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Determination of the Effects of Some Post-Harvest Treatments on the Quality of Banana Fruits During Storage and After Ripening

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Abstract
In this study, it was aimed to impact the effect of different post-harvest treatments on the shelf life of banana fruits of 'Dwarf Cavendish' banana cultivar after storage and ripening. 1) Modified atmosphere packaging (MAP), 2) 1-methylcyclopropene (1-MCP) + MAP, 3) Three different treatments (MAP + ethylene absorbent (EA)) were applied and only those using macro-aperture PE packaging were considered as control. Banana fruits were stored at 13°C and 90% RH for 30 days. Quality analyses were performed on samples taken at 10-day intervals. After 30 days of storage, the banana fruits were ripened to the ripeness level of No.3 and quality changes were determined after 4 days of shelf life. The treatments significantly limited the color change, softening of the peel and flesh, increased total soluble solids (TSS), ethylene secretion and respiration rate, especially in the last period of storage compared to the control. Green bananas treated with 1-MCP + MAP showed the best results during storage, but ripening problems were experienced. MAP + EA treatment delayed the coloration of banana fruits, softening of the flesh and increases in the TSS content during shelf life. MAP + EA treatment gave the best results both in terms of storage of banana fruits at green maturity and their resistance after ripening.
Keywords: Banana, MAP, 1-MCP, ethylene absorbent, ripening.

Hasat Sonrası Bazı Uygulamaların Depolama Süresince ve Olgunlaştırma Sonrasına Muz Meyvelerinin Kalitesine Etkilerinin Belirlenmesi

Özet
Çalışmada, 'Dwarf Cavendish' muz çeşidinin meyvelerinde hasat sonrası yapılan farklı uygulamaların, yeşil olum dönemindeki muz meyvelerinin depolanması ve olgunlaştırılması sonrasında raf ömrüne etkisinin belirlenmesi amaçlanmıştır. Muz meyvelerine 1) Modifiye atmosfer paketleme (MAP), 2) 1-metilsiklopropen (1-MCP) + MAP, 3) MAP + Etilen absorbantı (EA) olmak üzere üç farklı uygulama yapılmış olup sadece makro açıklıklı PE ambalaj kullanılanlar kontrol olarak kabul edilmiştir. Muz meyveleri 13°C ve %90 oransal nemde 30 gün boyunca muhafaza edilmiştir. 10'ar gün aralıklarla alınan örneklerde kalite analizleri yapılmıştır. Muz meyveleri 30 günlük depolama sonrasında 3 numara olgunluk seviyesine kadar olgunlaştırılmasına ilaveten 4 günlük raf ömrü sonrası kalite değişimleri belirlenmiştir. Uygulamalar, özellikle depolamanın son döneminde kontrole göre meyvelerin renk değişimini, kabuk ve meyve etindeki yumuşamayı, suda çözünür kuru madde (SÇKM), etilen salgı miktarı ve solunum hızındaki artışları belirgin şekilde sınırlandırmıştır. 1-MCP + MAP uygulanan yeşil muzlarda, depolama süresince en iyi sonucu vermesine rağmen olgunlaşma sorunu yaşanmıştır. MAP + EA uygulaması, muz meyvelerinin renklenmesini, meyve eti yumuşamasını ve SÇKM miktarındaki artışlarını raf ömrünce geciktirmiştir. MAP + EA uygulaması hem yeşil olumdaki muz meyvelerinin depolanması hem de olgunlaştırma sonrasındaki dayanımları açısından en başarılı sonuçları vermiştir.
Anahtar sözcükler: Muz, MAP, 1-MCP, etilen absorbantı, olgunlaştırma

Introduction

The rapid increase in both the area and quantity of banana production in Turkey has been influenced by significant growth in the greenhouse cultivation of bananas. Banana production in Turkey increased by 380% in the last decade and reached 997.244 tons in 2022 (TUİK, 2023). Parallel to this increase in banana production, there has been a significant increase in the number and capacity of banana ripening facilities. The fact that there is a surplus of product from time to time, especially in greenhouses in large areas, makes it necessary to preserve bananas under suitable conditions. On the contrary, in some periods, the storage of bananas is seen as a solution since the lack of product causes significant problems in the supply chain. However, since banana is a climacteric fruit, the storage process must be well managed. Otherwise, significant losses may occur as the fruit begins to ripen. Since storage directly affects the ripening process and shelf life of bananas, proper storage is of great importance (Kader et al., 2002).

