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Research Article

Effects of Different Postharvest Treatments on Storability and Fruit Quality of 'Angeleno' Plum

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ABSTRACT

This study investigated the effects of different postharvest treatments on the storage performance and fruit quality of 'Angeleno' plum (*Prunus salicina* L.). Fruits were harvested at commercial maturity in 2025 from a commercial orchard located in Umurbey, Lapseki district, Çanakkale province, Türkiye. After harvest, Siega Fresh® Finish and Siega Fresh® Citrus treatments were applied, and the fruits were stored under modified atmosphere packaging (MAP) conditions at 1 °C and 85–95% relative humidity. The storage period was 120 days for Siega Fresh® Finish and 90 days for Siega Fresh® Citrus, and fruit quality parameters were evaluated at regular intervals. During storage, fruit respiration caused changes in the internal atmosphere composition of MAP packages; oxygen concentration decreased from 20.8% to 10.1%, while carbon dioxide concentration increased from 0.04% to 7.5%. Weight loss gradually increased during storage, reaching 5.94% at 120 days and 7.18% after a three-day shelf-life period. Decay incidence also increased, reaching 11.2% at the end of storage. During storage, the L^* value decreased while the a^* value increased, soluble solids content increased, titratable acidity decreased, and pH showed a slight increase. The results indicate that Siega Fresh® treatments combined with MAP storage contributed to maintaining fruit quality and extending the storage life of 'Angeleno' plum.

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Farklı Hasat Sonrası Uygulamaların 'Angeleno' Erik Meyvelerinin Depolanabilirliği ve Meyve Kalitesi Üzerine Etkileri

ÖZET

Bu çalışmada, farklı hasat sonrası uygulamaların 'Angeleno' erik (*Prunus salicina* L.) çeşidinin depolama performansı ve meyve kalite özellikleri üzerine etkileri araştırılmıştır. Meyveler 2025 yılında Çanakkale ili Lapseki ilçesi Umurbey yöresinde bulunan ticari bir bahçeden ticari olgunluk döneminde hasat edilmiştir. Hasat sonrası Siega Fresh® Finish ve Siega Fresh® Citrus uygulamaları yapılmış ve meyveler modifiye atmosfer paketleme (MAP) koşullarında 1 °C sıcaklık ve %85–95 bağıl nemde depolanmıştır. Depolama süresi Siega Fresh® Finish için 120 gün, Siega Fresh® Citrus için ise 90 gün olarak belirlenmiş ve kalite parametreleri düzenli aralıklarla değerlendirilmiştir. Depolama süresince meyve solunumu nedeniyle MAP paketlerinin iç atmosferinde değişimler meydana gelmiş; oksijen oranı %20.8'den %10.1'e düşerken karbondioksit oranı %0.04'ten %7.5'e yükselmiştir. Depolama süresi ilerledikçe ağırlık kaybı artmış ve 120. günde %5.94'e ulaşmış, üç günlük raf ömrü sonunda %7.18 olarak belirlenmiştir. Çürüme oranı depolama sonunda %11.2'ye ulaşmıştır. Depolama sürecinde L^* değeri azalırken a^* değeri artmış, çözünür kuru madde yükselmiş, titre edilebilir asitlik azalmış ve pH değerinde hafif artış görülmüştür. Sonuçlar, Siega Fresh® uygulamalarının MAP depolama ile birlikte meyve kalitesinin korunmasına ve depolama süresinin uzatılmasına katkı sağladığını göstermektedir.

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INTRODUCTION

Plum (*Prunus salicina* L.) is one of the economically important stone fruit species belonging to the *Rosaceae* family and is widely cultivated worldwide (Ekemen and Serce, 2023; Say et al., 2025; Martínez-Gómez et al., 2026). Due to its suitability for fresh consumption, drying, and the production of various processed products, plum cultivation holds considerable economic importance in many countries. The majority of global plum production is concentrated in China, European countries, and the United States, while Türkiye also ranks among the important producing countries (FAO, 2023). In Türkiye, plum production can be carried out under diverse ecological conditions and is mainly concentrated in the Marmara, Aegean, and Mediterranean regions (Karamürsel et al., 2016).

