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Research Article

Influence of Modified Atmosphere Packaging on the Postharvest Quality and Chilling Injury of Tomato Harvested at Different Maturity Stages

Ferhan KÜÇÜKBASMACI SABIR[1], Emine Gül SELÇUK[2], Sevil UNAL[1]

[1]Selçuk University, Faculty of Agriculture, Department of Horticulture, Konya, Turkey
[2]Selçuk University, Graduate School of Natural and Applied Science, Konya, Turkey

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ABSTRACT

The present study was performed to determine effects of modified atmosphere packaging (MAP) on postharvest quality and chilling injury alleviation of tomatoes during low temperature storage. Tomatoes were harvested at two different stages (breaker and pink stage) and packed with MAP (Xtend® bags MAP). Air stored fruits were considered as control. All samples were stored at 5°C with 90% RH for 21 days. Weight loss, firmness, surface color, lycopene, ascorbic acid, total phenol, total antioxidant activity and chilling injury were investigated with intervals of 7 days. At the end of the storage, MAP of either breaker or pink fruits reduced the weight loss, maintained firmness and exhibited less biochemical changes than the control fruit. Moreover, tomatoes stored in MAP have less chilling injury than control at breaker maturity stage. The onset of chilling injury was also delayed by packaging compared to nonpackaged fruits. The general qualities of MAP fruits were better than those of air stored fruits. Overall findings indicate that MAP can be an effective method for enhancing the phytochemical content, delaying the senescence and chilling injury of tomatoes at breaker or pink maturity stages during low temperature storage.

1. Introduction

Consumption of fruits and vegetables is increasing, as consumers are becoming more aware of numerous health benefits associated with fresh agricultural commodities. Tomatoes are an important vegetable crops and are among major contributor of carotenoids (especially lycopene), phenolics, vitamin C and small amounts of vitamin E in daily diets. Results from the epidemiological studies have shown that tomatoes and tomato products may have protective effect against various forms of cancer and cardiovascular diseases (Dumas et al. 2003; Toor and Savage 2005; Javanmardi and Kubota 2006). However, relatively short shelf life of tomatoes limits the long distance commercial transport and availability of this produce around the year. As stated by Benhabiles et al. (2013), postharvest losses of tomatoes may drastically reach up to 50% of total production in countries where harvest amount peaks in short period (Kibar and Sabir 2018).

Low temperature storage has been the main strategy applied in postharvest technology to prolong the shelf life of fruits and vegetables and maintain their quality. For commodities such as tomatoes, however, low temperatures induce chilling injury (El Ghaouth et al. 1992). Optimum storage temperature depends on the maturity of the tomato fruit at harvest. Immature and mature-green tomatoes are more sensitive to chilling temperatures than pink or red tomatoes are. If held for longer than 2 weeks below 10°C or for longer than 6–8 days at 5°C, they may develop chilling injury (CI). As a result of CI, fruits develop symptoms such as a rubbery texture, watery flesh, irregular ripening and pitting or browning. In the cases where its impact is very severe, it brings significant deterioration of the produce and therefore has a great negative effect on its final market value and leads to substantial economic losses (Stevens et al. 2008; Aghdam et al. 2016).

Modified atmosphere packaging (MAP) is a technique used for prolonging the cold storage period of fruit and vegetables. This technique can be described as an alteration in the composition of gases in and around fresh produce by respiration and transpiration in package. Composition of the gas inside the package is modified by respiration of fruits, decreasing O_2 level while CO_2 increases during storage (Thompson 2003; Sandhya 2010). Storage of tomatoes in MAP reduced weight loss and decay, maintained firmness and delayed ethylene production, color change and ripening

* Corresponding author email: *fkbasmaci@selcuk.edu.tr*

in cold storage (Akbudak et al. 2007; Tano et al. 2007; Sabir and Agar 2010). The development of a modified atmosphere and high relative humidity inside the package retards senescence and prevents chilling injury (Wang and Qi 1997; Singh and Rao 2005).Wang and Qi (1997) found that cucumber sealed in low density polyethylene (LDPE) have less CI symptoms than unsealed fruits and LDPE packaging delayed onset of chilling injury. MAP has been studied for efficacy in inhibiting CI and extending shelf life of perishable produces such as papaya (Singh and Rao 2005) and apricot (Ezzat 2018).

