commercial level, giving the opportunity to store sweet pomegranates for longer storage durations.

Acknowledgments
The authors wish to acknowledge the financial support given by the Scientific Research Projects Coordination Unit of Akdeniz University. The authors thank Dr Luis Cisneros-Zevallos for critical review of the manuscript.

References

Arendse E, Fawole OA, Opara UL (2014). Effects of postharvest storage conditions on phytochemical and radical-scavenging activity of pomegranate fruit (cv. Wonderful). Sci Hortic 169: 125-129.

Artés F, Marin JG, Martinez JA (1996). Controlled atmosphere storage of pomegranate. Z Lebensm Unters Forsch 203: 33-37.

Artés F, Tudela JA, Gil MI (1998). Improving the keeping quality of pomegranate fruit by intermittent warming. Eur Food Res Technol 207: 316-321.

Artés F, Villaescusa R, Tudela JA (2000). Modified atmosphere packaging of pomegranate. J Food Sci 65: 1112-1116.

Ayhan Z, Eştürk O (2009). Overall quality and shelf life of minimally processed and modified atmosphere packaged ready-to-eat pomegranate arils. J Food Sci 74: 399-405.

Ben-Arie R, Or E (1986). The development and control of husk scald on 'Wonderful' pomegranate fruit during storage. J Am Soc Hort Sci 111: 395-399.

Ben-Arie R, Segal N, Guelfat-Reich S (1984). The maturation and ripening of the 'Wonderful' pomegranate. J Am Soc Hort Sci 109: 898-902.

Brand-Williams W, Cuvelier ME, Berset C (1995). Use of a free radical method to evaluate antioxidant activity. Food Sci Technol 28: 25-30.

Caleb OJ, Opara UL, Witthuhn CR (2012). Modified atmosphere packaging of pomegranate fruit and arils: a review. Food Bioprocess Technol 5: 15-30.

Cisneros-Zevallos L (2003). The use of controlled postharvest abiotic stresses as a tool for enhancing the nutraceutical content and adding-value of fresh fruits and vegetables. J Food Sci 68: 1560-1565.

D'Aquino S, Palma A, Schirra M, Continella A, Tribulato E, La Malfa S (2010). Influence of film wrapping and fludioxonil application on quality of pomegranate fruit. Postharvest Biol Technol 55: 121-128.

Elyatem SM, Kader AA (1984). Post-harvest physiology and storage behaviour of pomegranate fruits. Sci Hortic 24: 287-298.

Ercisli S, Agar G, Orhan E, Yildirim N, Hizarci Y (2007). Interspecific variability of RAPD and fatty acid composition of some pomegranate cultivars (*Punica granatum* L.) growing in Southern Anatolia Region in Turkey. Biochem Syst Ecol 35: 764-769.

Erkan M, Kader AA (2011). Pomegranate (*Punica granatum* L.). In: Yahia EM, editor. Postharvest Biology and Technology of Tropical and Subtropical Fruits. Cambridge, UK: Woodhead Publishing, pp. 287-311.

Esteban MA, Villanueva MJ, Lissarrague JR (1999). Effect of irrigation on changes in berry composition of Tempranillo during maturation. Sugars, organic acids, and mineral elements. Am J Enol Vitic 50: 418-434.

Fawole OA, Opara UL (2013). Effects of storage temperature and duration on physiological responses of pomegranate fruit. Ind Crops Produc 47: 300-309.

Fuleki T, Francis FJ (1968). Quantitative methods for anthocyanins. 2. Determination of total anthocyanin and degradation index for cranberry juice. J Food Sci 33: 78-82.

Ghafir SAM, Ibrahim IZ, Abusrewel GS, Suaad ZA (2010). Response of local variety 'Shlefy' pomegranate fruits to packaging and cold storage. Acta Hortic 877: 427-432.

Gil MI, Artés F, Tomás-Barberán FA (1996). Minimal processing and modified atmosphere packaging effects on pigmentation of pomegranate seeds. J Food Sci 61: 161-164.

Gil MI, Holcroft DM, Kader AA (1997). Changes in strawberry anthocyanins and other polyphenols in response to carbon dioxide treatments. J Agric Food Chem 45: 1662-1667.

Gil MI, Tomás-Barberán FA, Hess-Pierce B, Holcroft DM, Kader AA (2000). Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. J Agric Food Chem 48: 4581-4589.

Hess-Pierce BM, Kader AA (2003). Responses of 'Wonderful' pomegranates to controlled atmospheres. Acta Hortic 600: 751-757.

Holcroft DM, Gil MI, Kader AA (1998). Effect of carbon dioxide on anthocyanins, phenylalanine ammonia lyase and glucosyltransferase in the arils of stored pomegranates. J Am Soc Hort Sci 123: 136-140.

Holland D, Hatib K, Bar-Ya'akov I (2009). Pomegranate: botany. Hortic Breeding Hortic Rev 35: 127-191.

Kader AA, Watkins CB (2000). Modified atmosphere packaging – toward 2000 and beyond. HortTechnology 10: 483-486.

Karhan M, Aksu M, Tetik N, Turhan I (2004). Kinetic modelling of anaerobic thermal degradation of ascorbic acid in Rose Hip (*Rosa canina* L.) pulp. J Food Qual 27: 311-319.

Koyama S, Cobb LJ, Mehta HH, Seeram NP, Heber D, Pantuck AJ, Cohen P (2010). Pomegranate extract induces apoptosis in human prostate cancer cells by modulation of the IGF–IGFBP axis. Growth Horm IGF Res 20: 55-62.

