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**Research Article**

# Effects of modified atmosphere packaging and putrescine application on postharvest storage and shelf life of 'Rosy Glow' apple cultivar*

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**Abstract:** The current study evaluated the effects of modified atmosphere packaging (MAP) and Putrescine applications on fruit quality during postharvest storage and shelf life of 'Rosy Glow' apple cultivar. Quality parameters, i.e., weight loss, decay rate, total soluble solids content (SSC), titratable acidity (TA), fruit flesh firmness and color changes were investigated during different storage periods. Low levels of weight loss were observed in all applications during the 30th day while losses increased in control treatment after the 60th day (3.58%) and the lowest loss rate (1.27%) was recorded in the MAP + Putrescine application. The MAP + Putrescine group showed the lowest loss rate (2.28%) on the 120th day making it the most effective preservation technique. The decay rate increased during the storage period while MAP and Putrescine applications prevented decay and MAP+Putrescine combination kept the decay rate at the lowest level. The MAP+Putrescine application completely prevented the decay rate on the 120th day. The SSC ratio decreased during the storage period, MAP and Putrescine applications maintained the fruit carbohydrate content better whereas Putrescine application showed the highest SSC value. The TA values generally decreased during the storage, but MAP and Putrescine applications minimized TA loss. The MAP and Putrescine applications better maintained TA during shelf life. The MAP and Putrescine applications better maintained fruit flesh firmness, MAP application provided the highest firmness value on the 120th day. Firmness loss was more pronounced 'n the control group. In all applications, the changes were observed in L*, a*, b* and hue values over time. L* value remained lower in control on the 120th day, but MAP and MAP+Putrescine applications maintained the brightness level of the fruit peel. MAP treatment initially affected the hue angle more. As a result, MAP and Putrescine applications effectively maintained fruit quality in 'Rosy Glow' apple cultivar during storage while MAP+Putrescine combination stood out as the most effective preservation technique.

**Keywords:** Decay rate, fruit flesh firmness, titratable acidity, total soluble solids, weight loss.

## Modifiye atmosfer paketleme ve putresin uygulamalarının 'Rosy Glow' elma çeşidinin hasat sonrası depolama ve raf ömrü üzerine etkileri

**Öz:** 'Rosy Glow' elma çeşidinde hasat sonrası depolama ve raf ömrü süresince Modifiye Atmosfer Paketleme (MAP) ve Putresin uygulamalarının meyve kalitesi üzerine etkileri değerlendirilmiş ve farklı depolama dönemlerinde ağırlık kaybı, çürüme oranı, toplam çözünür kuru madde içeriği (SSC), titre edilebilir asitlik (TA), meyve eti sertliği ve renk değişimleri gibi kalite parametreleri incelenmiştir. Tüm uygulamalarda 30 gün boyunca düşük seviyelerde ağırlık kaybı gözlenirken, 60. günden sonra kontrol grubunda kayıplar artmış (%3,58) ve en düşük kayıp oranı (%1,27) MAP+Putresin uygulamasında kaydedilmiştir. 120. günde, MAP+Putresin grubu en düşük kayıp oranını (%2,28) göstererek en etkili muhafaza tekniği olmuştur. Depolama süresince çürüme oranı artarken, MAP ve Putresin uygulamaları çürümeyi önlemiş ve MAP+Putresin kombinasyonu çürüme oranını en düşük seviyede tutmuştur. 120. günde MAP+Putresin uygulaması çürüme oranını tamamen engellemiştir. SSC oranı depolama süresince azalmış, MAP ve Putresin uygulamaları meyve karbonhidrat içeriğini daha iyi korumuş ve özellikle Putresin uygulaması en yüksek SSC değerini vermiştir. TA değerleri depolama süresince genel olarak azalmış, ancak MAP ve Putresin uygulamaları TA kaybını en aza indirmiştir. Raf ömrü boyunca MAP ve Putresin uygulamaları TA değerini daha iyi korumuştur. MAP ve Putresin uygulamaları meyve eti sertliğini daha iyi korumuş,

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MAP uygulaması 120. günde en yüksek sertlik değerini sağlamıştır. Kontrol grubunda meyve eti sertliğindeki kayıp daha belirgin olmuştur. Tüm uygulamalarda L*, a*, b* ve hue açısı değerlerinde zaman içinde değişimler gözlenmiştir. L* değeri 120. günde kontrol grubunda diğer uygulamalara kıyasla daha düşük kalmıştır, ancak MAP ve MAP+Putresin uygulamaları meyve kabuğunun parlaklık seviyesini daha iyi korumuştur. MAP uygulaması başlangıçta hue açısını daha fazla etkilemiş, ancak zamanla diğer uygulamalarla benzer sonuçlar elde edilmiştir. Sonuç olarak, MAP ve Putresin uygulamaları 'Rosy Glow' elma çeşidinde depolama sırasında meyve kalitesini etkili bir şekilde korurken, MAP+Putresin kombinasyonu en etkili muhafaza tekniği olarak öne çıkmıştır.

**Anahtar kelimeler:** Ağırlık kaybı, çürüme oranı, meyve eti sertliği, titre edilebilir asitlik, toplam çözünebilir kuru madde.

## 1. Introduction

Apple (*Malus domestica* Borkh.) is a fruit species widely produced in the world by adapting to different climatic conditions. Türkiye has an important share in global apple production (Coskun & Askın, 2016; Gunay et al., 2021). The apple production has increased in Türkiye over the years. Similarly, preservation of fruit quality has gained great importance ove these years in the country. Sensitive fruits such as apples can suffer from various deteriorations and quality losses during post-harvest processes. Hence, preventing these losses directly contributes to the trade of the product (El Ghaouth et al., 2004; Sharma et al., 2009; Wani et al., 2022). The quality losses of apples are generally associated with high respiration rate, ethylene production, water loss and spoilage due to microorganisms. In this context, effective preservation methods must be applied to preserve fruit quality.