The objective of this work was to evaluate the effects of MAP on postharvest quality and alleviation of CI of tomatoes harvested at breaker and pink of maturity stages during low temperature storage (5°C).

2. Materials and Methods

Tomatoes (*Lycopersicon esculentum* Mill. cv. Hakan F_1) were harvested from greenhouse of Selcuk University in Konya-Turkey at breaker and pink ripening stages using the United States Department of Agriculture tomato ripeness color classification chart (USDA 1991). Fruits of tomatoes were transferred to laboratory of Department of Horticulture, Selcuk University. Afterwards, fruits were selected for unity and freedom from defects and blemishes, tomatoes were randomly divided into two equal lots at both maturity stages. First lot was evaluated as a control group unwrapped and stored in plastic box in air. The second lot was placed in modified atmosphere packaging (Xtend®) and then sealed (MAP).

All the samples were stored at 5°C and 85-90% RH for 21 days. At harvest and following 7, 14 and 21 days of cold storage, fruit were analyzed for weight loss, fruit skin color (hue angle), firmness, lycopene, ascorbic acid (AA), total phenols (TP), total antioxidant activity (TAA) and chilling injury (CI).

Tomatoes were weighted before storage and during storage at 7, 14 and 21 days. Results were expressed as percentage of weight loss relative to the initial weight.

Fruit skin color was determined on 8 individual fruits per treatment using a colorimeter (Minolta CR-400), with the Hunter scale (L, a*, b*). Two measurements were performed on fruit equatorial axes and results were calculated as hue angle using equations described by McGuire (1992).

Fruit firmness was measured using a digital penetrometer (fruit pressure tester, model 53205; TR, Forlì, Italy). After removing the epidermis at two equatorial sites, an 8 mm probe was used to measure the fruits firmness and results were expressed in Newton (N).

Ascorbic acid was determined as previously described by Pearson et al. (1970). Tomatoes were ground with a warring blender and 5 g sample was mixed with 0.4% oxalic acid and then filtered via filter paper. One milliliter filtrate and 9 mL 2,6-dichlorophenolindophenol sodium salt solution ($C_{12}H_6C_{l2}NO_2$-Na) was mixed and then read transmittance values at 520 nm in a spectrophotometer. Blank were prepared in the same way but using 1 ml filtrate and 9 ml distilled water. Results were expressed as mg 100 g^{-1}.

Lycopene content of tomatoes was performed as previously described by Sharma and Maguer (1996); Rao et al. (1998) with slight modifications. For lycopene analysis, pericarp tissue of tomatoes was blended with a warring blender for 1 min. One gram of homogeneous tissue and 50 mL hexane:ethanol:acetone (2:1:1, v/v) were shaken for 30 min. After shaking, 10 mL of distilled water were added and shaken for 5 min again. The solution was then placed in a separator funnel and, after phase separation, the upper phase was collected. The extract was filtered via Whatman No. 42 filter paper and lycopene concentration was determined by measuring the absorbance of the solution at 502 nm using a UV-visible spectrophotometer. Results were expressed as mg kg^{-1} fresh fruit weight.

Fruit extracts for antioxidant and phenol analyses were prepared using method described by Thaipong et al. (2006) with certain modifications. Five grams tomato tissue was homogenized in methanol using Ultra-Turrax homogenizer (IKA, T18 digital, Staufen, Germany) for 1 min. The homogenates were kept at 4°C for 14–16 h and then centrifuged at 8000 x *g* for 15 min at 5°C. The supernatants were recovered and stored at −20°C in dark color bottles until analysis.

Total phenols (TP) were determined according to the method of Singleton et al. (1999) with slight modifications. The 0.1 ml extract, 6.0 ml distilled water and 0.5 ml Folin-Ciocalteu's reagent were mixed and then were vortexed. The mixture were incubate 3 min and then 20% sodium carbonate solution supplemented and volume was made up 10 ml distilled water. The solution was incubated at 25°C for 2 h and the absorbance was measured at 760 nm. The content of total phenols was calculate basis of the calibration curve of gallic acid and was expressed as mg 100 g^{-1} FW.

