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ORIGINAL ARTICLE

Tomato quality in controlled atmosphere storage, modified atmosphere packaging and cold storage

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Abstract Effects of controlled atmosphere storage (CAS) and modified atmosphere packaging (MAP) in comparison with conventional cold storage on qualitative properties of green-mature harvested tomato were evaluated. Qualitative properties included firmness, redness value (a*), hue angle, Total Soluble Solids (TSS) content, Titratable Acidity (TA) and TSS/TA. Under CAS and MAP conditions, gas composition was 5 kPa O_2 and 3 kPa CO_2. Results showed that the ability of CAS and MAP to retard the ripening process was more than cold storage. With regard to maintaining texture and colour, CAS treatment was the best and MAP was better than cold storage. Although amongst storage treatments, the maximum value of TSS was observed in cold storage, its decreasing trend in CAS was slower than that in cold storage. Additionally, MAP and especially CAS slowed down the diminishing trend of TA in tomatoes.

Keywords Controlled atmosphere storage · Modified atmosphere packaging · Cold storage · Quality properties · Tomato

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Introduction

Tomato (Lycopersicon esculentum) is a climacteric fruit and its ripening process is regulated by ethylene (Carrari and Fernie 2006; Alexander and Grierson 2002) which affects physical, chemical, and physiological properties of the fruit (Leliévre et al. 1997). In this fruit, there is a sharp increase in respiration at the onset of ripening, usually in concert with increased production of ethylene (Giovannoni 2001). This causes changes in fruit skin colour, sugar content, organic acid metabolism, and tissue softening during the ripening process (Valero et al. 2005). Respiration can be defined as a metabolic process that provides energy for plant biochemical processes. It involves oxidative breakdown of organic reserves to simpler molecules, including O_2 and water, with the release of energy (Ravindra and Goswami 2008). These changes start while the fruit is still on the plant and somewhat accelerate after harvest and fruit reaches an over-ripe state in a short period of time (Guillén et al. 2006).

Qualitative attributes, such as texture, generally change with time, as part of the normal metabolism of the product (Tijskens and Polderdijk 1996). Low temperature is the most important factor in maintaining quality and extending the shelf-life of fruits and vegetables after harvest. Most of the physiological, biochemical and microbiological activities contributing to the deterioration of produce quality are largely dependent on temperature (Tano et al. 2007). However, gas composition of the ambient air also plays an important role. Shelf-life of fresh-cut fruits may be extended by atmospheres reduced in O_2 and elevated in CO_2, by means of modified atmosphere packaging (Verlinden and Nicolaï 2000; Hertog et al. 2001; Bai et al. 2003; Song et al. 2001) that slows deterioration and reduces ethylene production and respiration rates (Eduardo et al. 2006). Modified atmosphere packaging (MAP) is an ideal preservation technique (Mangaraj and Goswami 2009) for controlling product deterioration, providing an appropriate protective atmosphere around the product (Zhang et al. 2006; Cliffe-Byrnes and O'Beirne 2005). The basic difference between controlled atmosphere storage (CAS) and MAP systems is that gas levels are strictly maintained at all times under CAS system, whereas gas mixture is flushed into the package once and changes with time in the MAP system (Choubert and Baccaunaudb 2006). Controlled atmosphere storage or modified atmosphere packaging, combined with low temperature storage, can reduce respiration and ethylene production rates, then retard the softening, and slow down changes related to ripening and senescence (Ahvenainen 1996; Jacxsens et al. 1999; Saito and Rai 2005). The above review of literature shows that very few reports exist on controlled and modified atmosphere storage of tomatoes. The couple of reports on the subject are limited to the study of MAP and considering limited dependent variables. The objective of this study was to evaluate and compare the effects of three methods of tomato storage at green-maturity stage under MAP, CAS and cold storage on several postharvest qualitative properties.