Plum fruits are rich in phenolic compounds, flavonoids, vitamins, and anthocyanins and exhibit high antioxidant capacity. These compounds possess important biological activities beneficial to human health and may contribute to the prevention of cardiovascular diseases and certain chronic disorders due to their antioxidant properties (Deveci et al., 2023; Adilova et al., 2025). In particular, dark-colored plum cultivars have been reported to contain higher levels of anthocyanins and phenolic compounds, which significantly contribute to the nutritional value of the fruit (Abacı et al., 2014). The cultivar 'Angeleno', widely used in commercial production, is a late-maturing plum cultivar preferred in international markets due to its high yield potential, large fruit size, and good storage performance (Baysal and Yıldız, 2025). Nevertheless, plum fruits are highly susceptible to quality deterioration during the postharvest period. Water loss, fruit softening, color changes, and pathogen-induced decay during storage represent the major factors limiting the marketability of plum fruits (Kibar et al., 2024). Storage temperature, relative humidity, packaging systems, and postharvest treatments play crucial roles in maintaining fruit quality during storage. Postharvest treatments may limit pathogen development on the fruit surface and reduce physiological losses occurring during storage (Okcu et al., 2018). Commercial postharvest preparations are commonly used in combination with cold storage and modified atmosphere packaging to reduce postharvest losses and maintain fruit quality. For instance, Şen et al. (2022) reported that Siega Fresh® Finish and Siega Fresh® Citrus applications reduced decay development during storage of organically grown 'Hicaznar' pomegranate fruit, particularly when Siega Fresh® Finish and 6 L ton^{-1} Siega Fresh® Citrus were used. These preparations may help limit water loss, delay quality deterioration, and suppress decay development during storage, depending on the fruit species, cultivar, application method, and storage conditions. Therefore, the evaluation of commercial postharvest preparations such as Siega Fresh® Finish and Siega Fresh® Citrus is important for determining their potential contribution to maintaining fruit quality and extending the storage life of 'Angeleno' plum.

In addition, modified atmosphere packaging systems create a suitable gaseous environment around the fruit, thereby reducing respiration rate and contributing to the extension of storage life (Caleb et al., 2013). Some postharvest treatments used during storage are reported to form a protective layer on the fruit surface, reducing water loss and suppressing pathogen development. These treatments are considered important preservation strategies for maintaining quality attributes and reducing decay incidence during storage (Crisosto, 2025; Wu et al., 2025). However, the effectiveness of postharvest treatments may vary depending on fruit species, cultivar characteristics, and storage conditions. When studies on the storability of plum fruits are examined, it is observed that investigations evaluating the effects of postharvest treatments on fruit quality and storage performance are relatively limited. In particular, determining the effects of postharvest applications on the storage performance of the commercially important 'Angeleno' plum cultivar is of considerable importance for both production and marketing. Therefore, this study aimed to determine the effects of different postharvest treatments on the quality attributes and decay development of 'Angeleno' plum during storage.

MATERIAL AND METHODS

Plant Material

'Angeleno' plum (*Prunus salicina* L.) fruits used in this study were obtained from a commercial orchard located in Umurbey town of Lapseki district, Çanakkale province, Türkiye. The trees were grown under optimum management conditions during the 2025 production season, grafted onto Myrobolan 29C rootstock, 15 years old, and established at a spacing of 3 × 1 m between rows and within rows, respectively. The fruits were harvested manually at commercial maturity. Care was taken to prevent mechanical damage during harvesting, and the harvested fruits were transported to the laboratory in plastic crates. Among the harvested fruits, those without sunburn symptoms, disease or pest damage, or surface mechanical injuries, and showing uniformity in terms of size and color were selected for the experiment. The selected fruits were transferred to the Pomology Laboratory and prepared for the subsequent treatments.

Postharvest Treatments

In order to determine the effects of postharvest applications on the quality attributes and decay development of ‘Angeleno’ plum fruits during storage, two different treatments were applied. The commercial preparations used in the study were Siega Fresh® Finish and Siega Fresh® Citrus. Since the detailed formulations of these commercial preparations are proprietary, the products were described based on the available label and supplier information, including their application method, dosage, and treatment conditions. Both products were applied according to the manufacturer’s recommendations.

Siega Fresh® Finish Treatment

In the Siega Fresh® Finish treatment, plum fruits were placed into modified atmosphere packages (MAP) and transferred to the cold storage room with the package openings left open. Siega Fresh® Finish was applied in the storage environment using a ULV (Ultra Low Volume) device through the fogging method. A homogeneous mist was generated within the storage room, and the application was performed at the dosage recommended by the manufacturer. Following the application, the cold storage system was operated to allow precooling of the fruits. Fruits that did not receive Siega Fresh® Finish treatment were considered as the control group and were stored under the same storage conditions.

Siega Fresh® Citrus Treatment

In the Siega Fresh® Citrus treatment, the preparation was applied to the surface of plum fruits at three different doses: 2 L ton^{-1}, 3 L ton^{-1}, and 6 L ton^{-1}. The application was carried out using a hand sprayer to ensure uniform coverage of the fruit surface. Fruits treated only with water were considered as the control group. After treatment, the fruits were arranged in a single layer in plastic crates and allowed to dry under room conditions to remove excess surface moisture. The dried fruits were then placed into modified atmosphere packages (MAP) and subjected to precooling before storage.