Total antioxidant activity (TAA) was determined by the ferric reducing ability antioxidant power (FRAP) according to the procedure described by Benzie and Strain (1996). For this, 150 µL of extract and 2.85 mL of the FRAP reagent was incubated at 30°C for 30 min. After incubation, reaction mixture was measured at 593 nm on a UV-vis spectrophotometer. Standard curve was prepared using different concentrations of 1 mM trolox and expressed as µmol kg^{-1}.

Chilling injury (CI) index of fruits was evaluated at 20°C for 3 d after 7, 14 or 21 days in cold storage according to Aghdam et al. (2014). The fruits were returned to ambient temperature (20°C) for development of CI symptoms. The severity of the symptoms was assessed visually in a 4-stage scale: 0=no pitting; 1=pitting covering <25% of the fruit surface; 2= pitting covering <50%, but >25% of surface; 3= pitting covering <75%, but >50% of surface and 4= pitting covering >75% of surface. The average extent of cold damage

was expressed as a CI index, which was calculated using the following formula:

CI index (%)= Σ [(CI level) x (number of fruit at the CI level)]/ [(4 x total number of fruit)] x100

The experiment was a completely randomized design with three replications and each replication contained 8 fruits. For each maturity stage, data from analyzed parameters were subjected to analysis of variance separately. Sources of variation were treatment, storage time and their interaction. Means were compared by Student's t-test at $P \leq 0.05$, using JMP statistical software version 5.1 (SAS Institute Inc., Cary, NC, USA).

3. Results and Discussion

Weight loss increased during cold storage for both ripening stages, while the effect of modified atmosphere packaging on weight loss was found statistically significant (Table 1). At the end of the storage, weight loss of breaker tomatoes stored in MAP was 2.49%, while the value for the control fruit was 5.32%. Similarly, weight loss was 4.52% (control) and 1.92% (MAP) in pink tomatoes. MAP has been commonly used to extend the postharvest quality and life of the horticultural commodities. During the storage, the increase in CO_2 concentration inside MAP restricts the respiration of the produces and, by this way, the shelf life of the stored product prolongs. In the present study, effects of MAP on the postharvest quality and chilling injury of tomato harvested at different maturity stages have been investigated. The weight loss, known to be the major determinant of storage life and quality of fresh commodities, was significantly reduced by MAP for both maturity stages used in the study. In tomatoes, the acceptable range of weight loss during the storage ranges from 6 to 7% as indicated by Nunes (2008). Control tomatoes of both maturity stages were approaching to these values. However, weight loss values in the produces stored in MAP were far below the threshold values. The values recorded in the study were quite similar to those obtained in various vegetables such as cucumber, tomatoes, broccoli (Tano et al. 2007; Sabır and Ağar 2008; Jia et al. 2009; Sabir and Agar 2010).

Table 1
Changes in weight loss, firmness, color and chilling injury (CI) index of the tomatoes in response to MAP[x].

Treatment	Day	Breaker stage				Pink stage			
		Weight loss	Firmness	Color	CI index	Weight loss	Firmness	Color	CI index
Control	0	0.00 f	27.8 a	102.7 a	0.00 d	0.00 f	23.8 a	78.1	0.00
	7	1.71 d	24.8 c	88.4 c	0.49 cd	1.20 d	20.2 b	66.4	0.20
	14	3.68 b	21.8 d	72.8 e	1.16 b	2.83 b	18.3 c	59.6	0.28
	21	5.32 a	18.6 e	61.6 g	2.26 a	4.53 a	13.4 d	56.7	0.68
MAP	0	0.00 f	27.8 a	102.7 a	0.00 d	0.00 f	23.8 a	78.1	0.00
	7	0.71 e	26.6 ab	91.9 b	0.00 d	0.57 e	22.3 a	67.1	0.00
	14	1.42 d	25.4 bc	77.9 d	0.16 d	1.29 d	19.5 bc	60.3	0.10
	21	2.49 c	22.5 d	64.5 f	0.79 bc	1.92 c	18.2 c	56.4	0.31
$LSD_{0.05}$		0.58	1.49	1.50	0.51	0.39	1.55	N.S.	N.S.

