GIDA
THE JOURNAL OF FOOD
E-ISSN 1309-6273, ISSN 1300-3070

Research/ Araştırma
GIDA (2024) 49 (6) 1074-1094
doi: 10.15237/gida.GD24070

THE EFFECTS OF ETHYLENE SCAVENGING-ACTIVE PACKAGING AND STORAGE TEMPERATURE ON QUALITY AND SHELF LIFE OF CUCUMBER (*CUCUMIS SATIVUS* L.)

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Geliş/*Received*: 12.07.2024; Kabul /*Accepted*: 14.10.2024; Online baskı /*Published online*: 24.10.2024

Tiribolulu, T., Haskaraca, G., Ayhan, Z. (2024). The effects of ethylene scavenging-active packaging and storage temperature on quality and shelf life of cucumber (Cucumis sativus L.). GIDA (2024) 49 (6) 1074-1094 doi: 10.15237/ gida.GD24070

Tiribolulu, T., Haskaraca, G., Ayhan, Z. *(2024).* Etilen tutucu içeren aktif ambalajlamanın ve depolama sıcaklığının badem hıyarın (Cucumis sativus L.) kalite ve raf ömrüne etkisi. GIDA (2024) 49 (6) 1074-1094 doi: 10.15237/ gida.GD24070

ABSTRACT
This study aimed to determine the effects of ethylene scavenger incorporated active packaging and storage temperature on the shelf life of cucumbers. For this purpose, cucumbers were packaged using modified atmosphere packaging (5% O_2-10% CO_2-85% N_2) in two different low-density polyethylene (LDPE) packages, with and without ethylene scavenger, and stored at 4ºC and 10ºC for 20 days. The group of cucumbers without packaging was prepared as the control. Throughout the storage period, changes in physical, chemical, and sensory quality parameters of the cucumbers were monitored through analyses of headspace gas analysis, weight loss, color, texture, soluble solid content (%brix), pH, titratable acidity, and sensory evaluation. Due to cold injury at 4ºC, equilibrium atmosphere could not be achieved, and the %O_2 level dropped below the critical limit (2%) by the end of storage. At 10ºC, the products packaged without ethylene scavenger exhibited higher ethylene concentration during storage, negatively affecting the quality parameters, whereas the group with ethylene scavenger had lower ethylene accumulation and reduced cold injury, preserving product quality better. The cucumbers packaged with ethylene scavenger and stored at 10ºC was sensorially acceptable for the entire storage of 20 days suggesting the shelf life of 20 days only for this application.
Keywords: Active packaging, ethylene scavengers, post-harvest quality, chilling injury, cucumber

ETİLEN TUTUCU İÇEREN AKTİF AMBALAJLAMANIN VE DEPOLAMA SICAKLIĞININ BADEM HIYARIN (*CUCUMIS SATIVUS* L.) KALİTE VE RAF ÖMRÜNE ETKİSİ

ÖZ
Bu çalışmada, etilen tutucu içeren aktif ambalajlamanın ve depolama sıcaklığının badem hıyarın raf ömrü üzerine etkilerinin belirlenmesi amaçlanmıştır. Bu amaçla badem hıyarlar (*Cucumis sativus L.*), etilen tutucu katkı içeren ve içermeyen olmak üzere iki farklı düşük yoğunluklu polietilen (LDPE)

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ambalajda modifiye atmosfer kullanılarak (%5 O_2-%10 CO_2-%85 N_2) ambalajlanmış ve 4ºC ve 10ºC'de 20 gün depolanmıştır. Ambalajlanmamış ürün grubu kontrol olarak kullanılmıştır. Depolama süresince hıyarların fiziksel, kimyasal ve duyusal kalite parametrelerindeki değişimin izlenmesi için tepe boşluğu gaz analizi, kütle kaybı, renk, tekstür, suda çözünür kuru madde, pH, titrasyon asitliği ve duyusal analizler yapılmıştır. 4ºC'de hıyarlarda meydana gelen soğuk zararı nedeniyle denge atmosferine ulaşılamamış ve depolama sonunda %O_2 seviyesi kritik limitin (%2) altına inmiştir. 10ºC'de ise etilen tutucu içermeyen ambalajlı grupta depolama süresince etilen konsantrasyonun daha yüksek olması ürünün kalite parametrelerini olumsuz etkilerken, etilen tutucu içeren ambalajda etilen konsantrasyonunun daha düşük olması ve düşük soğuk zararı sayesinde ürün kalitesi daha iyi korunmuştur. 20 günlük depolama sonunda duyusal olarak kabul edilebilir tek ürün grubu, 10ºC'de etilen tutucu içeren uygulama olmuştur. Sonuçlara göre, 10ºC'de etilen tutucu katkı içeren ambalajlarda badem hıyarın raf ömrünün en az 20 gün olduğu tespit edilmiştir.
Anahtar kelimeler: Aktif ambalajlama, etilen tutucu, hasat sonrası kalite, soğuk zararı, badem hıyar

INTRODUCTION

Cucumber (*Cucumis sativus L.*) belongs to the *Cucurbitaceae* family and is a widely cultivated and popular plant consumed globally, with significant economic importance (Che and Zhang, 2019). With high total water content (95% on average), cucumbers are also rich in vitamins and minerals essential for human nutrition, such as vitamin K, vitamin A, calcium, molybdenum, potassium, manganese and magnesium (Manjunatha and Anurag, 2014; Maleki et al., 2018). Although there are slight variations in the figures over the years, an average of 87 million tons of cucumbers were produced worldwide in 2021. China holds the largest share of this production with approximately 75.5 million tons. Following China, Turkey produced about 1.9 million tons and Russia 1.6 million tons of cucumbers in 2021 (Anonymous, 2023). Cucumbers belong to the group of non-climacteric fruits, meaning they do not continue to ripen after harvest (Wang et al., 2013). Therefore, if not stored under proper conditions after harvest, they quickly deteriorate, leading to significant product and economic losses. Considering the annual production volumes, it can be estimated how substantial product and financial losses can be during improper storage and transportation. To prevent these losses, it is crucial to maintain proper packaging and storage conditions that minimize product losses until the products reach the consumer.

During storage, cucumbers continue cellular respiration by taking in oxygen from the environment and releasing metabolic products such as CO_2, water and ethylene (Sousa et al., 2017). If these metabolites released during respiration are not controlled in packaging and storage, quality losses such as color and texture changes and softening may occur in the products (Maleki et al., 2018). Indeed, it has been reported that most of the spoilage in cucumbers during storage is caused by yellowing due to the accumulation of ethylene gas and wrinkling due to cold injury when exposed to low temperatures (Manjunatha and Anurag, 2014). Cucumbers, which are highly sensitive to different storage temperatures, start to wrinkle, spot, yellow, and age when stored at temperatures below 10ºC. On the other hand, cucumbers stored at temperatures above 15ºC generally spoil through rotting and yellowing. Therefore, storage temperature is a crucial criterion for cucumbers and must be carefully controlled to extend the product's shelf life (Sabır and Ağar, 2008; Li et al., 2014).

In addition to temperature control, various packaging techniques are being tried to prevent quality losses that may occur during storage and to extend the shelf life of cucumbers (Farber et al., 2003). At this point, modified atmosphere packaging (MAP) has become a frequently used application. It has been reported that MAP packaging significantly contributes to preventing cold injury in cucumbers during storage, and slows down water loss in products by reducing respiration rate and ethylene production (Fahmy and Nakano, 2014). Many studies in the literature highlighted the advantages of MAP technology in extending the shelf life of fruits and vegetables (Sandhya, 2010; Manjunatha and Anurag, 2014;

Oliveira et al., 2015;). However, like many developments in various fields today, packaging technologies have also advanced significantly. In addition to applications such as MAP, where only the internal atmosphere of the packaging is altered, some active packaging applications incorporate emitter or absorber systems within the packaging that capture or slow down aging by absorbing metabolites resulting from cellular respiration (Yildirim et al., 2018; Ebrahimi et al., 2022; Fan et al., 2023). Active packaging helps extend the product's shelf life by altering the atmospheric conditions around the product during storage using absorber and emitter systems for various metabolites such as carbon dioxide, oxygen, ethylene, and ethanol (Ozdemir and Floros, 2004; Yildirim et al., 2018; Bhardwaj et al., 2019). Active packaging is generally applied by including absorber/scavenger or emitter substances in a sachet or incorporating them directly into the packaging material (Soltani Firouz et al., 2021). Removing ethylene, which is produced as a result of the metabolic activities of fruits and vegetables, is one of the most critical factors in extending the shelf life (Fonseca et al., 2021). For this purpose, ethylene absorbers, which are a type of active packaging system, are used in cucumber storage. Compounds such as zeolite, potassium permanganate and palladium are used to capture ethylene in ethylene absorber systems. Among these, zeolite is one of the most commonly used ethylene absorbers in the structure of packaging materials (Yildirim et al., 2018).

Cucumbers are one of the most widely produced vegetables globally, yet they are highly sensitive to both high and low storage temperatures. Furthermore, the accumulation of ethylene within packaging can accelerate their aging, making preservation through traditional methods particularly challenging. While classical refrigeration and modified atmosphere packaging (MAP) are commonly employed, there is a growing need for active packaging solutions that extend the post-harvest shelf life of cucumbers and minimize economic losses (Li et al., 2014).

