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Physiological Physical Chemical Characteristics and Sensory Evaluation of Minimally Processed Grapefruit Segments Packaged under Modified Atmosphere

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ABSTRACT

The objective of this study was to investigate physiological, physical, chemical, and sensory characteristics of minimally processed and modified-atmosphere-packaged grapefruit segments. Grapefruits were sanitized, peeled, segmented and packed under passive (21%O₂ +79% N₂) and two active modified atmospheres (20% O₂+10% CO₂ +70% N₂ and 70% O₂+20% CO₂ +10% N₂) in polypropylene trays. Physiological, physical, chemical, and sensory properties were monitored at 4 °C for 15 days. In general, there was no significant effect of MAP observed in chemical properties ($P > 0.05$). There was no significant effect of MAP treatment on a* and b* values ($P > 0.05$); however, the firmness values increased at all applications ($P \leq 0.05$). Grapefruit segments remained viable for 10 days under enriched oxygen (70%) and less than 10 days under active (20% oxygen) and passive MAP applications considering internal atmosphere and quality parameters. These results suggested that grapefruits could be prepared as ready to eat fruits with considerable shelf life, quality and convenience with using enriched oxygen MAP.

Keywords: Citrus; Rubyred; Shelf-life; Ready-to-eat; Quality; Preservation

Modifiye Atmosferde Ambalajlanan Az İşlenmiş Altıntop Segmentlerinin Fizyolojik Fiziksel Kimyasal Özellikleri ve Duyusal Değerlendirmesi

ESER BİLGİSİ

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ÖZET

Bu çalışmanın amacı az işlenmiş ve modifiye atmosferde ambalajlanmış altıntop segmentlerinin fizyolojik, fiziksel, kimyasal, ve duysal özelliklerinin incelenmesidir. Bu amaçla altıntop yüzeyleri dezenfekte edilmiş, soyulmuş, segmentlerine ayrılmış ve segmentler polipropilen tabaklarda pasif (%21 O₂ + %79 N₂) ve iki farklı aktif modifiye atmosfer (%20 O₂ + %10 CO₂ + %70 N₂ ve %70 O₂ + %20 CO₂ + %10 N₂) altında ambalajlanmıştır. Fizyolojik, fiziksel, kimyasal ve duysal özellikler 4°C'de 15 gün depolama süresince izlenmiştir. Genel olarak kimyasal özellikler üzerinde modifiye atmosferin önemli bir etkisi gözlenmemiştir ($P > 0.05$). MAP uygulamasının a* ve b* renk değerlerinde önemli bir etkisi olmazken ($P > 0.05$), sertlik değerleri bütün uygulamalarda artış göstermiştir ($P \leq 0.05$). Altıntop segmentleri yüksek oksijen uygulaması (%70) altında 10 gün dayanırken, aktif (%20 oksijen) ve

pasif (normal atmosfer koşulları) modifiye atmosfer uygulamaları altında 10 günden daha az dayanmıştır. Bu sonuçlar; altıntopların, yüksek oksijen uygulaması kullanılarak tüketime hazır segmentler halinde dikkate alınabilir bir raf ömrü, kalite ve tüketim kolaylığı ile hazırlanabileceğini göstermektedir.

Anahtar sözcükler: Turunçgil; Rubyred; Raf ömrü; Tüketime-hazır; Kalite; Muhafaza

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1. Introduction

Ready-to-eat or fresh-cut products are a rapidly growing sector of the horticultural industry (Soliva-Fortuny & Martin-Belloso 2003). Many terms are applied to fruits and vegetables cleaned and prepared in fresh form: lightly processed, minimally processed, prepared, pre-cut, fresh-processed, and partially processed etc. The term fresh-cut is widely used for these products (Cantwell 1997). The major factors responsible for extending the shelf life of fruits and vegetables include careful harvest at optimum maturity and food sanitation. When these are properly practiced, the implementation of optimum storage conditions through modified atmospheres can be quite effective, thus maximizing product shelf life and quality (Farber et al 2003).

Modified atmosphere packaging techniques constitute one of the fresh food preservation methods with no or only minimal use of additives and are accepted now as the technology of the future (Tas & Ayhan 2005). In modified atmosphere (MA) applications, the O₂ and CO₂ concentrations are modified initially and then change dynamically depending on respiration rate of product and the permeability of the film surrounding the produce (Erkan & Wang 2006). Reduced O₂ and/or enriched CO₂ levels reduce respiration and decrease ethylene production, inhibit or delay enzymatic reactions, alleviate physiological disorders, and preserve the product from quality losses (Day 1994; Soliva-Fortuny & Martin-Belloso 2003). However, exposure to O₂ and CO₂ levels outside the limits of tolerance may lead to anaerobic respiration and the production of undesirable metabolites and other physiological disorders (Zagory & Kader 1988). In fresh-cut fruit commodities, operations including peeling, cutting, coring, and/or slicing are critical to delimit the shelf life. These operations increase respiration and mass

transfer phenomena, thus microbiological spoilage and quality loss of the processed produce (Martin-Belloso & Soliva-Fortuny 2006). Agar et al (1999) observed that peeling and slicing of kiwifruit caused 30% mass loss after 3 days of storage in comparison with unpeeled slices.