The use of biological compounds such as MAP and putrescine has become remarkably widespread in recent years for fruit preservation. These compounds slow down the respiration rates of fruits by controlling their environmental conditions and changing the oxygen and carbon dioxide levels of the fruits. These methods have been successful in improving fruit quality and extending shelf life. The MAP protects fruit health and prevents quality losses. Moreover, MAP application exhibits effective results in fruits such as apples. This technology slows down fruit respiration, reduces ethylene production and controls fruit ripening (Ben Yehoshua, 1999; Sisler & Serek, 2003; Kader & Rolle, 2004; Rojas Grau & Martin-Belloso, 2007; Chien & Chien, 2013). Studies have shown that MAP significantly reduces quality losses by extending the shelf life of fruits. For example, Turk and Karaca (2015) reported that MAP applications ensured that apple fruits remained fresh for a longer time by maintaining their color and firmness. In addition, reducing ethylene level with MAP slows down fruit ripening (Ustunel et al., 2008; Kaushal et al., 2020).

Putrescine is an organic compound and a polyamine that plays a significant role in cellular growth, differentiation and aging processes (Erbas et al., 2018). Various studies show that putrescine application increased fruit quality and prevented physiological deterioration during storage. For example, Malik and Singh (2003) reported that putrescine application delay ripening by reducing ethylene production in apple fruits. In addition, Dibble et al. (1988) emphasized that putrescine applications prevented quality losses by slowing down the fruit respiration rate. The 'Rosy Glow' apple attracts attention with its bright pink skin and sweet, crisp texture, and can retain its value for longer time with the right preservation techniques. In this study, the effects of post-harvest applied putrescine (1 mM) and MAP technologies on fruit quality during post-harvest storage and shelf life in 'Rosy Glow' apple cultivar were investigated.

## 2. Materials and Methods

### 2.1. Plant material

The plant materials used in the study included ''Rosy Glow'' apple cultivar grafted onto the 'MM106' rootstock planted in a producer's orchard in Yunuslar town of Kurtalan district of Siirt province. The orchard is located at an altitude of 595 m and between the 370 55' 27' N parallel and 410 21' 17' E meridians. The trees were planted at 4×4 m distance, and a wire training system was established according to the central leader training system. Irrigation is carried out with a drip irrigation system, and other cultural practices such as pruning, fertilizing, and spraying are carried out regularly in the orchard.

### 2.2. Methods

Fruits harvested at commercial maturity were quickly transported to the Siirt University laboratory. Damaged fruits during transportation were sorted and excluded from the evaluation. Fruits selected according to color and size criteria were divided into 4 different groups and treatment applications were initiated. The fruits in the first group were regarded as control, immersed only in pure water and left to dry at room temperature. The dried fruits were placed in plastic bowls and stored in cold storage after weighing. The fruits in the second group were subjected to a pre-cooling process at 1°C for 24 hours to reduce the fruit temperature to 3–4°C. After cooling, the fruits were placed in 5 kg capacity Xtend® MAP packages closed with plastic clips. The packaged fruits were quickly transported to the cold storage. The fruits in the third group were immersed in 1 mM putrescine solution for 10 minutes and then dried on blotting paper for 20 minutes. The fruits in the fourth group were immersed in 1 mM putrescine solution for 10 minutes, dried on blotting paper for 20 minutes, and stored in MAP packages. Control and treated fruits were stored in cold storage at 1°C and 90±5% humidity for ~120 days. Measurements and analyses of fruit quality traits were carried out in Siirt University and Iğdır University laboratories. Apple samples were subjected to physical and chemical analyses at the beginning of storage and on 30$^{th}$, 60$^{th}$, 90$^{th}$ and 120$^{th}$ days. Each application was arranged in 3 replications and 30 fruits were used in replication. A total of 5 fruits were taken from each replication in each tretatment to determine the shelf life of fruits during each analysis period and kept at 20±1$^{o}$C for 5 days. Measurements and analyses were made at the end of 5 days.

2.3. Weight loss (%)

Initial weights (Wi) of the fruit were determined by a digital scale with a precision of 0.01 g (Radwag, Poland) at the beginning of the cold storage. Afterwards, final weights (Wf) were determined on 30$^{th}$, 60$^{th}$, 90$^{th}$ and 120$^{th}$ days of the storage. The weight loss was based on the weight at the beginning of each measurement period and determined as a percentage (%) through the equation given below (Eq.1).

$$WL = \frac{Wi - Wf}{Wi} \times 100 \qquad (1)$$

2.4. Decay rate (%)

Ten (10) fruits were used in each replication and the total number of fruit (TF) was determined before cold storage. The decayed fruits (DF) in each replication were determined during each observation period. The fruits were considered rotten if the development of mycelium was recorded on shell. The Eq .2 was used to compute the decay rate (DR, %).

$$DR = \frac{TF - DF}{TF} \times 100 \qquad (2)$$

2.5. Soluble solids content and titratable acidity (%)

The amount of water-soluble solids (SSC) was determined as % by refractometer and the amount of acidity was determined as malic acid by titration method as % in 10 ml of juice extracted from hawthorn fruit.

2.6. Fruit flesh firmness

The fruit firmness was measured by touching the opposite cheeks of the equatorial part of five fruits with a digital penetrometer (Agrosta 100 field, Agrotechnologie, France) with the 10-point tip of the device perpendicularly (Blankenship at al., 1997).

2.7. Fruit color

L*, a*, b* and hue angle values in fruit peels were determined using a Minolta, CR-400 color measurement device. The color measurement device was calibrated with a white standard plate (Y = 92.40 x = 0.3137 y = 0.3195). Fruit peel and flesh color were determined in 6 fruits from each treatment. Flesh color was measured bidirectionally from the center of the fruit, and flesh color was measured from two lateral parts of the longitudinal section (Sacks & Shaw, 1994; Gunduz & Ozdemir, 2003).

2.8. Statistical analyses

The randomized plot experimental design was established with three replications and 30 fruits in each replication to determine the change that occurred at each observation period. Data were analyzed with variance analysis, the significance level of the differences between the application means was determined with Duncan multiple research test.

