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The Effect of Putrescine and Modified Atmosphere Packaging (MAP) Treatments on Fruit Quality Characteristics of Strawberry (Kabarla cultivar) During Cold Storage

Soğuk Depolama Sırasında Çilek (Kabarla Çeşidi) Meyve Kalite Özellikleri Üzerinde Putresin ve Modifiye Atmosfer Paketleme (MAP) Uygulamalarının Etkisi

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THE EFFECT OF PUTRESCINE AND MODIFIED ATMOSPHERE PACKAGING (MAP) TREATMENTS ON FRUIT QUALITY CHARACTERISTICS OF STRAWBERRY (KABARLA CULTIVAR) DURING COLD STORAGE

ABSTRACT

Strawberry is a fruit species that must be harvested at full ripening and at the same time has an extremely short shelf life and deteriorates rapidly. Therefore, it is important to extend the shelf life after harvest. In this study, putrescine and modified atmosphere packaging (MAP) were applied during cold storage in order to maintain the quality and extend the shelf life of strawberry fruit. The commercial ripening fruit were treated with 1 mM putrescine and stored in MAP for 20 days. The quality characteristics such as weight loss, soluble solids content, titratable acidity, fruit color, organic acid and phenolic content were measured and analyzed on days 4, 8, 12, 16 and 20 of storage. At the end of 20 days of the cold storage, the highest weight loss was in control treatment (%). The decrease in soluble solids content (SSC) and titratable acidity (TA) values during cold storage was slowed down by MAP and putrescine treatments. Organic acids and phenolic compounds were significantly affected by storage time and MAP and putrescine treatments. After 20 days of the cold storage, citric acid (748.91 mg 100 g^{-1}) and malic acid (258.34 mg 100 g^{-1}), which were determined as basic organic acids, were highest in putrescine treatment. Shikimic acid (0.77 mg 100 g^{-1}) and isocitric acid (112.58 mg 100 g^{-1}) as phenolic compounds were highest in MAP and MAP+ putrescine treatments, respectively. These results releaved that the application of putrescine and modified atmosphere packaging (MAP) during cold storage significantly extends the market life of strawberries by preserving their quality attributes.

Keywords: Phenolic Compunds, Organic Acids, Soluble Solids Content, Weight Loss.

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SOĞUK DEPOLAMA SIRASINDA ÇİLEK (KABARLA ÇEŞİDİ) MEYVE KALİTE ÖZELLİKLERİ ÜZERİNDE PUTRESİN VE MODİFİYE ATMOSFER PAKETLEME (MAP) UYGULAMALARININ ETKİSİ

ÖZ

Çilek tam olgunlaştığında hasat edilmesi gereken ve aynı zamanda raf ömrü son derece kısa olan ve hızla bozulan bir meyve türüdür. Bu nedenle hasat sonrası raf ömrünün uzatılması önemlidir. Bu çalışmada, çilek meyvesinin kalitesini korumak ve pazar ömrünü uzatmak amacıyla soğuk depolama sırasında putresin ve modifiye atmosfer paketleme (MAP) uygulanmıştır. Ticari olgunlaşan meyveler 1 mM putresin ile muamele edilmiş ve 20 gün boyunca MAP içinde depolanmıştır. Ağırlık kaybı, çözünür katı madde içeriği, titre edilebilir asitlik, meyve rengi, organik asit ve fenolik içerik gibi kalite özellikleri depolamanın 4, 8, 12, 16 ve 20. günlerinde ölçülmüş ve analiz edilmiştir. Soğuk depolamanın 20. gününün sonunda en yüksek ağırlık kaybı kontrol uygulamasında (%) gerçekleşmiştir. Soğuk depolama sırasında SSC ve TA değerlerindeki düşüş MAP ve putresin uygulamaları ile yavaşlatılmıştır. Organik asitler ve fenolik bileşikler depolama süresi ile MAP ve putresin uygulamalarından önemli ölçüde etkilenmiştir. Soğuk depolamanın 20. gününden sonra, bazik organik asitler olarak belirlenen sitrik asit (748,91 mg 100 g^{-1}) ve malik asit (258,34 mg 100 g^{-1}) putresin uygulamasında en yüksekti. Fenolik bileşiklerden şikimik asit (0.77 mg 100 g^{-1}) ve izositrik asit (112.58 mg 100 g^{-1}) sırasıyla MAP ve MAP+ putresin uygulamalarında en yüksek bulunmuştur. Bu sonuçlar, çileklerin soğuk depolama sırasında putresin ve modifiye atmosfer paketleme (MAP) uygulamalarının, kalite özelliklerini koruyarak pazar ömrünü önemli ölçüde uzattığını göstermektedir.

Anahtar Kelimeler: Fenolik Bileşikler, Organik Asitler, Çözünebilir Katı Madde İçeriği, Ağırlık Kaybı.