The benefits of modified atmosphere packaging have been extensively studied in extending shelf-life of many fruits and vegetables. However, there are only limited studies regarding ready to eat citrus fruits. The application of MAP limited the microbial growth and enhanced the quality of strawberries (Garcia et al 1998), fresh cut mangoes and pineapples (Martinez-Ferrer et al 2002). It was reported that reduced levels of O₂ combined with appropriate permeability of plastic package extended the microbiological shelf life of fresh cut pears for almost 3 weeks under refrigerated storage (Soliva-Fortuny & Martin-Belloso 2003). However, packages with low permeability in combination with low O₂ atmospheres can stimulate the growth of anaerobic spoilage or pathogenic microorganisms (Soliva-Fortuny et al 2004).

Some researchers have suggested the use of super atmospheric or high O₂ concentrations ranging from 30 to 100 kPa for fruits and vegetables. Elevated O₂ atmospheres have been suggested to control microbiological growth, inhibit enzymatic discoloration, excessive moisture and flavor loss. Super atmospheric concentrations were reported as more effective against microorganisms when used with high CO₂ levels of 15-20 kPa. High CO₂ atmospheres also mostly inhibit aerobic microorganisms especially gram-negative bacteria and moulds (Kader & Ben-Yehoshua 2000).

Citrus species, especially grapefruits, are important because of their nutritional content and antioxidant properties associated with a low risk of degenerative diseases such as cancer, diabetes, cardiovascular and neurological problems (Del

Caro et al 2004). That is the reason why citrus species are of interest as “ready-to-eat” packaged products. There was also no study found in the literature on the quality and shelf life of segmented grapefruits. The use of high oxygen for grapefruit segments is especially of interest due to beneficial effects on the control of microbial growth and enzymatic reactions. There is also less risk for anaerobic respiration.

Low pH of the grapefruit, modified atmosphere packaging, and storage at low temperature along with good sanitation practices could prevent significant microbial growth. Pretel et al (1998) observed slight microbial activity in minimally processed ready-to-eat oranges during 11 days of storage at 4°C under passive atmosphere using two PP films with different permeability. There were also no significant change reported regarding to weight loss, acidity, °Brix and carotenoids. However, the orange segments were commercially viable for one week in terms of sensorial quality. PP with high permeability kept sensory quality better than PP with low permeability. They noted problems with loss of aroma, appearance of strange tastes and increase in ethanol level after one week of storage. Rapisarda et al (2006) also stated that there were low microbial counts observed in Tarocco orange slices packaged with 3 films of different permeability during 12 days of storage at 4°C. Minimally processed Tarocco clone slices packaged with the highest oxygen permeable film were the most appreciated regarding sensory evaluation. Terry & Overcast (1976) reported that there was only a slight or no microbial growth in different types of salad plants when the pH was less than 4.5 for mesophilic and psychrophilic bacteria.

The objective of this study was to investigate physiological (headspace oxygen and carbon dioxide), physical (colour and firmness), chemical (acidity, pH, °Brix and sugar content), and sensory qualities of minimally processed (sanitized, peeled, and segmented) and modified-atmosphere-packaged grapefruit segments during cold storage (4 °C). For this purpose, 3 different atmospheres (21%O₂ + 79%N₂ as passive MAP, 20% O₂+ 10% CO₂+ 70% N₂ as active MAP1 and 70% O₂+ 20% CO₂+ 10% N₂ as active MAP2) were applied.

2. Materials and Methods

2.1. Materials

The grapefruits (*C. paradisi*), variety Rubyred, harvested at Dörtöyl, Hatay, were stored overnight at 4°C prior to processing. Chemicals were obtained from Merck™ (Darmstadt, Germany). Polypropylene (mono PP with dimensions of 144×190×50 mm) trays and CPP/OPP film (oriented polypropylene; oxygen and carbon dioxide transmission rates of 1296 cm³·m⁻²·day⁻¹ and 3877 cm³·m⁻²·day⁻¹ at 24°C, respectively) were provided by Huhtamaki (Istanbul, Turkey) and A-Pack companies (Istanbul, Turkey), respectively.

2.2. Procedure for processing and packaging

PP trays were sanitized with 3% hydrogen peroxide solution. During the entire production processes, laboratory coats, sterile gloves, and caps were used to comply with industrial hygienic standards. All equipment was sanitized using 200 ppm chlorine solution prior to processing.

Fruits were selected for uniformity, washed with tap water and immersed in 200 ppm NaOCl for 3 min, then dried and peeled manually. After the peeling, fruits were carefully segmented and undamaged segments were placed inside the PP trays (400 g per tray) which were sealed with CPP/OPP (Cast Polypropylene/Oriented Polypropylene) film at 170°C. In this study 3 different gas compositions such as normal atmosphere (passive), active MAP1 (20% O₂+ 10% CO₂+ 70% N₂), and active MAP2 (70% O₂+ 20% CO₂+ 10% N₂) were applied with the modified atmosphere packaging machine (MECA 501, Mecaplastic, France) combined with a triple gas mixer (KM60-3; Witt, Germany). The PP trays were stored at 4°C for 15 days, and the physical and chemical quality parameters were measured at 0, 2nd, 5th, 10th and 15th days. Sensory analysis (Taş 2007) was performed at 0, 5th, 10th and 15th days.