## 3. Results and Discussion

3.1. Weight loss (%)

The weight loss rates were low in all applications during the first 30 days with non-significant differences among treatments. However, the differences between treatments increased after the 60$^{th}$ day. The highest weight loss was recorded for control (3.58%), whereas MAP+Putrescine resulted in the lowest (0.69%) weight loss. Likewsie, MAP+Putrescine resulted in the the lowest weight loss (1.27%) on the 90th day, while the loss in control was 3.27%. On the 120th day, MAP+Putrescine treatment resulted in the lowest loss (2.28%), while the loss in control increased to 3.56%.

During shelf life, the differences between the treatments were significant for different storage periods. On the 30+5th day, the highest loss was observed in control (11.15%), while lower losses were observed in the MAP application (8.75%) and the Putrescine application (5.99%). The lowest loss was observed in the MAP+Putrescine application (4.69%). On the 60+5th day, 17.60% loss was observed in control, similar losses were observed in the MAP and Putrescine applications while the lowest loss (3.26%) was recorded in the MAP+Putrescine application. On the 90+5th day, MAP (7.55%) and MAP+Putrescine (4.27%) applications provided lower losses than the control group. MAP+Putrescine application gave the lowest loss with 2.39% on the 120+5th day whereas the loss in control was the highest with 17.14% (Table 1).

**Table 1.** The effect of putrescine and MAP applications on weight loss of 'Rosy Glow' apple cultivar.

| Weight loss (%) | | | | |
|---|---|---|---|---|
| Applications | Storage time (day) | | | |
| | 30 | 60 | 90 | 120 |
| Control | 0.99a | 3.58a | 3.27a | 3.56a |
| MAP | 0.65a | 1.70c | 1.99b | 2.29b |
| Putrescine | 0.81a | 2.03b | 2.15ba | 2.67b |
| MAP+Putrescine | 0.57a | 0.69d | 1.27b | 2.28b |
| | Shelf life (day) | | | |
| Applications | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | 11.15a | 17.60a | 17.36a | 17.14a |
| MAP | 8.75ba | 7.84b | 7.55b | 7.34c |
| Putrescine | 5.99b | 8.01b | 2.79b | 12.61b |
| MAP+Putrescine | 4.69b | 3.26b | 4.27b | 2.39d |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

Weight loss occurs because of evaporation of water in the fruit through transpiration and increases in proportion to the storage period (Kader & Yahia, 2011; Candir et al., 2018; Kucuker et al., 2024). These losses cause significant economic problems for fruit producers (Sandhya, 2010). It is stated that weight loss occurs due to metabolic activities such as transpiration and respiration (Lownds et al., 1993). Applications of polyamines, especially MAP and putrescine, prevent weight loss by slowing down fruit respiration and delaying the degradation of cell walls (Champa et al., 2014; Fawole et al., 2020). MAP, Putrescine and MAP+Putrescine provided lower respiration rate and parallelly less weight loss. Archana and Suresh (2019) reported that putrescine and spermidine applications were effective in reducing weight loss. In addition, Avci (2016) and Ogurlu et al. (2024a) indicated that MAP application reduces weight loss by decreasing respiration rate. These findings show that MAP and putrescine are effective in preserving fruit quality, playing an important role in fruit preservation.

### 3.2. Decay rate (%)

Decay occurs in fruits during the post-harvest storage period, depending on the species and cultivar (Zafari et al., 2015). The decay rates increased as the storage period progressed. The decay rate of 1.33% in control group on the 30th day increased to 2.86% on the 120th day. MAP application resulted in a low decay rate (0.71%) on 30th day, which increased to 1.71% on the 120th day. Putrescine application showed a low decay rate (0.46%) on the 30th day, which increased to 1.52% on the 120th day. Similarly, MAP+Putrescine resulted in 1.55% decay rate on the 120th day. Observations during shelf life showed that no decay occurred in all applications on 30+5th day, while on the 60+5th day, 0.77% decay was observed in the control group, and no decay occurred in the other groups. On the 90+5th day, the decay rate increased to 1.71% in control, while 0.10% decay was observed in MAP+Putrescine application and 0.58% in MAP. On the 120+5th day, 1.77% decay rate was observed in control, 1.16% in MAP application, and no decay was observed in Putrescine and MAP+Putrescine applications. These results show that Putrescine and MAP+Putrescine applications completely prevented decay, while MAP application controlled decay (Table 2).

Polyamines such as putrescine and spermidine, which have anti-pathogenic properties, play a significant role in plant defense mechanisms (Hanif et al., 2020; Kucuker et al., 2023a). Champa et al. (2014) reported that polyamines are conjugated to phenolic compounds and hydroxycinnamic acid amides and that there is a good correlation between the accumulation of hydroxycinnamic acid amides and pathogen resistance. In our study, the decay rate in fruits increased in parallel with the storage period but was lower in treated fruits. Indeed, MAP have been reported to reduce the respiration rate by changing the gas atmosphere in the environment, thus slowing down the decay rate (Ogurlu et al., 2024b). Polyamine applications reduced rotting and cold-induced damage in peach (Zokaee Khosroshahi et al., 2008; Kibar et al., 2021), pomegranate (Barman et al., 2011), apricot (Martinez-Romero, 2006), papaya (Hanif et al., 2020), strawberry (Khosroshahi et al., 2007), mandarin (Ennab et al., 2020) and mango (Jawandha et al., 2012) fruits, and maintained fruit quality during cold storage.

### 3.3. Soluble solids content and titratable acidity

The amount of SSC and TA have a significant effect on the storage period of the fruit. The amount of SSC increases while the titratable acidity decreases as the ripening progresses in the fruit, (Mahto & Das, 2013; Abd El-Gawad et al., 2019; Kucuker et al., 2023b).

The SSC content was at similar levels during harvest in all applications in the current study (i.e., control = 16.2%, MAP = 15.61%, Putrescine = 14.96% and MAP+Putrescine = 16.41%). No significant difference was observed between the treatmentns on 30th and 60th days of storage. On the 90th day, the highest SSC was observed in control (18.96%) while lower values were observed in the Putrescine and MAP applications. Similarly, the lowest SSC value was found in control (14.40%) on 120th day, while MAP (16.41%) and MAP+Putrescine (16.40%) applications showed higher values. These results show that MAP and Putrescine better maintained carbohydrate content of the fruits. Observations made during the shelf life also yielded similar results. On the 30+5th day, higher SSC values were recorded with MAP and Putrescine, while a significant decrease was observed in these applications on the 60+5th day. On the 90+5th day, SSC values were close to each other in MAP and Putrescine applications, but this value decreased significantly in control. On the 120+5th day, the highest SSC value (10.65%) was obtained with Putrescine application. The lowest value was recorded in the control group with 7.80%. This reveals that Putrescine application best preserves the carbohydrate content of the fruits (Table 3).

