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Improving the Physicochemical Quality of Cold-Stored Apricot Fruits through Sodium Alginate Treatment

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ABSTRACT

In this study, sodium alginate (SA) treatments (0, 0.5, 1, and 1.5%) were employed to maintain the nutritional quality of apricots during cold (2 ± 0.5 °C) storage periods (0, 8, 16, and 24 d). The results showed that the control sample experienced the highest weight loss until day 24. All SA concentrations had a positive effect on maintaining fruit weight and firmness. Maximum values of total acids, vitamin C, and taste occurred at the final stage of storage in response to the SA (1%) treatment. Moreover, SA treated-apricot had the highest antioxidant activity in all periods of storage. In contrast to the trends observed for phenols, antioxidant activity, and vitamin C, the flavonoid content showed a gradual increase during storage. Despite the fact that the control sample showed the highest flavonoid content, all SA treatments increased the peroxidase and polyphenol oxidase activity, while better maintaining flavor and aroma compared to the control. Even though the nutritional value of apricots treated with SA was high, the SA (1%) treatment caused more acceptance from the consumer's point of view at the final stage of storage.

Introduction

During the 2020–2021 crop year, Iran produced over 344 thousand tons of apricots, ranking as the world's third-largest producer after Turkey (833 thousand tons) and Uzbekistan (529 thousand tons) (Ziaolhagh and Kanani, 2021). Yazd Province is one of the country's major production regions, and Abarkooh City is a key producer of the "Felkeeii" apricot. In 2021, storms caused more than $7 million in damage to apricot orchards in Abarkooh City during the harvest season. The lack of adequate infrastructure for apricot processing, including cold storage and edible coating technologies, has contributed to this problem (Moradinezhad and Jahani, 2016). Cold storage, especially when combined with early harvest, can help prevent aroma loss in fruits such as apricots (Ziaolhagh and Kanani, 2021). Therefore, the use of appropriate postharvest techniques is essential to preserve the quality of ripe apricots before they reach local markets and to reduce the risk of quality deterioration (Muzzaffar et al., 2018).

Edible coating is a technique used to delay ripening and extend the storage life of climacteric fruits. The application of sodium alginate (SA), chitosan, and gellan gum (Morsy and Rayan, 2019); gum tragacanth and chitosan (Ziaolhagh and Kanani, 2021); and chitosan nanoparticles (Algarni et al., 2022; Gull et al., 2021) has been shown to improve the qualitative traits of apricots and extend their shelf life in cold storage. SA, a polysaccharide biopolymer derived from brown algae, is particularly effective. Edible coatings slow color changes, reduce water loss and deterioration, and improve appearance (Zhang et al., 2023). When dissolved in water, SA and other alginates form a shiny, tasteless, odorless, and flexible gel.

The effectiveness of SA-based edible coatings has been demonstrated in extending the shelf life of tomato (Salama et al., 2019), green chili (Ramakrishnan et al., 2023), fresh pistachio (Shakerardekani et al., 2021), strawberry (Yan et al., 2024), and guava (Nair et al., 2018). These coatings enhance mechanical properties and improve appearance, flavor, and taste, as reported for strawberries (Emamifar and Bavaisi, 2020). SA reduces the selective permeability of fruit tissues to oxygen and carbon dioxide, increasing carbon dioxide levels while reducing oxygen, which decreases ethylene synthesis by limiting substrate availability for the conversion of ACC to ACO (Valero et al., 2013). Positive results have also been obtained by combining SA with cinnamaldehyde, pectins, and calcium lactate to extend the shelf life of watermelon (Sipahi et al., 2013). Additionally, SA coatings enriched with chlorogenic acid accelerated wound healing in pears by stimulating the phenylpropanoid pathway (Zhang et al., 2023). SA treatments applied to four plum varieties during storage effectively inhibited ethylene production, weight loss, acidity loss, and softening (Valero et al., 2013). Guerreiro et al. (2013) further reported that SA coatings enriched with essential oils reduced microbial spoilage in *Arbutus unedo* fruit while maintaining nutritional and sensory properties.

Despite the documented importance of SA as an effective edible coating, no detailed and comprehensive study has examined its effects on the nutritional value and sensory quality of “Felkeeii” apricot under cold storage conditions. Therefore, the present study investigated the effectiveness of SA coating in prolonging the shelf life and preserving the quality of “Felkeeii” apricot fruit following harvest.

Materials and Methods

Fruit preparations and postharvest management

In 2017, “Felkeeii” apricot fruits were harvested at commercial maturity while still firm, characterized by a light green background with yellow spots, from a commercial orchard in Abarkooh City, Yazd Province, Iran (30°46′ N, 52°58′ E). After transport to the postharvest laboratory, fruits showing defects, such as dark brown soft circular spots, sunburn, cracks, or bruises, were removed. The remaining fruits were randomly divided into 12 groups of 40, with four replications per treatment.

Sodium alginate (SA; Sigma Aldrich) was applied at concentrations of 0% (control, distilled water), 0.5%, 1%, and 1.5% by immersing the fruits for 5 min. Treated fruits were air-dried at room temperature and then stored in a temperature-controlled chamber at 2 ± 0.5 °C and 85 ± 5% relative humidity. For each replicate, ten fruits were packed in polyethylene terephthalate (PET) containers (60 × 165 × 245 mm) lined with low-density polyethylene (LDPE). Sampling was carried out at harvest (day 0) and after 8, 16, and 24 days of storage. After removal from cold storage, fruits were held at 25 °C for 4 h before analysis. Following each storage interval, various quantitative and qualitative attributes were evaluated.