Materials and methods

Plant material and treatments

Tomato fruits (var. super jeff) were harvested at mature-green stage from an experimental field (Karaj-Iran). Fruit maturation level was precisely selected and the fruit color was checked in the field using biological color chart of USDA (1991). Harvesting was carried out manually in the morning. Disease-free fruits having uniform shape, size, and weight without any injuries or defects were selected and hand washed with tap water. Then the fruit surface was dried using a soft cloth and placed in controlled/modified atmosphere and cold storage. Six tomatoes, placed in a sealed polyethylene bag (thickness 0.05 mm), were used for MAP treatment. For MAP and CAS treatments, an initial gas composition of 5 kPa O_2 and 3 kPa CO_2 was used (Saltveit 2003). Temperature for all storage treatments was 13 °C (Grierson and Kader 1986). Relative humidity in CAS and Cold storage were 85–90 % and 60–65 % respectively. Tomato samples were taken for quality analysis every 10 days starting from the day of harvest. The experiment duration was considered equal to 90 days of storage. On each sampling date, three packs (replications) form the MAP treatment and three tomatoes from each replication in the CAS and cold storage treatments were randomly taken. Tomatoes were evaluated for changes in colour, firmness, titratable acidity and total soluble solids content.

Firmness and colour

A destructive deformation test was used to evaluate fruit firmness by loading the tomatoes in a materials testing machine (Testometric m350-10CT, England). For firmness measurement, fruit sample was placed between two flat surfaces and the compressive force (N) required for 5 mm deformation of the fruit was recorded. Loading speed was 20 mm/min (Gormley and Egan 1978). Fruit color was determined using the Hunter Lab System with a Minolta Chroma Meter CR-200 (Minolta Camera Co Ltd, Japan). Hue angle and a* values were recorded as the mean of three measurements made along the equatorial region of the fruit for each sample with two replications for each measurement point. In a Minolta colorimeter, a* and b* values correspond to the degree of redness and yellowness, respectively. Hue angle values of tomatoes were recorded as $\tan^{-1}(b^*/a^*)$ (Choubert and Baccaunaudb 2006; Wyszecki and Stiles 1967).

Total soluble solids (TSS) content and titratable acidity (TA)

Total soluble solids (TSS) were determined for each sample fruit in two replications using an Atago DR-A1 digital refractometer (Atago Co. Ld., Japan) at 20 °C and expressed as °Brix (Javanmardia and Kubota 2006). Titratable acidity (TA) was obtained by titrating 5 ml of tomato juice with 0.1 N NaOH up to pH 8.1. The result was expressed as grams of citric acid per 100 g of fresh tomato weight (Mazumdar and Majumder 2003; Girardi et al. 2005). The TSS to TA ratio (ripening index) was also calculated.

Statistical analysis

Analysis of variance (ANOVA) was performed by using a completely randomized design with subsampling combined over time (Storage time). Factors considered in the statistical analysis of the data were storage type, storage time, replication and observation. There were 3 replications of the 3 treatments (CAS, MAP and Cold) with 3 subsamples (observations) per replication. The tomato samples (observations) were randomly selected from each replication in any treatment. Dependent variables were colour, firmness, titratable acidity (TA), total soluble solids (TSS) content and the ripening index. Data were analyzed using the General Linear Model procedure of SAS (SAS Institute, Cary, NC, USA 1988). The means were compared using the least significant difference (LSD) test at $P<0.05$.

Results and discussion

Firmness

Although, there was a significant difference in firmness loss among all treatments during storage time, the changes were slower in CAS and MAP treatments than in the conventional cold storage (Fig. 1a). Results indicated that CAS and MAP treatments maintained fruit firmness better than the cold storage. CAS and MAP treatments had a similar effect on preventing firmness loss in tomatoes during the first 10 days of storage. However, there was a steeper firmness decline in CAS compared to MAP on the 20th day. After 20 days of storage, CAS was able to maintain fruit firmness significantly better than MAP and this trend continued during further storage, indicating the superiority of continuous atmospheric maintenance. On day 40, tomato firmness in