**Table 2.** The effect of putrescine and MAP applications on decay rate of 'Rosy Glow' apple cultivar.

| Decay rate (%) | | | | |
|---|---|---|---|---|
| Applications | Storage time (day) | | | |
| | 30 | 60 | 90 | 120 |
| Control | 1.33a | 2.55a | 2.77a | 2.86a |
| MAP | 0.71a | 1.21b | 1.26b | 1.71b |
| Putrescine | 0.46a | 0.55b | 1.11b | 1.52b |
| MAP+Putrescine | 0.58a | 1.07b | 1.28b | 1.55b |
| | Shelf life (day) | | | |
| Applications | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | 0.00a | 0.77a | 1.71a | 1.77a |
| MAP | 0.00a | 0.00b | 0.58b | 1.16b |
| Putrescine | 0.00a | 0.00b | 0.00c | 0.00c |
| MAP+Putrescine | 0.00a | 0.00b | 0.10c | 0.12c |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

**Table 3.** The effect of putrescine and MAP applications on total soluble solids of 'Rosy Glow' apple cultivar.

| Soluble solids content (%) | | | | | |
|---|---|---|---|---|---|
| Applications | Storage time (day) | | | | |
| | Harvest | 30 | 60 | 90 | 120 |
| Control | 16.2 | 16.38a | 16.96a | 18.96a | 14.40b |
| MAP | | 15.61a | 16.45a | 17.34b | 16.41a |
| Putrescine | | 14.96a | 15.67a | 15.77c | 16.37a |
| MAP+Putrescine | | 16.41a | 15.73a | 15.80c | 1640a |
| | Shelf life (day) | | | | |
| Applications | | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | 16.2 | 10.33a | 14.36b | 8.50b | 7.80b |
| MAP | | 17.57a | 17.99a | 10.76a | 10.37a |
| Putrescine | | 15.60a | 18.93a | 10.57a | 10.65a |
| MAP+Putrescine | | 14.73a | 16.93ba | 10.87a | 10.60a |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

The TA content was at different levels in all applications at the time of harvest (i.e., control = 1.45%, MAP = 0.85%, Putrescine = 0.83%, and MAP+Putrescine = 0.86%). On the 30th day, a decrease in TA values was observed in all applications but decreased faster (0.77%) in the control group. A similar trend continued on 60th day, with control showing the lowest value at 0.70%, while the other applications had higher TA contents. On the 90th day, the highest TA value of 0.80% was recorded in MAP, while control showed the lowest value of 0.66%. On the 120th day, MAP and MAP+Putrescine applications had the highest TA values, while the lowest TA value (0.64%) was recorded for control group. A similar trend was observed throughout the shelf life. On the 30+5th day, TA values were 0.92%, 0.86% and 0.84% in MAP, Putrescine and MAP+Putrescine applications, respectively while the lowest value was recorded in control at 0.66%. On the 60+5th day, higher TA values were observed in MAP (0.80%) and Putrescine (0.65%) applications. On the 90+5th day, TA values remained higher with small differences between MAP and Putrescine applications. On the 120+5th day, MAP and Putrescine applications had the highest TA values, but control showed the lowest value (0.38%). This reveals that MAP and Putrescine applications preserved TA better (Table 4).

**Table 4.** The effect of putrescine and MAP applications on titratable acidity of 'Rosy Glow' apple cultivar.

| Titratable acidity (%) | | | | | |
|---|---|---|---|---|---|
| Applications | Storage time (day) | | | | |
| | Harvest | 30 | 60 | 90 | 120 |
| Control | 1.45 | 0.77b | 0.70b | 0.66c | 0.64b |
| MAP | | 0.85a | 0.84a | 0.80a | 0.78a |
| Putrescine | | 0.83a | 0.82a | 0.72b | 0.74a |
| MAP+Putrescine | | 0.86a | 0.85a | 0.73b | 0.75a |
| | Shelf life (day) | | | | |
| Applications | | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | 1.45 | 0.66b | 0.65b | 0.49b | 0.38c |
| MAP | | 0.93a | 0.92a | 0.80a | 0.75a |
| Putrescine | | 0.87a | 0.86a | 0.65a | 0.70a |
| MAP+Putrescine | | 0.88a | 0.84a | 0.76a | 0.65b |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

Indeed, it has been reported that different polyamine applications delay ripening and therefore slow down postharvest SSC and TA changes (Serrano et al., 2003; Jongsri et al., 2017). Our findings are consistent with findings indicating that post-harvest putrescine applications slow down the changes in sap and stone content in plum (Serrano et al., 2003), peach (Abbasi et al., 2019; Kaur & Kaur, 2019; Kibar et al., 2021) and papaya (Hanif et al., 2020) fruits. Similarly, Khan et al. (2013) reported that post-harvest MAP applications preserved the SSC content in plum fruits. Ozturk and Aglar (2019) suggested that MAP-applied fruits in cornelian cherry had higher TA content.