Weight loss and firmness

Apricot weight loss was expressed as a percentage (%) relative to the initial weight (m_0). At each sampling interval, packages were weighed immediately after removal from the refrigerator using a digital scale to obtain the recorded weight (m_1). The percentage of weight loss was calculated using the following formula (Guerreiro et al., 2013):

$$WL\ (\%) = [\frac{(m0 - m1)}{m0}] \times 100 \quad (1)$$

The firmness of five fruits per replicate was measured using a digital pressure gauge (Lutron FG5020, Taiwan) equipped with a 7.8-mm flat-head probe. The probe was applied to the equatorial region of each fruit at a nearly constant rate until skin rupture occurred, and the firmness values were recorded in Newtons (N).

Total soluble solids (TSS), and titratable acids (TA)

TSS of the fruit juice were measured after calibrating a refractometer with distilled water. To measure TA (malic acid %), 5 mL of apricot extract was mixed with 0.1 N NaOH and titrated via a phenolphthalein indicator (1 mL, 1%) until a persistent pink color appeared. The volume of sodium hydroxide was recorded and TA was calculated using formula 2.

$$TA\% = \frac{N \times V1 \times Eq\ wt}{V2} \times 10 \quad (2)$$

N: titrant normal (NaOH (mEq mL^{-1})), V1: titrant amount (mL), Eq wt: predominant acid weights (mg mEq^{-1}), V2: sample amount (mL)

Vitamin C measurement and flavonoid content (FC)

The vitamin C content in apricots was quantified by titration using 2,6-dichlorophenole-indophenol (DIP) solution. The concentration of vitamin C (mg 100 g^{-1} fresh weight) were calculated using the following parameters: (A) the volume of DIP required per 1 mL of apricot juice, (V1) the volume of DIP required per 1 mL of blank solution, (V2) the volume of DIP required per 1 mL of pure vitamin C solution, and (B) the volume of apricot juice present in 100 g of the sample (Chiabrando and Giacalone, 2017).

$$Vitamin\ C\ (mg\ 100g^{-1}) = \frac{A}{V2 - V1} \times B \quad (3)$$

Flavonoid (FC) content of apricot juice was determined by aluminum chloride colorimetric method. To do this, sample extracts (1 mL) in methanol were diluted in $AlCl_3$ solution (1 mL, 2% in methanol). After a reaction time of ten min, absorbance measurements were made (430 nm). FC was quantified via calibration curves from the absorbance of known concentrations of the quercetin standard. Data appeared as quercetin mg equivalents per 100 g fresh weight (Oms-Oliu et al., 2008a).

Total phenolic compound (TPC) and antioxidant activity (AA)

Total phenolic compounds in the fruit (TPC) were determined by KH_2PO_4 and K_2HPO_4 solutions, phosphate buffer with pH 7.8 was prepared. Five g of apricot fruit were ground. Then, it was poured into phosphate buffer (10 mL). The TPC was extracted by centrifuging the mixture at 5 °C for 50 min at 4900 rpm. Subsequently, the supernatant (100 µL) entered the phosphate-buffer (400 µL), diluted Folin-reagent (1:11 at 2.5 mL), and sodium-carbonate (7.5% at 2 mL). After placing the mixture in a hot-water bath (60 °C) for 5 min, we measured absorbance values (760 nm). To calculate TPC, standard values in gallic acid (1.0 mM) was used, ultimately appearing as mg gallic acid equivalents 100 g^{-1} fresh weight (Liu et al., 2021).

The 2,2-diphenyl-1-picrylhydrazyl- (DPPH) method enabled measurements of antioxidant activity (AA) in the apricot fruits (Megha et al., 2023). At first, methanol (11 mL, 80%) was mixed with fruit extracts (1.0 g). After being centrifuged (13,000 rpm) for 15 min, we placed the solution at 25 °C for 35 min. Subsequently, 900 µL of 500 µM DPPH solutions were diluted in 100 µL extracts inside ethanol. Each solution became thoroughly combined before remaining in a dark environment for 30 min. A control sample was prepared in a similar manner, using distilled water instead of the fruit extract. Absorbance values per solution were measurable at 515 nm and determined accordingly:

$$\%DPPH = [\frac{(Abs\ control - Abs\ sample)}{Abs\ control}] \times 100 \quad (4)$$

Evaluation of polyphenol oxidase (PPO) and peroxidase (POD)

In frozen apricot samples, 1.0 g of tissue was homogenized in an extraction medium containing 1.5% (w/v) polyvinylpyrrolidone, 0.5% (v/v) Triton X-100, and 100 mM phosphate buffer (pH 7). The homogenates were centrifuged at 13,000 rpm for 25 min, and the resulting supernatants were used for enzyme assays.

Polyphenol oxidase (PPO) activity was measured using pyrogallol as the substrate. The reaction mixture consisted of 200 µL pyrogallol (0.02 M), 2.5 mL potassium phosphate buffer (50 mM, pH 7.2), and 150 µL enzymatic extract. Absorbance was recorded at 5-second intervals for 3 min at 420 nm using a UV/VIS spectrophotometer (T60, PG Instruments Ltd., England). PPO activity was calculated using the molar extinction coefficient of pyrogallol (6.2 mM^{-1} cm^{-1}) according to Equation 5 (Oms-Oliu et al., 2008b).

$$A = \varepsilon bc \quad (5)$$

The enzyme activity was quantified in units (U) mg^{-1} of total proteins in 150 µL of each extract. POD activity was evaluated via a method described by Rastegar et al. (Rastegar et al., 2019). In this procedure, a 3.0 mL mixture was prepared, consisting of 2.77 mL potassium-phosphate buffer (50 mM, pH 7), H2O2 (1%, 100 µL), guaiacol (4%, 100 µL), and enzymatic extract (30 µL). The change in absorbance at 470 nm was monitored kinetically over 3 min. The pyrogallel extinction coefficient (26.6 mM^{-1} cm^{-1} at 470 nm) enabled calculations of POD activity, with one POD unit activity translated as the enzymatic content needed for producing 1.0 mM of tetragoacol each min.