Packaging and Storage Conditions

In both treatments, approximately 5 kg of ‘Angeleno’ plum fruits, corresponding to approximately 50 fruits, were placed in each modified atmosphere package (MAP). For the Siega Fresh® Finish treatment, 20 modified atmosphere packaging (MAP) were prepared for both treated and untreated groups. In the Siega Fresh® Citrus treatments, six modified atmosphere packaging (MAP) were prepared for each application dose and for the control group. The plum fruits placed in modified atmosphere packages were kept with open package mouths for 1 day at 1 °C and 90% relative humidity for precooling. After the precooling period, the package openings were sealed. Plum fruits treated with Siega Fresh® Finish were stored for 120 days, whereas fruits treated with Siega Fresh® Citrus were stored for 90 days at 1 °C and 85–95% relative humidity. During the storage period, samples were periodically removed from storage for evaluation. In the Siega Fresh® Finish treatment, samples were taken on days 30, 60, 90, and 120, while in the Siega Fresh® Citrus treatments, samples were taken on days 30, 60, and 90. The samples removed from storage were either analyzed immediately or evaluated after a shelf-life period. During the shelf-life evaluation, fruits were kept at 20 °C and 70% relative humidity for 3 days, after which quality analyses were performed. The experiments were arranged according to a completely randomized design. The Siega Fresh® Finish experiment was conducted with five replicates, while the Siega Fresh® Citrus experiment was arranged with two replicates. Each modified atmosphere package, containing approximately 50 fruits, was considered as one replicate.

Measurements and Quality Analyses

In-package Gas Composition

During storage, O_2 and CO_2 concentrations inside the modified atmosphere packages were measured using a portable O_2/CO_2 gas analyzer (PBI-Dansensor A/S, Ringsted, Denmark). Measurements were performed at regular intervals to monitor the atmospheric composition inside the packages during storage.

Weight Loss

Crates whose initial weights were determined before storage were weighed at monthly intervals during storage. Additional measurements were also conducted after the shelf-life period. Weighing was carried out using a digital balance with ±0.05 g precision (XB 12100, Presica Instruments Ltd., Switzerland). Weight loss during storage was calculated and expressed as percentage (%).

Decay Development

During storage, crates removed from storage at monthly intervals were examined and the plum fruits were separated as healthy and decayed fruits. The weights of decayed fruits were determined and expressed as a percentage (%) of total fruit weight. Decay development was evaluated in two categories: stem-end decay and decay occurring on other parts of the fruit surface. The sum of these two values was used to calculate the total decay incidence.

Fruit Peel Color

Fruit peel color was determined using a Minolta colorimeter (CR-400, Konica Minolta Co., Japan) and expressed as CIE L^*, a^*, and b^* color parameters. Measurements were taken from four different points on the equatorial region of each fruit. The L^* value represents lightness, where 0 indicates black and 100 indicates white. The a^* and b^* values describe color coordinates on a plane perpendicular to the L^* axis. Positive a^* values indicate red color, whereas negative values indicate green color. Positive b^* values represent yellow color, while negative values indicate blue color.

Soluble Solids Content (SSC)

Soluble solids content (SSC) was determined from fruit juice using a digital refractometer (HI 96801, Hanna Instruments, Woonsocket, RI, USA). Fruit juice was obtained by pressing the plum fruits, and the results were expressed as percentage (%).

Titratable Acidity (TA)

Titratable acidity was determined according to the neutralization principle. Fruit juice samples obtained from the fruits were titrated with 0.1 N NaOH solution using a digital benchtop pH meter (Orion Star A211, Thermo Scientific, Waltham, MA, USA) until the pH reached 8.1. For the analysis, fruit puree was diluted with distilled water and titrated until the endpoint (pH 8.1) was reached. Based on the volume of NaOH consumed, titratable acidity was calculated and expressed as g malic acid per 100 mL of fruit juice.

pH Value

The pH value of the fruit juice was measured using a pH meter (Orion Star A211, Thermo Scientific, Waltham, MA, USA).

Physiological Disorders

During storage, the occurrence of skin browning, surface spotting, and other physiological disorders in plum fruits was monitored and recorded.

Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) using SAS software (Version 9.0; SAS Institute Inc., Cary, NC, USA). When significant differences among treatments were detected, means were separated using Duncan's multiple range test at $P \leq 0.05$. Graphical visualizations of the results were prepared using Python (Version 3.9) with the Matplotlib library.

RESULTS AND DISCUSSION

In-Package Gas Composition

Significant changes were observed in the O_2 and CO_2 concentrations measured within the modified atmosphere packages during the storage period (Figure 1 - Table 1). At the beginning of storage, the O_2 concentration inside the package was measured at 20.8%, and this value gradually decreased during storage due to fruit respiration. The O_2 concentration declined to 15.6% on day 30, 12.4% on day 60, and 10.8% on day 90. In contrast, the CO_2 concentration increased throughout the storage period, rising from 0.04% at the beginning of storage to 3.8% on day 30, 5.6% on day 60, and 6.9% on day 90. These changes are primarily associated with the respiratory metabolism of the fruits. In plum fruits stored under modified atmosphere conditions, the reduction in O_2 concentration and the increase in CO_2 levels may contribute to extending the storage period by limiting the respiration rate (Crisosto and Kader, 2000; Liao et al., 2023). 'Angeleno' is a late-season Japanese plum cultivar, and its relatively low respiration rate contributes to maintaining a more stable atmospheric composition within the package during storage. The CO_2 concentration reached 7.5% at the end of storage. This level remained within a moderate range for MAP-stored plum fruits and no severe physiological disorders such as internal browning, surface injury, or off-flavour development were recorded during the storage period. However, Japanese plum cultivars may differ in their tolerance to elevated CO_2 concentrations depending on cultivar, maturity stage, storage temperature, and exposure duration. Therefore, the observed CO_2 level should be carefully considered when applying MAP systems for long-term storage of 'Angeleno' plum.

