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Effect of Modified Atmosphere Packaging on the Quality and Shelf Life of Minimally Processed Carrots

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Abstract: The objective of this study was to investigate the effect of modified atmosphere packaging on the quality and shelf life of minimally processed carrots during cold storage. Ready-to-eat carrots (Nantes) prepared by manual peeling and automatic slicing were packed with passive (in air) and active modified atmospheres at low (5% O₂, 10% CO₂, 85% N₂) and high oxygen concentrations (80% O₂, 10% CO₂, 10% N₂). Minimally processed carrots were packed in polypropylene (PP) trays sealed with PP based film. Microbial, chemical, physical, and sensory analyses were conducted in carrots for 21 days at 4 °C. There was no yeast or mold growth during the 21 days of storage; however, the growth of mesophilic aerobic bacteria was observed at all treatments. The carrots packed with high oxygen and passive MAP retained quality properties better compared to low oxygen. The whiteness index did not significantly change during the 21 days of storage in all applications, indicating the good retention of orange color. The texture values declined for both passive and active MAP applications after 14 days of storage indicating a significant softening (P ≤ 0.05). According to oxygen level in the headspace and sensory results, shelf life of minimally processed carrots is suggested as 7 days for high oxygen and passive MAP application; however, it is limited to only 2 days for modified atmosphere with low oxygen.

Key Words: Minimally processed carrots, modified atmosphere packaging, shelf life, whiteness index, ready to eat/use

Tüketime Hazır Havuç Dilimlerinde Modifiye Atmosfer Paketlemenin Kalite ve Raf Ömrüne Etkisi

Özet: Bu çalışmanın amacı modifiye atmosfer paketlemenin tüketime hazır havuç dilimlerinde kalite ve raf ömrüne etkisini araştırmaktır. Kabuk soyma ve otomatik dilimlemeyle hazırlanan tüketime hazır havuçlar (Nantes) pasif (hava atmosferinde), düşük (%5 O₂, %10 CO₂, %85 N₂) ve yüksek oksijen (%80 O₂, %10 CO₂, %10 N₂) konsantrasyonlarına sahip aktif modifiye atmosferlerde ambalajlanmıştır. Tüketime hazır havuçlar polipropilen (PP) tabak ve PP bazlı üst film kullanılarak ambalajlanmıştır. 4 °C'de 21 gün süre ile depolanan havuçlarda mikrobiyal, kimyasal, fiziksel ve duyuşsal analizler yapılmıştır. Üründe 21 günlük depolama boyunca maya-küf gelişimi gözlenmezken, mezofilik aerobik bakteri gelişimi her üç uygulamada da görülmüştür. Yüksek oksijen ve pasif MAP ile ambalajlanmış tüketime hazır havuçlarda incelenen kalite kriterleri, düşük oksijen uygulamasına göre daha iyi korunmuştur. Bütün uygulamalarda beyazlık indeksi (WI) 21 günlük depolama süresince önemli bir değişim göstermemiş, havuç parlak turuncu rengini korumuştur (P > 0.05). Tekstür değerlerinin pasif ve aktif MAP uygulamaları için özellikle 14. günden sonra azalması istatistiksel olarak önemli bir yumuşamayı işaret etmektedir (P ≤ 0.05). Ambalaj içindeki oksijen oranı ve duyuşsal analiz sonuçlarına göre, tüketime hazır havuç dilimleri için önerilen raf ömrü yüksek oksijen ve pasif MAP uygulamaları için 7 gün iken, düşük oksijen uygulaması için 2 günle sınırlanmıştır.

Anahtar Sözcükler: Tüketime hazır havuç, modifiye atmosfer paketleme, raf ömrü, beyazlık indeksi, tüketime/kullanıma hazır

Introduction

Minimally processed carrots consumed as ready-to-eat snacks or salad vegetables have become increasingly popular (Amanatidou et al., 2000; Barry-Ryan et al., 2000). However, sales are limited because of rapid deterioration during storage. The main problems that limit the shelf life of minimally processed carrots to 4 to

5 days are high respiration rate, development of off-flavors, acidification, loss of firmness, discoloration, and microbial spoilage (Amanatidou et al., 2000; Barry-Ryan et al., 2000; Barry-Ryan and O'Beirne, 2000).