2.3. Analysis

2.3.1. Physiological analysis (headspace oxygen and carbon dioxide content)

The headspace oxygen (%) and carbon dioxide (%) content of PP trays sealed with CPP/OPP film was

determined using a gas analyzer (PBI Dansensor, Ringsted, Denmark) by a needle through an adhesive septum fixed on the lidding material. The gas measurements were taken from two parallel packages for each treatment on each analysis day. The measurements were taken at 2 different sides of each package and the average of 4 measurements was calculated.

2.3.2. Physical analysis (colour and firmness)

The colour measurements were performed with a colorimeter (Model CR 400, Minolta, Osaka, Japan). The colorimeter was calibrated to a standard white tile. The CIE scale L*, a* and b* values were recorded in the middle of the one side of each segment. Twenty segments from two parallel packages (10 segments per package) were measured for each treatment on each sampling day (Taş 2007).

The firmness was measured with a texture analyzer (TA-XT Plus; Stable Micro Systems, Surrey, England) using a blade set (HDP/BS). Speed of 12 mm s⁻¹ and penetration distance of 35 mm were used to cut the segments at the center, and the firmness was expressed as maximum cutting force (N). The segments similar in thickness were selected for firmness measurement. Twenty segments from two parallel packages (10 segments per package) were measured for each treatment on each sampling day (Taş 2007).

2.3.3. Chemical analysis

Each sample (about 50g from) was blended for 2 min and filtered by using cheesecloth. The prepared juice of the sample was used for chemical analysis. Acidity was determined by potentiometric titration with 0.1 N NaOH up to pH 8.1 using 10 ml of macerate diluted with 50 ml water. Results were expressed as citric acid %. Soluble solids were measured by hand refractometer (Model N-50E; Atago, Tokyo, Japan) and expressed as °Brix at 20 °C. The pH was determined by using a pH meter (Model pH-315i; WTW, Weilheim, Germany) (AOAC 1990). The juice of the sample was centrifuged at 3000 rpm for 10 min and the supernatant was filtered by using a 0.45-µm-pore-size filter to determine sugar content (fructose, glucose, sucrose, and total sugar) of grapefruit

segments by using a HPLC (Shimadzu, Japan) equipped with refractive index detector (Model RID-10A, Shimadzu, Japan) (Escalona et al 2005). Chemical analysis was repeated twice for each package and the average of four measurements of two parallel packages were calculated (Taş 2007).

2.3.4. Sensory analysis

Grapefruit segments of two parallel packages were evaluated for visual appearance, aroma, texture, acidity, sweetness, and product acceptability using a 5-point scale with 6 trained panelists. Score 3 was considered the limit of acceptance. The testing was done in a clean, quiet, air-conditioned and odour free room where each panelist used separate tables during judgments. The attributes and product acceptability were expressed as follows:

Visual appearance 5: excellent/fresh; 4: good; 3: acceptable; 2: poor; 1: very poor.

Aroma 5: natural; 4: loss of aroma; 3: no aroma; 2: light strange aroma; 1: strong strange aroma.

Firmness 5: excellent firmness/juiciness; 4: firm/juicy; 3: acceptable firmness/juiciness; 2: hard; 1: very hard.

Acidity 5: very good; 4: good; 3: acceptable; 2: acidic; 1: too much acidity.

Sweetness 5: very sweet; 4: sweet; 3: acceptable sweetness; 2: low in sweetness; 1: no sweetness at all.

Product acceptability 5: very good; 4: good; 3: acceptable; 2: bad; 1: very bad.

2.4. Statistical analysis

Two parallel packages were used for each analysis. Data were subjected to analysis of variance (ANOVA) and a Duncan multiple comparison test to determine significant differences between treatments using the MSTAT statistical package (Freed 1991). Significance of differences was represented at 5% ($P \leq 0.05$).

3. Results and Discussion

3.1. Development of headspace atmosphere in the packages

The modified atmosphere inside the bags as oxygen and carbon dioxide and the time necessary to reach

equilibrium depended on the respiratory intensity of the fruits and the permeability of the film (Pretel et al 2000). The concentrations of O₂ and CO₂ (%) in the package headspace during storage are presented in Figures 1 and 2, respectively. For all treatments, decrease in oxygen and increase in carbon dioxide levels were observed during storage. Oxygen levels decreased continuously in all treatments until the concentrations reached 0% for passive and active MAP1 at day 10, and 2.4% for high oxygen treatment (active MAP2) at day 15, whereas CO₂ levels increased in passive and active MAP1 for 10 days and tended to stabilize after 10 days. The CO₂ level continued to increase at MAP2 during storage as seen in Figure 2. The atmospheres underwent anaerobic condition at passive and active MAP1 before 10 days. Anaerobic respiration could stimulate the growth of anaerobic spoilage and pathogenic microorganisms (Garcia et al 1998; Kader et al 1989). Thus, the storage time of grapefruit segments was limited to less than 10 days for passive and active MAP1 by considering the internal atmospheres. Although the atmosphere was aerobic at the 15th day of storage for high oxygen MAP (MAP2), the segments were not acceptable by the sensory panel which could be attributed to very high CO₂ (54.98%) level in the headspace. Thus, the storage time is suggested as 10 days under high oxygen application.