Table 1. *Changes in internal atmosphere composition (%) in modified atmosphere packages during storage of 'Angeleno' plum**

Storage period (days)	O_2 (%)	CO_2 (%)
0	20.80 ± 0.12^a	0.04 ± 0.01^e
30	15.60 ± 0.18^b	3.80 ± 0.14^d
60	12.40 ± 0.21^c	5.60 ± 0.20^c
90	10.80 ± 0.25^d	6.90 ± 0.18^b
120	10.10 ± 0.27^d	7.50 ± 0.22^a

*Values are expressed as mean ± standard error (SE). Different letters within the same column indicate significant differences according to Duncan's multiple range test at $P \leq 0.05$.

Weight Loss

Weight loss in 'Angeleno' plum fruits showed a gradual and continuous increase throughout the storage period (Figure 1 - Table 2). At the beginning of storage, no measurable weight loss was detected. However, as storage progressed, a progressive increase in fruit weight loss was observed. By day 30, the average weight loss reached 1.42%. This value increased further to 2.87% on day 60, indicating that the rate of water loss became more pronounced as storage duration extended. On day 90, the average weight loss rose to 4.36%, and by day 120 it reached 5.94%. Following the shelf-life evaluation conducted after cold storage, weight loss increased even more and reached an average value of 7.18% after three days of shelf-life conditions. These results indicate that storage duration and subsequent shelf-life exposure substantially contribute to the increase in weight loss in plum fruits (Droby et al., 2011). The gradual increase in weight loss during storage is primarily associated with physiological processes such as transpiration and respiration occurring in fruit tissues. Transpiration leads to the loss of water through the fruit surface, particularly through the cuticle and lenticels, which results in a reduction in fresh weight (Lobo et al., 2017). At the same time, respiration causes the consumption of carbohydrates and other organic substrates, leading to further reductions in fruit mass. As storage duration increases, these physiological processes continue, causing cumulative losses in fruit weight. In addition, the integrity of fruit tissues gradually declines during prolonged storage, which may further facilitate water loss from the fruit surface (Gonzalez-Aguilar et al., 2011). Packaging conditions also play an important role in determining the extent of weight loss during storage. Modified atmosphere packaging (MAP) helps to limit moisture loss by maintaining a high relative humidity environment around the fruit, thereby reducing the water vapor pressure gradient between the fruit surface and the surrounding atmosphere (Kumar and Kumar, 2016). High humidity conditions within the package environment slow down the rate of transpiration and contribute to the maintenance of fruit turgor and freshness during storage (Cardoso, 2025). Therefore, the use of MAP systems is widely considered an effective strategy to reduce postharvest water loss and preserve fruit quality in plums and other climacteric fruits. Research conducted on Japanese plum cultivars has reported that fruit weight loss increases steadily as storage duration extends, largely due to enhanced transpiration and respiration processes occurring during cold storage (Mashabatu, et al., 2024). The progressive increase observed in the present study is consistent with the general physiological behavior of plum fruits during storage. In addition to physiological processes, several other factors such as storage temperature, relative humidity, fruit maturity stage at harvest, and packaging conditions may influence the magnitude of weight loss during storage. Similar trends have been reported in previous studies on plum and other stone fruits, where weight loss increased progressively with storage duration due to transpiration, respiration, and tissue water loss. Manganaris et al. (2008) emphasized that postharvest weight loss in plum fruits is closely associated with storage conditions and fruit physiological activity. Likewise, studies on peach and other climacteric stone fruits have shown that appropriate postharvest treatments and packaging systems may reduce moisture loss by limiting transpiration and maintaining a more favorable storage atmosphere. In this respect, the weight loss values obtained in the present study are consistent with previous findings and indicate that the combination of Siega Fresh® applications with modified atmosphere packaging contributed to limiting excessive water loss during storage. From a commercial perspective, weight loss is considered an important indicator of postharvest fruit quality. Excessive weight loss may lead to fruit shriveling, loss of firmness, and a reduction in market acceptability. In plum fruits, weight loss values within the range of approximately 5–8% during storage are generally regarded as acceptable limits for maintaining market quality and consumer acceptance. The results obtained in the present study indicate that the observed weight loss levels remained within this acceptable range even after prolonged storage and subsequent shelf-life conditions. Nevertheless, the continuous increase in weight loss with extended storage highlights the importance of appropriate postharvest handling practices and packaging systems to maintain fruit quality and reduce moisture loss during long-term storage.