Panel test (sensory evaluation)

Apricots treated with SA coatings underwent sensory evaluations at various time points (0, 8, 16, and 24 d). Ten panelists evaluated four apricots treated with different SA coatings, consuming water between samples to prevent residual flavors influencing subsequent assessments (Oms-Oliu et al., 2008a). A structured hedonic scale ranging from one (severe dislike) to five (significant favorability) was used for evaluating flavor, aroma, and overall acceptance. Grade "excellent" was shown with 5, "very good" with 4, "good" with 3, "moderate" with 2, "poor" with 1, "extremely poor" with 0.

Statistical analysis

This experiment was done using a completely randomized design in a factorial (4 replicates). The factors examined were SA, evaluated at 4 different levels, and storage duration, with 3 levels. SAS 9.4 software operated for the analysis of variance (ANOVA), and the mean values per treatment were presented after conducting Duncan's test ($P \leq 0.05$).

Results

Firmness and weight loss

Firmness and weight loss were significantly affected by the interaction between storage time and treatment ($P < 0.01$). As shown in Figure 1A, fruit firmness decreased by 76% from harvest to the first evaluation after removal from cold storage (day 8). Firmness continued to decline gradually throughout storage, with the control fruit exhibiting the lowest firmness by the end of the experiment. Weight loss increased across all treatments during storage (Fig. 1B). By day 24, the highest weight loss occurred in the control group, whereas fruits treated with all concentrations of SA showed the lowest weight loss. Overall, the findings indicate that 1% and 1.5% SA treatments were most effective in preserving firmness over the 24-day storage period, which in turn contributed to reduced weight loss.

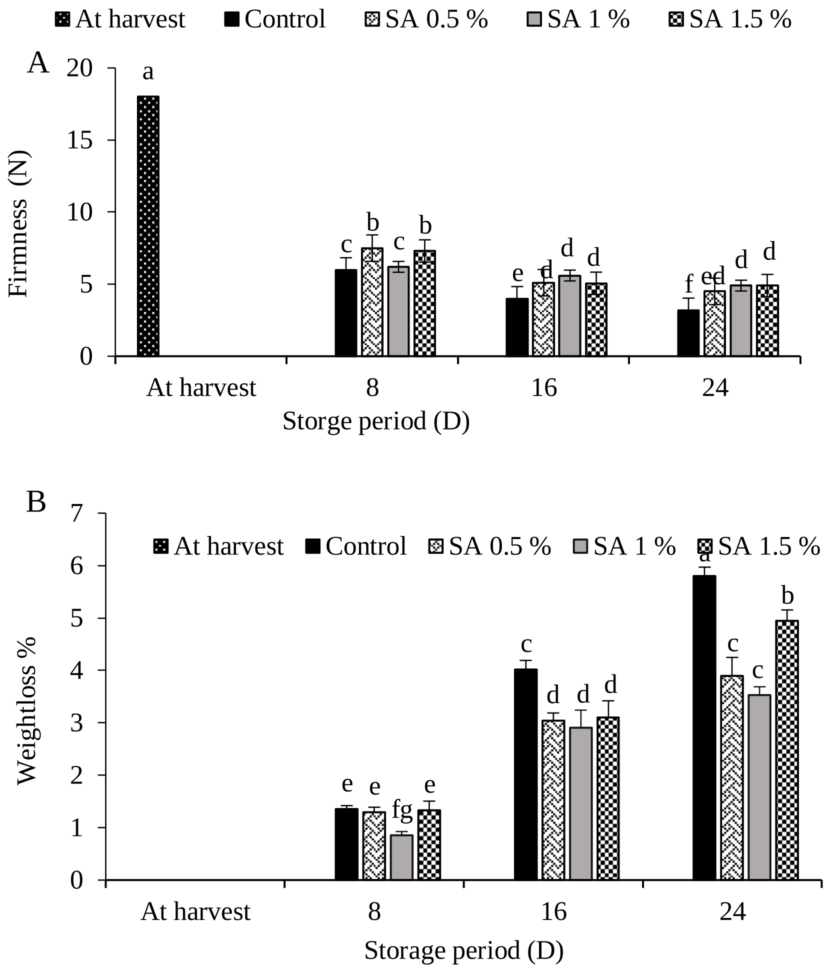


Fig. 1. Interaction effects of post-harvest immersion of sodium alginate treatments with storage period on (**A**) firmness and (**B**) weight loss of apricot fruit (*Prunus armeniaca.* cv: Felkeeii) stored at 2 ± 0.5 °C, 85 ± 5% RH.

Total soluble solids (TSS), and treatable acidity (TA)

Figures 2A and 2B show that the interaction between treatment type and storage time did not significantly affect total soluble solids (TSS). However, the individual effects of treatment and storage period on TSS were statistically significant ($P < 0.01$). The highest TSS values were observed in the control treatment, which did not differ significantly from the 1% SA treatment. Across the storage period, TSS increased by 32.3% compared with harvest time.

In contrast, the interaction between SA treatment and storage time had a significant effect on titratable acidity (TA) ($P < 0.01$). As shown in Figure 2C, TA in the control samples decreased by 65% over time. By day 24 of storage, the highest TA (0.25%) was recorded in the 1% SA treatment, while the control group showed the lowest TA.