[x] Means followed by different letters within a column are significantly different at $p \leq 0.05$ according to Student's t-test. N.S.: Nonsignificant

Changes in fruit skin hue angle values during storage were indicated in Table 1. At harvest, hue angle of fruit skin was 102.7° and 78.1° in breaker and pink fruits, respectively. During storage, the hue angle significantly decreased and this decline accelerated rapidly after 7 d in pink fruits which could be related to the ripening process of tomatoes. At the end of the storage, hue angle values ranged from 61.6° (control) to 64.5° (MAP) in breaker fruits while they were 56.7° (control) and 56.4° (MAP) in pink fruits. Color differences between the treatments were insignificant in pink stage.

Firmness of all fruits reduced during the storage period but breaker fruits demonstrated higher firmness when compared with the pink fruits (Table 1). The lowest firmness values were always determined in control while MAPs preserved the fruit firmness during storage. Initial firmness values of breaker and pink fruits were 27.8 N and 23.8 N, respectively. At breaker stage, firmness in control (18.6 N) and MAP (22.5 N) tomatoes were 33.22 and 19.31% lower than those of initial values, respectively. At pink stages, reduction of firmness values was more rapid compared with breaker. At the end of the storage, fruit firmness were 13.4 N (control) and 18.2 N (MAP) in pink fruits. In this ripening stage, fruit firmness was reduced by 43.65% in control and by 23.34% in MAP compared to initial value. Softening in cold storaged tomatoes was more progressive in accordance with the prolonged maturity. Firmness is one of the prime considerations determining the postharvest quality and shelf life of tomatoes (Nunes 2008; Kibar and Sabir 2018). Softening of the fruit texture can be induced through the partial degradation of cells by polygalactronase (PG) and the ripening process increases the activity of PG (Lee 2003). In this study, softening was prevented by MAPs as reported by Nakhasi et al. (1991).

Changes in ascorbic acid (AA) of tomatoes during the storage were presented in Table 2. AA contents of tomatoes increased during storage in both stages but the differences between the treatments were statistically insignificant. At the beginning of the storage, AA was 24.3 mg $100g^{-1}$ in breaker stages. At 21 days, AA content of breaker tomatoes in MAP was measured 34.8 mg $100g^{-1}$ while the content for the control fruit

was 38.7 mg $100g^{-1}$. AA content at harvest was 26.5 mg $100g^{-1}$ at pink tomatoes and this value increased along with the prolonged storage. At the end of the storage, AA content of pink tomatoes stored in MAPs and control were 38.6 mg $100g^{-1}$ and 40.7 mg $100g^{-1}$.

Tomato color is greatly correlated with lycopene content, and as the fruit develops from the mature green stage to the red stage, lycopene concentration increases significantly (Nunes 2008). Lycopene value of all fruits reduced during the storage period and pink fruits demonstrated higher value when compared with the breaker fruits. MAP prevented the lycopene accumulation during the storage period in both ripening stages (Table 2). Lycopene synthesis of MAPs breaker fruits began at 14 days, while accumulation of lycopene was initiated at 7 days for control. At pink stage, initial lycopene value was 10.2 mg kg^{-1} and underwent a remarkable increase with prolonged storage. At the end of the storage, lycopene contents of tomatoes were 39.9 mg kg^{-1} (control) and 29.8 mg kg^{-1} (MAP) in breaker fruits and were 53.1 mg kg^{-1} (control) and 41.9 mg kg^{-1} (MAP) in pink fruits. In marketing of the majority of horticultural produces, skin color is an effective factor on the preference of the consumer. The color in tomatoes is greatly correlated with lycopene content (Sabir and Agar 2011). As tomatoes ripen, the color changes from green in immature fruit to deep dark red in fully mature fruit, lycopene concentration increases significantly (Hobson and Grierson 1993). Decrease in hue angle and the increase in lycopene synthesis were markedly restricted by MAP during the prolonged maturity stage. This was most probably due to lower respiration level of the tomatoes in MAP in comparison to the control produces. Such findings were also recorded by Sabir and Agar (2010) who investigated a restriction effect of MAP on the lycopene synthesis during storage in tomatoes.