### 3.4. Fruit flesh firmness

Fruit flesh firmness is one of the important quality parameters in apples (Song et al., 2013). As the fruit ripens, the fruit flesh firmness decreases because of the breakdown of cell wall components such as pectin substances, hemicellulose and cellulose and the decrease in turgor pressure within the cell (Mannozzi et al., 2018; Kucuker et al., 2023a). Fruit flesh firmness has an important effect on marketing and post-harvest processes in fruits, and it decreases with the progression of ripening. It is known that softening in fruits occurs because of weight loss and cell wall breakdown by enzymes such as polygalacturonase and pectinesterase (Martinez-Ferrer et al., 2002), and the main reason for weight loss and fruit flesh softening is transpiration due to the water pressure gradient between the fruit tissues and the surrounding atmosphere (Ozturk, 2012). Similar fruit flesh firmness was observed with all applications at harvest in the current study (i.e., control = 8.63%, MAP = 8.56%, Putrescine = 8.41%, and MAP+Putrescine = 8.60%). Softening was observed in fruits with all applications on the 30th day, but the highest firmness (8.60 kg) was determined in the MAP+Putrescine applications. On the 60th day, fruit firmness decreased in all applications and the lowest value (8.10 kg) was recorded with control. On the 90th day, 7.75 kg fruit flesh firmness values were measured in MAP application, 8.11 kg in Putrescine application and 8.13 kg in MAP+Putrescine application. It was determined that the firmness was lower in control fruits (7.96 kg). On the 120th day, the lowest firmness value was measured in control with 7.56 kg, while higher fruit firmness was noted in other applications. Regarding shelf life, MAP application maintained the highest hardness value (8.48 kg) on 30+5th day, while the firmness decreased more rapidly in the control group (6.91 kg). Similarly, MAP application resulted in the highest firmness value (8.34 kg) on all observation periods. This shows that MAP application maintained fruit firmness compared to the other treatments (Table 5).

MAP is an effective method for reducing weight loss and fruit softening during cold storage of various fruits and vegetables (Cantin et al., 2008; Guillen et al., 2013; Khan et al., 2013). Polyamines delay ripening by changing the stability of the cell wall in the fruit, and contribute to the protection of fruit flesh (Kucuker et al., 2023a). Putrescine application preserved fruit flesh firmness in fruit species such as plum (Serrano et al., 2003; Khan et al., 2008) and peach (Kaur et al., 2019; Kibar et al., 2021).

**Table 5.** The effect of putrescine and MAP applications on fruit flesh firmness of 'Rosy Glow' apple cultivar.

| Fruit flesh firmness (kg) | | | | | |
|---|---|---|---|---|---|
| Applications | Storage time (day) | | | | |
| | Harvest | 30 | 60 | 90 | 120 |
| Control | 8.63 | 8.16b | 8.10b | 7.96b | 7.56b |
| MAP | | 8.56a | 8.37a | 8.04a | 7.75ab |
| Putrescine | | 8.41a | 8.35a | 8.20a | 8.11a |
| MAP+Putrescine | | 8.60a | 8.59a | 8.25a | 813a |
| | Shelf life (day) | | | | |
| Applications | | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | 8.63 | 6.91b | 5.54b | 4.47b | 4.53b |
| MAP | | 8.56a | 8.48a | 8.34a | 7.56a |
| Putrescine | | 8.40a | 8.10a | 7.65a | 7.51a |
| MAP+Putrescine | | 8.57a | 7.96a | 7.34a | 7.28a |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

3.5. Fruit color

Fruit color is an observable maturity criterion in many fruit species and is an important quality trait that affects consumer preferences. The color changes occur in the fruit with post-harvest ripening and it is very important to reduce these changes. Similar L* values were observed in all applications at the time of harvest. The L* values increased in all applications on 30th day wşth the highest values recorded for MAP and Putrescine. Control and MAP+Putrescine had the highest L* values on 60th day, while the highest L* value was noted for control on 120th day. The a* value was at similar levels in all applications at harvest, and changes were observed in different applications on the 30th day. On the 120th day, MAP+Putrescine application showed low a* value. The b* value increased in all groups from day 30 days to onwards and the significant increase was observed for MAP. Although there were differences among treatments for hue, similar changes occurred in all treatments over time. Shelf life data indicated that the L* value of control was lower. MAP, Putrescine and MAP+Putrescine applications preserved the light level of the fruit peel better. In a* value, control had lower values on the 90+5th and 120+5th days while the MAP+Putrescine application showed the highest a* value. In the b* value, the Putrescine application showed the highest value on 30+5th day. In terms of hue, the MAP application initially showed higher values, but over time the differences between all applications decreased. These findings show that the MAP application affected the color tone more in the initial stages, but the other applications provided similar effects over time (Table 6). Similarly, Ozturk et al. (2021) reported that physiological and biochemical changes in MAP-applied medlar fruits were less during storage and fruit color was preserved. Cantin et al. (2008) suggested that color changes were lower with MAP application in Japanese plums. Martínez-Romero (2006) reported that putrescine reduced color changes in fruits in a study in which they treated apricot fruits harvested at commercial maturity with 1 mM putrescine and stored at 10 °C for 6 days, while Valero et al. (1998) found that lemon fruits treated with putrescine preserved their color index during storage. Gain, Martinez-Romero et al. (2002) stated that color change was lower in apricot fruits treated with putrescine.