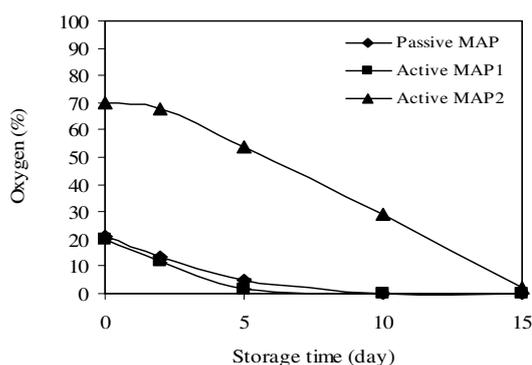


Figure 1-Headspace oxygen concentration (%) during cold storage (Points without error bars are smaller than symbols)

Şekil 1-Soğuk depolama sürecinde tepe boşluğu oksijen konsantrasyonu (%) (Hata çizgisi görünmeyen noktalar sembollerden daha küçüktür)

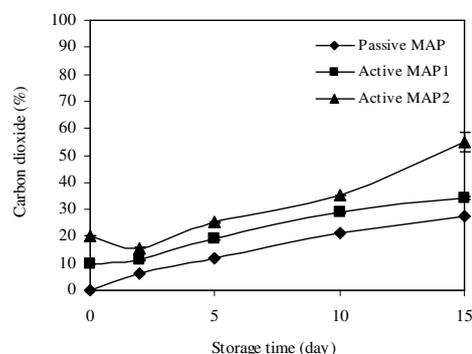


Figure 2-Headspace carbon dioxide concentration (%) during cold storage (Points without error bars are smaller than symbols)

Şekil 2-Soğuk depolama sürecinde tepe boşluğu karbondioksit konsantrasyonu (%) (Hata çizgisi görünmeyen noktalar sembollerden daha küçüktür)

3.2. Influence of modified atmosphere on physical quality of grapefruit segments

Fruit colour is an important attribute in purchase decisions, especially when a product is packaged and can not be touched or smelled (Gonzalez-Aguilar et al 2000). Effects of modified atmosphere packaging on physical parameters (colour and firmness) in grapefruit segments stored at 4°C are shown in Table 1. No differences were observed in the colour (a* and b* values) of grapefruit segments among all treatments (passive MAP, active MAP1 and MAP2) ($P > 0.05$). However, L* value was significantly affected by MAP treatment ($P < 0.01$). Grapefruit segments under passive MAP had brighter color than that of the active MAP treatments. Storage time significantly affected a* ($P < 0.05$) and b* values ($P < 0.0001$) but no significant effect on L* value ($P = 0.0917$).

In general there was no significant difference in segment firmness among 3 MAP conditions ($P = 0.0842$). However, storage time affected segment firmness significantly ($P < 0.0001$). Increases in firmness values were observed in the first 5 days of storage and tended to reverse for the rest of the storage at all applications. Increase in firmness may be attributed to surface drying of the segments due to water loss by respiration and transpiration

Table 1-Effect of modified atmosphere packaging on physical parameters (colour and firmness) of grapefruit segments stored at 4°C*Çizelge 1-Modifiye atmosfer paketlemenin 4°C'de depolanan altıntop segmentlerinde fiziksel özellikler (renk ve tekstür) üzerine etkisi*