Although numerous studies have explored the effects of MAP on cucumber preservation, there is a noticeable gap in research specifically addressing the use of ethylene-absorbing packaging materials (Wills et al., 2018; Mori et al., 2022). In this study, we investigated the impact of active packaging containing ethylene absorbers and varying storage temperatures (+4ºC and +10ºC) on the quality parameters of cucumbers stored under modified atmosphere conditions.

MATERIALS AND METHODS

Materials

Cucumbers sourced from the Sakarya fruit and vegetable wholesale market were used in this study. LDPE (low-density polyethylene) with ethylene-scavenging properties and LDPE without ethylene-scavenging properties were used in packaging. The ethylene scavenging LDPE pouches/bags (20 cm x 20 cm in size) were obtained from PEAKfresh (Peakfresh Products, Germany). The materials of these bags with a thickness of 25 μm, an oxygen transmission rate (OTR) of 23,000-24,000 cc/m^2/day at 22ºC and 0% relative humidity, a water vapor transmission rate (WVTR) of 25-27 g/m^2/day at 22ºC and 90% relative humidity, and an ethylene absorption rate of 3900 cc/m^2/day at 22ºC and 90% relative humidity were used. The LDPE films without ethylene scavenging properties were obtained as rolls from Sümer Plastic Inc. (Istanbul, Turkey). These films were cut into appropriate sizes, folded in half (final package size of 20 cm x 20 cm), and heat-sealed on three sides using a heat-sealing machine (ME-400 CFN, Mercier Corporation, Taiwan) at 100ºC to form similar size pouches. At this stage, LDPE films with a thickness of 25 μm, an oxygen transmission rate of 4500 cc/m^2/day at 22ºC and 0% relative humidity, and a water vapor transmission rate of 7.36 g/m^2/day at 37.8±1.1ºC and 90% relative humidity were used.

All chemicals, including NaOH and phenolphthalein, were sourced from Merck (Merck Chemicals GmbH, Darmstadt, Germany), unless otherwise specified.

Methods

Packaging and Storage of Cucumbers

The cucumbers were purchased a day before the study (packaging) and quickly transported to the Food Packaging Laboratory at the Department of Food Engineering, Faculty of Engineering, Sakarya University. The cucumbers were transported in their original till-basket at ambient temperature. They were divided into two groups and stored in a refrigerator at 4°C and 10°C until packaging. Just before packaging, the cucumbers were taken out of the refrigerators, divided into 450 ± 50 g portions, and packaged using two different types of LDPE bags: one with ethylene-scavenging properties and one without.

The portioned cucumbers were packaged under modified atmosphere conditions using a MAP machine (Reepack RV 300, Italy) with a gas mixture of 5% O_2, 10% CO_2, and 85% N_2, maintaining 1:1 headspace ratio. The packed cucumbers were then stored at 4°C and 10°C for 20 days.

A control group of cucumbers was also stored to observe the effect of unpacked storage, and these were kept at 4°C and 10°C in an open atmosphere. Accordingly, six different groups were formed: cucumbers stored in an open atmosphere without packaging (AP4 and AP10), cucumbers packaged under MAP conditions (5% O_2 – 10% CO_2 – 85% N_2) in LDPE packages without ethylene-absorbing properties (MAP4 and MAP10), and cucumbers packaged under MAP conditions (5% O_2 – 10% CO_2 – 85% N_2) in LDPE packages with ethylene-absorbing properties (E-MAP4 and E-MAP10). The MAP conditions used in the study were determined through preliminary trials, considering the formation of an equilibrium atmosphere within the package and the headspace conditions (data were not shown). The experimental design and groups used in the study are schematically shown in Figure 1. Physical, chemical, and sensory quality analyses were performed on cucumbers stored at 4°C and 10°C on days 0, 5, 10, 15, and 20 of storage. The experiment was set up with three repetitions, and unless otherwise specified, analyses were performed in duplicate.

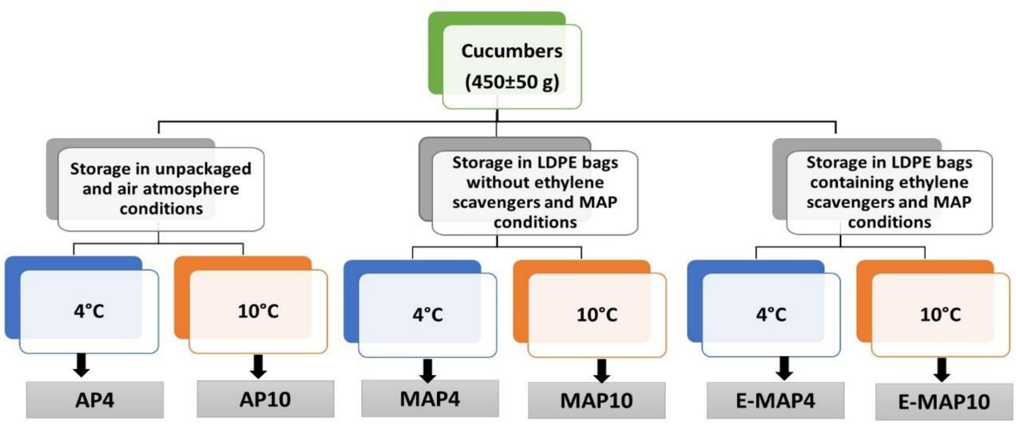


Figure 1. Experimental design

Weight Loss

The weight losses of the cucumbers were determined gravimetrically. Accordingly, the cucumbers were weighed with a precision balance (Sartorius, GE 2101, Germany) with an accuracy of ±0.01 g on each analysis day, and the percentage (%) weight loss values were calculated.

Headspace Oxygen, Carbon Dioxide, and Ethylene Concentration

The oxygen and carbon dioxide (%v/v) concentrations in the headspace of the packages were determined on each analysis day using an

Oxybaby gas analyzer (Witt Oxybaby, Germany) (Sezer et al., 2017).

The ethylene concentration accumulated inside the packages was determined using a gas chromatography (GC) (Shimadzu, Model GC-2010, Japan) with a flame ionization detector (FID). For this purpose, 1 ml of air was drawn from the headspace of the package using a leak-proof syringe and injected into the GC to determine the ethylene concentration. A Poropak-Q column (1.8 m, Restek, USA) and nitrogen gas (Kuşaklı Sınai ve Tıbbi Gazlar Ind. Trade. Co. Ltd., Sakarya, Turkey) as the carrier gas were used during the analysis. The oven temperature was set to 50ºC, the injector temperature to 210ºC, and the detector temperature to 250ºC throughout the analysis (Tian et al., 2004). The concentration of ethylene gas in the package was determined based on a calibration curve drawn using ethylene gas (99% purity) and air mixtures at five different concentrations, and the results were calculated as mg/kg.

Color Analysis

During storage, changes in the L*, a*, and b* color values of the cucumbers were monitored. On each analysis day, three cucumbers from each group were taken, and measurements were made from two opposite points on each cucumber using a pre-calibrated color measurement device (PCE-CSM 7, Meschede, Germany). The results were calculated as the average of 18 measurements taken for each application (Guiné et al., 2014).

Texture Analysis

To monitor the textural changes in the cucumbers during storage, texture analysis was performed using a TA.XT Plus texture analyzer (TA.XT Plus, UK). Texture analysis was carried out by taking measurements from two opposite points of the samples using a 4 mm diameter cylindrical probe, a speed of 5 mm/s, and a penetration distance of 5 mm. On each analysis day, three samples from each repetition were taken, and the results were calculated as the average of 18 measurements taken for each application. The results of the texture analysis were expressed as the maximum penetration force in Newtons (N) (Sezer et al., 2017).

Chemical Analysis

During storage, the pH, titratable acidity and soluble solid content (SSC) analyses of the cucumbers were performed. Homogenized cucumbers using a laboratory blender (Waring, Germany) were used for pH, titratable acidity and SSC analyses.

pH Analysis

The pH analysis of the cucumbers was carried out according to the standard method described in AOAC (AOAC, 2005). For this purpose, 20 g of homogenized cucumbers were weighed and transferred to a 200 mL volumetric flask, filled to the mark with distilled water, and the prepared mixture was filtered through filter paper. A 20 ml aliquot of the resulting solution was taken into a beaker, and the pH was measured using a pre-calibrated pH meter (WTW-315i, Weilheim, Germany).

Titratable Acidity

For titratable acidity analysis, 20 g of homogenized cucumbers were transferred to a 200 ml volumetric flask, filled to the mark with distilled water, and filtered through coarse filter paper. A 25 ml aliquot of the filtrate was taken into an erlenmeyer flask and titrated with 0.1 N NaOH in the presence of phenolphthalein indicator, and the results were calculated as a percentage of malic acid (AOAC, 2005).

Soluble Solid Content (SSC)

For SSC determination, 1-2 drops of the homogenized sample were taken and measured with a refractometer (Atago N-50, Japan), and the values were expressed as % Brix (AOAC, 2005).