Total phenolic compounds (TPC), flavonoid, vitamin C, and antioxidant activity (AA)

TPC, flavonoids, vitamin C, and antioxidant activity AA were significantly affected by the interaction between storage time and treatment ($P < 0.01$). According to treatment comparisons, TPC in the control samples decreased by 92% during storage, whereas all SA treatments better preserved TPC (Fig. 3A). By day 24, the 0.5% and 1% SA treatments did not differ significantly from each other and were more effective than the control in maintaining TPC. Flavonoid levels generally increased across treatments during storage (Fig. 3B). The highest flavonoid content was observed in the control samples at the end of storage. As shown in Figure 3C, vitamin C content decreased significantly over the storage period. On day 8, fruits treated with 1.5% SA had the highest vitamin C content. By day 16, vitamin C levels in the other treatments were not significantly different from the control. At the end of storage, the 1% SA treatment maintained the highest vitamin C content. Antioxidant activity declined with increasing storage duration (Fig. 3D). However, fruits treated with SA maintained higher antioxidant activity than the control throughout the storage period. On day 24, the 1% and 1.5% SA treatments exhibited the highest antioxidant activity compared with the other treatments.

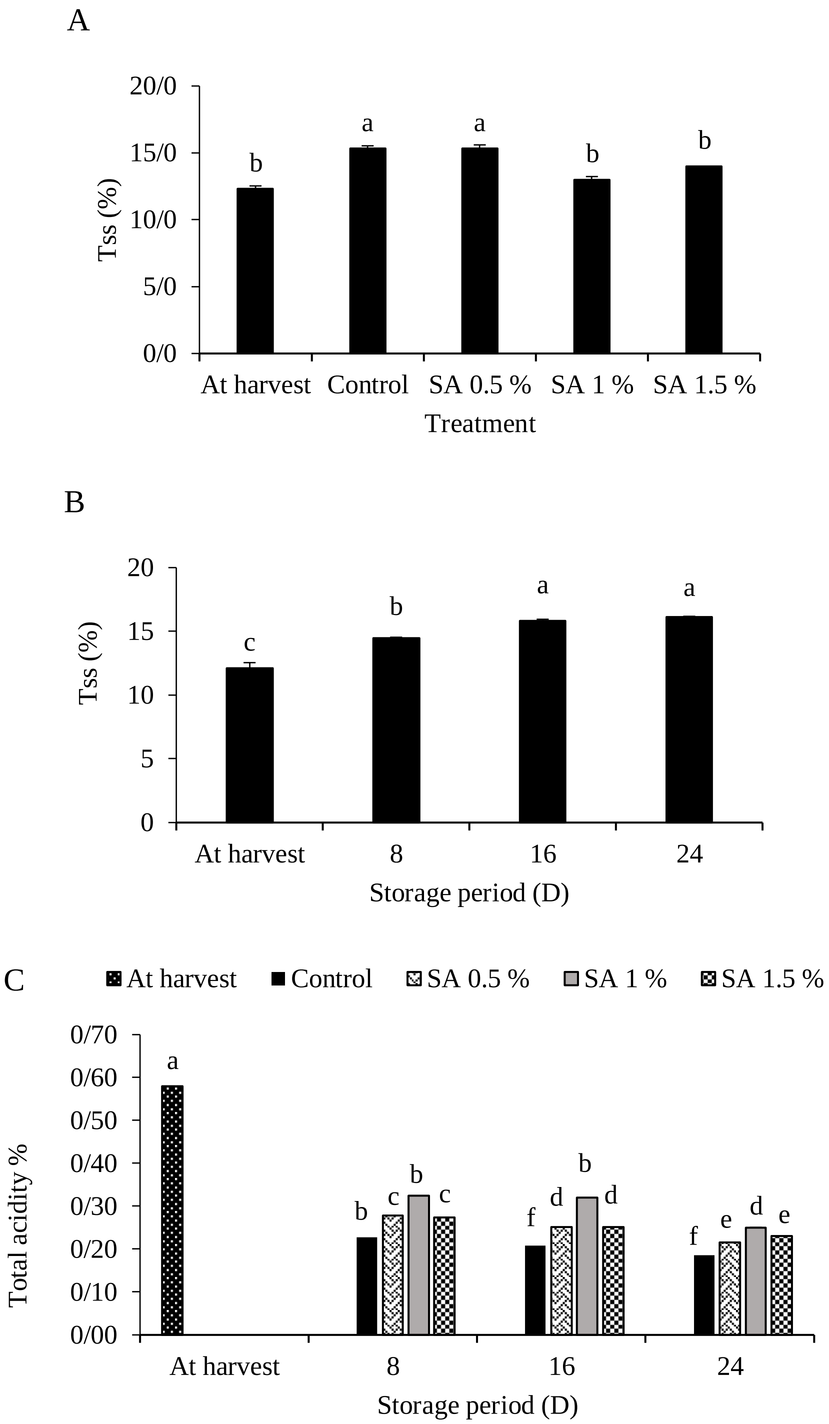
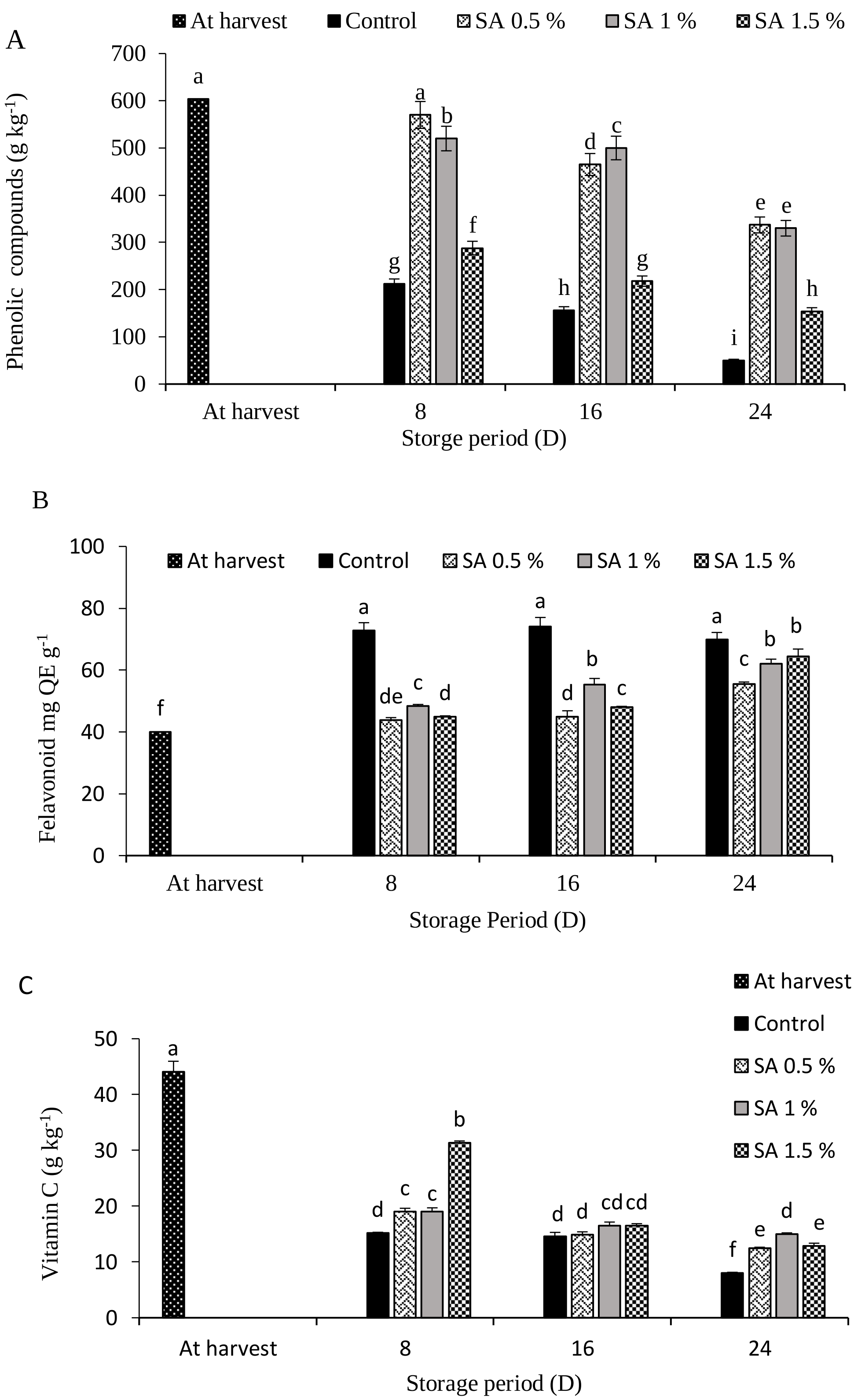