Table 2. *Weight loss (%) of 'Angeleno' plum during cold storage and shelf life**

Storage period (days)	Weight loss (%)
0	0.00 ± 0.00^{e}
30	1.42 ± 0.11^{d}
60	2.87 ± 0.16^{c}
90	4.36 ± 0.19^{b}
120	5.94 ± 0.23^{a}
Shelf life (3 days)	7.18 ± 0.26^{a}

*Values are expressed as mean ± standard error (SE). Different letters within the same column indicate significant differences according to Duncan's multiple range test at P ≤ 0.05.

Decay Development

An increase in decay incidence in 'Angeleno' plum fruits was observed with the progression of the storage period (Figure 1 - Table 3). During the first 30 days of storage, the decay rate was determined as 1.6%, increasing to 3.8% on day 60 and 7.4% on day 90. By the 120th day of storage, the total decay incidence reached 11.2%. A substantial proportion of decay was observed to originate from the stem end of the fruit, accounting for approximately 60% of the total decay incidence. The stem cavity is known to represent a physiologically sensitive region where tissue damage and micro-cracks facilitate pathogen penetration during storage. In plum fruits, postharvest decay occurring during cold storage is frequently associated with fungal pathogens such as *Monilinia* spp. and *Botrytis cinerea*, which are recognized as the major causal agents of postharvest rot in stone fruits (Kaseke et al., 2025). The increase in decay incidence observed with prolonged storage duration may therefore be attributed to the progressive weakening of fruit tissues and the favorable conditions for pathogen development. Modified atmosphere conditions appeared to exert a partial limiting effect on decay development. The reduced oxygen concentration and moderately elevated carbon dioxide levels within the package atmosphere are known to slow down fruit respiration and metabolic activity while also inhibiting the growth and sporulation of several postharvest pathogens (Balaguera-López et al., 2024; Mieszczakowska-Frac et al., 2025). These findings indicate that modified atmosphere conditions may delay the onset and progression of decay during long-term storage of plum fruits. This result is in agreement with previous reports indicating that postharvest decay in plum and other stone fruits is strongly influenced by storage duration, fruit maturity, surface injuries, and the development of fungal pathogens. Similar findings were reported by Şen et al. (2022), who observed that Siega Fresh® Finish and Siega Fresh® Citrus applications reduced decay development during storage of organically grown pomegranate fruits. Although pomegranate differs from plum in fruit structure and physiology, the reduction in decay incidence observed with Siega Fresh® applications supports the potential use of such commercial postharvest preparations in reducing storage losses. In the present study, the lower decay development observed in treated fruits compared with the control also confirms the practical importance of combining postharvest treatments with modified atmosphere storage.

Table 3. *Changes in decay incidence (%) of 'Angeleno' plum during storage**

Storage period (days)	Stem-end decay (%)	Other decay (%)	Total decay (%)
30	0.90 ± 0.07^{d}	0.70 ± 0.05^{d}	1.60 ± 0.09^{d}
60	2.30 ± 0.11^{c}	1.50 ± 0.09^{c}	3.80 ± 0.14^{c}
90	4.50 ± 0.18^{b}	2.90 ± 0.12^{b}	7.40 ± 0.21^{b}
120	6.70 ± 0.25^{a}	4.50 ± 0.18^{a}	11.20 ± 0.34^{a}

*Values are expressed as mean ± standard error (SE). Different letters within the same column indicate significant differences according to Duncan's multiple range test at P ≤ 0.05.

Comparative evaluation of Siega Fresh® Finish and Siega Fresh® Citrus applications

Both Siega Fresh® Finish and Siega Fresh® Citrus treatments contributed to the preservation of postharvest quality in 'Angeleno' plum fruits; however, their effects differed depending on the application method, dosage, and storage duration. Siega Fresh® Finish was applied by ULV fogging in the cold storage room and the fruits subjected to this treatment were stored for up to 120 days. The fogging method may have allowed a more homogeneous distribution of the preparation within the storage environment and around the fruit, which could support quality preservation during long-term storage. On the other hand, Siega Fresh® Citrus was applied directly to the fruit surface by spraying at different doses, and its effect was more closely related to the control of decay development during the 90-day storage period. This difference is mainly associated with the way the products were applied. Siega Fresh® Finish acted through the storage atmosphere by fogging, whereas Siega Fresh® Citrus functioned as a direct surface treatment before packaging. Therefore, Siega Fresh® Finish may be more suitable for supporting long-term storage, while Siega Fresh® Citrus may be more effective in reducing surface-related decay problems when used at an appropriate dose. In this study, the higher dose of Siega Fresh® Citrus showed a more noticeable effect on limiting decay development, whereas Siega Fresh® Finish contributed to maintaining fruit quality over a longer storage period. These results show that the two applications should be considered as different postharvest strategies rather than similar treatments. Siega Fresh® Finish is more closely associated with fogging-based treatment of the storage environment, while Siega Fresh® Citrus is based on direct fruit-surface application. In commercial practice, the choice between these treatments may depend on the primary storage objective, such as extending storage duration, reducing decay incidence, or preserving fruit quality during shelf life. It should also be noted that the Siega Fresh® Citrus treatment was conducted with two replicates due to limitations in available fruit material and experimental packaging capacity. Considering this limitation, the results obtained from the Citrus treatments should be interpreted with caution. Further studies with at least three replicates are needed to confirm the dose-dependent effects of Siega Fresh® Citrus on ‘Angeleno’ plum during storage.