The quality and shelf life of minimally processed products can be extended by modified atmosphere packaging and cold storage by minimizing stress reactions

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(Huxsoll et al., 1989; Kader et al., 1989; Labuza and Breene, 1989; Bolin and Huxsoll, 1991a; Church, 1994; Church and Parsons, 1995; Barry-Ryan et al., 2000; Farber et al., 2003). Typically, concentrations of 5% to 10% CO₂ and 2% to 5% O₂ are applied to extend the shelf life of minimally processed products. However, Amanatidou et al. (2000) recommended a combination of 50% O₂ and 30% CO₂ to prolong the shelf life up to 5 to 7 days compared to storage in air, and in previously recommended modified atmosphere (1% O₂ and 10% CO₂). Alasalvar et al. (2005) reported that MAP treatment (90% N₂, 5% O₂, 5% CO₂) gave better sensory quality and extended the shelf life for purple carrots but no difference was observed for orange carrots. It was also reported that oxygen enriched atmosphere close to 80% or those in combination with carbon dioxide could be beneficial for decay control if they do not compromise flavor and odor (Wszelaki et al., 1999). On the other hand, it was stated that harvested carrots are physiologically too mature for senescence control and thus modified atmosphere was not beneficial (Bruemmer, 1988). Seljasen et al. (2004) suggested that package type and storage temperature had the greatest influence on the sensory quality of carrots. Packaging materials should provide enough ventilation and carrots should be kept at chilled conditions during the whole distribution chain to maintain the product quality (Seljasen et al., 2004). The main problems limiting the shelf life of minimally processed carrots were reported as white blush discoloration and microbial spoilage (Emmambux and Minaar, 2003).

There are only limited investigations on the effect of oxygen enriched atmosphere on the quality and shelf life of minimally processed carrots and the reports related to low oxygen applications of carrots are contradictory (Amanatidou et al., 2000; Alasalvar et al., 2005). Most of the studies focused on only partial quality indices of carrots.

The objective of this study was to investigate the effects of modified atmosphere packaging in passive (air) or active (low and enriched oxygen) atmospheres on the quality and shelf life of minimally processed carrots during cold storage. For this purpose, physical, chemical, microbiological, and sensory quality parameters of minimally processed modified-atmosphere-packaged carrots that were kept at 4 °C for 21 days were examined.

Materials and Methods

Materials

Carrots (*Daucus carota*) of the cultivar Nantes grown in Hatay, Turkey, were obtained from a local market the day before the processing and kept at 4 °C until processing. Chemicals were supplied from Merck (Darmstadt, Germany). Polypropylene (PP) trays (mono PP with the dimensions of 144 × 190 × 50 mm) and CPP/OPP film (oxygen and carbon dioxide permeability of 1296 cm³ m⁻² day⁻¹ and 3877 cm³ m⁻² day⁻¹, respectively, at 24 °C) were provided by Huhtamaki (İstanbul, Turkey) and A-Pack (İstanbul, Turkey), respectively.

Minimal Processing and Packaging of Carrots

All carrots were precleaned with tap water, peeled with a stainless steel knife, dipped into citric acid solution (0.1% w/v) for 15 min, and then sliced (diameter of 28 mm and thickness of 2.5 mm) with an industrial cutting machine (Ersoz, Turkey). The sliced carrots were dipped into citric acid solution (0.1% w/v) for 10 min and dried under air for 15 min. The dried carrots were packaged (350 g for each package) using 3 different gas compositions: air as passive MAP, 5% O₂, 10% CO₂, 85% N₂ (low oxygen) and 80% O₂, 10% CO₂, 10% N₂ (high oxygen) as active MAP applications in PP trays sealed with CPP/OPP film at 170 °C. A modified atmosphere packaging machine (MECA 501, France) combined with a gas mixer (KM60-3, Witt, Germany) was used for packaging. Packaged carrots were stored at 4 °C for 21 days, and quality parameters were measured on days 0, 2, 7, 14, and 21. Two packs were analyzed for each application on the sampling days.

During the entire production processes, laboratory coats, sterile gloves, and caps were used to comply with industrial hygiene standards. All equipment was sanitized using 200 mg kg⁻¹ chlorine solution prior to processing of carrots. PP trays were sanitized with hydrogen peroxide solution (3% v/v).

Headspace Gas Analysis

The headspace contents of oxygen (%) and carbon dioxide (%) in the packs were determined using a gas analyzer (PBI Dansensor, Ringsted, Denmark) by a needle through an adhesive septum previously fixed on the lidding material.