Fig. 2. Interaction and individual effects of post-harvest immersion of Sodium Alginate treatments with storage period on (**A** and **B**) total soluble solids, and (**C**) total acidity of apricot fruit (*Prunus armeniaca*. cv: Felkeeii) stored at 2 ± 0.5 °C, 85 ± 5% RH.


A
At harvest
Control
SA 0.5 %
SA 1 %
SA 1.5 %
Phenolic compounds (g kg-1)
Storge period (D)
B
Felavonoid mg QE g-1
Storage Period (D)
C
Vitamin C (g kg-1)
Storage period (D)
At harvest
8
16
24

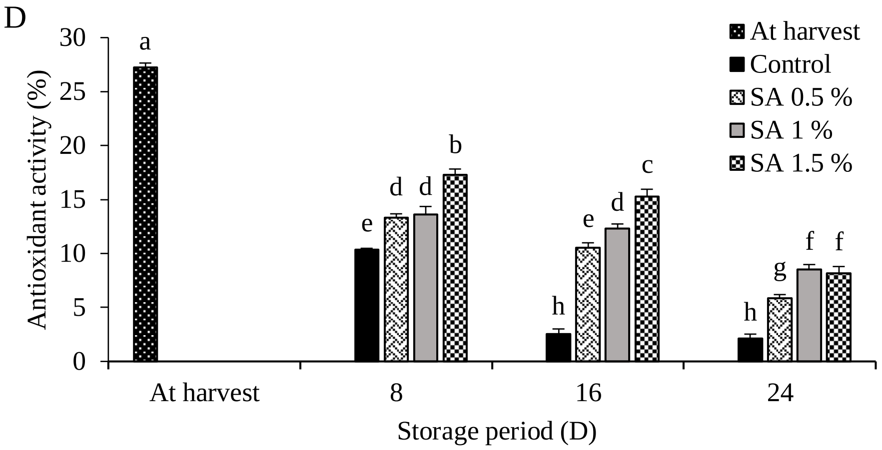


Fig. 3. Interaction effects of post-harvest immersion of Sodium Alginate treatments with storage period (**A**) the total phenolic compound, (**B**) flavonoids, (**C**) vitamin C and (**D**) antioxidant activity of apricot fruit (*Prunus armeniaca.* cv: Felkeeii) stored at 2 ± 0.5 °C, 85 ± 5% RH.