**Table 6.** The effect of putrescine and MAP applications on fruit color of 'Rosy Glow' apple cultivar.

| Fruit color | | | | | | |
|---|---|---|---|---|---|---|
| Applications | | Storage Time (day) | | | | |
| | | Harvest | 30 | 60 | 90 | 120 |
| Control | L* | 55.61 | 58.40a | 59.27a | 54.67a | 63.08a |
| MAP | | | 50.31a | 61.50a | 56.45a | 55.65a |
| Putrescine | | | 54.78a | 53.24a | 61.75a | 59.84a |
| MAP+Putrescine | | | 54.08a | 61.86a | 57.50a | 60.94a |
| Control | a | 18.22 | 22.52a | 22.01a | 27.44a | 23.01a |
| MAP | | | 26.04a | 16.63a | 33.29a | 22.98a |
| Putrescine | | | 32.38a | 30.59a | 19.76a | 22.41a |
| MAP+Putrescine | | | 26.97a | 21.05a | 26.87a | 21.39a |
| Control | b | 31.55 | 34.37a | 35.00a | 34.40a | 36.96a |
| MAP | | | 31.93a | 42.05a | 41.66a | 43.22a |
| Putrescine | | | 31.71a | 33.84a | 42.14a | 42.90a |
| MAP+Putrescine | | | 26.97a | 37.83a | 36.02a | 40.56a |
| Control | hue angle | 58.14 | 56.67a | 55.77a | 57.33a | 56.60a |
| MAP | | | 52.06a | 67.77a | 59.15a | 61.20a |
| Putrescine | | | 65.09a | 48.13a | 65.02a | 62.11a |
| MAP+Putrescine | | | 48.70a | 61.00a | 55.21a | 63.06a |
| | | | Shelf life (day) | | | |
| Applications | | | 30+5 | 60+5 | 90+5 | 120+5 |
| Control | L* | 55.61 | 79.34a | 55.94b | 46.37b | 52.66b |
| MAP | | | 83.61a | 80.10a | 80.85a | 78.88a |
| Putrescine | | | 82.70a | 80.82a | 80.93a | 67.85a |
| MAP+Putrescine | | | 80.14a | 78.23a | 80.66a | 80.09a |
| Control | a | 18.22 | 4.05a | 3.65a | 2.81b | 3.59b |
| MAP | | | 4.28a | 3.91a | 5.68a | 5.65ba |
| Putrescine | | | 4.20a | 4.77a | 4.69ba | 5.37ba |
| MAP+Putrescine | | | 4.33a | 5.99a | 6.35a | 7.24a |
| Control | b | 31.55 | 31.77c | 37.81a | 26.60a | 25.73a |
| MAP | | | 34.83b | 39.51a | 39.85a | 35.53a |
| Putrescine | | | 37.63a | 37.92a | 39.07a | 42.28a |
| MAP+Putrescine | | | 31.52c | 27.41a | 42.65a | 37.32a |
| Control | hue angle | 58.14 | 82.42b | 81.20a | 50.90a | 48.79a |
| MAP | | | 87.84a | 85.06a | 81.04a | 78.13a |
| Putrescine | | | 81.15b | 82.94a | 81.70a | 69.21a |
| MAP+Putrescine | | | 81.87b | 84.60a | 81.64a | 81.40a |

* Means in columns with the same lower case do not differ according to Duncan' s test at P<0.05.

## 4. Conclusion

Different treatments applied to 'Rosy Glow' apples had significant effects on weight loss rates. MAP+Putrescine combination provided the lowest weight loss and preserved apple quality for a longer period. This combination gave particularly superior results after the 60th day and lower losses. MAP+Putrescine application is an effective solution for preserving apple quality during storage. Shelf life data indicated that the same combination prevent decay and maintained the fruit quality, providing the lowest losses compared to other applications. The preservation of fruit quality was not limited to weight loss only, but also had visible effects on decay rates, soluble solids content, titretable acidity, flesh firmness and color changes. MAP and Putrescine applications preserved fruit firmness and kept acidity in the fruit under control. The MAP+Putresin combination resulted in the lowest decay rates and highest firmness values. In addition, these applications minimized fruit color changes and preserved their aesthetic quality for a longer time. As a result, MAP and Putrescine applications stand out as methods that effectively preserve fruit quality. Especially the MAP+Putrescine combination provides the most efficient results in apple storage.

## Conflict of interest

The authors declare no conflicts of interest.

## Authorship contribution statement

S.K: Investigation, writing – original draft, writing – review and editing. E.K: Formal analysis, data curation, investigation, writing – original draft. E.A: Formal analysis, visualization, writing –original draft. S.D: Writing – original draft.

## References

Abbasi, N. A., Ali, I., Hafiz, I. A., Alenazi, M. M., & Shafiq, M. (2019). Effects of Putrescine Application on Peach Fruit during Storage. *Sustainability*, *11*(7), 2013. https://doi.org/10.3390/su11072013

Abd El-Gawad, M. G., Zaki, Z. A., & Ekbal, Z. A. (2019). Effect of some postharvest treatments on quality of 'Alphonse' mango fruits during cold storage. *Middle East Journal of Agriculture Research*, 8(4), 1067–1079. https://doi.org/10.36632/mejar/2019.8.4.9

Archana, T. J., & Suresh, G. J. (2019). Putrescine and spermine affects the postharvest storage potential of banana cv. Grand Naine. *International Journal of Current Microbiology and Applied Sciences*, 8 (1), 3127–3137.

Avcı, V. (2016). Japon Grubu (*Prunus salicina* L.) *Black Amber Erik Çeşidinin Muhafaza Performansının Belirlenmesi* [Yüksek Lisans Tezi, Ordu Üniversitesi Fen Bilimleri Enstitüsü]. Ordu Üniversitesi. http://earsiv.odu.edu.tr:8080/xmlui/handle/11489/918

Barman, K., Asrey, R., & Pal, R. K. (2011). Putrescine and carnauba wax pretreatments alleviate chilling injury, enhance shelf life and preserve pomegranate fruit quality during cold storage. *Scientia Horticulturae,* 130, 795-800. https://doi.org/10.1016/j.scienta.2011.09.005

Ben-Yehoshua, S. (1999). Effect of modified atmosphere and controlled atmosphere on postharvest physiology and quality of fresh fruits. *Postharvest Biology and Technology*, 15(3), 221-228. https://doi.org/10.1016/S0925-5214(98)00073-3

Blankenship, S. M., Parker, M., & Unrath, C. R. (1997). Use of maturity indices for predicting poststorage firmness of Fuji apples. *HortScience*, 32 (5), 909-910. https://doi.org/10.21273/HORTSCI.32.5.909

Candir, E., Özdemir, A. E., & Aksoy, M. C. (2018). Effects of chitosan coating and modified atmosphere packaging on postharvest quality and bioactive compounds of pomegranate fruit cv. 'Hicaznar'. *Scientia Horticulturae,* 235, 235-243. https://doi.org/10.1016/j.scienta.2018.03.017

Cantín, 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. *HortTechnology hortte*, *18*(2), 261-265. https://doi.org/10.21273/HORTTECH.18.2.261

Champa, W. A. H., Gill, M. I. S., Mahajan, B. V. C., & Arora, N. K. (2014). Postharvest treatment of polyamines maintains quality and extends shelf-life of table grapes (*Vitis vinifera* L.*)* cv. flame seedless. *Postharvest Biology and Technology*, 91, 57-63. https://doi.org/10.1016/j.postharvbio.2013.12.014

Chien, S. H., & Chien, C. S. (2013). Effects of putrescine on the shelf life and quality of harvested fruits. *International Journal of Postharvest Technology and Innovation*, 3(1), 34-47. https://doi.org/10.1504/IJPTI.2013.052315

Coskun, S., & Askın, M. A. (2016). Bazı yerli elma çeşitlerinin pomolojik ve biyokimyasal özelliklerinin belirlenmesi. *Ziraat Fakültesi Dergisi*, 11 (1), 120 131.