Microbial Analysis

A 10 g sample of carrots was taken from each package under hygienic conditions for microbiological analysis and homogenized with 90 ml of sterile peptone water (1 g l^{-1}) using a stomacher (Mayo, Italy). Total aerobic bacteria and total yeast and molds were enumerated using the spread plate method. Plate Count Agar (PCA) and Potato Dextrose Agar (PDA) acidified with tartaric acid were used for total aerobic bacteria and total yeast and mold, respectively. PCA was incubated at $37 \text{ }^\circ\text{C}$ for 48 h, and PDA at $22 \text{ }^\circ\text{C}$ for 5 days. Duplicate samples were examined on each day of analysis. The results were presented as $\log \text{ CFU g}^{-1}$ (Ünlütürk and Turantaş, 2002).

Physical Analysis

Color Measurement

Color measurements were performed using a Minolta chromameter model CR-400 (Minolta, Japan). The L, a, and b values were measured and the results were expressed as whiteness index (WI) using the equation $WI = 100 - [100 - L]^2 + a^2 + b^2]^{0.5}$ (Bolin and Huxsoll, 1991b). The colorimeter was calibrated to a standard white tile. Carrot disks of 20 from 2 packages (10 disks per package) were measured for each application and the means of the 20 measurements were calculated.

Texture Measurement

The firmness was measured with a texture analyzer (TA-XT Plus, UK) using a Warner/Blatzer (HDP/BS) blade set. Test speed of 5 mm s^{-1} and penetration distance of 30 mm were used, and the firmness was expressed as maximum cutting force (N). The data are presented as means of 20 independent measurements.

Chemical Analysis

A 60 g sample of carrots was blended for 2 min with an equal amount of distilled water (pH 7). The pH and brix (soluble solids) of the macerate were determined using a WTW-315i pH meter (WTW, Germany) and ATAGO N-50E (Atago, Japan) hand refractometer, respectively. Acidity was determined by potentiometric titration with 0.1 N NaOH up to pH 8.1 using 5 ml of macerate diluted with 50 ml of distilled water. Results were expressed as malic acid % (AOAC, 1990).

Sensory Analysis

Minimally processed carrots packaged with different atmospheres were evaluated for overall visual quality,

color, odor, texture, and taste using a 5-point rating scale and overall product acceptance using a 9-point hedonic scale with 6 trained panelists. For product attributes and acceptance, scores above 3 and 5 were considered acceptable, respectively.

Statistical Analysis

Data were subjected to analysis of variance (2-way ANOVA) and Duncan's multiple range test at 95% confidence level using the statistical program MSTATC. The effects of application and storage time and the interactions on the quality parameters were investigated (Freed, 1991).

Results

The headspace gas concentrations of the packs are shown in Figures 1 and 2, representing $\text{O}_2\%$ and $\text{CO}_2\%$, respectively. Headspace oxygen decreased in all applications. Oxygen dropped to 0 in 2 days at low oxygen active MAP, in 7 days at passive MAP (air), and in 14 days at high oxygen MAP application (Figure 1). The increase in $\text{CO}_2\%$ was parallel with the decrease in oxygen concentration (Figure 2).

There was no yeast or mold growth during the 21 days of storage in any of the applications. This might be due to the pH of the product (6.3-4.3), which encourages bacterial growth instead of yeast and mold growth. The effect of MAP on the total mesophilic aerobic bacteria is presented by Table 1. In general, there was no significant difference observed among the 3 different atmospheres in terms of total aerobic mesophilic bacteria. However, the effect of storage time on the total mesophilic aerobic bacteria was statistically significant. The initial count of aerobic mesophilic bacteria was 3.78-3.90 $\log \text{ CFU g}^{-1}$ at day 0 and increased to 7.48-8.25 $\log \text{ CFU g}^{-1}$ during storage.

The effect of active and passive modified atmospheres on the color (whiteness index) of minimally processed carrots is shown in Table 2. The results showed that the whiteness index (WI) did not significantly change during the 21 days of storage in any of the applications, indicating good retention of orange color with no significant surface drying ($P > 0.05$). This was probably due to the effect of citric acid and low water vapor transmission rate of the PP film used for packaging.

The texture measurements of carrot disks packaged with 3 different atmospheres are shown in Table 3. In

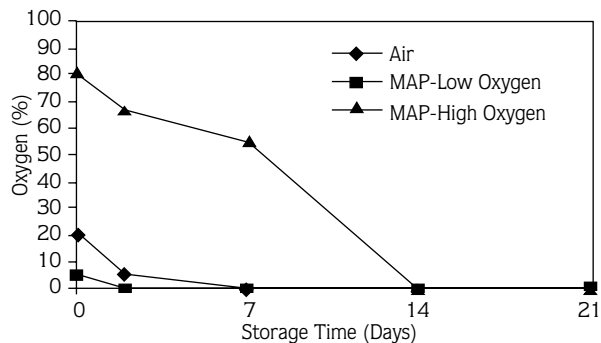


Figure 1. Effects of modified atmosphere packaging on the headspace oxygen concentration (%) during storage.