Sensory Evaluation

The sensory evaluation of the cucumbers was conducted according to the method demonstrated by Manjunatha and Anurag (2014) and Al-Juhaimi et al. (2012), with some modifications. The evaluation was carried out by a panel of six experienced panelists, who assessed color, flavor, texture, and overall acceptance on a 5-point scale. The scale points used for evaluating each sensory attribute are as follows:

For surface color: 1 = very bad/severe yellowing on the skin, 3 = moderate/slightly yellow, 5 = very good/dark green
For texture: 1 = soft/not crispy, 3 = moderate/acceptable, 5 = crispy/firm
For flavor: 1 = very bad/unwanted flavor/loss of flavor, 3 = acceptable, 5 = very good/intense fruit flavor
For overall acceptance: 1 = dislike very much, 3 = acceptable, 5 = like very much

Statistical Analysis
The variance analysis of the results obtained from the study was performed using IBM SPSS 20 statistical software. The differences between applications during storage were evaluated by Duncan's multiple comparison test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Weight Loss

Figure 2 shows the effect of active packaging and storage temperature on the weight loss (%) of cucumbers during storage. It was observed that the weight loss in cucumbers packaged using LDPE bags with and without ethylene scavenger stored at both 4° or 10 °C was negligible (below 1%) during the entire storage period (P >0.05). However, cucumbers stored in air atmosphere at 4° and 10 °C without packaging had a weight loss of 31.99% and 47.21%, respectively, at the end of 20 days of storage. Weight loss during storage of fresh fruits and vegetables is a significant parameter as it leads to economic losses and negatively affects the sensory quality of the products (Sezer et al., 2017). On the other hand, it has been reported that packaging significantly reduces weight loss (Halloran et al., 1996). The results from the study showed that significant weight loss occurred in cucumbers stored without packaging at 4° and 10 °C during storage, leading to sensory defects (especially wrinkling) and reducing the quality of the products. Therefore, a weight loss exceeding 30% in cucumbers sold without packaging indicates significant economic losses. On the other hand, the insignificant weight loss in cucumbers packaged with both types of LDPE bags can be attributed to the low moisture permeability of the PE-based materials used.

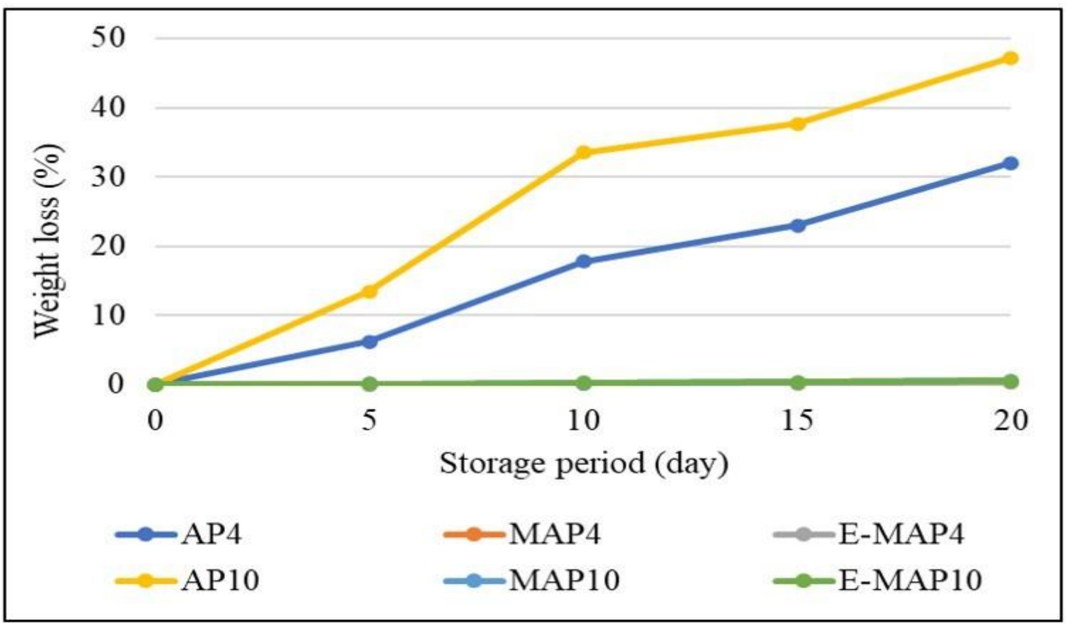


Figure 2. Effect of active packaging and storage temperature on weight loss of cucumber

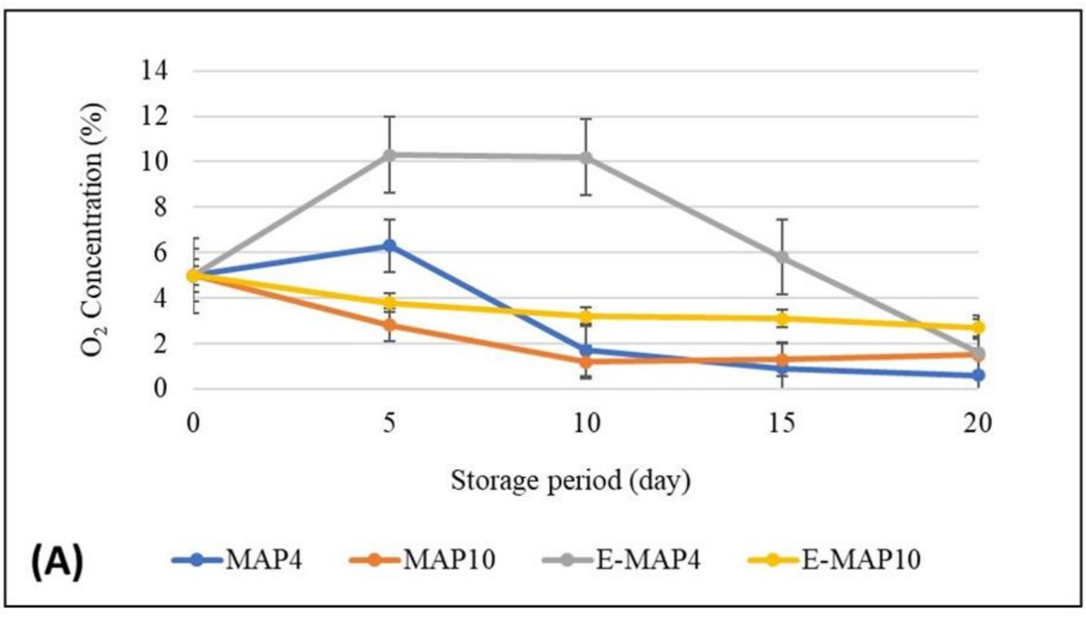
It has been stated that cucumbers stored under passive MAP in polyethylene packaging exhibit significant differences in weight loss compared to those stored in open air (Sabır and Ağar, 2008). In a study investigating the effects of different packaging materials and methods on the storage stability of cucumbers, Sabır and Ağar (2008) reported that at the end of 21 days of storage, the highest weight loss was observed in cucumbers stored without packaging (15.86%), while the lowest weight loss was found in MAP-applied groups (0.23%) (Sabır and Ağar, 2008). It was also reported that cucumbers packaged with perforated and non-perforated LDPE packaging materials and stored at 5°C for 18 days experienced weight losses of less than 1% and 9%, respectively, at the end of storage (Wang and Qi, 1997). Similarly, Kargwal et al. (2021) reported that the weight loss of cucumbers packed with PE bags under MAP conditions and stored at 10°C for 27 days ranged from 0.98% to 1.06%, whereas it reached 14.38% in unpacked samples.

Oxygen, Carbon Dioxide and Ethylene Concentration in Headspace

O_2 and CO_2 Concentration

The effect of active packaging and storage temperature on the O_2 and CO_2 gas ratios in the headspace of the packages during storage is shown in Figure 3 (A and B). When fruits and vegetables like cucumbers, which continue their respiration during post-harvest, are stored in MAP packaging, the critical oxygen level inside the package must remain above 2% to prevent the onset of anaerobic fermentation and establish an equilibrium atmosphere (Badillo and Segura-Ponce, 2020).

It was observed that the desired equilibrium atmosphere was not achieved at 4ºC in cucumbers stored under active MAP (5% O_2, 10% CO_2, 85% N_2), and the O_2 level dropped below the critical limit (2%) that could cause anaerobic fermentation by the end of 20 days. This decrease can be explained by the fact that cucumbers are sensitive to cold. At temperatures below 10ºC, cold injury occurs in cucumbers, increasing the respiration rate of the product. With the increase in respiration rate, the product consumes oxygen more quickly, preventing the formation of an equilibrium atmosphere. In the MAP4 group, the O_2 level rapidly decreased from the 5th day of storage, measuring 1.5% at the end of the storage period. Correspondingly, in this group, the CO_2 concentration in the headspace initially at 10% increased up to 11.4% by the end of the storage period.