Enzyme activity (PPO and POD)

During the storage period, both PPO and POD activities were significantly influenced by the interaction between storage time and treatment ($P < 0.01$). POD activity increased throughout storage. On day 8, the control sample showed the lowest POD activity, while the 1% SA treatment exhibited the highest POD activity (Fig. 4A). By the end of the storage period, POD activity remained lowest in the control group, with no significant differences observed among the SA treatments. Regarding PPO activity, the 1.5% SA treatment showed the highest levels on days 8, 16, and 24 (Fig. 4B). PPO activity increased across all treatments during storage. The control sample consistently showed the lowest PPO activity, whereas the SA treatments exhibited significantly higher values. Among the SA treatments, the 1% SA concentration recorded the highest PPO activity.

Panel test

Sensory traits were significantly affected by the interaction between storage time and treatment ($P < 0.01$). Taste evaluation showed that the most desirable scores occurred at harvest and on day 8 of storage (Fig. 5A). By the end of the storage period, all treatments were approximately 14% less appealing in taste compared with the 1% SA treatment. As shown in Figure 5B, fruit flavor and aroma improved during storage. At the end of the storage period, the highest scores for flavor and aroma were recorded in the control and 0.5% SA treatments. Throughout storage, the 1% and 1.5% SA treatments were effective in preventing undesirable changes in flavor and aroma. Overall acceptability scores remained high for all treatments during the storage period (Fig. 5C). On day 24, both the control and 1.5% SA treatments received a score of 4. Considering that scores above 2.5 indicate consumer acceptability, these treatments can also be regarded as acceptable from the consumer standpoint.

Discussion

Apricot softening is a critical concern throughout the postharvest supply chain and is strongly influenced by cultivar, storage conditions, storage duration, and harvest maturity (Rebeaud et al., 2023). The enzymes polygalacturonase and pectin methylesterase play key roles in apricot softening during cold storage (Muzzaffar et al., 2018). SA films create an effective moisture barrier that reduces water vapor permeability and helps maintain firmness. Similar observations have been reported in previous studies, where SA (2%)-$CaCl_2$–treated strawberries (Alharaty and Ramaswamy, 2020), SA (3%)-treated cherries (Díaz-Mula et al., 2012), and SA (2%)-chitosan–treated figs (Reyes-Avalos et al., 2016) retained firmness and moisture content during cold storage.

SA coatings function as protective outer layers that reduce evaporation and transpiration, thereby helping maintain weight in various fruits, including watermelon (Sipahi et al., 2013), cantaloupe melon (Senturk Parreidt et al., 2018), bananas (Yu et al., 2024), strawberries (Yan et al., 2024), and fresh-cut apples (Sarengaowa et al., 2018). In pears, SA 2% coatings combined with other treatments delayed the activity of polygalacturonase, pectin methylesterase, and cellulase, thus contributing to improved firmness retention (Megha et al., 2023). Valero et al. (2013) also reported that SA 3% effectively inhibited ethylene production, reduced softening, acidity, and water loss, and decreased carotenoid and anthocyanin levels, thereby delaying color changes in plums during storage.