Bananas, a climacteric fruit, are sensitive to very low ethylene levels (0.3 – 0.5 $\mu L\ L^{-1}$) (Peacock, 1972). Under suitable conditions, banana fruits can be stored for up to 4-6 weeks (Kader, 2002; Kozak, 2003). To extend the shelf life of fruits, ethylene-triggered ripening should not begin. Therefore, in order to extend the storage life of banana fruits, it is of great importance to delay or slow down these ripening-induced changes caused by ethylene. In order to prevent ripening in banana fruits, ethylene and related effects must be in control. Although different methods have been proposed for this purpose, the most widely used application is the inhibition of ethylene production of banana fruit. For this purpose, lowering the temperature, increasing the CO_2 concentration, and using ethylene absorbers and ethylene inhibitor 1-MCP are suggested as the most successful methods (Şen and Türk, 2008; Li et al., 2011; Zhu et al., 2015).

MAP technology slows down aging by reducing the moisture loss of fruits and vegetables by changing the composition of the atmosphere inside the package. This technology prevents excessive accumulation of moisture on the inner surface of the packaging and, at the same time, limits water loss in the fruit by preventing moisture from escaping more than desired from the environment. Due to these positive effects, modified atmosphere packages (MAP) have found widespread use in storage, transportation and distribution due to their ability to extend the post-harvest life of many vegetables and fruits, including bananas. (Sabır and Ağar, 2010; Laribi et al., 2012).

1-MCP inhibits ethylene movement and delays or eliminates the biochemical events caused by it. Because 1-MCP is non-toxic, effective at very low concentrations, easy to apply, odorless, and suitable for commercial applications, 1-MCP has been used in many studies (Watkins, 2006). 1-MCP has obvious effects in delaying the ripening of harvested banana fruits. However, inappropriate concentration, processing methods and treatment time can adversely affect yellowing, normal ripening, formation of volatiles, and softening, which are important components of banana fruit quality (Zhu et al., 2015).

By absorbing ethylene gas from fruits and vegetables, ethylene absorbers retard the rapid ripening and aging of these products after harvest and maintain their quality during storage, shelf life and transportation (Watada, 1986; Lougheed et al., 1987). Various ethylene holder systems have been successfully used in the preservation of tropical fruits such as bananas, kiwis, avocados, pears, apples, tomatoes and similar products (Esturk et al., 2014; Martínez-Romero et al., 2009; Li et al., 2011).

This study aimed to determine the impact of different post-harvest treatments on the shelf life of banana fruits after storage and ripening.

Materials and Methods

This study utilized fruits of the 'Dwarf Cavendish' banana variety grown in greenhouse in the Gazipaşa district of Antalya (36º 13'-36º 34' north latitudes and 32º 15'-32º 38' eastern longitudes). Banana cultivation in greenhouse was carried out in the form of soil cultivation, plant nutrition, pruning, disease and pest control as standard practices (Kozak, 2003).

Harvesting and preparation for packing

The banana bunch that harvested at commercial maturity period (when 1/3 of the angular structure of the fruit is lost) were packaged by applying standard packing house procedures and then brought to the Cold Storage and Packaging Unit in Ege University, by a vehicle set at 14+2°C. Here, all fruits were immersed in water containing 1000 ppm imazalil (50% w/v imazalil, Citrosol 500, Citrosol, Spain) for 2 minutes to prevent possible rot development.