Fruit Peel Color

Significant changes were observed in the peel color parameters of ‘Angeleno’ plum fruits during the storage period (Figure 1 - Table 4). At the beginning of storage, the average $L*$ value was measured as 31.8, decreasing to 28.4 by the 90th day of storage. The reduction in $L*$ values indicates that the fruit surface gradually became darker during storage. Reductions in $L*$ values during cold storage have been reported in several plum cultivars and are generally associated with the accumulation of anthocyanin pigments and the progression of fruit ripening processes (Manganaris et al., 2008; Hayat et al., 2023). The $a*$ values increased from 18.6 at the beginning of storage to 21.3 after 90 days of storage, indicating an enhancement of red coloration in the fruit peel. ‘Angeleno’ plum is characterized by a dark purple skin color, which is closely associated with the presence of anthocyanin pigments. The increase in $a*$ values observed during storage may therefore be related to continued anthocyanin accumulation and changes in phenolic metabolism occurring in the peel tissues. Previous studies have demonstrated that anthocyanin synthesis and stabilization may continue during storage, particularly under conditions that promote pigment formation and oxidative metabolism (Shan et al., 2023). Only slight changes were observed in $b*$ values during storage. The $b*$ value decreased from 6.4 at the beginning of storage to 5.7 on day 90, suggesting that the yellow color component remained relatively stable throughout the storage period. Similar results have been reported for Japanese plum cultivars, where limited changes in $b*$ values were observed during storage compared with the more pronounced variations in $L*$ and $a*$ parameters (Serrano et al., 2005). The changes observed in peel color parameters during storage are likely associated with ripening-related metabolic processes and pigment accumulation in plum fruits. These findings are comparable with previous studies reporting that color changes in plum fruits during storage are mainly related to anthocyanin metabolism, ripening progression, and cultivar-specific pigment characteristics. In dark-colored plum cultivars such as ‘Angeleno’, decreases in $L*$ values and increases in $a*$ values are expected as the peel becomes darker and red-purple coloration becomes more intense during storage. Similar color changes have also been reported in other stone fruits during cold storage, where pigment accumulation and oxidative changes affected external fruit appearance. The color changes observed in the present study are consistent with the typical postharvest behavior of dark-skinned plum cultivars.

Table 4. *Changes in skin color parameters (L*, a*, b*) of ‘Angeleno’ plum during storage***

Storage period (days)	*L**	*a**	*b**
0	31.80 ± 0.42[a]	18.60 ± 0.31[d]	6.40 ± 0.21[a]
30	30.70 ± 0.38[b]	19.20 ± 0.34[c]	6.10 ± 0.19[ab]
60	29.60 ± 0.40[c]	20.10 ± 0.29[b]	5.90 ± 0.22[bc]
90	28.40 ± 0.36[d]	21.30 ± 0.33[a]	5.70 ± 0.20[b]
120	27.80 ± 0.44[d]	22.00 ± 0.35[a]	5.50 ± 0.18[c]

**Values are expressed as mean ± standard error (SE). Different letters within the same column indicate significant differences according to Duncan’s multiple range test at $P \leq 0.05$.

Soluble Solids Content (SSC)

Changes in soluble solids content (SSC) of ‘Angeleno’ plum fruits remained relatively moderate throughout the storage period (Figure 1 - Table 5). At harvest, the mean SSC value was determined as 15.2%, increasing to 16.1% by day 60 and reaching 16.8% at day 90 of storage. The gradual rise in SSC values during storage may be attributed to physiological and biochemical processes occurring in fruit tissues. In particular, moisture loss from the fruit surface can lead to the concentration of soluble components, resulting in higher SSC readings. In addition, metabolic transformations associated with ripening may promote the conversion of complex carbohydrates into simpler soluble sugars, contributing to the observed increase in SSC values. A comparable increase in SSC during storage has been reported in plum and other stone fruits, where dehydration effects and ongoing metabolic activity influence the accumulation of soluble sugars within the fruit tissues (Umeohia and Olapade, 2024).