Dibble, A. R. G., Davies, P. J., & Mutschler, M. A. (1988). Polyamine content of longkeeping Alcobaca tomato fruit. *Plant Physiology*, 86(2), 338-340. https://doi.org/10.1104/pp.86.2.338

El Ghaouth, A., Wilson C., & Wisniewski M. (2004). Biologically-based alternatives to synthetic fungicides for the control of postharvest diseases of fruit and vegetables. *Diseases of Fruits and Vegetables*, 511-535. https://doi.org/10.1007/1-4020-2607-2_14

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. https://doi.org/10.3390/agronomy10010115

Erbas, D., Koyuncu, M. A., Ozusoy, F., & Onursal, C. E. (2018). Derim öncesi putresin uygulamasının 0900 Ziraat kiraz çeşidinin meyve kalitesi üzerine etkileri. *Akademik Ziraat Dergisi,* 7(2), 151-156. https://doi.org/10.29278/azd.476202

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 and Human Wellness*, *9*(2), 146–161. https://doi.org/10.1016/J.FSHW.2020.02.007

Guillen, F., Diaz-Mula, H. M., Zapata, P. J., Valero, D., Serrano, M., Castillo, S., & Martinez- Romero, D. (2013). Aloe arborescens and Aloe vera gels as coatings in delaying postharvest ripening in peach and plum fruit. *Postharvest Biology and Technology,* 83, 54-57. https://doi.org/10.1016/j.postharvbio.2013.03.011

Gunay, M., Karaca, H., & Kaya, A. (2021). Türkiye'de Elma Üretimi ve Ticaretinin Ekonomik Analizi. *Tarım Ekonomisi Araştırmaları Dergisi*, 35(4), 112-123.

Gunduz, K. & Ozdemir, E. (2003). Amik ovasında yüksek tünel ve açıkta yetiştirilen çileklerde renklenmenin objektif yöntemle belirlenmesi. *Türkiye IV. Ulusal Bahçe Bitkileri Kongresi*, 08-12 Eylül, 120-122, Antalya.

Hanif, A., Ahmad, S., Jaskani, M. J., & Ahmad, R. (2020). Papaya treatment with putrescine maintained the overall quality and promoted the antioxidative enzyme activities of the stored fruit. *Scientia Horticulturae*, 268, 109-367. https://doi.org/10.1016/j.scienta.2020.109367

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. https://doi.org/10.5897/AJAR12.1425

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. https://doi.org/10.1016/j.scienta.2017.06.011

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

Kader, A. A., & Rolle, R. S. (2004). Modified atmosphere packaging and its effects on the quality of fresh fruits and vegetables. *Postharvest Biology and Technology*, 32(2), 123-142. https://doi.org/10.1016/j.postharvbio.2004.01.005

Kaur, M. & Kaur, A. (2019). Improvement in storability and quality of peach cv. Flordaprince with post-harvest application of various chemicals. *Journal of Pharmacognosy and Phytochemistry,* 8(1): 460-464.

Kaushal, M., Sharma, A., & Kaur, C. (2020). Effect of Modified Atmosphere Packaging on the Storage Quality of Apples. *Postharvest Biology and Technology*. 173, 1-8.

Khan, A. S., Singh, Z., Abbasi, N. A., & Swinny, E. E. (2008). Pre-or post-harvest applications of putrescine and low temperature storage affect fruit ripening and quality of "*Angelino*" plum. *Journal of Science Food Agriculture,* 88(10): 1686 1695. https://doi.org/10.1002/jsfa.3265

Khan, M. S., Zeb, A., Rahatullah, K., Ahmed, I. N., & Ahmed, S. (2013). Storage life extension of plum fruit with different colored packaging and storage temperatures. *IOSR Journal of Environmental Science Toxicology and Food Technology*, 7(3), 86-93. https://doi.org/10.9790/2402-0738693

Khosroshahi, M. R. Z., & Esna-Ashari, M. (2007). Post-harvest putrescine treatments extend the storage-life of apricot (*Prunus armeniaca* L.*)* 'Tokhm-sefid' fruit. *The Journal of Horticultural Science Biotechnology*, 82 (6), 986-990. https://doi.org/10.1080/14620316.2007.11512337

Kibar, H., Tas, A., & Gundogdu, M. (2021). Evaluation of biochemical changes and quality in peach fruit: effect of putrescine treatments and storage. *Journal of Food Composition and Analysis*, (102), 04048, 3-16. https://doi.org/10.1016/j.jfca.2021.104048

Kucuker, E., Aglar, E., Sakaldas, M., Sen, F., & Gundogdu, M. (2023a). Impact of postharvest putrescine treatments on phenolic compounds, antioxidant capacity, organic acid contents and some quality characteristics of fresh fig fruits during cold storage. *Plants (Basel, Switzerland)*, 12(6), 1291. https://doi.org/10.3390/plants12061291

Kucuker, E., Aglar, E., Gundogdu, M., Tekin, O., Ogurlu, F., & Kizgin Ozcengiz, C. (2023b). New approaches in fig preservation: use of melatonin to maintain postharvest quality of fig (*Ficus carica L.*) Fruit during cold storage. *Erwerbs-Obstbau*, *65*(6), 2585-2595. https://doi.org/10.1007/s10341-023-00958-w

Kucuker, E., Kuru Berk, S., Melda Colak, A., & Gundogdu, M. (2024). Melatonin use in post-harvest fruit physiology: effect of melatonin treatments on quality properties, primer and seconder metabolites contents of hawthorn fruit during cold storage. *Journal of Plant Growth Regulation*, 1-14. https://doi.org/10.1007/s00344-024-11522-5

Lownds, N. K., Banaras, M., & Bosland, P. W. (1993). Relationships between postharvest water loss and physical properties of pepper fruit (*Capsicum annuum* L.). *Hort Science*, 28(12), 1182-1184. https://doi.org/10.21273/HORTSCI.28.12.1182.