1. INTRODUCTION

Strawberry that consumed as a table food, increases the interest of producers in the fruit due to its important health effects and the fact that it can be processed in various ways in different industrial sectors. It is especially preferred in jam, marmalade and ice cream production. The fact that strawberry fruit contains high amounts of vitamin C and phenolic compounds increases the interest in the fruit (Aaby et al., 2005).

Worldwide, it is known that fresh fruit and vegetables suffer a loss of approximately 25-30% from the field to the table. For this reason, the storage of the more perishable products in appropriate conditions and the technologies used in transportation processes play a major role in preventing the loss of products until the consumer (Khosroshahi et al., 2007).

Strawberries have a soft fruit structure without a protective outer skin. Therefore, it is important to maintain its quality after harvest. Various factors such as microorganisms, enzymes, biochemical reactions, light can cause it to lose its nutritional values and pose a health risk. It requires the preservation of products in cold storage and the successful management of this process. This depends on a good knowledge of plant and crop physiology both pre-harvest and post-harvest (Hashmi et al., 2013).

The various methods have been used to date to extend the shelf life of strawberries at postharvest. These methods include *Aloe vera* (Sogvar et al., 2016), putrescine (Zafari et al., 2015) and 1-MCP (Jiang et al., 2001) MAP (Belay et al., 2016).

Polyamines are known as natural compounds found in almost all living organisms, playing important roles in many physiological processes such as cell growth and development. Polyamines commonly found in plant cells are putrescine (diamine), spermidine (triamine) and spermine (tetramine). Putrescine, which delays the removal of the epicuticular waxes that protect the membrane integrity of the fruit and play an important role in water exchange from the peel, can be used to extend the storage period and shelf life (Khosroshahi et al., 2007).

Modified atmosphere packaging (MAP) can extend the storage life of products and contribute to the prevention of product losses (Belay et al., 2016; Peano et al., 2017; Falagán and Terry, 2018). By controlling the respiration rate and gas permeability of the product with MAP applications, an atmosphere close to the optimal storage atmosphere recommended to maintain fruit quality and safety is achieved (Guillaume et al., 2010).

The aim of this study was to determine the effects of Putrescine and MAP treatments on some quality parameters of strawberry fruit during cold storage.

2. MATERIAL AND METHOD

This study was carried out with 'Kabarla' strawberry (*Fragaria vesca*) cultivar hand-harvested from the producer orchard in Diyarbakır province in 2023. Kabarla is a neutral day strawberry variety that produces large, firm, sweet, and bright red fruit. It begins to bear fruit with very little delay compared to other neutral day varieties and continues to produce fruit for an extended period. It bears fruit throughout the summer in highland regions. Its yield is also very good in coastal areas, making it a high-yielding variety. The harvested samples were kept in cold storage and quickly transfered with refrigerated vehicle (15±0.5 °C and 80±5%) to the laboratory of GAP International Agricultural Research and Training Center Directorate (GAPUTAEM). Some of the fruit were used for harvest time analysis and the rest were divided into 4 groups. The control group was applied with water only, the second group fruit were immersed in putrescine for 15 min, the third group fruit were immersed in putrescine for 15 minutes and then placed in MAP packages and the fourth group fruit were placed in MAP packages without any treatment and stored in cold storage (0 ◦C and 90% relative humidity) for 4, 8, 12,

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16 and 20 days. The fruit at the end of the storage period were analyzed and stored at -20 ◦C for organic acid and phenolic compounds analysis. The research was designed according to completely randomized block design with three replications. For each replicate, 10 fruit were used.

2.1 Weight loss, Soluble Solids Content and Titratable Acidity

Weight loss was measured using a digital scale (±0.01 g) (Radwag PS 4500/C/1, Poland) for the fruit designated for each analysis period (3 rep). Weight loss was determined as the difference between the initial and final weights. The measurement values were expressed as a percentage (%). Five fruit in each replication were washed with distilled water. Fruit were homogenized by a blender (Promix HR2653, Philips, Turkey) and the homogenate was filtered through cheesecloth, to obtain juice filtrate. SSC was determined with a digital refractometer (Atago PAL-1, USA) and recorded as a percentage (%). pH was determined with pH meter. For TA measurement, 10 mL of distilled water was added to 10 mL of juice. Then 0.1 N sodium hydroxide (NaOH) was added until the solution's pH reached 8.2. Based on the amount of NaOH consumed in titration, titratable acidity was determined and stated as g malic acid kg^{-1}. For vitamin C measurement, 0.5 mL juice was added to 5 mL of 0.5 % oxalic acid

2.2. Color Characteristics

Fruit color values were measured on the 4^{th}, 8^{th}, 12^{th} 16^{th} and 20^{th} days of the storage period. The color characteristics were determined with a colorimeter (Minolta, model CR–400, Tokyo, Japan) from three different points on the equatorial section of fruit skin. The CIE L*, a* and b* values of fruit skin color were determined.