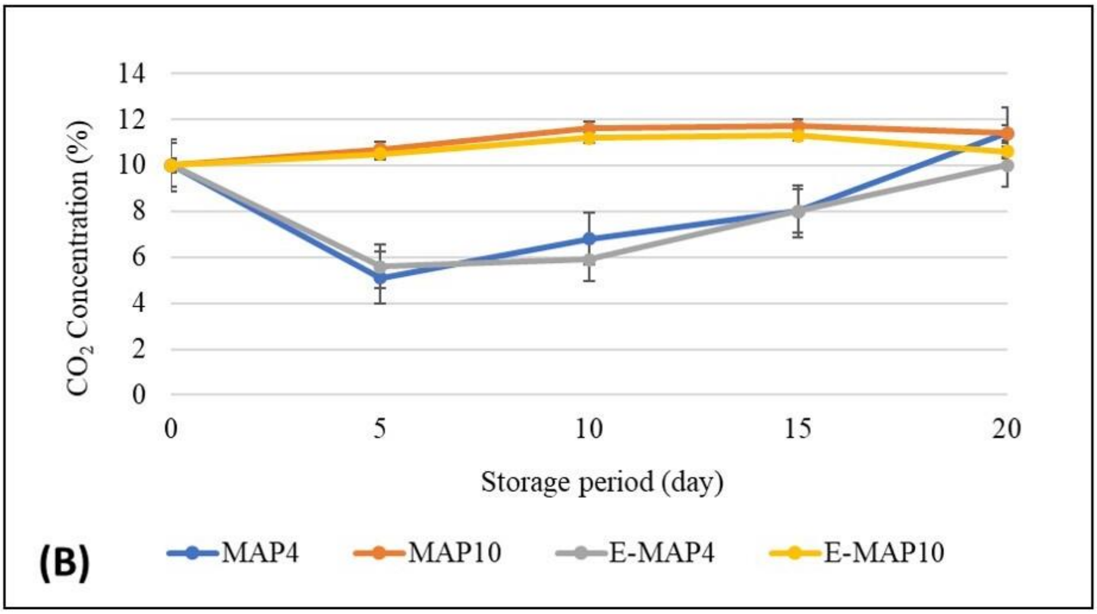


Figure 3. Effect of active packaging and storage temperature on headspace gas composition (A: effect on oxygen concentration, B: effect on carbondioxide concentration)

Similarly, at 10ºC, the targeted equilibrium atmosphere was not achieved in LDPE packages without scavenger (MAP10). Although no cold injury occurred in cucumbers at this temperature, the decrease in oxygen concentration due to increased respiration at higher temperatures prevented reaching equilibrium atmosphere possibly due to insufficient O_2 permeability of the packaging material to replace the oxygen used by the respiration. At the end of the storage, the O_2 and CO_2 concentrations were observed to be 1.5% and 11.4%, respectively.

In LDPE packages with ethylene scavengers stored at 10ºC (E-MAP10), an equilibrium atmosphere was achieved on the 5th day due to lower cold injury and higher OTR of the packaging material, with an O_2 concentration of 2.7% on the 20th day. CO_2 levels stabilized around 11% in groups stored at 10ºC. The changes in O_2 and CO_2 concentrations in the E-MAP4 group can be explained by the high sensitivity of the product to cold. In this group, the O_2 concentration reached 10% on the 10th day of storage but then quickly dropped to 1.5% by the end of the storage period. Correspondingly, the increased sensitivity to cold accelerated the respiration of the cucumbers, increasing CO_2 production from the 5th day onwards.

Overall, the headspace gas analysis results showed that equilibrium atmosphere was achieved in cucumbers stored in LDPE packages with ethylene absorbents at 10ºC by the end of storage. Cucumbers are non-climacteric products with low ethylene production but they are ethylene sensitive. By capturing the low ethylene production in packages with scavengers, the impact of ethylene on the product was minimized. Considering the high cold injury at 4ºC, a more suitable atmosphere was formed for cucumbers at 10ºC.

Ethylene Concentration

The effect of active packaging and storage temperature on the ethylene concentration in the headspace is shown in Figure 4. During the first 5 days of storage, the ethylene concentration in the headspace increased to approximately 1 mg/kg in all groups. There was no significant change in ethylene concentration in all applications until the 10th day of storage, but after the 10th day, significant increases in ethylene concentration were observed (1.4 mg/kg) in packages without ethylene scavengers at both temperatures (P <0.05). At the end of storage, the difference in ethylene concentration between packages with and without ethylene scavengers was found to be statistically significant (P <0.05). The lowest ethylene concentration (0.92 mg/kg) was measured in LDPE packages with ethylene scavengers stored at 4ºC, however, it was determined that storage temperature did not significantly affect the ethylene concentration measured in cucumber packages (P >0.05). Although cucumbers produce ethylene at a low rate (0.1-1.0 µl/kg.h at 20ºC), they are sensitive to it. Even 0.5 mg/kg ethylene in cucumbers can increase yellowing and spoilage (Srilaong and Tatsumi, 2003). Therefore, the ethylene concentration in the headspace remaining below 1 mg/kg even at the end of 20 days in packages with ethylene scavengers is thought to significantly contribute to extending the shelf life of the products.

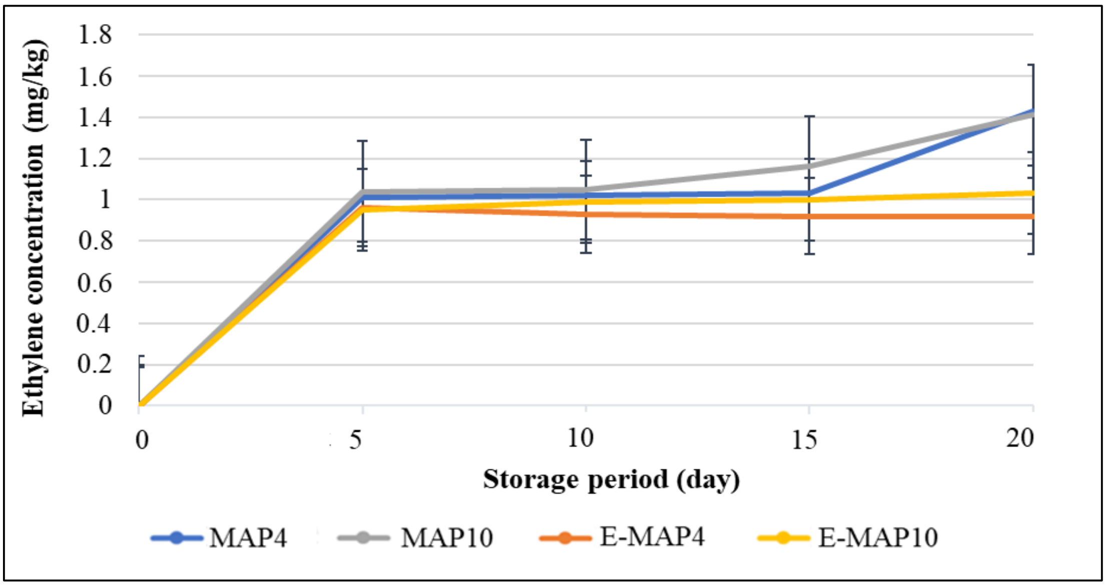


Figure 4. Effect of active packaging and storage temperature on ethylene concentration in the headspace

Color

The effect of active packaging, storage temperature, and storage period on color (L*, a*, b*) is presented in Table 1. Color is one of the most critical parameters affecting the shelf life of ripe fruits and vegetables (Fagundes et al., 2015). Active packaging, storage temperature and storage period had significant effects on the L* value of cucumber (P <0.05). Due to cold injury to the product at 4ºC, measurements could not be taken on the 20th day of storage in the unpackaged groups, while the results obtained in the packaged groups were measured as 33.52 and 32.40 in the MAP4 and E-MAP4 applications, respectively. The initial L* value (39.86) was determined as 34.89, 36.06, and 42.89 at the end of storage in the AP10, MAP10, and E-MAP10 applications, respectively. While the L* values of the product in the E-MAP10 group increased during the storage period, a decrease was observed in other groups. This could be associated with microbial growth considering the sticky layer formed on the surface of the cucumbers. Better quality in color was obtained in the groups stored at 10ºC compared to those stored at 4ºC.

In a study investigating the effects of ultraviolet (UV-C) irradiation on cold injury in cucumbers, it was reported that the change in L* value was lower at 10ºC compared to 4ºC, and storage at higher temperatures (10ºC) was more effective in preserving the product's brightness (Küşümler, 2011).