Mahto, R. & 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. https://doi.org/10.1016/j.postharvbio.2013.07.018.

Malik, A. U., & Singh, Z. (2003). Abscission of mango fruitlets as influenced by biosynthesis of polyamines. *The Journal of Horticultural Science and Biotechnology*, 78(5), 721–727. https://doi.org/10.1080/14620316.2003.11511689

Mannozzi, C., Tylewicz, U., Chinnici, F., Siroli, L., Rocculi, P., Rosa, M. D., & Romani, S. (2018). Effects of chitosan based coatings enriched with procyanidin byproduct on quality of fresh blueberries during storage. *Food Chemistry,* 251, 18-24. https://doi.org/10.1016/j.foodchem.2018.01.015

Martinez-Ferrer M., Harper, C., Perex-Munnoz M., & Chaparro M. (2002). Modified atmosphere packaging of minimally processed mango and pineapple fruits. *Journal of Food Science,* 67, 3365–3371. https://doi.org/10.1111/j.1365-2621.2002.tb09592.x

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. https://doi.org/10.1016/j.postharvbio.2005.09.006

Ogurlu, F., Kucuker, E., Aglar, E., Kizgin Ozcengiz, C., & Uyak, C. (2024a). New approaches in pear preservation: Putrescine and modified atmosphere packaging applications to maintain fruit quality during cold storage. *Food Science & Nutrition*, 12(9), 6627-6636. https://doi.org/10.1002/fsn3.4290

Ogurlu, F., Kucuker, E., & Aglar, E. (2024b). Effects of *Aloe vera* and modified atmosphere packaging on the quality and biochemical properties of pear fruit during cold storage. *Applied Fruit Science*, *66*(3), 823-832. https://doi.org/10.1007/s10341-024-01070-3

Ozturk, B., & Aglar, E. (2019). Effects of modified atmosphere packaging (MAP) and AV treatments on quality characteristics of cornelian cherry fruits during cold storage. *Akademik Ziraat Dergisi,* 8(1), 1-8. https://doi.org/10.29278/azd.592897

Ozturk, B., Yildiz, M., Yildiz, K., & Gun, S. (2021). Maintaining the postharvest quality and bioactive compounds of jujube (*Ziziphus jujuba* Mill. Cv. 'Li'*)* fruit by applying 1-methylcyclopropene*. Scientia Horticulturae,* 275, 109671. https://doi.org/10.1016/j.scienta.2020.109671

Ozturk B. (2012). *Jonagold elma çeşidinde aminoethoksivinilglisinin (AVG) hasat önü dökümüne, 'Braeburn' elma çeşidinde metil jasmonatın (MEJA) renklenme üzerine etkileri.* [Doktora Tezi, Gazosmanpaşa Üniversitesi Fen Bilimleri Enstitüsü] Ulusal Tez Merkezi.

https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=fXtWHf0EQsxy_1KKq6OTsw&no=X-ydWv7C6v7w6vL78DfV0g

Rojas-Graü, M. A., & Martín-Belloso, O. (2007). Effects of modified atmosphere packaging on the quality of fresh fruits and vegetables. *Food Research International*, 40(3), 263-271. https://doi.org/10.1016/j.foodres.2006.11.003

Sacks, E. J. & Shaw, D. V. (1994). Optimum allocation of objective color measurements for evaluating fresh strawberries. *Journal of the American Society for Horticultural Science jashs*, 119(2), 330-334. https://doi.org/10.21273/JASHS.119.2.330

Sandhya, S. (2010). Modified atmosphere packaging of fresh produce: current status and future needs. *LWT-Food Science Technology,* 43, 381-392. https://doi.org/10.1016/j.lwt.2009.05.018

Serrano, M., Martínez-Romero, D., Guillen, F., & Valero, D. (2003). Effects of exogenous putrescine on improving shelf life of four plum cultivars. *Postharvest Biology and Technology,* 30, 259-271. https://doi.org/10.1016/S0925-5214(03)00113-3

Sharma, R., Singh, D., & Singh, R. (2009). Biological control of postharvest diseases o fruits and vegetables by microbial antagonists: a review. *Biological Control*, 50(3), 205-221. https://doi.org/10.1016/j.biocontrol.2009.05.001

Sisler, E. C., & Serek, M. (2003). Putrescine and other polyamines in the regulation of fruit ripening. *HortScience*, 38(3), 589-593. https://doi.org/10.21273/HORTSCI.38.3.589

Song, H. Y., Jo, W. S., Song, N. B., Min, S. C., & Song, K. B. (2013). Quality change of apple slices coated with Aloe vera gel during storage. *Journal of Food Science*, 78(6), C817-C822. https://doi.org/10.1111/1750-3841.12141

Turk, R. & Karaca, H. (2015). Ülkemizde taze ürün depolayan soğuk muhafaza tesislerinde teknik ve ekonomik nitelikler. *12. Ulusal Tesisat Mühendisliği Sempozyumu Bildiriler Kitabı*, Makine Mühendisleri Odası Yayını, Ankara, ss.777-795.

Ustunel, M. A., Esturk, O. & Ayhan, Z. (2008). MAP'nin kirazın fiziksel özelliklerine (Renk ve Tekstür) etkisi. *Türkiye 10. Gıda Kongresi*, Erzurum, 241-244.

Valero, D., Martinez-Romero, 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. Burm cv. Verna). *Jounal of Agriculture Food Chemistry*, 46 (6): 2102-2109. https://doi.org/10.1021/jf970866x

Wani, S. H., Khan, M. S., & Tufail, M. (2022). Postharvest Management of Apples: New Approaches to Reduce Quality Losses. *Horticultural Science*, 57(3), 157-165.

Zokaee Khosroshahi, M. R., & Esna-Ashari, M. (2007). Post-harvest putrescine treatments extend the storage-life of apricot (*Prunus armeniaca* L.) 'Tokhm-sefid' fruit. *The Journal of Horticultural Science and Biotechnology*, 82(6), 986–990. https://doi.org/10.1080/14620316.2007.11512337