2.3. Organic Acids

5 g fruit was homogenized with sulfuric acid and centrifuged. Extraction was passed through a 0.45 µm membrane filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA) and SEP-PAK C18 cartridge. The acids were analyzed in high performance liquid chromatography (HPLC) with Aminex HPX - 87 H, 300 mm x 7.8 mm column (Bevilacqua and Califano 1989).

2.4. Phenolic Compounds

Rodriguez-Delgado et al. (2001) was used for the determination of phenolic compounds. 5 g fruit was homogenized, diluted with distilled water and centrifuged. The extract was filtered with a 0.45µm millipore filter and transferred to HPLC. Chromatographic separation was performed on Agilent 1100 HPLC system, using a DAD detector and a 250*4.6 mm, 4µm ODS column.

2.5. Statistical Analysis

The normal distribution control of the data obtained from the study was done by Kolmogorov-Smirnov test and the homogeneity control of variances was done by Levene test. Descriptive statistics are given as mean and standard error. Data analysis was done by analysis of variance. Differences between groups were determinate by Tukey's multiple comparison test. SAS package program (SAS 9.1 version, USA) was used for statistical analysis. The level of significance was considered as α=5% in statistical analyzes.

3. RESULTS AND DISCUSSION

3.1. Weight loss, Soluble Solids Content and Titratable Acidity

One of the most important quality characteristics during storage is weight loss. In the study, it was determined that weight loss increased during the storage period. The highest weight loss occurred in control fruit stored for 20 days (6.55%). At the end of the cold storage, MAP+Putrescine was the most effective at reducing weight loss (0.81%). Weight loss occurred in all treatments during storage. These losses were the lowest in the MAP treatment on 4th and 8th days of the cold storage and in the MAP+Putrescine treatment on 12th, and 16th and 20th days (0.42, 0.46, 0.68%, respectively) (Table 1). Weight loss, which occurs as a result of water evaporation through fruit transpiration, increases with storage time and may cause economic losses (Kader and Yahia 2011). The 3-10% weight loss in fruit after harvest is due to water loss due to transpiration and respiration, which varies depending on the cuticle and physical properties of the fruit (Ben-Yehoshua and Rodov, 2002). Post-harvest applications such as MAP, spermidine, putrescine are effective in delaying cell wall degradation, reducing respiration and reducing weight loss (Onik et al., 2020; Rastegar et al., 2020). The low weight loss occurring in polyamine-applied fruit can be attributed to stabilization and consolidation of cell integrity and permeability of tissues (Champa et al., 2014). Putrescine application can reduce the permeability of tissues, maintain cell integrity and reduce fruit weight loss (Fawole et al., 2020). Previous studies were reported that putrescine applications decreased the weight loss in fruit species including peach (Kibar et al., 2021; Bregoli et al., 2016) plum (Serrano et al., 2003), lemon (Valero et al., 1998), strawberry (Khosroshahi et al., 2007), mango (Jawandha et al., 2012), apricot (Martinez-Romero et al., 2002; Davarynejad et al., 2013) and mandarin (Ennab et al, 2020). It is reported that the respiration rate decreases with MAP application, thus increasing the duration of cold storage (Nielsen and Leufvén, 2008). Ozturk et al. (2019) found that modified atmosphere packaging application significantly reduced the weight loss in black cherry, Islam et al. (2022) in jujube, Cantin et al. (2008) in Japanese plums. As fruit ripen, titratable acidity decreases and SSC content increases. The SSC content of the fruit applied with MAP on 4th day at cold storage was higher than the other applications, and the difference was significant. During the following storage period, the SSC value in the fruit decreased during cold storage and the control fruit had lower SSC at the end of the storage period. TA decreased during storage and control fruit had lower TA values than putrescine applied fruit (Table 1).

The decrease in SSC and TA content of strawberry fruit during cold storage may be due to metabolic changes and utilization of respiratory substrate (Nguyen et al. 2020). SSC and titratable acidity, which are important harvest criteria in fruit, are the main quality characteristics that determine the storage period of the fruit (Mahto and Das, 2013). However, during the postharvest storage process, acid metabolism causes the conversion of starch and acid to sugars, leading to a decrease in titratable acidity and an increase in SSC (Duan et al., 2011). This can accelerate the progression of the ripening process in fruit. Putrescine can inhibit these degradation processes occurring in fruit and delay the chemical changes of fruit ripeness (Jongsri et al., 2017). Studies in different fruit species show that increases and decreases in the SSC content are often associated with an increase in the respiration rate. This is attributed to events such as the conversion of sugar to CO_2 and H_2O, the conversion of starch to sugar, the reduction of fruit water content and the breakdown of polysaccharides in the cell wall (Martinez-Romero et al., 2006; Díaz-Mula et al., 2012). Hazrati et al. (2017) reported that MAP application decreased TA content in peach and Islam et al. (2022) reported that MAP application decreased TA content in jujube fruit but presented higher TA content than control fruit. Ozturk and Aglar (2019) observed that MAP application increased the SCC content in cornelian cherry fruit.