Table 1. Effect of active packaging and storage temperature on L*, a* and b* color values of cucumber

		Day 0	Day 5	Day 10	Day 15	Day 20
L*	AP4	39.86±1.78^{Aa}	38.91±2.12^{Aa}	32.40±2.11^{Db}	30.89±1.79^{Dc}	N.A.
	MAP4	39.86±1.78^{Ab}	36.68±2.28^{Bc}	41.31±2.02^{Aa}	34.00±1.70^{Cd}	33.52±1.40^{Dd}
	E-MAP4	39.86±1.78^{Aa}	37.53±2.24^{ABb}	40.38±2.00^{Cb}	33.24±1.99^{Cc}	32.40±1.73^{Dc}
	AP10	39.86±1.78^{Aa}	37.86±1.96^{ABa}	37.91±2.36^{Ba}	36.16±2.00^{Ab}	34.89±4.19^{Ac}
	MAP10	39.86±1.78^{Aa}	37.66±1.44^{ABb}	40.02±1.92^{ABa}	37.28±2.19^{Bb}	36.06±1.16^{Cc}
	E-MAP10	39.86±1.78^{Ac}	36.95±1.78^{Bd}	39.77±2.45^{Bc}	41.38±1.97^{Ab}	42.89±1.46^{Ba}
a*	AP4	-1.32±0.45^{Aa}	-4.44±1.11^{Cc}	-2.79±1.21^{Ab}	-3.54±1.40^{CDd}	N.A.
	MAP4	-1.32±0.45^{Aa}	-2.82±1.11^{Bb}	-4.10±0.70^{Bc}	-2.53±1.26^{Bb}	-4.02±1.02^{Bc}
	E-MAP4	-1.32±0.45^{Aa}	-1.95±1.06^{Aa}	-3.32±0.82^{Ac}	-1.42±0.95^{Aa}	-2.60±1.19^{Ab}
	AP10	-1.32±0.45^{Aa}	-2.73±0.79^{Bb}	-2.87±0.92^{Ab}	-3.96±0.90^{Dc}	-5.30±1.41^{Cd}
	MAP10	-1.32±0.45^{Aa}	-1.93±1.67^{Ab}	-3.05±0.63^{Ac}	-2.92±0.88^{BCc}	-3.48±1.42^{Ac}
	E-MAP10	-1.32±0.45^{Aa}	-1.69±0.88^{Aa}	-3.36±1.02^{Ab}	-3.60±0.73^{CDb}	-4.33±0.69^{Bc}
b*	AP4	18.23±2.53^{Aa}	18.86±2.89^{BCa}	18.41±2.27^{Ca}	15.77±3.80^{Db}	N.A.
	MAP4	18.23±2.53^{Ab}	18.24±2.10^{Cb}	25.25±2.12^{Aa}	17.77±2.63^{Cb}	15.14±1.85^{Dc}
	E-MAP4	18.23±2.53^{Ac}	20.23±2.14^{ABb}	22.05±2.65^{Ba}	16.73±2.70^{CDc}	14.07±1.73^{Dd}
	AP10	18.23±2.53^{Ac}	21.30±1.83^{Ab}	25.98±2.53^{Aa}	26.18±2.72^{Aa}	22.97±4.47^{Bb}
	MAP10	18.23±2.53^{Ac}	19.78±1.36^{ABb}	22.65±2.20^{Ba}	21.99±2.14^{Ba}	19.16±1.27^{Cbc}
	E-MAP10	18.23±2.53^{Ac}	18.91±2.48^{BCc}	23.30±3.17^{Bb}	24.77±2.40^{Ab}	27.59±2.94^{Aa}

A-D: For the same parameter, differences between means in the same column for a given storage day are statistically significant (P <0.05).

a-d: For the same parameter, differences between means in the same row for a given application are statistically significant (P <0.05).

(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition, N.A.: Could not be analyzed)

The effects of packaging method, temperature and storage period on the a* values of cucumbers were found to be statistically significant (P <0.05). The negative a* value indicates the greenness of the products. According to Table 1, a decrease in the a* value was observed in all applications at the end of storage compared to the beginning. This decrease indicates that the color of the cucumbers has darkened and ripened. The a* value, initially at -1.32, dropped to -5.30 in the AP10 application at the end of storage. The a* value closest to the initial value (-2.60) at the end of storage was obtained in the E-MAP4 application. The use of ethylene scavenger at low temperatures limited the change in a* value. It is thought that the wrinkles occurred in the cucumbers in the E-MAP4 application may have affected the color (Manjunatha and Anurag, 2014).

The change in skin color is a part of the natural development of agricultural products during maturation and aging. During this process, pigments such as carotenoids and anthocyanins replace chlorophyll, causing the green color of the fruit to disappear and change to the ripened color. While color change accelerates due to stress factors such as cold injury, it also occurs naturally during storage (Küşümler, 2011).

Similar to L* and a* values, the effect of packaging method, temperature, and storage period on the b* value of cucumbers was also statistically significant (P <0.05). A decrease in b* value indicates a color change in the cucumber. The most significant color change in terms of b* values occurred in the E-MAP4 and MAP4 applications. It is thought that the color change in the E-MAP4 group was due to cold injury. In the groups stored at 10ºC, an increase in b* value was observed at the end of the storage period. The initial b* value of 18.23, was determined as 22.97, 19.16, and 27.59 in the AP10, MAP10, and E-MAP10 applications at the end of the storage, respectively. In the E-MAP10 application, the b* value increased during storage, and the color of the product darkened which is in line with the change in a* value. In a study by Küşümler (2011), cucumbers were stored at 5º and 10ºC, and it was reported that the b* value decreased at lower temperatures and increased at higher temperatures. The literature reports that reducing the oxygen level can delay the breakdown of chlorophyll and, consequently, the yellowing of the fruit skin (Suslow and Cantwell, 2006). In our study, it was observed that active packaging along with active modified atmosphere packaging at 10ºC delayed the color change of the cucumbers.

Texture

The effect of active packaging and storage temperature on penetration force (N) is presented in Table 2. It was determined that active packaging, storage temperature, and storage period had significant effects on the penetration force of cucumbers (P <0.05). The penetration resistance of cucumbers was measured as 25.88 N at the 0th day of storage, and the tissue hardness was maintained in the E-MAP10 group throughout the storage period, with a measurement of 25.42 N on the 20th day. However, a significant decrease was observed during the storage for the products stored at 4ºC (P <0.05) and measured as 11.71 N and 1.51 N in MAP4 and E-MAP4 groups, respectively. This can be explained by the softening of the cucumbers due to cold injury at low temperatures. Better results were obtained in penetration force in the groups stored at 10ºC.

Table 2. Effect of active packaging and storage temperature on penetration force (N) of cucumber

	Day 0	Day 5	Day 10	Day 15	Day 20
AP4	25.88±2.05^{Aa}	26.53±2.59^{ABCa}	21.59±2.91^{Bb}	0.61±0.35^{Ec}	N.A.
MAP4	25.88±2.05^{Aa}	25.02±2.86^{Ca}	19.05±2.78^{Cb}	19.73±3.25^{Cb}	11.71±4.15^{Cc}
E-MAP4	25.88±2.05^{Aa}	25.33±3.10^{ABCa}	22.67±1.78^{Bb}	5.33±1.48^{Dc}	1.51±1.70^{Dd}
AP10	25.88±2.05^{Ab}	25.61±2.47^{BCb}	25.51±2.63^{Ab}	29.26±3.47^{Aa}	19.56±2.99^{Bc}
MAP10	25.88±2.05^{Ab}	27.89±2.00^{Aa}	24.86±2.10^{Abc}	24.60±2.30^{Bbc}	23.88±3.37^{Ac}
E-MAP10	25.88±2.05^{Aab}	27.19±1.53^{ABa}	24.99±2.27^{Ab}	25.72±1.89^{Bab}	25.42±1.75^{Aab}

A-E: Differences between means in the same column for a given storage day are statistically significant (P <0.05).
a-d: Differences between means in the same row for a given application are statistically significant (P <0.05).
(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition, N.A.: Could not be analyzed)

Significant differences were found between applications at the end of storage (P <0.05), and the best results were obtained in the E-MAP10 and MAP10 groups. It was determined that temperature was a more important factor than ethylene scavenger packaging on cucumber firmness. Singh et al. (2024) stated that the firmness of cucumber is correlated with the cellulose, hemicellulose and pectin content. Also, they were reported that at harvest, the firmness of cucumbers was 8.24 N, while, after 28 days of storage, the firmness declined by approximately 50%, reaching 4.68 N and 4.72 N for the control cucumbers stored at 10°C and 15°C, respectively. Also, they were concluded that packaged cucumbers maintained higher firmness levels compared to control. Kahramanoğlu and Usanmaz (2019) observed that cucumber firmness decreased over a 24-day storage period, with MAP demonstrating superior preservation of firmness compared to control samples. Similarly, in the Octobus pickling cucumber variety, it was reported that storage under controlled atmosphere and passive modified atmosphere reduced firmness in all applications at the end of the 30-day storage period, but this reduction occurred most rapidly in the fruits stored under a controlled atmosphere (Akbudak et al., 2007).

pH

The effect of active packaging and storage temperature on the pH of cucumbers is presented in Table 3. It was determined that active packaging and storage period had significant effects on the pH value of cucumbers (*P* <0.05). Generally, an increase in pH was observed during storage in all groups. This increase can be explained by the ripening of the products as the storage period progresses. In many fruits, acidity decreases with ripening, whereas the pH value increases (Karaçalı, 2004). At the end of the 20-day storage, the pH value was the highest in the MAP4 and MAP10 groups, with values of 6.84 and 6.68, respectively, indicating that the fruit was more ripened compared to other applications. In a study investigating the effects of chitosan-limonene containing coatings on the shelf life of cucumbers stored at 4ºC and 10ºC for 15 days under active and passive modified atmosphere, the pH value, initially 5.82, increased to 6.40 and 6.60 at the end of storage at 4ºC and 10ºC, respectively. It was stated that the change in pH was related to the respiration rate and metabolic activity of the product (Maleki et al., 2018).