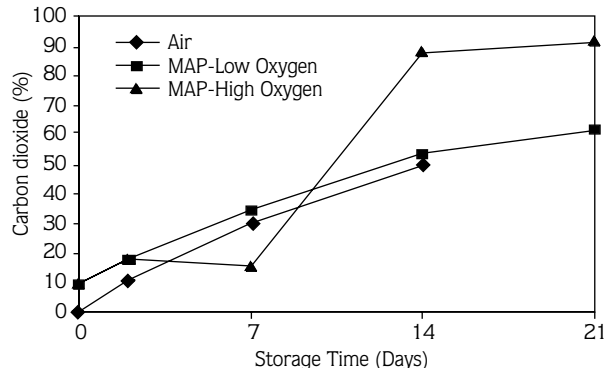


Figure 2. Effects of modified atmosphere packaging on the headspace carbon dioxide concentration (%) during storage.

Table 1. The effects of MAP on the total mesophilic aerobic bacteria (log CFU g⁻¹).

Application	Total Mesophilic Aerobic Bacteria (log CFU g ⁻¹)*				
	Day 0	Day 2	Day 7	Day 14	Day 21
Passive MAP (Air)	3.84ef	4.06ef	5.40c	7.46b	7.92ab
Low O ₂ MAP**	3.90ef	4.28de	5.47c	7.56b	8.25a
High O ₂ MAP***	3.78f	4.47d	5.70c	7.43b	7.48b

* Means followed by the different letters indicate significant difference (P ≤ 0.05)

** 5% O₂, 10% CO₂, 85% N₂

*** 80% O₂, 10% CO₂, 10% N₂

Table 2. The effects of MAP on the color (whiteness index) of minimally processed carrots during cold storage.

Application	Whiteness Index (n = 20)*				
	Day 0	Day 2	Day 7	Day 14	Day 21
Passive MAP (Air)	43.12cde	44.85abc	45.54ab	46.56a	43.90bcd
Low O ₂ MAP**	41.28ef	42.44de	43.19cde	43.79bcd	39.97fg
High O ₂ MAP***	39.09g	41.94def	44.98abc	42.59de	41.39ef

* Means followed by the different letters indicate significant difference (P ≤ 0.05)

** 5% O₂, 10% CO₂, 85% N₂

*** 80% O₂, 10% CO₂, 10% N₂

general, there was no significant difference in terms of texture values between the MAP applications until day 14 of storage (P > 0.05). The texture values representing the resistance to shear or firmness declined at both passive and active MAP applications especially after 14 days of storage, indicating significant softening (P ≤ 0.05).

The results of the chemical analysis (pH, acidity, and brix) of minimally processed and MA packaged carrots are given in Table 4. The pH tended to increase until day 7 and then to decrease after that for all treatments. There was no significant difference observed between modified atmosphere treatments at any given day in terms of brix (P > 0.05). However, brix tended to increase during

Table 3. The effects of MAP on the firmness (maximum force, N) of minimally processed carrots during cold storage.

Application	Firmness (Max. Force, N) (n = 20)*				
	Day 0	Day 2	Day 7	Day 14	Day 21
Passive MAP (Air)	95.57ab	101.38a	90.07bc	94.54ab	60.84f
Low O ₂ MAP**	96.00ab	89.25bc	77.37de	86.64bcd	53.24f
High O ₂ MAP***	82.76cde	93.87ab	76.53de	73.61e	61.20f

* Means followed by the different letters indicate significant difference ($P \leq 0.05$)

** 5% O₂, 10% CO₂, 85% N₂

*** 80% O₂, 10% CO₂, 10% N₂

Table 4. The effects of MAP on the chemical properties (pH, acidity, and brix) of minimally processed carrots during cold storage.