Titratable Acidity (TA)

Titratable acidity values of ‘Angeleno’ plum fruits showed a gradual decline throughout the storage period (Figure 1 - Table 5). The initial acidity level was determined as 1.12 g malic acid 100 mL^{-1}, decreasing to 0.94 g malic acid 100 mL^{-1} on day 60 and further to 0.81 g malic acid 100 mL^{-1} by day 90 of storage. The reduction in titratable acidity during storage is generally associated with the utilization of organic acids in respiratory metabolism. Organic acids, particularly malic acid, serve as important substrates in the tricarboxylic acid (TCA) cycle, and their progressive consumption during storage leads to a gradual decline in acidity levels in fruit tissues (Cao et al., 2022; Zhang et al., 2024). Comparable decreases in titratable acidity during storage have been reported for plum and other stone fruit species, where the decline in organic acid content is closely related to the continuation of metabolic activity and ripening-related processes after harvest (Shin et al., 2023). The reduction in acidity may influence the sensory characteristics of the fruit by altering the balance between sugars and organic acids, thereby affecting both flavor perception and the maturity index of plum fruits.

pH Value

A slight increase in pH values was observed in ‘Angeleno’ plum fruits during the storage period (Figure 1 - Table 5). The initial pH value of 3.21 increased to 3.48 by day 90 of storage. The rise in pH values during storage is closely related to the decline in titratable acidity observed in fruit tissues. As storage progresses, organic acids particularly malic acid, which represents the predominant organic acid in plum fruits are gradually metabolized through respiratory pathways. The utilization of these acids as substrates in metabolic processes results in a reduction in total acidity, consequently leading to an increase in pH values (Usenic et al., 2008; Miletic et al., 2012; Pott et al., 2020). A comparable increase in pH during storage has been reported in plum and other stone fruits, where the progressive degradation of organic acids associated with postharvest metabolic activity alters the acid–sugar balance of the fruit (Du et al., 2024; Zhang et al., 2025). These biochemical changes may influence flavor perception and contribute to the progression of fruit ripening during storage.

The changes observed in SSC, titratable acidity, and pH values were also consistent with previous studies on plum and related stone fruits. During storage, increases in SSC are generally associated with water loss and the conversion of complex carbohydrates into soluble sugars, whereas decreases in titratable acidity result from the use of organic acids as respiratory substrates. Previous studies on plum cultivars have similarly shown that organic acid levels tend to decrease during storage, while pH values gradually increase as fruit ripening advances. These changes indicate that the metabolic activity of ‘Angeleno’ plum continued during storage, although the combination of postharvest treatments and modified atmosphere packaging may have slowed the rate of quality deterioration.

Table 5. *Changes in soluble solids content (SSC), titratable acidity (TA) and pH of ‘Angeleno’ plum during cold storage**

Storage period (days)	SSC (%)	TA (g malic acid 100 mL^{-1})	pH
0	15.20 ± 0.28^{c}	1.12 ± 0.04^{a}	3.21 ± 0.03^{d}
30	15.60 ± 0.25^{bc}	1.05 ± 0.05^{ab}	3.28 ± 0.04^{c}
60	16.10 ± 0.30^{b}	0.94 ± 0.04^{b}	3.36 ± 0.03^{b}
90	16.80 ± 0.33^{ab}	0.81 ± 0.03^{c}	3.48 ± 0.04^{a}
120	17.20 ± 0.35^{a}	0.73 ± 0.03^{d}	3.55 ± 0.05^{a}

*Values are expressed as mean ± standard error (SE). Different letters within the same column indicate significant differences according to Duncan’s multiple range test at $P \leq 0.05$.

Changes in physiological and quality parameters of the fruits during the storage period are presented in Figure 1. The composition of storage gases showed a gradual decrease in O_2 concentration and a corresponding increase in CO_2 concentration, indicating the continuation of respiratory activity during storage (Fig. 1a). Weight loss increased progressively with prolonged storage time (Fig. 1b), which can be mainly attributed to water loss through transpiration as well as metabolic processes associated with respiration.

Similarly, the decay incidence increased markedly toward the later stages of storage (Fig. 1c), suggesting that prolonged storage conditions may weaken tissue integrity and promote microbial development.

Changes were also observed in skin color parameters during storage (Fig. 1d).

The *L** value gradually decreased, indicating a reduction in brightness, while a* values slightly increased, reflecting an enhancement of red coloration. In contrast, *b** values showed a decreasing trend, suggesting a reduction in yellow tones over time. These changes are likely associated with pigment metabolism and biochemical transformations occurring during the storage period.

Regarding quality parameters, SSC exhibited a slight increasing trend, whereas TA gradually decreased and pH values slightly increased throughout storage (Fig. 1e). The increase in SSC may be related to water loss and concentration of soluble solids, while the decrease in TA is commonly associated with the utilization of organic acids during respiration. The observed changes suggest that storage duration played an important role in determining the physiological responses and quality attributes of the fruits.