Post-harvest treatments

After separating the banana hands into 5-7 fruits before the application a) Control (commercial application, PE packaging with macro-openings), b) MAP (LifePack, Aypek, Bursa, Türkiye), c) 1-MCP + MAP, d) MAP + ethylene absorbent (EA) treatment was applied. MAP package is based on polyethylene (PE) and is 20 µm thick. The 1-MCP treatment was applied to banana fruits at 14°C for 24 hours at a concentration of 0.084 g m^{-3} (625 ppb) in a 1 m^3 gas-tight zippered PVC tent (Volcano Cube®, GrainPro Inc., Philippines). Ethylene absorbent; ethylene absorbent frames (green keper, Absorbertech, Istanbul, Turkey) containing 4.5 g potassium permanganate were placed in MAP bags and sealed after pre-cooling. The treated products were kept at 14°C for 24 hours and then the MAP packages were sealed with clips.

Storage and ripening

Control and treated banana fruits were stored at 13°C and 90% relative humidity for 30 days (Thompson and Burden, 1995). Samples were taken at 10 days intervals during storage and some quality analyses were performed. At the end of 30 days of storage, some of the bananas were placed in a PVC tent and ripened to a level 3 of ripeness by adding ethylene in an ethylene generator (Inkatec®, Turkey) at 17°C for 20-22 h and then kept at 20ºC and 65-75% relative humidity for 4 days for quality analysis.

The study was established with four replicates according to the random plots experimental design and each package containing approximately 1 kg of fruit (5-7 pieces) was considered as one replicate.

Physical analysis

Weight loss; the banana fruits that were weighed before the preservation after each storage period and after ripening weights were weighed again with a precision scale and determined as percentages (%).

Peel color; was determined by measuring CIE L*, a*, b* with a colorimeter (CR-400, Konica Minolta, Japan) at three different points of 5 fruits from each replicate (McGuire, 1992).

Peel and fruit flesh firmness were measured in immature (green) banana fruits by dipping the 8 mm diameter tip of a fruit texture meter (GS-15, GÜSS Manufacturing Ltd., South Africa) at a speed of 10 cm min^{-1} to a depth of 10 mm from three different parts of the fruit surface. The flesh firmness of ripe fruits was measured with the same tool using an 11 mm diameter tip. The results are given in Newton (N) force.

Chemical analysis

TSS content of banana fruits was measured from the banana juice using a digital refractometer (PR-1, Atago, Japan) (Karaçalı, 2016). Titratable acid (TA) content was titrated with a digital burette (Bürette Digital III, Brand, Germany) by adding 0.1 N NaOH solution until the pH value reached 8.1 after 10 ml sample taken from banana juice, and calculated in terms of malic acid using the amount of NaOH used and presented as % (Karaçalı, 2016).

Respiration rate and amount of ethylene secretion

After the green ripe banana fruits were kept in jars at 20°C for 3 hours, a gas sample was extracted from the space at the top and given to a gas chromatography device (Agilent 6890 N, USA).

Pathological and physiological disorders

The rate of pathological and physiological disorders was calculated by proportioning the number of banana fruits with rot and disorders after each storage period and ripening to the total number of fruits.

Sensory evaluation

After ripening, banana fruits were evaluated by 5 trained panelists using a 1-5 scale (according to appearance, taste and texture (Altuğ and Elmacı, 2011).

Statistical analysis

The data obtained from the experiment were subjected to analysis of variance using a statistical package program (SPSS® Statistics 19, IBM, USA), and the differences between the averages between storage periods and after ripening were determined by Duncan test (P≤0.05).

Results and Discussion

Storage of green banana fruits

The influence of different treatments on the weight loss of banana fruits of 'Dwarf Cavendish' variety was significant (P≤0.05) at the end of 30 days of storage, while it was insignificant in the earlier periods. At the end of storage, the weight loss of banana fruits in the control was the highest with 2,01% and the lowest with 1,40% in 1-MCP + MAP treatments (Table 1). This was because the moisture loss was higher due to the higher opening spot rate of the packages used in the control compared to the packages used in the treatments. Because MAP packages with a more limited opening rate increase the humidity in the environment where the product is located and limit the moisture loss in the fruits (Rodov et al., 2009; Sandhya, 2010). It has been reported in different studies that MAP application limits water loss in green and ripe bananas by the results of this study (Canan et al., 2009; Kudachikar et al., 2011; Canan, 2012). The limited weight loss during storage in all treatments was because the packaging used limited water loss from banana fruits.