Application	Chemical Properties (n=4)*					
	Day 0	Day 2	Day 7	Day 14	Day 21	
pH	Passive MAP (Air)	6.3cde	6.3cde	6.5abc	6.2de	4.6h
	Low O ₂ MAP**	6.2ef	6.4bcd	6.6ab	5.5g	4.3i
	High O ₂ MAP***	6.2de	6.4bcde	6.7a	5.9f	4.4hi
Acidity (%)	Passive MAP (Air)	0.13gh	0.15ef	0.13gh	0.12hi	0.33c
	Low O ₂ MAP	0.16e	0.14fg	0.11i	0.17d	0.45a
	High O ₂ MAP	0.13g	0.13gh	0.12hi	0.14fg	0.40b
Brix	Passive MAP (Air)	6.0b	6.5ab	7.0a	7.0a	7.0a
	Low O ₂ MAP	6.1b	6.6ab	6.5ab	7.0a	7.0a
	High O ₂ MAP	6.0b	7.0a	6.5ab	7.0a	7.0a

* Means followed by the different letters indicate significant difference ($P \leq 0.05$)

** 5% O₂, 10% CO₂, 85% N₂

*** 80% O₂, 10% CO₂, 10% N₂

storage in all applications. The increase in brix during storage indicated an increase in total soluble solids.

Panelists' scores for sensory evaluation of sliced carrots packaged with air, low and high oxygen MA during 14 days of storage are presented in Table 5. In general, most of the sensory attributes evaluated for carrots were not acceptable after 7 days of storage in all applications. On day 14, the product was not tasted due to the noticeable off-odor. In terms of visual quality and color, minimally processed carrots treated with low and high oxygen were acceptable until day 14 of storage. The odor scores on days 2 and 7 were higher than those on day 0; however, they significantly decreased after day 7

for all MA applications, indicating noticeable off-odor formation possibly caused by microbial growth. Panelists' scores showed that carrots were acceptable in terms of texture on day 7; however, the scores were less than acceptable for all applications on day 14, possibly due to the decrease in firmness. The texture measurements by TA-XT plus were parallel with the sensory scores.

The overall product acceptability scores were close to 6 (5.5-5.8) at the end of day 7 with no difference between applications; however, on day 14, the acceptability scores significantly decreased in all treatments applied.

Table 5. The effects of MAP on the sensory quality of minimally processed carrots during cold storage.

Sensory Properties	Application	Panelist Scores (n = 6)*			
		Day 0	Day 2	Day 7	Day 14
Visual quality	Air	3.7abcd	4.5a	3.3abcd	2.5d
	Low O ₂	4.2abc	4.3ab	3.8abc	3.2bcd
	High O ₂	4.0abc	3.5abcd	4.0abc	3.0cd
Color	Air	4.0abcd	4.3ab	3.7bcd	2.3e
	Low O ₂	4.7a	4.3ab	3.5bcd	3.3cd
	High O ₂	4.2abc	3.2de	4.2abc	3.2de
Odor	Air	3.5ab	4.2a	4.0a	2.3bc
	Low O ₂	3.8a	4.5a	3.5ab	1.3c
	High O ₂	3.8a	4.5a	3.8a	2.0c
Texture	Air	4.3a	3.8abc	3.7abc	2.5e
	Low O ₂	3.3abcde	4.3a	3.2bcde	2.8cde
	High O ₂	3.8abc	4.0ab	3.5abcd	2.7de
Taste	Air	3.7ab	4.2a	3.0bc	NT**
	Low O ₂	3.5ab	3.8ab	3.0bc	NT**
	High O ₂	3.8ab	3.5ab	2.5c	NT**
Overall Product	Air	6.7a	7.8a	5.7a	2.5b
Acceptability	Low O ₂	5.5a	7.0a	5.8a	1.8b
	High O ₂	7.0a	5.7a	5.5a	2.7b

* Means followed by the different letters indicate significant difference ($P \leq 0.05$)

** Not Tasted

Discussion

The results showed that the respiration was very high for sliced carrots for all applications. Anaerobic atmosphere occurred after days 2 and 7 in low oxygen and passive atmospheres, respectively. Optimum packaging film for carrot should maintain the optimum gas composition and lead to low condensation preventing moisture loss during storage (Workneh et al., 2001). The packaging material (PP trays sealed with PP film) used in this study prevented moisture loss more successfully than creating optimum gas composition. Workneh et al. (2001) reported that LDPE film allowed a lower respiration rate and was preferred to the PP although the lowest microbial counts were observed in PP film up to 14 days. The lower the respiration rates the longer the storage life.