Table 1. Effect of MAP and Putrescine applications on weight loss, soluble solids content and titratable acidity of strawberry fruit during storage

	Applications	Storage Time (day)					
		Harvest	4	8	12	16	20
Weight Loss (%)	Control		0.62±0.03a	2.11±0.14a	5.01±2.82a	5.21±2.47a	6.55±0.76a
	MAP		0.16±0.00c	0.25±0.90c	0.44±0.14c	0.54±0.09c	0.81±0.17c
	Putrescine		0.38±0.10b	1.13±0.16b	3.14±1.26b	3.45±0.76b	3.52±1.60b
	MAP+Put		0.20±0.04c	0.36±0.10c	0.42±0.07c	0.46±0.02d	0.68±1.38d
SSC (%)	Control	10.58	9.57±0.41ab	9.04±0.73a	8.73±0.87b	8.13±0.43b	7.73±0.64b
	MAP		10.17±0.27a	9.13±0.32a	9.13±0.52a	8.77±0.53a	8.13±0.33a
	Putrescine		9.58±0.40ab	9.43±0.52a	9.33±0.66a	8.47±0.39a	8.40±0.51a
	MAP+Put		9.27±0.38b	9.13±0.52a	9.00±0.79a	8.60±0.43a	8.13±0.40a
TA (%)	Control	1.07	0.79±0.03b	0.75±0.01c	0.73±0.06b	0.70±0.03c	0.65±0.44c
	MAP		0.91±0.02a	0.86±0.02a	0.85±0.04a	0.75±0.03a	0.75±0.02b
	Putrescine		0.83±0.01ab	0.78±0.01b	0.77±0.04b	0.76±0.04a	0.77±0.02a
	MAP+Put		0.90±0.05a	0.82±0.02ab	0.81±0.01ab	0.74±0.06bc	0.73±1.02b

Means in columns with the same letter do not differ according to Tukey's test at $P<0.05$

3.2. Fruit Color (L, a*, b*)

L* values in MAP and putrescine applied fruit generally increased during the storage period. On the 20th day of the storage period, MAP+Putrescine application exhibited the highest L* value at all times with 25.66 and showed a significant difference compared to the other applications at the same time. On the 4th, 8th and 12th days of cold storage, a values were statistically similar in all treatments. On the 16th day of the cold storage, the control group had the lowest value. On the 20th day of the cold storage, the values of the control group were lower than the values of the other applications. b* value had similar values in all applications on the 4th and 12th days. At the end of the cold storage, the highest value was measured in MAP+Putrescine application with 44.09. Fruit color is an important quality characteristic that affects consumer preferences as well as an indicator of ripeness for many fruit species. In the post-harvest period, the color changes are observed in the fruit with the ripening process and it is of great importance to control these changes. In our study, it was observed that MAP, putrescine and MAP+Putrescine applications slowed down fruit ripening and therefore the color change was lower (Table 2). Ozturk et al. (2019) found that L* value was higher in a study in which MAP treatments were applied to blackcurrant fruit. Ozturk et al. (2022) found that physiological and biochemical changes in MAP applied medlar fruit during storage were less and fruit color was preserved.

Table 2. Effect of MAP and Putrescine applications on color characteristics of strawberry fruit during storage

	Applications		Storage Time (day)				
		Harvest	4	8	12	16	20
L	Control	25.72	17.43±3.34a	18.44±0.16ab	25.48±1.58a	16.19±0.84b	23.82±2.71ab
	MAP		16.64±0.87a	17.59±1.55b	21.60±2.91a	17.31±2.24b	22.81±0.59ab
	Putrescine		21.53±3.59a	21.07±1.69ab	23.53±1.50a	21.81±1.98b	21.65±1.65ab
	MAP+Put		17.64±3.20a	24.19±3.66a	24.59±2.34a	23.09±0.92ab	25.66±1.55a
a*	Control	53.80	43.56±2.87a	43.91±1.21a	43.52±3.99a	37.58±1.87c	39.85±3.01b
	MAP		44.27±0.87a	44.51±1.31a	45.24±2.15a	41.82±1.77b	50.94±0.47a
	Putrescine		42.31±3.59a	42.59±2.33a	45.20±1.87a	46.34±1.53ab	48.40±1.81a
	MAP+Put		45.27±3.30a	47.43±1.14a	49.09±1.99a	49.66±0.82a	51.25±1.79a
b*	Control	46.71	29.89±5.75a	31.64±1.21ab	33.30±2.97a	24.88±1.59c	35.44±3.51b
	MAP		28.55±1.50a	30.17±1.31b	33.74±2.45a	29.61±3.88bc	39.17±1.03ab
	Putrescine		32.21±5.76a	35.37±2.33a	38.39±3.54a	38.81±1.05a	39.56±2.84ab
	MAP+Put		30.27±5.50a	36.39±1.14a	42.25±4.03a	37.94±2.04ab	44.09±2.67a