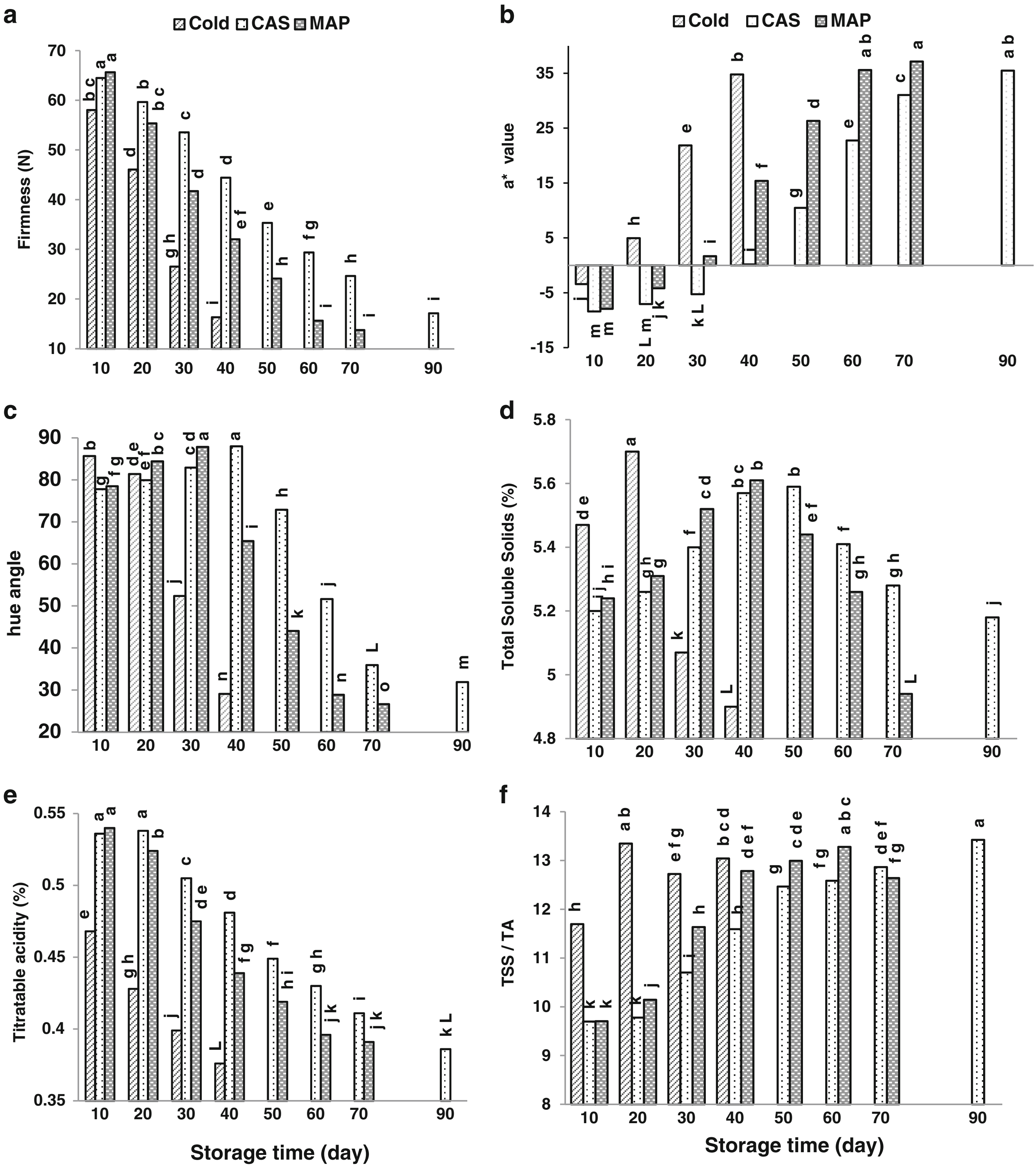

Fig. 1 Changes in quality of tomato during storage under different conditions (n=9), Cold (cold storage), CAS (Controlled atmosphere storage), MAP (Modified atmosphere packaging). Values with different letters on each bar differ significantly (P<5 %)

cold storage reached its lowest value and due to its unacceptable appearance, further measurements were discontinued. This phenomenon occurred on day 70 in the MAP treatment. Tomatoes in CAS treatment kept an acceptable level of firmness till the 90th day. Results showed that 90 days of storage under CAS was more effective than 40 days of cold storage in preventing tomato firmness decline. Similar results have been obtained by Antunes and Sfakiotakis (2002) in kiwifruit and Lo Scalzo et al. (2005), Siddiqui et al. (1996) and Vanoli et al. (2009), who found lower rate of firmness loss in apples during the storage period in CAS compared to Cold storage. Cenci et al. (1997) also reported that CAS treatment enhances the retention of textural properties by preventing the synthesis of cell wall degrading enzymes. Softening is due to the breakdown of cell wall structure's carbohydrates and the increase in soluble pectin substances that results in weakening of the cell walls and reduction of the cohesive forces binding cells together (Heyes et al. 1994; O'Donoghue et al. 1997). Heyes et al. (1994) also suggested that higher CO_2 concentration results in suppression of the degradation of protopectin to soluble pectin thus reducing fruit softening. Similar observations in MAP of 'Robusta' and 'Poovan' bananas stored under low temperature conditions were reported by Kudachikar et al. (2011) and Kudachikar et al. (2007).