| Treatment | Storage Time | L* | a* | b* | Firmness, N |
|---------------------|--------------|---------------------------|---------------------------|---------------------------|---------------------------|
| Passive MAP | Day 0 | 48.54±3.173 ^{ab} | 1.44±0.471 ^{ab} | 6.72±0.899 ^{abc} | 23.33±10.603 ^b |
| | Day 2 | 49.43±3.267 ^a | 1.25±0.586 ^{bc} | 6.31±1.060 ^{bcd} | 23.46±7.778 ^b |
| | Day 5 | 48.47±2.814 ^{ab} | 1.65±0.419 ^a | 7.40±0.796 ^a | 25.83±7.960 ^{ab} |
| | Day 10 | 49.47±2.189 ^a | 1.31±0.472 ^{abc} | 6.98±1.453 ^{ab} | 27.47±8.042 ^{ab} |
| | Day 15 | 48.73±1.920 ^{ab} | 1.24±0.631 ^{bc} | 6.27±1.506 ^{bcd} | 29.72±5.299 ^a |
| Active MAP1 | Day 0 | 47.91±2.496 ^{ab} | 1.39±0.455 ^{ab} | 5.59±0.961 ^d | 16.91±5.116 ^c |
| | Day 2 | 47.89±3.393 ^{ab} | 1.20±0.451 ^{bc} | 5.90±1.061 ^d | 23.27±5.996 ^b |
| | Day 5 | 47.17±2.571 ^{bc} | 1.49±0.402 ^{ab} | 7.42±0.711 ^a | 27.67±6.457 ^{ab} |
| | Day 10 | 48.58±2.848 ^{ab} | 1.44±0.574 ^{ab} | 7.33±1.035 ^a | 25.07±7.738 ^{ab} |
| | Day 15 | 47.99±2.529 ^{ab} | 1.13±0.622 ^{bc} | 6.11±1.412 ^{cd} | 25.81±5.908 ^{ab} |
| Active MAP2 | Day 0 | 47.95±2.377 ^{ab} | 1.34±0.511 ^{abc} | 5.88±1.015 ^d | 18.12±4.535 ^c |
| | Day 2 | 45.49±2.168 ^c | 1.67±0.522 ^a | 6.78±1.137 ^{abc} | 23.53±5.672 ^b |
| | Day 5 | 47.80±2.913 ^{ab} | 1.48±0.602 ^{ab} | 6.91±1.164 ^{abc} | 26.97±8.495 ^{ab} |
| | Day 10 | 47.17±2.561 ^{bc} | 1.01±0.414 ^c | 6.11±1.039 ^{cd} | 28.68±6.921 ^a |
| | Day 15 | 49.76±2.289 ^a | 1.21±0.615 ^{bc} | 6.23±1.222 ^{bcd} | 26.66±6.360 ^{ab} |
| Main effects | | | | | |
| Passive MAP | | 48.93±2.705 ^a | 1.38±0.534 ^a | 6.74±1.231 ^a | 25.96±8.314 ^a |
| Active MAP1 | | 47.91±2.767 ^b | 1.33±0.516 ^a | 6.47±1.287 ^a | 23.74±7.206 ^a |
| Active MAP2 | | 47.63±2.791 ^b | 1.34±0.574 ^a | 6.38±1.165 ^a | 24.79±7.413 ^a |
| | Day 0 | 48.13±2.674 ^{ab} | 1.39±0.473 ^{ab} | 6.06±1.060 ^c | 19.45±7.691 ^c |
| | Day 2 | 47.60±3.363 ^b | 1.37±0.556 ^{ab} | 6.33±1.127 ^c | 23.42±6.437 ^b |
| | Day 5 | 47.81±2.774 ^{ab} | 1.54±0.481 ^a | 7.24±0.927 ^a | 26.82±7.593 ^a |
| | Day 10 | 48.41±2.640 ^{ab} | 1.25±0.516 ^b | 6.81±1.280 ^b | 27.07±7.604 ^a |
| | Day 15 | 48.83±2.338 ^a | 1.19±0.614 ^b | 6.20±1.363 ^c | 27.39±6.014 ^a |
| P values | | | | | |
| Storage (S) | | 0.0917 | 0.0037 | <.0001 | <.0001 |
| Treatment (T) | | 0.0015 | 0.7801 | 0.066 | 0.0842 |
| S×T | | 0.0024 | 0.0185 | 0.0011 | 0.1889 |

* Mean values followed by the different letter for a given parameter are significantly different ($P \leq 0.05$)

(Comparisons could be made between treatments for a given storage day or between storage days for a given treatment)

** Active MAP1 with low oxygen (20% O₂+ 10% CO₂+ 70% N₂)*** Active MAP2 with high oxygen (70% O₂+ 20% CO₂+ 10% N₂)

as stated by Martin-Belloso & Soliva-Fortuny (2006) and Erkan & Wang (2006). However, our sensory panel did not find significant changes in firmness for all treatments during storage. Water loss of minimally processed fruits was one of the important problems and this might be overcome using packaging materials with low water vapor transmission rate and low storage temperature (Martin-Belloso & Soliva-Fortuny 2006).

3.3. Influence of modified atmosphere on chemical quality of grapefruit segments

Important chemical properties such as titratable acidity, pH, soluble solids, and sugar content of the grapefruit segments are shown in Table 2. For citrus fruits (grapefruit, orange, mandarin), citric acid is a major organic acid followed by malic acid and quinic acid (Cemeroglu et al 2001). No significant changes were observed in titratable acidity in terms of citric acid, pH and soluble solids among passive

Table 2-Effect of modified atmospheres on chemical parameters (titratable acidity, pH, soluble solids, sugars) of grapefruit segments stored at 4°C

Çizelge 2-Modifiye atmosfer paketlemenin 4 °C'de depolanan altıntop segmentlerinde kimyasal özellikler (titrasyon asitliği, pH, çözümlü kuru madde, şekerler) üzerine etkisi