The impacts of different post-harvest treatments on the L*, a*, and b* values of banana fruit peel showed significant (P≤0.01) differences after 30 days of storage, while these differences were insignificant after 10 and 20 days of storage. After storage, the peel L* value of banana fruits in the control was 59.62, which was higher than the treatment (56.12-57.15) (Table 1). At the end of storage, the peel a* value of control banana fruits was the highest at -12.25, while the peel a* value of banana fruits treated with 1-MCP + MAP was the lowest at -15.86. There was an increase of 26% in the control banana fruits at the end of storage compared to the beginning. This increase shows that there is a decrease in the green color tone in the control fruits. At the end of storage, the peel b* value of untreated banana fruits was 36.53, which was higher than the b* value of treated bananas (33.93-34.56) (Table 2). The highest L*, a* and b* values of the control banana fruits at the end of storage indicate that there is a partial color change in the peel of these fruits. This change in peel color is an indication that the maturity of banana fruits in the control is more advanced. After harvest, MAP + EA and MAP treatments, especially 1-MCP + MAP, limited the maturity of banana fruits, which also limited the color change in the peel. Similarly, studies reported that 1-MCP (Lohani et al., 2004; Boonyaritthongchai and Kanlayanarat, 2010; Ünal et al., 2016), MAP (Kudachikar et al., 2011), ethylene absorbent (Scott et al., 1974; Paydaş et al., 1987) and 1-MCP + MAP (Jiang et al., 1999) treatments has delayed the peel color change in banana fruits.

The impact of different post-harvest treatments on fruit flesh firmness of bananas showed a significant (P≤0.01) difference at the end of storage, while it was similar in the previous storage period. The average flesh firmness of bananas treated after storage was 75% higher than the control (25.69 N). As the storage period progressed, the decreases in the fruit flesh firmness of bananas were limited in the treatments, while significant differences occurred in the control and a 49% decrease was determined compared to the beginning (50.21 N) (Figure 1). The effect of different treatments on the peel firmness of banana fruits was significant (P≤0.05) after 30 days of storage. The peel firmness of treated banana fruits (93.8-99.1 N) was higher than the control (82.5 N) (Table 3).

The fact that the firmness of the peel and fruit flesh of the treated banana fruits at the end of storage was higher than the control and the changes were more limited compared to the beginning can be explained by the delaying effect of these treatments on ripening. Because with ripening in banana fruits, softening occurs in the firmness of the peel and fruit flesh. These firmness decreases in the control banana fruits are consistent with the color changes in the peel. Because ripening in banana fruits is characterized by yellowing of the peel and softening of the flesh (Turner, 2001). Consistent with the outcomes of this study, it has been reported that the flesh firmness of 1-MCP treated bananas was higher than control fruits and the softening was delayed. (Jiang et al., 1999; Jiang et al., 2004; Boonyaritthongchai and Kanlayanarat, 2010; Ünal et al., 2016). Similarly, fruit flesh firmness of bananas was higher in MAP (Nguyen et al., 2003; Chauhan et al., 2006; Kudachikar et al., 2011), ethylene absorbent ($KMnO_4$) (Scott et al., 1974) and 1-MCP + MAP (Jiang et al., 1999) treatments compared to the control.