Colour

The decrease of 'greenness' and increase of 'redness' in tomato fruit was associated with increase in a* (a value).

Significant differences ($p<0.01$) in a* (degree of redness) were found between storage treatments on the tomato samples (Fig. 1b). After 40 days of storage, tomatoes in CAS were still relatively green but samples in cold storage were quite red. The differences between storage treatments might be due to the fact that ripening and respiration rates in cold storage were higher than those in CAS and MAP. No significant changes in the colour of tomatoes stored in CAS were found during the first 30 days. In other words, in terms of colour, tomatoes stored in CAS had similar properties to the reference sample. MAP treatment was able to preserve tomato colour for longer periods, but not as long as CAS. Also, the rate of change of redness in CAS was much slower than that of cold storage. The differences between storage treatments were so significant that it was easy to visually distinguish tomato samples from different storage methods. There was a significant increase in a* value during 40 days of cold storage while its increase was at much lower rates in CAS storage and the increase was not significant in MAP and CAS. Colour changes might be described by the hydroxylation of carotenoids and synthesis of xanthophylls (Gross 1991). The decline of chlorophyll content might also have occurred due to increased chlorophyllase activity and increased oxidation processes (Gross 1991; Wills et al. 1988). Batu and Thompson (1998) have also reported that tomato colour was highly affected by the storage treatment, and that MAP treatment gave better results than cold storage. Similar trends in MAP under low temperature have been reported by Kudachikar et al. (2007) and Kudachikar et al. (2011) in banana and Isaak et al. (2006) in plantain.

Storage time induced changes in hue angle of tomatoes depending on the type of storage treatment. There was a peak in the hue angle which occurred after 10 days in cold storage, 30 days in MAP and 40 days in CAS (Fig. 1c). Results showed that after the peak, hue angle markedly decreases with time. This decrease is slowest in CAS and fastest in cold storage, since the tomato samples in CAS after 90 days of storage had the same level of hue angle as those in cold storage after 40 days of storage. Results presented here indicate the importance of CAS storage used for keeping colour of tomatoes. Berrang et al. (1990) and Hodges et al. (2006) reported that although there was no significant difference in hue angle of cauliflower between CAS and cold storage but it was found that CAS samples were in better condition than those of cold storage. Similar results were found for peach and persimmon by Wright and Kader (1997a, b). Results of this study were consistent with findings of Lizana and Levano (1977) who reported that color in pepino varies with the stage of maturity and storage conditions.

Total soluble solids content

'Fruitiness' (Bucheli et al. 1999) and 'sweetness' (Kamal et al. 2001) have been identified as two critical contributors to flavor of fresh tomatoes. The major sugar substances that contribute to sweetness are glucose and fructose that play a major role in taste (Stevens et al. 1977). A strong positive correlation is observed between trained panel response to sweetness and reducing sugar or total soluble solids content (Malundo et al. 1995; Bucheli et al. 1999; Tandon et al. 2003). With respect to TSS, the most significant changes were observed in cold storage, which increased significantly from 5.07 to 5.47 then decreased to 4.9 during 40 days of storage (Fig. 1d). Minimum changes were found in CAS where TSS increased from 5.2 to 5.59 then decreased to 5.18 during 90 days. There was a peak in TSS graph of tomato occurring after 20 days of cold storage, 40 days of MAP, and 50 days of CAS. Results indicated a decreasing trend after the peak in TSS value. Significant differences ($P<0.01$) were found in TSS content in cold storage between different stages of the experiment, but the loss of TSS in MAP and CAS were lower than Cold storage during the storage period. Values of TSS increased during the first stages of storage for all treatments, although the highest value of TSS (5.7) for all treatments and experiment stages was obtained in cold storage after 20 days. The most effective treatment in delaying the TSS loss was CAS after 90 days of storage (5.18) since TSS of cold storage was 4.9 on day 40. Generally, tomato fruit in CAS and MAP treatments retained significantly higher total soluble solids than those in cold storage for all the storage periods. This was in harmony with the study by Erkan et al. (2004) who observed that soluble solids of apple were higher in 2 % O2 and 2 % Co2 environment than in normal atmosphere after 9 months of storage. There was no difference in soluble solids content of peach and persimmon fruits among storage treatments over the 7 and 8-day storage periods, respectively (Wright and Kader 1997a, b).