| Treatment | Storage time | Titratable acidity, % citric acid | pH | Soluble solids, °Brix | Fructose, % | Glucose, % | Sucrose, % | Total sugar, % |
|---------------------|--------------|-----------------------------------|----------------------------|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|
| Passive MAP | Day 0 | 1.51±0.078 ^c | 3.25±0.035 ^{abc} | 8.50±0.000 ^a | 2.21±0.057 ^{ab} | 2.24±0.064 ^a | 3.50±0.134 ^{bc} | 7.94±0.255 ^a |
| | Day 2 | 1.71±0.007 ^a | 3.26±0.021 ^a | 8.25±0.354 ^{ab} | 2.29±0.163 ^{ab} | 2.29±0.170 ^a | 3.91±0.389 ^{ab} | 8.48±0.721 ^a |
| | Day 5 | 1.58±0.049 ^{abc} | 3.24±0.049 ^{abcd} | 8.50±0.000 ^a | 2.28±0.141 ^{ab} | 2.30±0.134 ^a | 3.79±0.071 ^{abc} | 8.37±0.346 ^a |
| | Day 10 | 1.59±0.148 ^{abc} | 3.17±0.014 ^{cd} | 8.50±0.000 ^a | 2.39±0.021 ^{ab} | 2.42±0.021 ^a | 3.49±0.191 ^{bc} | 8.29±0.233 ^a |
| | Day 15 | 1.61±0.042 ^{abc} | 3.19±0.007 ^{abcd} | 8.25±0.354 ^{ab} | 2.31±0.283 ^{ab} | 2.34±0.269 ^a | 3.58±0.417 ^{abc} | 8.23±0.969 ^a |
| Active MAP1 | Day 0 | 1.66±0.064 ^{ab} | 3.25±0.021 ^{abc} | 8.50±0.000 ^a | 2.21±0.057 ^{ab} | 2.24±0.064 ^a | 3.50±0.134 ^{bc} | 7.94±0.255 ^a |
| | Day 2 | 1.60±0.042 ^{abc} | 3.26±0.049 ^a | 8.50±0.000 ^a | 2.33±0.014 ^{ab} | 2.44±0.113 ^a | 3.68±0.057 ^{abc} | 8.45±0.071 ^a |
| | Day 5 | 1.66±0.071 ^{ab} | 3.25±0.028 ^{ab} | 8.50±0.000 ^a | 2.34±0.042 ^{ab} | 2.36±0.035 ^a | 3.95±0.156 ^a | 8.65±0.078 ^a |
| | Day 10 | 1.58±0.071 ^{abc} | 3.18±0.049 ^{bcd} | 8.00±0.000 ^b | 2.32±0.007 ^{ab} | 2.34±0.014 ^a | 3.51±0.014 ^{abc} | 8.17±0.021 ^a |
| | Day 15 | 1.62±0.064 ^{abc} | 3.19±0.014 ^{abcd} | 8.00±0.000 ^b | 2.23±0.071 ^{ab} | 2.26±0.057 ^a | 3.50±0.106 ^{bc} | 7.99±0.233 ^a |
| Active MAP2 | Day 0 | 1.63±0.106 ^{abc} | 3.26±0.057 ^{abc} | 8.50±0.000 ^a | 2.21±0.057 ^{ab} | 2.24±0.064 ^a | 3.50±0.134 ^{bc} | 7.94±0.255 ^a |
| | Day 2 | 1.60±0.021 ^{abc} | 3.19±0.064 ^a | 8.50±0.000 ^a | 2.36±0.064 ^{ab} | 2.39±0.078 ^a | 3.73±0.205 ^{abc} | 8.47±0.346 ^a |
| | Day 5 | 1.68±0.148 ^{ab} | 3.17±0.035 ^{abcd} | 8.50±0.000 ^a | 2.33±0.057 ^{ab} | 2.34±0.071 ^a | 3.74±0.269 ^{abc} | 8.41±0.141 ^a |
| | Day 10 | 1.65±0.163 ^{ab} | 3.21±0.021 ^d | 8.50±0.000 ^a | 2.42±0.035 ^a | 2.44±0.035 ^a | 3.74±0.078 ^{abc} | 8.59±0.007 ^a |
| | Day 15 | 1.54±0.014 ^{bc} | 3.25±0.035 ^{abcd} | 8.00±0.000 ^b | 2.20±0.057 ^b | 2.25±0.049 ^a | 3.46±0.078 ^c | 7.90±0.184 ^a |
| Main effects | | | | | | | | |
| Passive MAP | | 1.60±0.091 ^a | 3.22±0.042 ^a | 8.40±0.211 ^a | 2.29±0.134 ^a | 2.32±0.133 ^a | 3.65±0.272 ^a | 8.26±0.474 ^a |
| Active MAP1 | | 1.62±0.057 ^a | 3.22±0.044 ^a | 8.30±0.258 ^a | 2.29±0.066 ^a | 2.33±0.091 ^a | 3.63±0.202 ^a | 8.24±0.311 ^a |
| Active MAP2 | | 1.62±0.095 ^a | 3.21±0.050 ^a | 8.40±0.211 ^a | 2.30±0.097 ^a | 2.33±0.094 ^a | 3.63±0.185 ^a | 8.26±0.340 ^a |
| | Day 0 | 1.60±0.096 ^a | 3.25±0.020 ^a | 8.50±0.000 ^a | 2.21±0.044 ^c | 2.24±0.049 ^b | 3.50±0.104 ^c | 7.94±0.197 ^c |
| | Day 2 | 1.63±0.060 ^a | 3.26±0.035 ^a | 8.42±0.204 ^a | 2.32±0.085 ^{ab} | 2.37±0.119 ^a | 3.77±0.225 ^{ab} | 8.47±0.359 ^a |
| | Day 5 | 1.64±0.091 ^a | 3.22±0.049 ^{ab} | 8.50±0.000 ^a | 2.32±0.076 ^{abc} | 2.33±0.075 ^{ab} | 3.83±0.173 ^a | 8.47±0.218 ^a |
| | Day 10 | 1.60±0.108 ^a | 3.17±0.028 ^c | 8.33±0.258 ^a | 2.37±0.050 ^a | 2.40±0.049 ^a | 3.58±0.154 ^{bc} | 8.35±0.220 ^{ab} |
| | Day 15 | 1.59±0.051 ^a | 3.19±0.015 ^{bc} | 8.08±0.204 ^b | 2.25±0.142 ^{bc} | 2.28±0.133 ^{ab} | 3.51±0.203 ^c | 8.04±0.478 ^{bc} |
| P values | | | | | | | | |
| Storage (S) | | 0.7979 | 0.0520 | 0.0002 | 0.0577 | 0.0782 | 0.0319 | 0.0625 |
| Treatment (T) | | 0.7779 | 0.8303 | 0.1529 | 0.9186 | 0.9515 | 0.9587 | 0.9870 |
| S×T | | 0.4474 | 0.8736 | 0.0197 | 0.864 | 0.7701 | 0.7518 | 0.9154 |