Table 1. Impact of post-harvest applications on weight loss and peel L* value of banana fruits during storage
Çizelge 1. Hasat sonrası uygulamaların depolama süresince muz meyvelerinin ağırlık kaybına ve kabuk L* değerine etkileri

Applications	Weight Loss (%)			L*			
	Storage period (days)			Storage period (days)			
	0	10	20	0	10	20	30
Control	0.98$^{n.s.}$	1.61$^{n.s.}$	2.01 a^{z*}	54.10	54.01$^{n.s}$	55.96$^{n.s}$	59.62 a^{z**}
MAP	0.90	1.40	1.65 ab	54.10	56.22	55.93	57.15 b
1-MCP+MAP	0.81	1.27	1.40 b	54.10	54.73	56.57	56.12 b
MAP+EA	0.85	1.35	1.61 ab	54.10	55.63	57.10	56.92 b

^{z} Duncan test was used to determine the differences between the mean data in each column.
^{z} Her sütundaki ortalama veriler arasındaki farkları belirlemek için Duncan testi kullanıldı.
$^{n.s.}$ non-significant; significant according to $^{*}P \leq 0.05$, $^{**}P \leq 0.01$.
$^{n.s.}$ önemsiz; *P≤0,05, **P≤0,01'e göre anlamlıdır.

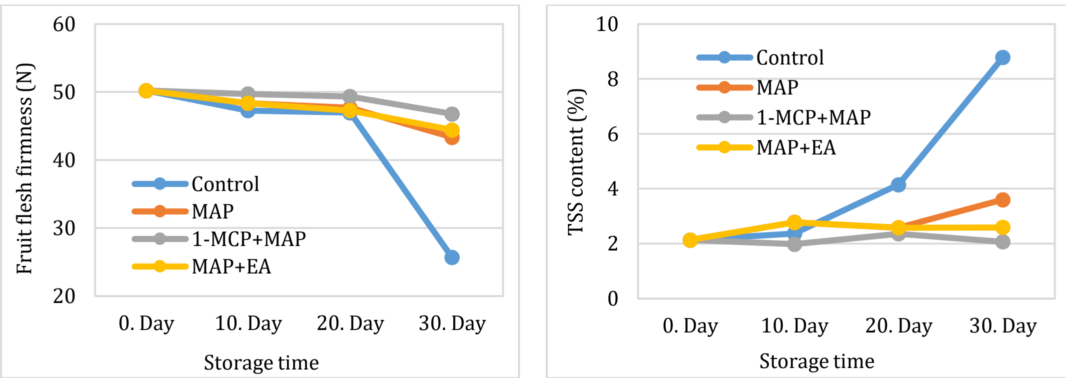

Figure 1. Impact of post-harvest applications on fruit flesh firmness and TSS content of bananas during storage.
Şekil 1. Hasat sonrası uygulamaların depolama süresince muzların meyve eti sertliği ve SÇKM miktarına etkileri.

Table 2. Impact of post-harvest applications on a* and b* values of banana fruit peel during storage
Çizelge 2. Hasat sonrası uygulamaların depolama süresince muz meyvelerinin kabuk a* ve b* değerine etkileri

Applications	a*				b*			
	Storage time (days)				Storage time (days)			
	0	10	20	30	0	10	20	30
Control	-16.57	-15.87$^{n.s.}$	-15.18$^{n.s.}$	-12.25 a**	34.81	34.05$^{n.s.}$	34.89$^{n.s.}$	36.53 a^{z**}
MAP	-16.57	-15.26	-15.68	-14.86 b	34.81	33.95	33.56	34.56 b
1-MCP+MAP	-16.57	-16.47	-14.87	-15.86 c	34.81	34.01	33.66	34.49 b
MAP+EA	-16.57	-15.03	-14.32	-15.40 bc	34.81	33.56	34.69	33.93 b

^{z} Duncan test was used to determine the differences between the mean data in each column.
^{z} Her sütundaki ortalama veriler arasındaki farkları belirlemek için Duncan testi kullanıldı.
$^{n.s.}$ non-significant; significant according to $^{**}P \leq 0.01$.
$^{n.s.}$ önemsiz; **P≤0,01'e göre anlamlıdır.