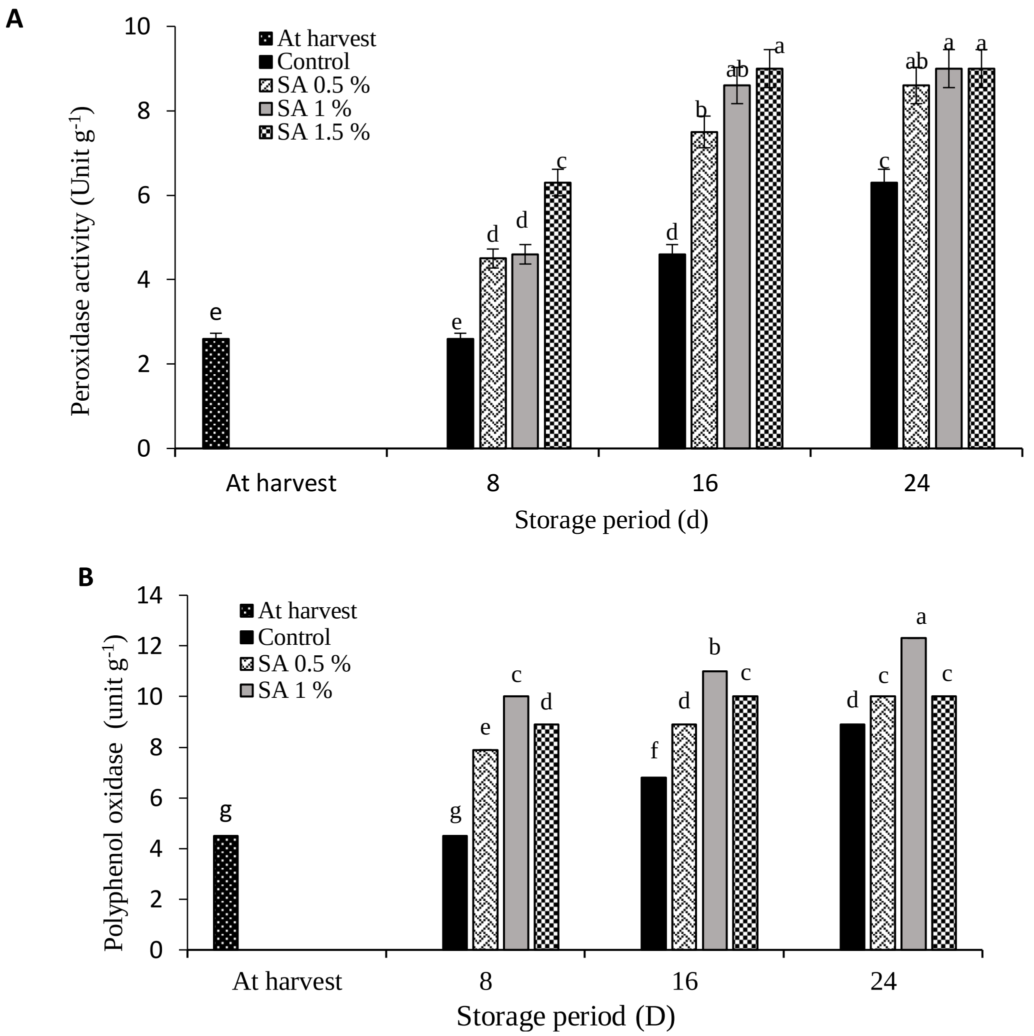
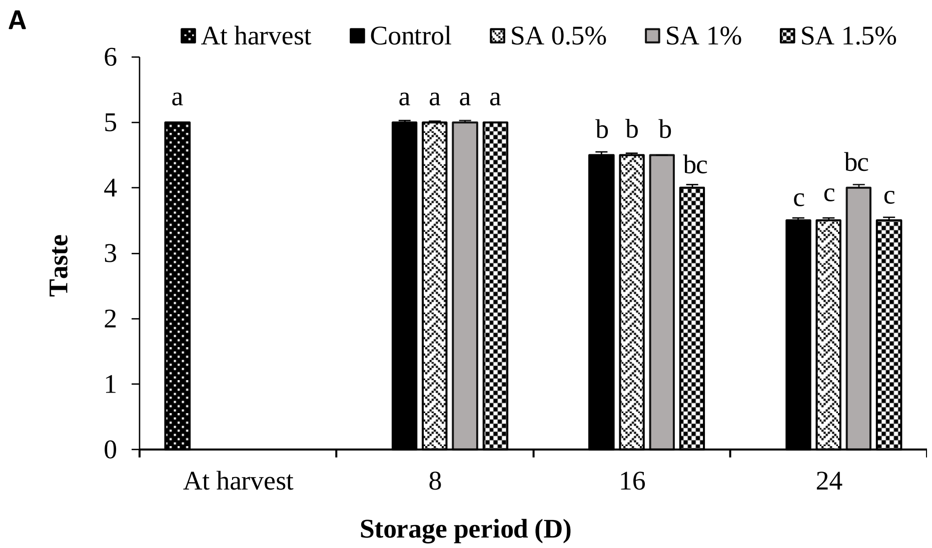
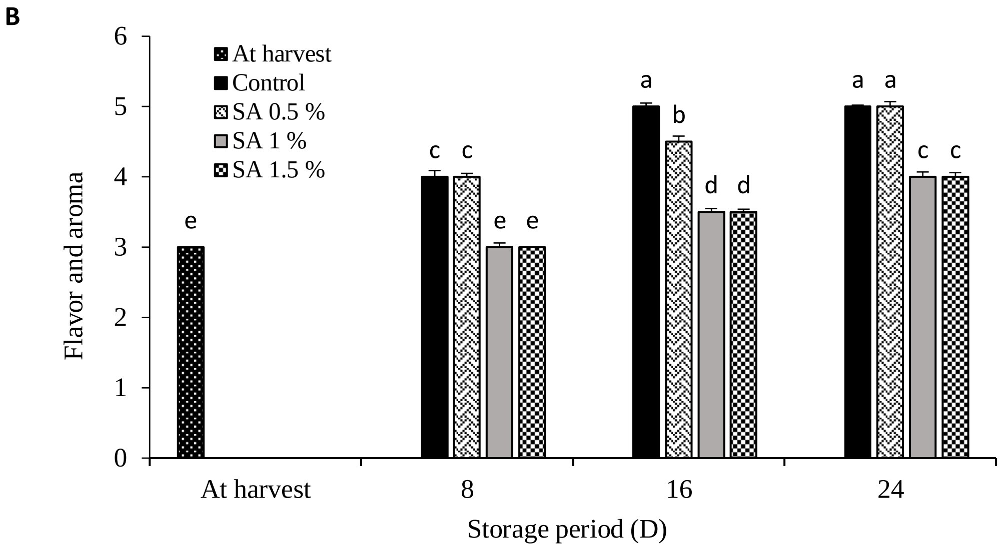


Fig. 4. Interaction effect of post-harvest immersion of Sodium Alginate treatments with storage period on (**A**) peroxidase and (**B**) polyphenol oxidase activities of apricot fruit (*Prunus armeniaca*. cv: Felkeeii) stored at 2 ± 0.5 °C, 85 ± 5% RH.





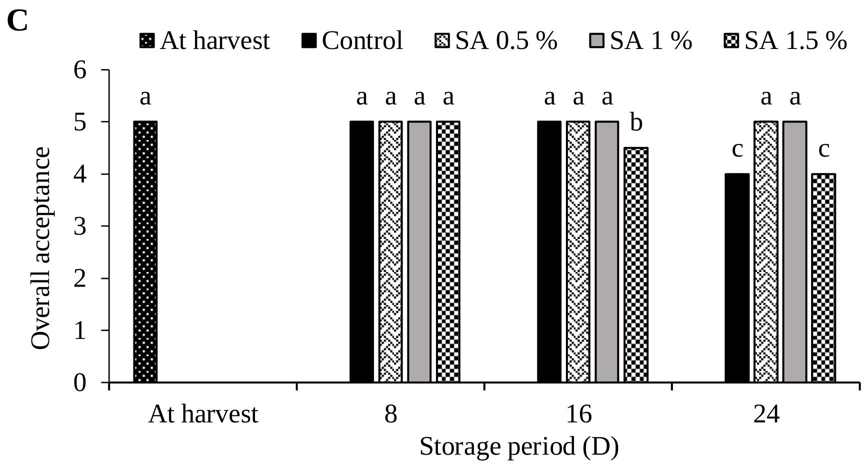


Fig. 5. Interaction effect of post-harvest immersion of sodium alginate treatments with storage period on the (**A**) taste, (**B**) flavor and aroma, and (**C**) overall acceptance of apricot fruit (*Prunus armeniaca*. cv: Felkeeii) stored at 2 ± 0.5 °C, 85 ± 5% RH.