*Mean values followed by the different letter for a given parameter are significantly different ($P \leq 0.05$)

(Comparisons could be made between treatments for a given storage day or between storage days for a given treatment)

Active MAP1 with low oxygen (20% O₂+ 10% CO₂+ 70% N₂)*Active MAP2 with high oxygen (70% O₂+ 20% CO₂+ 10% N₂)

and active MAP applications ($P > 0.05$). The storage time also did not have significant effect on titratable acidity ($P = 0.7979$) and pH ($P = 0.052$). However, there was significant effect of storage time on total soluble solids ($P < 0.001$). The effects of storage became significant for active MAP1 application after day 5 and for high oxygen application after day 10. MAP application with different gas compositions did not have any significant effect on the sugar content of grapefruit segments as shown in Table 2 ($P > 0.05$). The sugar

content (fructose, glucose and total sugar) of grapefruit segments did also not change significantly during storage ($P > 0.05$). Studies with fresh-cut pears (Senesi et al 1999) and kiwifruit (Agar et al 1999) showed that sugar content did not significantly change under refrigerated storage, as expected because sugar content is not much influenced by the atmospheric conditions (Soliva-Fortuny & Martin-Belloso 2003). Our results are in agreement with the results by Pretel et al (1998) who reported no significant changes in chemical

attributes (pH, titratable acidity, and soluble solids) during 11 days of storage of minimally processed oranges (Pretel et al 1998).

3.4. Influence of modified atmosphere on sensory quality of grapefruit segments

The results of the sensory evaluation are presented in Table 3. In general, there was no significant difference in sensory quality of grapefruit segments between passive (air) and active MAP1 ($P > 0.05$) for 15 days. There were no significant effect of MAP treatment*storage time interaction on any of the attributes tested ($P > 0.05$). However, MAP treatment had significant effect on visual appearance ($P < 0.001$), sweetness ($P < 0.05$) and product acceptability ($P < 0.0001$). Storage time

significantly affected all sensory attributes tested and product acceptability ($P < 0.05$). Although grapefruit segments packaged under air or active MAP with 20% oxygen were found acceptable for 15 days in terms of sensory quality, the atmosphere was anaerobic after the 10th day which could be risky for consumption. The scores for grapefruit segments treated with high oxygen were below acceptability limit (score 3) at the 15 days of storage for most of the sensory attributes and the product acceptability. That's why the viability of grapefruit segments packaged with high oxygen was limited to 10 days. This might be due to negative effects of CO₂ (about 55%) on the sensory attributes at the 15th day of storage under MAP2.

Table 3-Effect of modified atmosphere packaging on the sensory attributes of grapefruit segments stored at 4°C

Çizelge 3-Modifiye atmosfer paketlemenin 4°C'de depolanan altıntop segmentlerinde duyusal özellikler üzerine etkisi