Lee SK, Kader AA (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol Technol 20: 207-220.

López-Rubira V, Conesa A, Allende A, Artés F (2005). Shelf life and overall quality of minimally processed pomegranate arils modified atmosphere packaged and treated with UV-C. Postharvest Biol Technol 37: 174-185.

Maisuthisakul P, Suttajit M, Pongsawatmanit R (2007). Assessment of phenolic content and free radical-scavenging capacity of some Thai indigenous plants. Food Chem 100: 1409-1418.

Melgarejo P, Salazar DM, Artés F (2000). Organic acids and sugars composition of harvested pomegranate fruits. Eur Food Res Technol 211: 185-190.

Mena P, Garcia-Viguera C, Navarro-Rico J, Moreno DA, Bartual J, Saura D, Marti N (2011). Phytochemical characterisation for industrial use of pomegranate (*Punica granatum* L.) cultivars grown in Spain. J Sci Food Agric 91: 1893-1906.

Miguel G, Fontes C, Antunes D, Neves A, Martins D (2004). Anthocyanin concentration of "Assaria" pomegranate fruits during different cold storage conditions. J Biomed Biotechnol 5: 338-342.

Miguel G, Fontes C, Martins D, Neves A, Antunes D (2006). Effects of postharvest treatment and storage time on the organic acid content in 'Assaria' and 'Mollar' pomegranate (*Punica granatum* L.) fruit. Ital J Food Sci 18: 317-322.

Mirdehghan SH, Rahemi M, Serrano M, Guıllén FM, Martínez-Romero D, Valero D (2007). The application of polyamines by pressure or ımmersion as a tool to maintain functional properties in stored pomegranate arils. J Agric Food Chem 55: 755-760.

Nanda S, Sudhakar RDV, Krishnamurthy S (2001). Effects of shrink film wrapping and storage temperature on the shelf life and quality of pomegranate fruits cv. Ganesh. Postharvest Biol Technol 22: 61-69.

O'Grady L, Sigge G, Caleb OJ, Opara UL (2014). Effects of storage temperature and duration on chemical properties, proximate composition and selected bioactivecomponents of pomegranate (*Punica granatum* L.) arils. LWT-Food Sci Technol 57: 508-515.

Philip T, Kuykendall JR (1973). Changes in titrable acidity, °Brix, pH, potassium content, malate and tartrate during berry development of Thompson seedless grapes. J Food Sci 38: 874-876.

Poyrazoğlu E, Gökmen V, Artık N (2002). Organic acids and phenolic compounds in pomegranates (*Punica granatum* L.) grown in Turkey. J Food Comp Anal 15: 567-575.

Saxena A, Bawa AS, Raju PS (2009). Phytochemical changes in fresh-cut jackfruit (*Artocarpus heterophyllus* L.) bulbs during modified atmosphere storage. Food Chem 115: 1443-1449.

Sayyari M, Castillo S, Valero D, Díaz-Mula HM, Serrano M (2011). Acetyl salicylic acid alleviates chilling injury and maintains nutritive and bioactive compounds and antioxidant activity during postharvest storage of pomegranates. Postharvest Biol Technol 60: 136-142.

Sayyari M, Valero D, Babalar M, Kalantari S, Zapata PJ, Serrano M (2010). Prestorage oxalic acid treatment maintained visual quality, bioactive compounds, and antioxidant potential of pomegranate after long-term storage at 2 °C. J Agric Food Chem 58: 6804-6808.

Selcuk N, Erkan M (2014). Changes in antioxidant activity and postharvest quality of sweet pomegranates cv. Hicrannar under modified atmosphere packaging. Postharvest Biol Technol 92: 29-36.

Selcuk N, Erkan M (2015). Changes in phenolic compounds and antioxidant activity of sour-sweet pomegranates cv. Hicaznar during long-term storage under modified atmosphere packaging. Postharvest Biol Technol 109: 30-39.

Shwartz E, Glazer I, Bar-Ya'akov I, Matityahu I, Bar-Ilan I, Holland D, Amir R (2009). Changes in chemical constituents during the maturation and ripening of two commercially important pomegranate accessions. Food Chem 115: 965-973.

Spanos GA, Wrolstad RE (1990). Influence of processing and storage on the phenolic composition of Thompson seedless grape juice. J Agric Food Chem 38: 1565-1571.

Tang M, Bie ZL, Wu MZ, Yi HP, Feng JX (2010). Changes in organic acids and acid metabolism enzymes in melon fruit during development. Sci Hortic 123: 360-365.

Ustun D, Candir E, Ozdemir AE, Kamiloglu O, Soylu EM, Dilbaz R (2012). Effects of modified atmosphere packaging and ethanol vapor treatment on the chemical composition of 'Red Globe' table grapes during storage. Postharvest Biol Technol 68: 8-15.

Valero D, Valverde JM, Martinez-Romero D, Guillen F, Castillo S, Serrano M (2006). The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safety and functional properties of table grapes. Postharvest Biol Technol 41: 317-327.

Vinson JA, Jang J, Dabbagh YA, Serry MM, Cai S (1995). Plant polyphenols exhibit lipoprotein-bound antioxidant activity using an in vitro oxidation model heart disease. J Agric Food Chem 43: 2798-2799.

Zagory D, Ke D, Kader AA (1989). Long term storage of 'Early Gold' and 'Shinko' Asian pears in low oxygen atmospheres. In: Fellman JK, editor. Proceedings of the Fifth International Controlled Atmosphere Research Conference, pp. 353-357.