Table 3. Effect of active packaging and storage temperature on pH of cucumber

	Day 0	Day 5	Day 10	Day 15	Day 20
AP4	5.98±0.03^{Ac}	6.08±0.08^{BCb}	6.42±0.08^{ABa}	6.30±0.33^{Ba}	6.14±0.10^{Cb}
MAP4	5.98±0.03^{Ab}	6.11±0.13^{BCb}	6.27±0.55^{Bb}	6.65±0.07^{Aa}	6.68±0.07^{ABa}
E-MAP4	5.98±0.03^{Ac}	6.18±0.10^{Bb}	6.46±0.16^{ABa}	6.50±0.16^{ABa}	6.63±0.03^{Ba}
AP10	5.98±0.03^{Ab}	6.00±0.11^{Cab}	6.33±0.14^{Ba}	6.18±0.11^{Ba}	6.02±0.19^{CDab}
MAP10	5.98±0.03^{Ad}	6.41±0.07^{Ac}	6.72±0.09^{Ab}	6.73±0.07^{Ab}	6.84±0.04^{Aa}
E-MAP10	5.98±0.03^{Ab}	6.14±0.09^{Bb}	6.76±0.20^{Aa}	6.63±0.42^{Aa}	6.59±0.18^{Ba}

A-D: Differences between means in the same column for a given storage day are statistically significant (*P* <0.05).
a-d: Differences between means in the same row for a given application are statistically significant (*P* <0.05).
(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition)

Titration acidity (%)

The effect of active packaging and storage temperature on titration acidity is presented in Table 4. It was determined that packaging, temperature, and storage period had significant effects on the titration acidity of cucumbers (*P* <0.05). The highest titration acidity was measured at 0.20% in the unpackaged group stored at 4ºC. In a study, the titration acidity of the control group products was found to be higher than that of the group containing ethylene scavenger, and this was explained as an indication that ripening was faster in the control group (Duman, 2011).

Controlling two key factors, respiration rate and ethylene production, closely affects fundamental quality parameters such as color, acidity, and texture, which are quality indicators for fruits and vegetables (Çavuşoğlu, 2014).

Table 4. Effect of active packaging and storage temperature on titration acidity (Malic acid %) of cucumber (% Malic acid)

	Day 0	Day 5	Day 10	Day 15	Day 20
AP4	0.18±0.02^{Aab}	0.20±0.02^{Aab}	0.26±0.05^{Ca}	0.16±0.01^{Bb}	0.20±0.02^{Aab}
MAP4	0.18±0.02^{Ab}	0.18±0.01^{Ab}	0.21±0.02^{Ba}	0.16±0.01^{Bb}	0.17±0.01^{Bb}
E-MAP4	0.18±0.02^{Ab}	0.19±0.02^{Ab}	0.32±0.03^{ABa}	0.20±0.03^{ABb}	0.18±0.01^{Ab}
AP10	0.18±0.02^{Ab}	0.19±0.01^{Ab}	0.28±0.04^{BCa}	0.21±0.06^{Ab}	0.17±0.03^{Bb}
MAP10	0.18±0.02^{Ab}	0.18±0.01^{Ab}	0.21±0.02^{Ba}	0.16±0.01^{Bb}	0.18±0.01^{Ab}
E-MAP10	0.18±0.02^{Ab}	0.20±0.01^{Ab}	0.33±0.02^{Aa}	0.15±0.01^{Bbc}	0.16±0.01^{Bb}

A-C: Differences between means in the same column for a given storage day are statistically significant (P <0.05).
a-c: Differences between means in the same row for a given application are statistically significant (P <0.05).
(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition)

Soluble Solid Concentration

The effect of active packaging and storage temperature on SSC is presented in Table 5. The Initial brix value of 2.20% decreased to 1.50% at the end of storage in the unpackaged groups (AP4 and AP10), 1.60% in the scavenger-free LDPE groups (MAP4 and E-MAP10), and 1.40% in the E-MAP4 group and 1.70% in the E-MAP10 group containing ethylene scavenger. At the end of the storage, the difference between E-MAP4 (1.40%) and E-MAP10 (1.70%) was found to be statistically significant, but the differences between other applications were not statistically significant. The decrease in % brix value during storage can be explained by the utilization of sugars in the product through respiration (Halloran et al., 1996).

Table 5. Effect of active packaging and storage temperature on brix (%) of cucumber

	Day 0	Day 5	Day 10	Day 15	Day 20
AP4	2.20±0.10^{Aa}	2.20±0.40^{Aa}	2.10±0.10^{Aa}	1.70±0.20^{Bb}	1.50±0.01^{ABb}
MAP4	2.20±0.10^{Aa}	2.00±0.30^{Aa}	2.10±0.10^{Aa}	1.80±0.10^{Bb}	1.60±0.20^{ABb}
E-MAP4	2.20±0.10^{Aa}	2.10±0.10^{Aab}	2.10±0.10^{Ab}	2.10±0.10^{Ab}	1.40±0.20^{Bc}
AP10	2.20±0.10^{Aa}	2.10±0.10^{Aa}	2.00±0.30^{ABa}	2.20±0.20^{Aa}	1.50±0.20^{ABb}
MAP10	2.20±0.10^{Aa}	2.10±0.10^{Aa}	1.70±0.20^{Bb}	1.80±0.10^{Bb}	1.60±0.10^{ABc}
E-MAP10	2.20±0.10^{Aa}	2.00±0.20^{Aa}	1.70±0.20^{Bb}	1.60±0.20^{Bb}	1.70±0.10^{Ab}

A-B: For the same analysis parameter, differences between means in the same column are statistically significant (P <0.05).
a-c: For the same analysis parameter, differences between means in the same row are statistically significant (P <0.05).
(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition, N.A.: Could not be analyzed)

Sensory Evaluation

The effect of active packaging and different storage temperatures on the sensory properties of cucumbers is presented in Table 6. Photos taken at the beginning of storage (day 0), on the 5th day, on the 10th day, and on the 20th day are shown in Figures 5, 6, 7, and 8, respectively. The products were evaluated in terms of peel color, texture, flavor, and overall product acceptance. Accordingly, the acceptability of unpackaged groups stored at 4ºC and 10ºC (AP4 and AP10) in terms of color values was limited to 5 days, while the acceptability of packaged groups stored at 4ºC (MAP4 and E-MAP4) was limited to 10 days. The color of the LDPE-packaged group stored at 10ºC (MAP10) was found to be acceptable on the 15th day. At the end of storage, only the E-MAP10 group was found to be acceptable in terms of color values.

Table 6. Effect of active packaging and storage temperature on sensorial properties of cucumber

		Day 0	Day 5	Day 10	Day 15	Day 20
Color	AP4	5.00±0.0^{Aa}	4.80±0.08^{Aa}	2.00±0.36^{Cb}	1.00±0.31^{Cc}	1.00±0.21^{Dc}
	MAP4	5.00±0.0^{Aa}	4.50±0.23^{Aa}	3.50±0.78^{Bb}	2.50v0.89^{Bc}	2.00±0.76^{Cc}
	E-MAP4	5.00±0.0^{Aa}	4.75±0.14^{Aa}	3.75±0.38^{Bb}	2.25±0.45^{Bc}	2.00±0.44^{Cc}
	AP10	5.00±0.0^{Aa}	5.00±0.0^{Aa}	2.75±1.14^{BCb}	1.00±0.50^{Cc}	1.00±0.32^{Dc}
	MAP10	5.00±0.0^{Aa}	4.75±0.13^{Aa}	4.50±0.28^{Aa}	3.50±0.34^{Ab}	2.50±0.36^{Bc}
	E-MAP10	5.00±0.0^{Aa}	4.50±0.33^{Aab}	4.75±0.24^{Aa}	4.00±0.67^{Abc}	3.50±0.45^{Ac}
Texture	AP4	5.00±0.0^{Aa}	5.00±0.0^{Aa}	3.00±0.54^{Cb}	1.00±0.44^{Dc}	1.00±0.21^{Dc}
	MAP4	5.00±0.0^{Aa}	4.00±0.45^{Aa}	4.25±0.23^{ABab}	2.25±0.33^{Cc}	1.50±0.22^{CDc}
	E-MAP4	5.00±0.0^{Aa}	4.75±0.20^{Aa}	3.50±0.37^{ABa}	2.25±0.78^{Cc}	2.00±0.44^{BCc}
	AP10	5.00±0.0^{Aa}	5.00±0.0^{Aa}	4.00±0.33^{ABb}	1.00±0.50^{Dc}	1.00±0.21^{Dc}
	MAP10	5.00±0.0^{Aa}	5.00±0.0^{Aa}	4.50±0.20^{Aa}	3.25±0.59^{Bb}	2.50±0.66^{Bc}
	E-MAP10	5.00±0.0^{Aa}	4.50±0.24^{Aab}	4.25±0.37^{ABab}	4.00±0.42^{Abc}	3.25±0.69^{Ac}
Flavor	AP4	5.00±0.0^{Aa}	4.75±0.12^{Aa}	2.75±1.04^{Bb}	N.A.	N.A.
	MAP4	5.00±0.0^{Aa}	4.25±0.35^{Ab}	4.25±0.44^{Ab}	2.25±1.20^{Ab}	1.00±0.33^{Cc}
	E-MAP4	5.00±0.0^{Aa}	4.50±0.22^{Aa}	3.50±0.51^{ABb}	2.50±0.45^{Ac}	2.00±0.76^{Bc}
	AP10	5.00±0.0^{Aa}	4.75±0.16^{Aa}	3.75±0.13^{ABab}	N.A.	N.A.
	MAP10	5.00±0.0^{Aa}	4.25±0.41^{Aa}	4.25±0.22^{Aa}	3.00±0.55^{Ab}	2.00±0.45^{Bc}
	E-MAP10	5.00±0.0^{Aa}	4.00±0.55^{Aa}	3.80±0.45^{ABb}	3.00±0.78^{Ac}	3.00±0.43^{Ac}
Overall	AP4	5.00±0.0^{Aa}	4.75±0.14^{Aa}	2.25±1.12^{Cb}	1.00±0.44^{Dc}	1.00±0.22^{Dc}
	MAP4	5.00±0.0^{Aa}	4.25±0.33^{Ab}	4.25±0.36^{Ab}	2.25±0.58^{Cc}	1.50±0.56^{Cc}
	E-MAP4	5.00±0.0^{Aa}	4.75±0.22^{Aa}	3.25±0.63^{Bb}	2.25±0.54^{Cc}	2.00±0.63^{Bc}
	AP10	5.00±0.0^{Aa}	5.00±0.0^{Aa}	3.25±0.77^{Bb}	1.00±0.62^{Dc}	1.00±0.34^{Dc}
	MAP10	5.00±0.0^{Aa}	4.50±0.24^{Aa}	4.50±0.21^{Aa}	3.00±0.46^{Bb}	2.00±0.74^{Bc}
	E-MAP10	5.00±0.0^{Aa}	4.25±0.35^{Aab}	4.25±0.46^{Aab}	4.00±0.57^{Ab}	3.00±0.47^{Ac}