Table 3. Impact of post-harvest applications on peel firmness and TA content of banana fruits during storage
Çizelge 3. Hasat sonrası uygulamaların depolama süresince muz meyvelerinin kabuk sertliğine ve TA miktarına etkileri

Applications	Peel firmness (N)				TA content (%)			
	Storage time (days)				Storage time (days)			
	0	10	20	30	0	10	20	30
Control	110.5	108.3 n.s.	96.4 n.s.	82.5 b z*	0.79	0.76 n.s.	0.65 n.s.	0.57 n.s.
MAP	110.5	107.3	98.9	93.8 a	0.79	0.73	0.65	0.60
1-MCP+MAP	110.5	106.2	98.4	99.1 a	0.79	0.78	0.70	0.64
MAP+EA	110.5	110.2	104.1	97.6 a	0.79	0.70	0.63	0.61

[z] Duncan test was used to determine the differences between the mean data in each column.
[z] Her sütundaki ortalama veriler arasındaki farkları belirlemek için Duncan testi kullanıldı.
n.s. non-significant; significant according to *$P \leq 0.05$.
n.s. önemsiz; **P≤0,05'e göre anlamlıdır.

While the impact of different treatments on the amount of TSS of banana fruits was significant ($P \leq 0.01$) after 20 and 30 days of storage, it was insignificant in the first period of storage (day 10). On the 20th day of storage, it was found that the amount of TSS of banana fruits in the control (4.15%) was higher than the ones that were applied with treatments (2.36% - 2.58%). These differences between the treatments and the control were more pronounced at the end of the storage period, and it was found that the control bananas had the highest amount of TSS (8.78%) and 1-MCP + MAP treated bananas had the lowest amount (2.07%) (Figure 1). The limiting effect of the treatments on the increase in the amount of TSS indicates that they delayed ripening. Because it is expected development that there will be an increase in the TSS content in banana fruits with ripening (Turner, 2001). Indeed, this is confirmed by the fact that the changes in the TSS content of banana fruits treated with 1-MCP + MAP (Jiang et al., 2004), MAP + EA (Kozak, 2003) and MAP (Kudachikar et al., 2011) were very limited during storage.

The impact of different treatments on the TA content in banana fruits did not show significant differences and the TA content in banana fruits, which was 0.79% at the beginning of storage, varied between 0.57% and 0.64% after 30 days of storage (Table 3). It is thought that the lack of a close relationship between the TA content of banana fruits and ripening is effective in this. Indeed, it was reported that 1-MCP treatment had no significant effect on the TA content of banana fruits (Jiang et al., 2004).

The impact of different treatments on the respiration rate of banana fruits was found to be significant ($P \leq 0.01$) during the storage period, and the respiration rate of banana fruits in the control was found to be the highest and the lowest in 1-MCP + MAP treatments. At the end of 30 days of storage, the respiration rate of banana fruits in the control was 14.96 ml CO_2 kg.h^{-1}, which was significantly higher than the treatments. This was because the treatments delayed the ripening of banana fruits. An increase in respiration rate is observed with ripening in banana fruits showing climacteric rise (Karaçalı, 2016). Similarly, it has been reported that 1-MCP application (Boonyaritthongchai and Kanlayanarat, 2010) and the combination of 1-MCP and MAP packaging can significantly extend the post-harvest life of banana fruits by reducing the respiration rate (Jiang et al., 1999; Li et al., 2023). Chauhan et al. (2006) reported that the synergy created by the co-application of MAP packs and potassium permanganate delayed the onset of the respiratory climacteric during banana ripening and delayed ripening.

The effect of different treatments on the amount of ethylene secretion of banana fruits showed significant ($P \leq 0.01$) differences during storage and the amount of ethylene secretion of banana fruits treated with 1-MCP + MAP was significantly lower than the control. At the end of storage, the amount of ethylene secretion of banana fruits in the control was the highest with 4.23 µl C_2H_4 kg.h^{-1} and the lowest with 0.42 µl C_2H_4 kg.h^{-1} in the 1-MCP + MAP treated banana fruits (Table 4). The fact that 1-MCP + MAP treatment significantly limited the amount of ethylene secretion in banana fruits can be explained by the fact that 1-MCP blocks ethylene secretion. When 1-MCP is applied to fruits, it binds to ethylene receptors and slows down the rate of ethylene synthesis and all related reactions by preventing ethylene from binding to these receptors (Sisler and Serek, 1997; Watkins, 2006). In addition to being an ethylene inhibitor, 1-MCP also inhibits ethylene production by inhibiting ACC oxidase activity in the peel. The ethylene limiting effect of MAP and MAP + EA treatments at the end of storage is consistent with the slowing effect of these treatments on aging.