| Treatment | Storage Time | Visual appearance | Aroma | Firmness | Acidity | Sweetness | Product acceptability |
|-----------------|--------------|-------------------------|-------------------------|------------------------|--------------------------|--------------------------|--------------------------|
| Passive MAP | Day 0 | 4.3±0.516 ^a | 4.8±0.408 ^a | 4.8±0.41 ^a | 4.2±1.329 ^{ab} | 3.8±0.408 ^{ab} | 4.8±0.408 ^a |
| | Day 5 | 4.3±0.516 ^a | 4.2±1.169 ^{ab} | 4.7±0.52 ^a | 4.5±0.548 ^a | 4.2±0.753 ^a | 4.7±0.516 ^{ab} |
| | Day 10 | 4.2±0.753 ^{ab} | 4.3±0.816 ^{ab} | 4.3±1.03 ^{ab} | 4.3±1.211 ^a | 4.2±0.753 ^a | 4.2±1.169 ^{ab} |
| | Day 15 | 4.0±0.894 ^{ab} | 4.3±0.816 ^{ab} | 3.8±0.75 ^{ab} | 3.3±1.033 ^{abc} | 3.7±0.816 ^{ab} | 4.2±0.753 ^{ab} |
| Active MAP1 | Day 0 | 4.3±0.816 ^a | 4.8±0.408 ^a | 4.8±0.41 ^a | 4.0±1.265 ^{ab} | 3.3±0.816 ^{abc} | 4.5±0.548 ^{ab} |
| | Day 5 | 4.3±0.516 ^a | 4.7±0.516 ^a | 4.0±0.63 ^{ab} | 4.2±0.408 ^{ab} | 3.7±0.516 ^{ab} | 4.2±0.753 ^{ab} |
| | Day 10 | 4.0±0.632 ^{ab} | 4.2±0.753 ^{ab} | 4.0±0.89 ^{ab} | 3.8±1.169 ^{ab} | 3.7±0.816 ^{ab} | 3.8±0.983 ^{abc} |
| | Day 15 | 3.7±1.211 ^{ab} | 4.3±0.816 ^{ab} | 3.8±0.98 ^{ab} | 2.8±1.329 ^{bc} | 3.0±1.095 ^{bc} | 3.7±0.816 ^{bc} |
| Active MAP2 | Day 0 | 4.3±0.816 ^a | 4.7±0.516 ^a | 4.7±0.52 ^a | 4.0±0.894 ^{ab} | 3.3±0.816 ^{abc} | 4.3±0.816 ^{ab} |
| | Day 5 | 3.3±1.211 ^{ab} | 5.0±0.000 ^a | 4.5±0.55 ^{ab} | 4.5±0.548 ^a | 4.0±0.632 ^{ab} | 4.0±0.894 ^{ab} |
| | Day 10 | 3.2±0.753 ^{bc} | 4.3±0.816 ^{ab} | 3.8±0.98 ^{ab} | 3.8±1.169 ^{ab} | 3.5±1.225 ^{ab} | 3.0±0.894 ^{cd} |
| | Day 15 | 2.3±0.816 ^c | 3.7±1.033 ^{ab} | 3.5±0.84 ^b | 2.3±1.366 ^c | 2.3±1.033 ^c | 2.3±0.516 ^d |
| Main effects | | | | | | | |
| Passive MAP | | 4.2±0.658 ^a | 4.4±0.830 ^a | 4.4±0.78 ^a | 4.1±1.100 ^a | 3.9±0.690 ^a | 4.5±0.779 ^a |
| Active MAP1 | | 4.1±0.830 ^a | 4.5±0.659 ^a | 4.2±0.82 ^a | 3.7±1.160 ^a | 3.4±0.830 ^b | 4.0±0.806 ^a |
| Active MAP2 | | 3.3±1.122 ^b | 4.4±0.830 ^a | 4.1±0.85 ^a | 3.7±1.274 ^a | 3.3±1.083 ^b | 3.4±1.100 ^b |
| | Day 0 | 4.3±0.686 ^a | 4.8±0.428 ^a | 4.8±0.43 ^a | 4.1±1.110 ^a | 3.5±0.707 ^{ab} | 4.6±0.616 ^a |
| | Day 5 | 4.0±0.907 ^a | 4.6±0.778 ^{ab} | 4.4±0.61 ^{ab} | 4.4±0.502 ^a | 3.9±0.639 ^a | 4.3±0.752 ^a |
| | Day 10 | 3.8±0.808 ^{ab} | 4.3±0.752 ^{ab} | 4.1±0.94 ^{bc} | 4.0±1.138 ^a | 3.8±0.943 ^a | 3.7±1.085 ^b |
| | Day 15 | 3.3±1.188 ^b | 4.1±0.900 ^b | 3.7±0.83 ^c | 2.8±1.249 ^a | 3.0±1.085 ^b | 3.4±1.037 ^b |
| <i>P</i> values | | | | | | | |
| Storage (S) | | 0.0023 | 0.0356 | 0.0005 | 0.0002 | 0.0051 | <.0001 |
| Treatment (T) | | 0.0002 | 0.9032 | 0.3287 | 0.3090 | 0.0135 | <.0001 |
| S×T | | 0.2262 | 0.3080 | 0.8044 | 0.9233 | 0.6885 | 0.2899 |

*Mean values followed by the different letter for a given parameter are significantly different ($P \leq 0.05$).

(Comparisons could be made between treatments for a given storage day or between storage days for a given treatment)

** Active MAP1 with low oxygen (20% O₂+ 10% CO₂+ 70% N₂)

*** Active MAP2 with high oxygen (70% O₂+ 20% CO₂+ 10% N₂)

4. Conclusion

The grapefruit segments were viable for 10 days under high oxygen (70% oxygen) due to sensory attributes and acceptability scores, and less than 10 days for passive and active MAP with 20% oxygen due the internal atmosphere at 4 °C. Although the package atmosphere was aerobic during 15 days at high oxygen application, the segments were found not acceptable by the sensory panel after 10 days possibly due to negative effects of high amount of carbon dioxide on the sensory attributes. High oxygen application provided further advantages over passive MAP or active MAP1 considering the internal oxygen level at 10 days of storage. Grapefruit segments can be prepared as ready-to-eat fruits with considerable shelf life of 10 days, good quality and convenience to the consumer using enriched oxygen MAP using PP trays sealed with CPP/OPP film. This study could be repeated using packaging film with higher permeability to increase the shelf life more than 10 days.

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