Titratable acidity

The sour taste in tomatoes is attributed mainly to citric and malic acids (Petro-Turza 1987). Free amino acids may play the role of taste-enhancement or buffering effect (Bucheli et al. 1999) with glutamic acid, the major free amino acid present in tomatoes (Kader et al. 1978). 'Sourness' closely correlates with titratable acidity (Malundo et al. 1995; Bucheli et al. 1999; Tandon et al. 2003). Measurement of titratable acidity (TA) revealed that TA decreased during all storage treatments (Fig. 1e). However, these changes were more severe in cold storage with a value of 0.376 after 40 days of storage compared to 0.439 for MAP and 0.481 for CAS. There was a significant decline in TA with time for cold storage while its loss was at much lower rates when using CAS and the decrease was not significantly different for MAP and CAS. Results indicated that the effects of both CAS and MAP were obvious on retarding the titratable acidity loss; especially for tomato fruits kept in CAS, while tomatoes in cold storage did not exhibit any large reduction in TA during storage. Analysis shows that tomato samples in CAS had higher TA values after 90 days of storage than the ones in cold storage during the first 40 days. Decline in the acidity level has been associated with quality loss during tomato postharvest storage, and together with soluble solids content, can influence consumer's acceptability (Guillén et al. 2006; Zapata et al. 2008).

Wright and Kader (1997a, b) found that there were significant differences in titratable acidity of strawberries in all storage treatments during a 7-day storage period. Intact fruits in air treatment showed an increase, sliced fruit stored under 2 % O2 showed no changes, and sliced fruits in air treatments showed a decreasing trend in TA. Erkan et al. (2004) reported that titratable acidity of apples decreased continuously during a 9-month storage period, while statistically significant differences were found between CAS and normal-atmosphere storage of apples, whereas the differences in titratable acid among apples kept at different CAS concentrations were not statistically significant. Girardi et al. (2005) showed that decline of titratable acidity during storage is inevitable but CAS treatment can help to better retain titratable acidity. Sabır et al. (2011) reported that MAP slightly restrained the decrease in TA values compared to control treatment after 2 weeks of storage.

Repining index (TSS/TA)

Out of the 3 treatments, the highest variations of TSS/TA were found in the cold storage treatment (Fig. 1f). Results showed that TSS/TA in cold storage first reached the maximum value at 13.35, then there was a decrease followed by an increasing trend. In MAP treatment, TSS/TA values from 10 to 70 days of storage, except in the first and last (on day 70) experimental stages, were significantly higher than those of CAS. However, TSS/TA value (13.422) after 90 days of storage was the highest in CAS. This may be due to the fact that the decrease in TA loss in MAP was higher than that of CA, therefore, the ratio of TSS/TA was higher. Results of analysis indicated an increasing trend in TSS/TA in CAS during all the storage periods while TSS/TA in MAP showed a decreasing trend during the first 60–70 days of storage.

Hodges et al. (2006) found that soluble solids to titratable acidity ratio was highest in controlled atmosphere storage of cauliflower than air storage of the late-harvest crop, but there was no difference between controlled atmosphere storage and air storage for the two earlier harvests. Sabır et al. (2011) reported that during storage, the increased trend of TSS/TA was lower in MAP than other treatments, although the effects of treatments were not significant.

Conclusions

Results indicated the importance of storage treatment and its effect on slowing the decline in qualitative properties of tomatoes during storage. Controlled and modified atmosphere storage significantly retarded the ripening process compared to conventional cold storage. Tomato quality, measured by Firmness, colour, TSS, TA, ripening index, was preserved in Controlled atmosphere storage for almost 90 days, better than MAP and superior to conventional cold storage.

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