Climacteric fruits such as apricots undergo several physiological changes during storage, including softening, increased TSS (sweetness), enhanced volatile production, and reduced TA (Rebeaud et al., 2023). The high pH of the apricot cell vacuole results from the gradual conversion of accumulated organic acids into sugars and the respiratory consumption of remaining acids. However, cold storage combined with edible coatings such as SA slows respiration and ethylene production, thereby helping maintain fruit quality, extend shelf life, and delay ripening and senescence, as demonstrated in kiwifruit (Liu et al., 2020). Previous studies on coated mangoes (Hmmam et al., 2023; Rastegar et al., 2019) showed that 1–3% SA treatments resulted in lower TSS and higher TA and pH, attributable to the barrier effect of SA, which slows respiration and reduces metabolic activity. Similar findings have been reported in strawberries (Emamifar and Bavaisi, 2020), mangoes (Yin et al., 2019), and guava (Nair et al., 2018). Sodium alginate can also be formulated with antimicrobial agents to produce films that inhibit microbial spoilage. For instance, SA films integrated with photoresponsive nanospheres have shown promise in preserving highly perishable foods (Rana et al., 2024).

Apricot fruit contains antioxidant compounds such as flavonoids, vitamin C, and carotenoids. In this experiment, TPC, vitamin C, and AA decreased during storage, while flavonoid content increased. The results showed that, except for flavonoids, all other antioxidant compounds were highest in the SA treatments. Flavonoids are a group of secondary phenolic metabolites in plants, and their synthesis in fresh produce can increase during refrigerated storage or when tissues are peeled and cut, exposing them to light (Pérez-Gregorio et al., 2011). Previous studies have reported conflicting effects of SA-based coatings on antioxidant retention. For example, SA–sunflower oil coatings did not prevent vitamin C loss in fresh-cut melon (Oms-Oliu et al., 2008a), whereas applying SA together with anti-browning agents to fresh-cut pears increased vitamin C and total phenolic content without affecting firmness (Oms-Oliu et al., 2008b). SA coatings have also been shown to maintain higher antioxidant activity and total phenolics in fresh-cut mango (Salinas-Roca et al., 2018), blueberry (Chiabrando and Giacalone, 2017), and sweet cherry fruits (Liu et al., 2021).

During storage in the present study, POD and PPO activities increased, with the highest enzyme activities observed in the SA treatments. Edible coatings enriched with natural extracts are known to enhance antioxidant activity in fruits and reduce the accumulation of free radicals during storage (Ncama et al., 2018; Singh et al., 2009). Chen et al. (2016) reported that applying SA (combined with *Ficus hirta* fruit extract) to mandarin fruits reduced weight loss, malondialdehyde content, decay, and respiration rate, while increasing the activity of defense-related enzymes. Similarly, Zhu et al. (2019) found that SA application and SA-enriched treatments were more effective in reducing PPO, POD, and cellulase activities in mushrooms. Several studies have identified a direct relationship between ethylene production and PPO activity, suggesting a signaling role for ethylene. Since apricot is a climacteric fruit, the increased PPO activity observed here may be attributed to ethylene influence (Algarni et al., 2022; Xu et al., 2021).

Considering that apricots are climacteric fruits, the lack of flavor at harvest may be due to harvesting the fruit before full ripening. By the end of the storage period, the SA 1.5% and SA 1% treatments exhibited lower flavor intensity than the other samples, likely due to their ability to slow ripening. In fresh-cut mango, the highest consumer acceptance was recorded for the SA treatment (Salinas-Roca et al., 2018). In apricot fruit, ethylene production, respiration rate, and the resulting degradation of cellular tissues all increase during the postharvest stage. Moreover, the development of chilling injury can act synergistically with fruit decay during storage (Rebeaud et al., 2023). Studies on banana (Kulviwat et al., 2023) and strawberry (Fan et al., 2009) have shown that SA application can inhibit microbial decay, which supports the findings of the present investigation.

Conclusion

The results of our study demonstrated that soaking apricot fruit in different concentrations of sodium alginate markedly influenced several quality attributes. Although apricot flavor typically declines during storage, certain aspects of flavor may still improve. Among the treatments, sodium alginate 1% showed strong potential for maintaining these sensory properties through the end of the storage period. Sodium alginate treatment effectively preserved fruit firmness, weight, total acidity, antioxidant activity, phenolic content, and vitamin C. Although sodium alginate (1.5%) exhibited the highest antioxidant activity, its effects were not significantly different from sodium alginate (1%) on day 24 of storage. However, sodium alginate treatments were not effective in controlling POD and PPO activities. Based on these findings, sodium alginate 1% appears to be the most suitable concentration for extending the shelf life of apricot fruit up to 24 days. Future research should investigate combining sodium alginate with other antimicrobial compounds to enhance its efficacy and further prolong the storage life of apricot fruits.

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Author Contributions
Lab experiments, AK; planning the experiment and preparing the manuscript, FN; analyzing the data, SHM and ME. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest
The authors indicate no conflict of interest in this work.

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