Minimally processed carrots were microbiologically spoiled by bacteria rather than yeast and mold. It was reported that microbial growth increased due to the increase in surface by peeling and cutting, high pH, and the moisture content of minimally processed carrots (Amanatidou et al., 2000). It was suggested by Deutsche Gesellschaft für Hygiene und Mikrobiologie that the microbial load should not be more than $7.7 \log \text{CFU g}^{-1}$ in order to guarantee 5-6 days of shelf life for minimally processed carrots (DGHM, 2002). In our study, the total aerobic mesophilic bacteria count was around $7.5 \log \text{CFU g}^{-1}$ at day 14; however, the carrots were not acceptable in terms of sensory properties in any application. Minimally processed carrots sustained bacterial spoilage by typical lactic acid fermentation (Emmambux and Minaar, 2003). It was also reported that oxygen at

increased levels was toxic to living cells due to the formation of superoxide radicals that are destructive to cell metabolisms. However, there was no significant difference observed between low and high oxygen atmospheres on the total mesophilic aerobic bacterial count except for the count on day 21.

One of the important criteria is whitening or white blush formation caused by drying at the surface of the peeled and sliced carrots (Emmambux and Minaar, 2003; Klaiber et al., 2004). A mechanism proposed for white discoloration on peeled carrots is related to physical and physiological responses to wounding. The physical response is reflected as a color change because of the reversible surface dehydration and physiological response as a result of the activation of phenolic metabolism and the production of lignin resulting in an irreversible color change (Cisneros-Zevallos et al., 1995; Emmambux and Minaar, 2003).

Emmambux and Minnaar (2003) reported that a polymeric packaging film maintaining a high relative humidity with a good moisture barrier should be considered to prevent white blush formation, which is the most important shelf life determinant for minimally processed carrots. Amanatidou et al. (2000) also reported that dipping in citric acid solution prevented the whitening of the carrot. They found that carrots dipped in citric acid, coated with Na alginate, and packaged under 50% O₂ and 30% CO₂ or 1% O₂ and 10% CO₂ atmospheres did not have any change in color until 12 days of storage. However, they observed a significant increase in whiteness index on day 12 comparing to day 0 under high oxygen MAP (80%-90% O₂). Although they stated that air and low oxygen application (1%) caused surface darkening due to the oxidation of phenolics, we did not observe any darkening under air and low oxygen application during the 21 days of storage.

Amanatidou et al. (2000) reported that carrots packaged with air significantly softened after 12 days of storage; however, packaging with high oxygen (70%-90% O₂) resulted in increases in texture values. The softening of the carrots was attributed to the growth of pectolytic pseudomonas (Amanatidou et al., 2000). However, Klaiber et al. (2004) observed an increase in the firmness of the minimally processed carrots during 9 days of storage resulting from the dehydration and the onset of lignification during storage.

The texture values were correlated with sensory texture scores. The panelist scores for texture ranged between 2.5 and 2.7, which was less than acceptable, indicating a significant softening for all applications after 14 days of storage. However, there was no significant difference between passive and active MAP applications in terms of firmness on day 7 according to the panelists' ratings, with acceptable firmness and juiciness.

The increase in pH could be attributed to the increase in microorganisms that consume organic acids. Barry-Ryan and O'Beirne (2000) reported similar results for pH. Similar to pH, acidity (%) decreased until day 14 and, after that, acidity increased for all applications possibly due to microbial spoilage. The increase in brix could be due to the increase in metabolic activities in which starch transformed into sugars (Cemeroglu et al., 2001).

Barry-Ryan et al. (2000) reported that sensory quality of grated carrots in MA implied that anaerobic catabolism was a major factor since off-odors, microbial loads, softening, and slime production were characteristics of fermentation. This deterioration occurred more rapidly with the depletion of oxygen compared to the rise in carbon dioxide (Barry-Ryan et al., 2000).

Previous studies suggested 4-5 days of shelf life for minimally processed carrots (Amanatidou et al., 2000; Barry-Ryan et al., 2000; Barry-Ryan and O'Beirne, 2000). However, in our study the shelf life of minimally processed carrots was suggested as 7 days for high oxygen and passive MAP applications. On the other hand, the shelf life was limited to 2 days in low oxygen atmosphere. MAP with high oxygen could be suggested for preservation of minimally processed carrots since the oxygen in the package was consumed in 2 days and anaerobic atmosphere occurred due to high respiration rate in the low oxygen MAP application.

Packaging film with high permeability of oxygen and carbon dioxide, low transmission rate of water vapor, storage temperature (0-4 °C), and good sanitation practices should be considered together in order to maintain the quality while increasing the shelf life of minimally processed and modified atmosphere packaged carrots. MAP with enriched oxygen could be suggested for preservation of minimally processed carrots to avoid anaerobic metabolism.

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