Means in columns with the same letter do not differ according to Tukey's test at $P<0.05$

3.3. Organic Acids (mg 100 g^{-1})

The changes in the organic acid content of strawberry fruit during storage were analyzed in terms of three different acids. Citric acid, malic acid and succinic acid were the main organic acids detected in strawberry fruit. The fruit were found to have the highest content of citric acid, malic acid and succinic acid, respectively (Table 3). All organic acids were found to be significantly affected by putrescine and MAP applications. The amount of organic acids decreased during storage and the highest decrease was observed after 20 days of storage (Table 3). Citric acid values were highest in putrescine application with 748.91 and lowest in control group with 577.10 at the end of the storage period. Malic acid values showed the lowest value in the control group on the 20th day of the storage period. Succinic acid values were significantly higher in MAP+Putrescine treatments on the 12th and 16th days. After 20 days of the cold storage, putrescine application provided the best protection in citric and malic acid values, while MAP+purescine application was the best protection in succinic acid values. The highest decrease in all organic acid values at all times was found in control fruit (Table 3). Polyphenols are secondary metabolites that improve the quality of fruit and vegetables and contribute to the defense mechanism of plants. These components affect the quality characteristics of fruit such as firmness, taste, bitterness and color and also have antioxidant properties (Sreekumar et al., 2014). A decrease in acidity occurs during the fruit ripening process because organic acids are used as substrates for the respiration process and the amount of organic acids decreases as the respiration rate increases. Hormone-like treatments such as polyamines and salicylic acid can slow down the decrease in acidity in fruit and maintain the amount of organic acids in fruit by slowing down the ripening process (Patel et al., 2019; Liu et al., 2019). Jongsri et al. (2017) reported that putrescine application increased acidity in mango.

Table 3. Effect of MAP and Putrescine applications on organic acids of strawberry fruit during storage (mg 100 g^{-1})

	Applications	Harvest	Storage Time (day)				
			4	8	12	16	20
Citric acid	Control	652.44	566.06±20.12d	563.60±20.30d	592.28±18.10d	586.62±4.01d	577.10±2.98d
	MAP		643.79±15.36c	656.05±9.54c	658.23±7.17c	646.79±5.33c	600.41±14.95c
	Putrescine		844.78±6.63b	755.91±8.97b	752.26±23.17a	754.65±4.61a	748.91±5.91a
	MAP+Put		994.08±7.56a	794.85±9.01a	666.74±3.48b	654.08±4.19b	653.10±2.69b
Malic acid	Control	245.00	301.41±5.51c	263.10±6.38c	255.76±5.02d	247.45±2.18d	211.45±1.96d
	MAP		337.36±6.37a	287.48±5.61b	277.36±6.54c	277.19±3.55c	241.33±4.43c
	Putrescine		325.01±4.20b	303.33±5.56a	304.31±6.73a	298.96±2.28a	258.34±2.35a
	MAP+Put		341.15±5.90a	288.16±5.63b	295.26±2.64b	287.54±3.62b	251.33±1.98b

Succinic acid	Control	58.00	82.54±4.21c	73.58±2.46c	69.89±1.41c	59.25±1.21d	33.63±0.62d
	MAP		95.51±5.49b	94.75±1.14b	92.15±2.75b	90.56±1.20b	80.54±1.63a
	Putrescine		98.70±1.61b	93.08±1.23b	90.83±2.98b	68.86±0.68c	40.78±0.73c
	MAP+Put		114.33±1.26a	114.56±1.28a	125.18±0.75a	124.13±1.36a	43.80±0.74b

Means in columns with the same letter do not differ according to Tukey's test at P<0.05

3.4. Phenolic Compounds (mg 100 g^{-1})

Phenolic compounds are important compounds affecting the taste and color formation of fruit. Phenolic compound contents of strawberry fruit were analyzed during storage and shikimic acid and isocitric acid contents were determined. It was determined that MAP and Putrescine applications significantly affected the amount of phenolic compounds in the fruit. Isocitric acid values increased in all applications on the 4th and 8th days of storage and decreased in all applications except MAP on the 12th day. At the end of the cold storage, MAP+putrescine application had the highest value and control group had the lowest value. Shikimic acid values increased on the 4th day of the cold storage and decreased on the 8th day in all applications except MAP. On day 12th, there was an increase in control and MAP applications, while on days 16th and 20th, there was a decrease in all applications and MAP application gave significantly higher values (Table 4). Polyamines such as spermidine and putrescine are used to improve fruit quality by increasing the levels of beneficial compounds such as natural antioxidants, phenolics, flavor compounds, polyphenols and soluble solids (Liu et al., 2019). These compounds can also lead to an increase in the content of compounds such as anthocyanins, phenols, flavonoids (Pang et al., 2020; Wang et al., 2020; Xia et al., 2020).