Quality of banana fruits after ripening

Color changes (L*, a*, and b* values), fruit flesh firmness, TSS content and taste scores of banana fruits stored for 30 days with different treatments after ripening (4 days of shelf life in addition to ripening to ripeness level number 3) are presented in Table 5. The impact of post-harvest treatments on the peel L*, a*, and b* values of ripened banana fruits showed significant ($P \leq 0.01$) differences, and the peel L*, a* and b* values were the lowest in 1-MCP + MAP treatments, while L* and b* values were the lowest in MAP and a* values were the highest in control. The post-ripening peel a* value of 1-MCP + MAP treated bananas was -14.45, indicating that the peel retained its green color and there was no yellowing.

Table 4. Impact of post-harvest applications on respiration rate (ml CO_2 kg.h^{-1}) and ethylene secretion (µl C_2H_4 kg.h^{-1}) of banana fruits during storage

Çizelge 4. Hasat sonrası uygulamaların depolama süresince muz meyvelerinin solunum hızı (ml CO_2 kg.h^{-1}) ve etilen salgı miktarına (µl C_2H_4 kg.h^{-1}) etkileri

Applications	Respiration rate (ml CO_2 kg.h^{-1})				Ethylene secretion amount (µl C_2H_4 kg.h^{-1})			
	Storage time (days)				Storage time (days)			
	0	10	20	30	0	10	20	30
Control	3.27	6.38 a^{z**}	6.84 a**	14.96 a**	0.19	2.32 a^{z**}	2.44 a**	4.23 a**
MAP	3.27	5.31 b	5.96 b	7.92 b	0.19	2.24 a	2.28 a	2.79 b
1-MCP+MAP	3.27	3.65 c	3.85 c	4.38 c	0.19	0.21 b	0.29 b	0.42 c
MAP+EA	3.27	4.87 b	5.32 b	7.29 b	0.19	2.24 a	2.32 a	2.69 b

^{z} Duncan test was used to determine the differences between the mean data in each column.

^{z} Her sütundaki ortalama veriler arasındaki farkları belirlemek için Duncan testi kullanıldı.

Table 5. Changes in L*, a* and b* values, fruit flesh firmness, TSS content and overall acceptance score of post-harvest peel after ripening after storage for different periods of time according to post-harvest treatments

Çizelge 5. Farklı sürelerde depolandıktan sonra olgunlaştırılan sonrası kabuk L*, a* ve b*, meyve eti sertliği, SÇKM miktarı ve genel beğeni puanlarının hasat sonrası uygulamalara göre değişimleri

Applications	L*	a*	b*	Fruit flesh firmness (N)	TSS content (%)	Overall acceptance (1-5 scale)
Control	66.47 b**	3.21 a**	42.39 b**	13.44 c**	17.93 a**	4.4 a**
MAP	67.58 a	0.49 b	46.33 a	15.79 b	17.28 a	4.6 a
1-MCP+MAP	55.97 c	-14.45 d	33.90 c	83.85 a	3.20 c	1.2 b
MAP+EA	68.02 a	0.38 b	43.17 b	16.08 b	16.15 b	4.6 a

^{z} Duncan test was used to determine the differences between the mean data in each column.

^{z} Her sütundaki ortalama veriler arasındaki farkları belirlemek için Duncan testi kullanıldı.

n.s. Significant according to *$P \leq 0.05$, *$P \leq 0.01$.

n.s. önemsiz; *$P \leq 0.05$, **$P \leq 0,01$'e göre anlamlıdır.