Changes in the TP of tomatoes during the storage are illustrated in Table 2. TP values of stored fruits linearly increased during the storage, whereas MAPs significantly inhibited rising in TP. Initial TP values of breaker and pink fruits were 48.2 and 68.7 mg $100g^{-1}$, respectively. At the end of the study, TP was maximum in control fruits for both stages (220.4 and 121.7 mg $100g^{-1}$ for breaker and pink tomatoes, respectively). At 21 d, TP values of breaker and pink fruits stored in MAPs were 151.0 and 101.5 mg $100g^{-1}$, respectively.

Initial TAA for the breaker and pink stage of tomatoes were 1.80 μmol kg^{-1} and 2.82 μmol kg^{-1}, respectively (Table 2). During prolonged storage times, TAA increased either in control or MAP. At 21 d, TAA of tomatoes were 4.18 μmol kg^{-1} (control) and 3.96 μmol kg^{-1} (MAP) in breaker fruits and were 4.64 μmol kg^{-1} (control) and 4.22 μmol kg^{-1} (MAP) in pink fruits.

CI index of stored tomatoes linearly increased during storage, whereas MAP significantly inhibited the increase in CI index especially breaker stages. Chilling injury symptoms started to in control fruits by 7th day of storage in both maturity stage (Table 1). The initial symptoms include small pitting and water soaked areas and which increased in size with the prolonged storage. The onset of CI symptoms in MAPs tomatoes were delayed. At the end of the storage, CI index of tomatoes were 2.26 (control) and 0.79 (MAP) in breaker fruits and were 0.68 (control) and 0.31 (MAP) in pink fruits. Chilling injury is one of the physiological disorders causing significant loses during the storage of horticultural produces. Storing the produces at their cold endurance levels would prevent the cold storage chilling injury. Studies revealed that MAP can decrease the chilling injury by maintaining the moisture content inside the package around the produces (Wang and Qi 1997; Gonzales-Aguilar et al. 2003). The results of the current investigation demonstrated that chilling injury in MAPs was considerably lower than those of control. In certain studies conducted on perishable produces, such as papaya and cucumber, the chilling injury levels were significantly prevented by MAP (Wang and Qi 1997; Gonzales-Aguilar et al. 2003).

4. Conclusions

Tomatoes are one of the most commonly consumed vegetables across the world. However, a greater part of the produced tomatoes are lost after harvest due to their perishable structure and improper postharvest handling processes. Low temperature storage is a prime strategy to maintain the postharvest life of tomatoes. However, certain factors one of which is chilling injury, remarkable restrict the storage potential of the cold sensitive produces like tomatoes. Nonetheless, MAP was proven to protect the commodities against the environmental constraints while it also restricts the respiration in varying levels. In the present study, overall investigations revealed that MAP at cold storage (5 °C) of the tomatoes harvested at two different maturity stages (breaker and pink maturity) was obviously effective on maintenance of postharvest quality, preventing the chilling injury and extending the storage duration of the tomatoes.

Table 2
Changes in lycopene, ascorbic acid (AA), total phenol (TP) and total antioxidant activity (TAA) of the tomatoes in response to MAP[x].

Treatment	Day	Breaker stage				Pink stage			
		Lycopene	AA	TP	TAA	Lycopene	AA	TP	TAA
Control	0	0.0 f	24.3	48.2 d	1.80 d	10.2 g	26.5	68.7 d	2.82 e
	7	12.3 e	34.0	96.9 c	3.91 b	21.6 e	34.7	95.3 c	4.85 a
	14	33.9 b	38.8	163.4 b	4.14 ab	36.7 c	34.6	109.3 b	3.31 d
	21	39.8 a	38.7	220.4 a	4.18 a	53.1 a	40.4	121.6 a	4.64 a
MAP	0	0.0 f	24.3	48.2 d	1.80 d	10.2 g	26.5	68.7 d	2.83 e
	7	0.4 f	29.4	53.7 d	3.01 c	17.1 f	32.9	70.4 d	3.72 c
	14	22.5 d	32.5	148.2 b	3.93 b	28.7 d	37.3	107.2 b	4.02 b
	21	29.8 c	34.8	151.0 b	3.96 ab	41.9 b	38.6	101.5 bc	4.22 b
$LSD_{0.05}$		3.86	N.S.	16.56	0.23	4.38	N.S.	11.03	0.29

[x] Means followed by different letters within a column are significantly different at $p \leq 0.05$ according to Student's t-test. N.S.: Nonsignificant

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