Table 4. Effect of MAP and Putrescine applications on phenolic compounds of strawberry fruit during storage (mg 100 g^{-1})

	Applications	Storage Time (day)					
		Harvest	4	8	12	16	20
Shikimic acid	Control	0.64	0.72±0.01d	0.71±0.04d	1.03±0.01c	0.55±0.03d	0.30±0.02c
	MAP		0.92±0.00c	0.81±0.01c	1.23±0.03a	0.85±0.01b	0.77±0.01a
	Putrescine		1.09±0.01a	0.91±0.01b	0.91±0.02cd	0.64±0.01c	0.40±0.01b
	MAP+Put		1.06±0.01b	1.35±0.05a	1.13±0.02b	1.16±0.03a	0.44±0.01b
İzocitric acid	Control	110	110.57±0.32d	112.41±2.61d	108.08±0.66c	111.06±1.47d	89.09±1.82d
	MAP		117.55±0.47c	117.72±1.77c	120.10±0.81a	117.54±2.28c	98.27±2.06c
	Putrescine		127.58±0.49a	128.81±0.65b	105.40±1.21cd	127.64±1.15b	108.40±1.05b
	MAP+Put		125.60±0.31b	147.41±1.45a	113.66±2.34bc	170.03±1.71a	112.58±1.01a

Means in columns with the same letter do not differ according to Tukey's test at P<0.05

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4. CONCLUSION

The study aimed to evaluate the effects of MAP, putrescine, and MAP+Putrescine applications on the storage performance of strawberry fruit. According to the results of the study; in terms of fruit weight loss, MAP, Putrescine and MAP+-Putrescine applications extended the shelf life of the fruit, and these applications significantly reduced fruit weight loss. The lowest weight loss values were observed in MAP+Putrescine application and the highest weight loss was observed in putrescine applications during storage period.

In strawberry fruit, MAP, putrescine and MAP+ Putrescine applications all did not delayed ripeness and the lower SSC in control, but the higher titratable acidity values were found with MAP, putrescine and MAP+ Putrescine applications. It was observed that MAP, putrescine and MAP+ Putrescine applications slowed down ripening and therefore color change was lower. In strawberry fruit, MAP, putrescine and MAP+ Putrescine applications caused changes in the ratio of organic acids and individual phenolic compounds during storage, and these changes varied depending on the type of organic acids and individual phenolics. In general, organic acids and individual phenols decreased in all applications, while the significantly maintained their values compared to the control. As a result, it was concluded that MAP, putrescine and MAP+ Putrescine applications can be used effectively to delay ripeness and maintain quality in strawberry fruit during cold storage.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval.

Author Contribution Rates

Design of Study: FO (20%), HO (5%), CKO (10%), EK (40%), EA (25%)

Data Acquisition: FO (30%), HO (10%), CKO (30%), EK (20%), EA (10%)

Data Analysis: FO (25%), HO (20%), CKO (25%), EK (15%), EA (15%)

Writing up: FO (5%), HO (20%), CKO (5%), EK (50%), EA (20%)

Submission and Revision: FO (15%), HO (10%), CKO (15%), EK (30%), EA (30%)

REFERENCES

Aaby, K., Skrede, G., Wrolstad, R. E. 2005. Phenolic composition and antioxidant activities in flesh and achenes of strawberries (*Fragaria ananassa*). Journal of Agricultural and Food chemistry, *53*(10), 4032-4040.

Belay, Z. A., Caleb, O. J., Opara, U. L., 2016. Modelling approaches for designing and evaluating the performance of modified atmosphere packaging (MAP) systems for fresh produce: A review. Food Packaging and Shelf Life, 10, 1-15.

Ben-Yehoshua, S. and Rodov, V., 2002. Transpiration and water stress. In J. Barz, & J. K. Brecht (Eds.), Postharvest Physiology and Pathology of Vegetables, 111-159.

Bevilacqua, A. E., Califano, A. N., 1989. Determination of organic acids in dairy products by high performance liquid chromatography. Journal of Food Science, 54(4), 1076-1076.

Bregoli A.M., Ziosi V, Biondi S., Claudio B., Costa G., Torrigiani P., 2016. A comparison between intact fruit and fruit explants to study the effect of polyamines and aminoethoxyvinylglycine (AVG) on fruit ripening in peach and nectarine (Prunus persica L. Batch), Postharvest Biology Technology, 42(1), 31-40.

Cantı´n, C.M., Crisosto, C.H., Day, K.R., 2008. Evaluation of the effect of different modified atmosphere packaging box liners on the quality and shelf life of 'Friar' plums, Preliminary and Regional Reports, 18(2), 261-265.