A-D: For the same parameter, differences between means in the same column for a given storage day are statistically significant (P <0.05).

a-c: For the same parameter, differences between means in the same row for a given application are statistically significant (P <0.05).

(AP4: at 4ºC without packaging and in air atmosphere, AP10: at 10ºC without packaging and in air atmosphere, MAP4: at 4ºC in pure LDPE packaging and in MAP condition, MAP10: at 10ºC in pure LDPE packaging and in MAP condition, E-MAP4: at 4ºC in LDPE packaging containing ethylene scavengers and in MAP condition, E-MAP10: at 10ºC in LDPE packaging containing ethylene scavengers and in MAP condition, N.A.: Could not be analyzed)

Figure 5. Images of cucumbers on the 0th day of storage

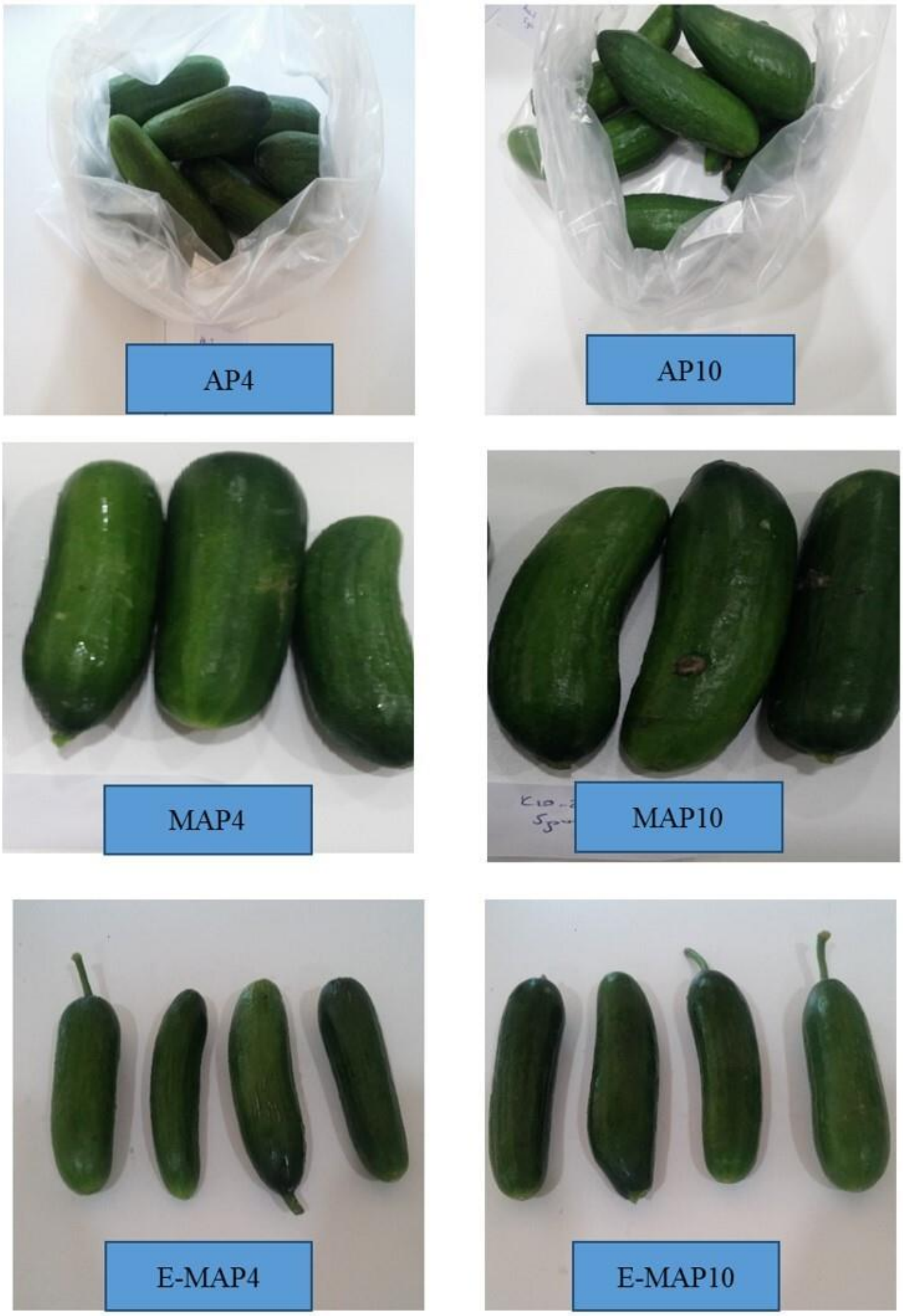


Figure 6. Images of cucumbers on the 5th day of storage

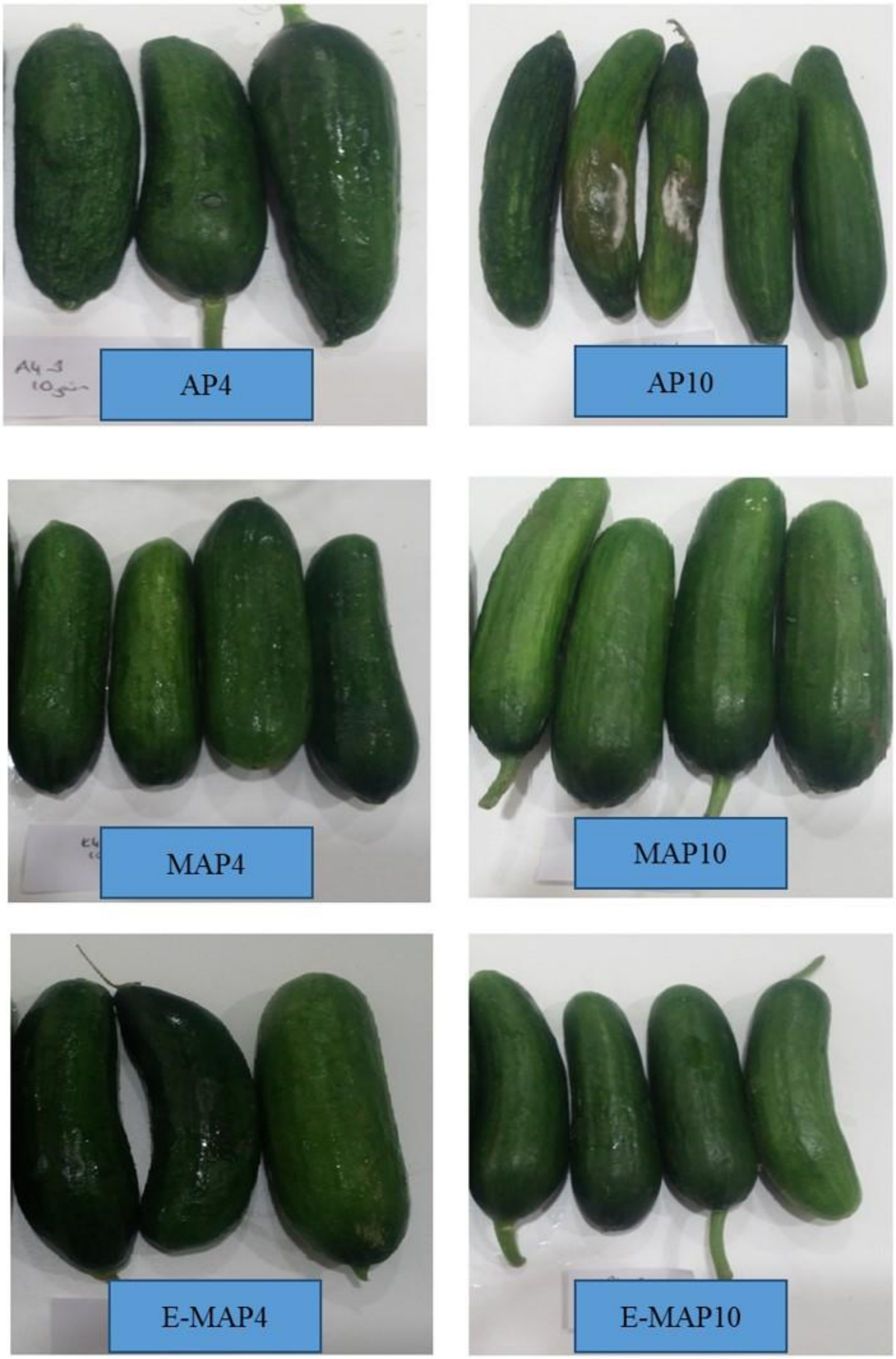


Figure 7. Images of cucumbers on the 10^{th} day of storage

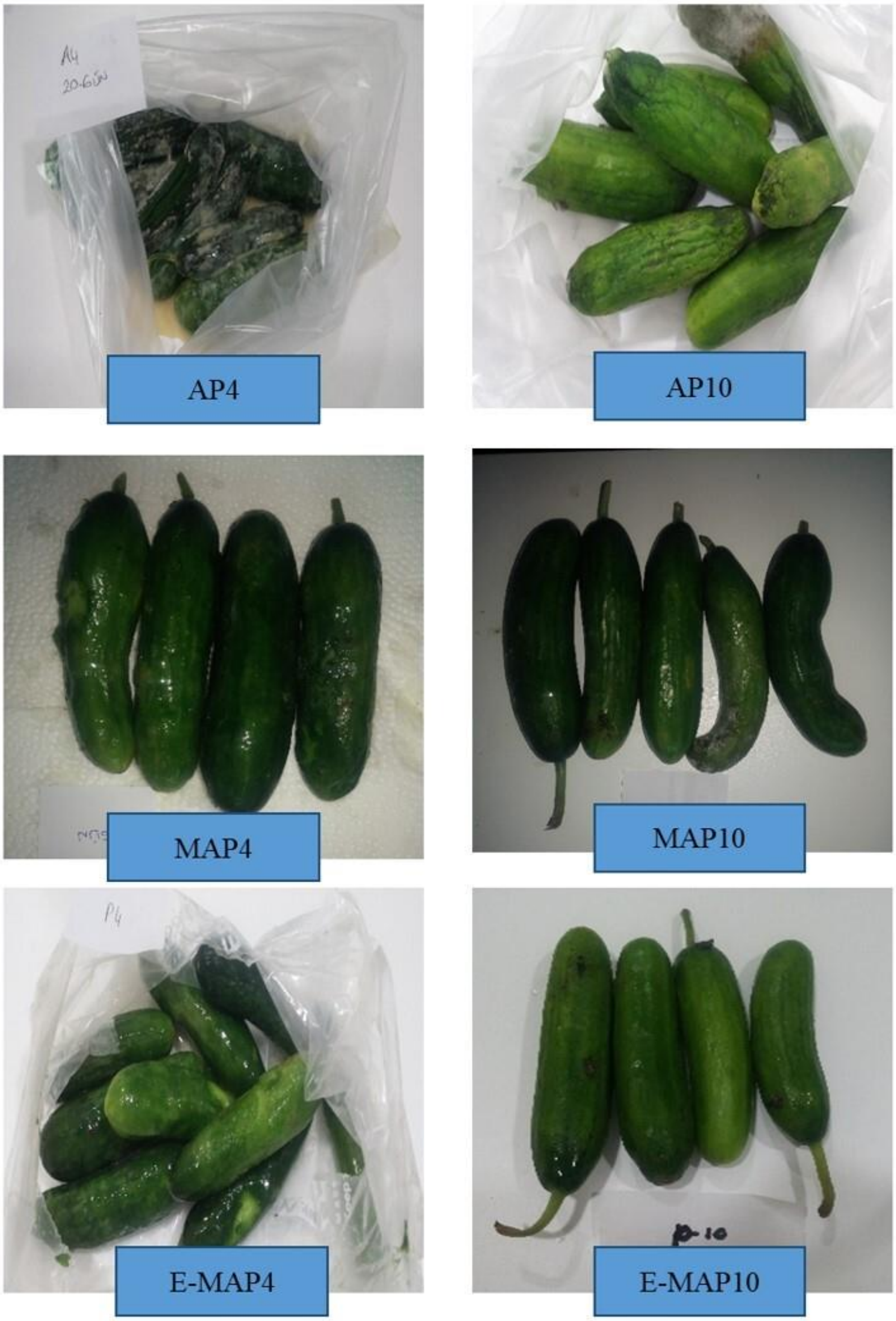


Figure 8. Images of cucumbers on the 20th day of storage

In terms of texture, the textural acceptability of unpackaged groups and packaged groups stored at 4ºC was limited to 10 days, while the textural acceptability of products stored in LDPE packages without ethylene scavenger at 10ºC (MAP10) was limited to 15 days. At the end of storage, only the E-MAP10 group was found to be acceptable in terms of texture. It was determined that all groups stored at 4ºC experienced softening due to cold injury related to the cold storage temperature.

In terms of flavor values, the acceptability of the unpackaged AP4 group was 5 days, while the acceptability of the AP10 group was 10 days. After the 15th day, tasting could not be performed on unpackaged groups due to microbial growth on the surface. The acceptability of packaged groups stored at 4ºC (MAP4 and E-MAP4) in terms of flavor was 10 days. At the end of storage, only the E-MAP10 group was acceptable in terms of flavor. It was determined that active packaging and storage temperature had a significant effect on flavor (P <0.05).

When evaluating overall acceptance, the acceptability of the unpackaged (AP4) group was limited to 5 days, while the acceptability of the AP10 group was 10 days. The acceptability of packaged groups stored at 4ºC was 10 days. The acceptability of products packaged in LDPE packaging without an ethylene scavenger and stored at 10ºC (MAP10) was determined as 15 days. At the end of storage, only the E-MAP10 application remained above the acceptability threshold. As a result, the cucumbers in LDPE bags with an ethylene scavenger stored at 10ºC were acceptable in terms of all sensory attributes and overall product acceptance.