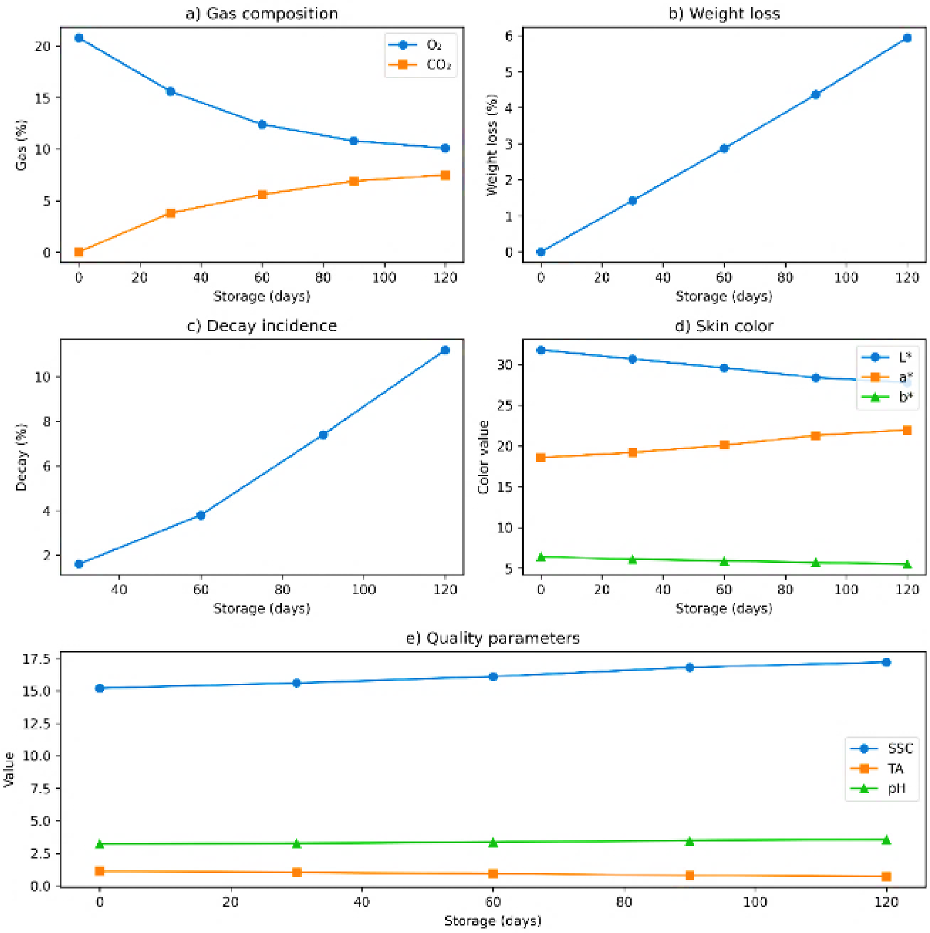

Figure 1. *Effects of storage duration on internal atmosphere composition (O_2 and CO_2), weight loss, decay incidence, skin color parameters (L*, a*, b*) and quality characteristics (SSC, TA and pH) of 'Angeleno' plum during cold storage. Values represent mean ± SE. Means followed by different letters differ significantly according to Duncan's multiple range test ($P \leq 0.05$).*

CONCLUSION

In this study, the effects of Siega Fresh® Finish and Siega Fresh® Citrus applications on the quality attributes of 'Angeleno' plum (*Prunus salicina* L.) fruits stored under modified atmosphere conditions were evaluated throughout the storage period. The findings indicated that both treatments were effective in limiting quality deterioration occurring during storage. During the storage period, a decrease in O_2 concentration and a concomitant increase in CO_2 concentration were observed within the package atmosphere as a consequence of fruit respiration. The application of Siega Fresh® Finish and Siega Fresh® Citrus in combination with modified atmosphere packaging contributed to maintaining the gas composition within the package at levels suitable for plum fruits. This condition contributed to regulating the respiration rate of the fruit during storage. As storage progressed, an increase in weight loss and decay incidence was observed in the fruits. However, fruits treated with Siega Fresh® Finish and Siega Fresh® Citrus exhibited lower weight loss compared with the control group. In terms of decay development, treated fruits showed lower overall decay incidence, and the Siega Fresh® Citrus treatment, in particular, demonstrated a pronounced effect in reducing decay development. Changes in peel color parameters were observed during storage. A decrease in L^* values and an increase in a* values were detected, indicating that the peel color gradually shifted toward darker and more intense red tones during storage. This change is likely associated with the continued metabolic activity of anthocyanin pigments present in the fruit skin tissues during the storage period. While soluble solids content showed slight increases during storage, titratable acidity decreased. The utilization of organic acids in respiratory metabolism is considered the primary factor responsible for this change. A slight increase in pH values was observed during storage. The results demonstrate that the application of Siega Fresh® Finish and Siega Fresh® Citrus in combination with modified atmosphere packaging contributed to maintaining the quality attributes of 'Angeleno' plum during storage. These treatments may support longer storage periods by reducing decay development and slowing quality deterioration, thereby helping maintain the marketability of the fruit.

Compliance with Ethical Standards

This research was conducted in accordance with research and publication ethics.

Ethical approval

Ethical approval was not required for this study.

Conflict of interest

The author declares that there is no conflict of interest.

Author contributions

The author solely contributed to the conception, design, data collection, analysis, and writing of the article.

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Data availability

The data supporting the findings of this study are available from the author upon reasonable request.

Statement of Use for Artificial Intelligence and Its Types

Artificial intelligence and its various types were not used in the writing of this article.

Approval for Publication

All authors declare that they have seen and approved the final version of the submitted manuscript.

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