Champa, W. A.H., Gill, M.I.S., Mahajan, B.V.C., Arora, N.K., 2014. Postharvest treatment of polyamines maintains quality and extendsshelf-life of table grapes (Vitis vinifera L.) cv. flame seedless postharvest, Biology and Technology, 91 (2014) 57-63.

Davarynejad, G., Zarei, M., Ardakani, E., Nasrabadi, E.M., 2013. Influence of putrescine application on storability, postharvest quality and antioxidant activity of two iranian apricot (Prunus armeniaca L.), Cultivars Not Scientia Biolgicae, 5(2), 212-219.

Díaz-Mula, H. M., Serrano, M., Valero, D., 2012. Alginate coatings preserve fruit quality and bioactive compounds during storage of sweet cherry fruit. Food and Bioprocess Technology, 5, 2990-2997.

Duan, J., Wu, R., Strik, B.C., Zhao, Y., 2011. Effect of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions, Postharvest Biology and Technology, 59, 71-79.

Ennab, H.A., El-Shemy, M.A., Alam-Eldein, S.M., 2020. Salicylic acid and putrescine to reduce post-harvest storage problems and maintain quality of murcott mandarin fruit, Agronomy, 10(1), 115.

Falagán, N., Terry, L. A., 2018. Recent advances in controlled and modified atmosphere of fresh produce. Johnson Matthey Technology Review, 62(1), 107-117.

Fawole, O.A., Atukuri, J., Arendse, E., Opara, U.O., 2020. Postharvest physiological responses of pomegranate fruit (Cv. Wonderful) to exogenous putrescine treatment and effects on physico-chemical and phytochemical properties, Food Science Human Wellness, 9, 146-161.

Guillaume, C., Schwab, I., Gastaldi, E., Gontard, N., 2010. Biobased packaging for improving preservation of fresh common mushrooms (*Agaricus bisporus L.*). Innovative food science & emerging technologies, 11(4), 690-696.

Hashmi, M. S., East, A. R., Palmer, J. S., Heyes, J. A., (2013). Hypobaric treatment stimulates defence-related enzymes in strawberry. Postharvest biology and technology, 85, 77-82.

Hazrati, S., Kashkooli, A.B., Habibzadeh, F., Tahmasebi-Sarvestani, Z., Sadeghi, A.R., 2017. Evaluation of AV gel as an alternative edible coating for peach fruits during cold storage period, Gesunde Pflanzen, 69 (3), 131-137.

Islam, A., Açıkalın, R., Ozturk, B., Aglar, E., Kaiser, C., 2022. Combined effects of AV gel and modified atmosphere packaging treatments on fruit quality traits and bioactive compounds of jujube (Ziziphus jujuba mill.) fruit during cold storage and shelf life, Postharvest Biology and Technology, 187, 111855.

Jawandha, S.K., Gill, M.S., Singh, N., Gill, P.P.S., 2012. Effect of post-harvest treatments of putrescine on storage of mango cv. langra, African Journal of Agricultural Research, 7(48), 6432-6436.

Jiang, Y., Joyce, D. C., Lerry, L.A., 2001. 1-Methylcyclopropene treatment affects strawberry fruit decay. Postharvest Biology Technology, volume 23, Issue 3, Pages 227-232

Jongsri, P., Rojsitthisak, P., Wangsomboondee, T., Seraypheap, K., 2017. Influence of chitosan coating combined with spermidine on anthracnose disease and qualities of 'Nam Dok Mai' mango after harvest, Sciantia Hortuculturae, 222, 180-187.

Kader, A.A., and Yahia, E.M., 2011. Postharvest biology of tropical and subtropical fruits. In: Yahia, E.M. (Ed.), Post-harvest Biology and Technology of Tropical and Subtropical Fruits 1. Woodhead Publishing, 2011, 79-111.

Khosroshahi, M.R.Z., Esna-Ashari, M., Ershadi, A., 2007. Effect of exogenous putrescine on post-harvest life of strawberry (*Fragaria ananassa* Duch.) fruit cultivar selva, Scientia Horticultrae, 114, 27–32.

Kibar, H., Tas, A., Gundogdu, M., 2021. Evaluation of biochemical changes and quality in peach fruit: effect of put-rescine treatments and storage, Journal of Food Composition and Analysis, 104048, 3-16.

Liu, J., Liu, H., Wu, T., Zhai, R., Yang, C., Wang, Z., 2019. Effects of melatonin treatment of postharvest pear fruit on aromatic volatile biosynthesis, Molecules, 24, 4233.

Mahto, R., and Das, M., 2013. Effect of gamma irradiation on the physico-chemical and visual properties of mango (Mangifera indica L.), cv. "Dushehri" and "Fazli" stored at 20°C, Postharvest Biology Technology, 86, 447-455.

Martinez-Romero, D., Alburquerque, N., Valverde, J.M., Guillen, F., Castillo, S., Valero, D., Serrano, M., 2006. Postharvest sweet cherry quality and safety maintenance by aloe vera treatments: a new edible coating, Postharvest Biology and Technology, 39, 93-100.