1-MCP application limits ethylene synthesis by preventing the binding of ethylene to receptors and this inhibits all ethylene-dependent metabolic activities. Since the activity of enzymes that break down chlorophyll, which gives the green color to the peel of banana fruits, is inhibited, no color change and yellowing occurs. Similarly, it has been reported that the transformation of the fruit peel to turn yellow color is delayed in 1-MCP treated bananas (Boonyaritthongchai and Kanlayanarat, 2010) and discoloration occurs (Harris et al., 2000), therefore, the effect of 1-MCP application on the ripening of banana fruit in the storage of green bananas may not be accepted in commercial applications due to the variable and inconsistent effect of 1-MCP application on the ripening of banana fruit (Harris et al., 2000; Pelayo et al., 2003; Canan, 2012). It was found that the post-ripening coloration of bananas stored with MAP and MAP + EA was at the desired levels. Similar results were reported by different researchers (Chauhan et al., 2006; Kudachikar et al., 2011).

The impact of post-harvest treatments on fruit flesh firmness of banana fruits ripened at the end of storage was found to be significant ($P \leq 0.01$) throughout the shelf life, and the fruit flesh firmness of bananas treated with 1-MCP + MAP was significantly higher (83.85 N) than the control. One of the signs of ripening in banana fruits is the softening of the flesh (Prabha and Bhagyalakshmi, 1998). The fact that 1-MCP inhibited ripening was effective in the fact that fruit flesh firmness was significantly higher in bananas treated with 1-MCP + MAP. 1-MCP exerts this effect by limiting the activity of enzymes via ethylene. 1-MCP treatment suppresses the effect of ethylene during ripening and limits the activities of polygalacturonase, pectin lyase, pectin methyl esterase, and cellulase, which are the enzymes responsible for softening in bananas (Lohani et al., 2004; Zhu et al., 2015). The higher fruit flesh firmness of treated bananas compared to the control can be explained by the slowing effect of these treatments on the ripening of banana fruits. Indeed, it was reported that the flesh firmness of bananas kept in MAP was better than the control fruits (Nguyen et al., 2003).

The impact of post-harvest treatments on the amount of TSS in ripened banana fruits was found to be significant (P≤0.01) throughout the shelf life, and it was determined that the amount of TSS (3.20%) of 1-MCP + MAP treatments was very low compared to the other treatments. The fact that 1-MCP + MAP treatment prevented the increase in the amount of TSS is related to the fact that 1-MCP slows down the breakdown of starch by limiting ethylene synthesis. As a matter of fact, it was reported that 1-MCP application to ethylene treated bananas delayed the increases in the amount of TSS (Jiang et al., 2004).

1-MCP + MAP treated banana fruits had very poor scores (1.0-1.4), which were significantly lower than the control and other treatments (4.4-4.6). The taste scores of control, MAP and MAP + EA treated bananas were 4 and above, indicating that the eating quality of banana fruits was good due to yellow skin, soft flesh and improved taste. The reason why 1-MCP + MAP treated banana fruits had very low appreciation scores was that the expected yellowing of the peel color, softening of the fruit flesh, and conversion of starch to sugar did not occur due to the lack of ripening in the fruits. It was reported that the decreases in flesh firmness and starch content of 1-MCP-treated bananas were significantly delayed (Jiang et al., 2004). Therefore, banana fruits treated with 1-MCP + MAP lost their marketability due to this feature.

During the storage period and after ripening in addition to 30 days of storage, rot development and physiological disorders were not observed in both control and treatments. This was because 1000 ppm imazalil was applied to all fruits and storage conditions were suitable for banana fruit (Turner, 2001; Canan, 2009; Kerbel, 2016; Karaçalı, 2016).

Conclusion

Although 1-MCP + MAP-treated green bananas gave the best results during storage, they lost their marketable quality because they did not ripen after ethylene treatment, yellowing of the peel, softening of the fruit flesh, and no increase in the TSS content and sugar composition. MAP + EA treatment gave the most successful results because it limited the increases in coloration, softening of fruit flesh, TSS content, respiration rate and ethylene secretion amount in banana fruits during storage and gave very good post-ripening appreciation scores.

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