Overall, packaging and storage temperature had a significant effect on the sensory properties of cucumber (P <0.05). Among all applications, better results for all sensory attributes were obtained at 10ºC compared to 4ºC. Sing et al. (2024) reported that packaging under modified atmosphere conditions significantly extended the overall acceptance of cucumbers beyond 20 days when stored at 10ºC (21 days) and 15ºC (28 days). Similarly, in a study investigating the quality changes of cucumbers stored at 10ºC for 30 days by packaging them with modified atmosphere and shrink film, it was reported that at the end of the 30th day, products packaged with modified atmosphere received a score of 3.6 out of 5, maintaining their marketability, while those wrapped with shrink film received a score of 2.0, losing their marketability. It was stated that the presence of rot and loss of green color in products wrapped with shrink film at the end of storage resulted in a low score (Şen, 2013).

CONCLUSIONS

The effects of different packaging applications (unpackaged, MAP packaging in LDPE bags, or MAP packaging in LDPE bags with an ethylene scavenger) and different storage temperatures (4ºC and 10ºC) on the shelf life of cucumbers were investigated. Based on the evaluation of physiological, physical, chemical, and sensory parameters, our results indicated that the packaging of cucumbers in LDPE bags containing an ethylene scavenger and storage at 10°C is the optimal conditions for extending the shelf life of cucumbers to 20 days. In contrast, unpackaged cucumbers stored at 4ºC had a shelf life of 5 days, while unpackaged cucumbers at 10ºC and those packaged in LDPE at 4ºC (with or without an ethylene scavenger) had shelf lives of 10 days. Cucumbers packaged in LDPE without an ethylene scavenger at 10ºC (MAP10) lasted for 15 days.

This study highlights the substantial benefit of using LDPE packaging with an ethylene scavenger, demonstrating a 100% increase in shelf life compared to unpackaged cucumbers. Given the significant economic implications of packaging on the shelf life and weight loss, future research could explore cost-effective packaging solutions and evaluate their environmental impact. Additionally, studies could investigate the long-term effects of different storage temperatures on sensory attributes and nutritional quality.

CONFLICT OF INTEREST
There is no known conflict of interest among the authors.

AUTHOR CONTRIBUTIONS
Tuncay Tiribolulu: data collection, statistical analyses, original manuscript writing. Guliz Haskaraca: statistical analyses, original manuscript writing, writing - review and editing. Zehra Ayhan: experimental design, conceptualization, writing - review and editing, supervision, consultancy.

ACKNOWLEDGEMENTS
This study was produced from Tuncay Tiribolulu's master's thesis under the supervision of Prof. Dr. Zehra Ayhan.

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