Martínez-Romero, D., Serrano, M., Carbonell, A., Burgos, L., Riquelme, F., Valero D., 2002. Effects of postharvest putrescine treatment on extending shelf life and reducing mechanical damage in apricot, Journal Of Food Science, 67(5), 1712-1716.

Nielsen T., and Leufvén A., 2008. The effect of modified atmosphere packaging on the quality of Honeoye and Korona strawberries, Food Chemistry, 107, 1053-1063.

Nguyen, V. T., Nguyen, D. H., Nguyen, H. V., 2020. Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.). Postharvest Biology and Technology, 162, 111103.

Onik, J.C., Wai, S.C., Li, A., Lin, Q., Sun, Q., Wang, Z., 2020. Melatonin treatment reduces ethylene production and maintains fruit quality in apple during postharvest storage, Food Chemistry, 337, 127753.

Ozturk, A., Ozturk, B., Karakaya, O., Gün, G., Ates, U., Yıldız, K., Siddiqui, M.W., Gündoğdu, M., 2022. Preliminary results: combination of MAP and AV gel in medlar fruit, Erwerbs-Obstbau, 64, 37–45.

Ozturk, B., Aglar, E., 2019. The influence of modified atmosphere packaging on quality properties of kiwifruits during cold storage and shelf life. Journal of the Institute of Science and Technology, 9(2), 614-625.

Ozturk, B., Karakaya, O., Yıldız, K., Saracoğlu, O., 2019. Effects of AV gel and MAP on bioactive compounds and quality attributes of cherry laurel fruit during cold storage, Scientia Horticulturae, 249, 31-37.

Pang, L., Wu, Y., Pan, Y., Ban, Z., Li, L., Li, X., 2020. Insights into exogenous melatonin associated with phenylalanine metabolism in postharvest strawberry, Postharvest Biology and Technology, 168, 111244.

Patel, N., Gantait, S., Panigrahi, J., 2019. Extension of postharvest shelf-life in green bell pepper (*Capsicum annuum* L.) using exogenous application of polyamines (spermidine and putrescine), Food Chemistry, 275, 681-687.

Peano, C., Giuggioli, N. R., Girgenti, V., Palma, A., D'Aquino, S., Sottile, F., 2017. Effect of palletized MAP storage on the quality and nutritional compounds of the Japanese Plum cv. Angeleno (*Prunus salicina* L.). Journal of Food Processing and Preservation, 41(2), e12786.

Rastegar, S., Khankahdani, H.H., Rahimzadeh, M., 2020. Effects of melatonin treatment on the biochemical changes and antioxidant enzyme activity of mango fruit during storage, Scientia Horticulturae, 259, 108835.

Rodrigez-Delgado, M.M., Aleman- Nava, G.S., Rodrigez-Delgado, J.M., Dieck-Assad, G., Martinez-Chapa, S.O., Barcelo, D., Parra, R., 2015. Laccase-based biosensors for detection of phenolic compounds, Trends in Analytical Chemistry, 74 (2015), 21-45.

Serrano, M., Martínez-Romero, D., Guillén, F., Valero, D., 2003. Effects of exogenous putrescine on improving shelf life of four plum cultivars, Postharvest Biology and Technology, 30, 259-271.

Sogvar, O.B., Saba, M.K., Emamifar, A., 2016. AV and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit, Postharvest Biology and Technology, 114, 29-35.

Sreekumar, S., Sithul, H., Muraleedharan, P., Azeez, J.M., Sreeharshan, S., 2014. Pomegranate fruit as a rich source of biologically active compounds, BioMed Research International, 686921, 1-8.

Valero, D., Martinez R.D., Serrano M., Riquelme F., 1998. Influence of post-harvest treatment with putrescine and calcium on endogenous polyamines, firmness and abscisic acid in lemon (Citrus lemon L. Burn cv. Verna), Jounal of Agriculture Food Chemistry, 46, 2102-2109.

Wang, L., Sang, W., Xu, R., Cao, J., 2020. Alteration of flesh color and enhancement of bioactive substances via the stimulation of anthocyanin biosynthesis in 'Friar' plum fruit by low temperature and the removal, Food Chemistry, 310, 125862.

Xia, H., Shen, Y., Shen, T., Wang, X., Zhang, X., Hu, P., 2020. Melatonin accumulation in sweet cherry and its influence on fruit quality and antioxidant properties, Molecules, 25, 753.

Zafari, E., Mohammadkhani, A., Roohi, V., Fadaei, A., Zafari, H. (2015). Effect of exogenous putrescine and Aloe vera gel coating on post-harvest life of strawberry (*Fragaria ananassa* Duch.) fruit, cultivar Kamarosa. International Journal of Agriculture and Crop Sciences (IJACS), 8(4), 578-584.