

Improving Shelf Life of Strawberry Through Application of Sodium Alginate and Ascorbic Acid Coatings

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Abstract

In the present study, effects of edible coatings using sodium alginate (SA) and sodium alginate in combination with ascorbic acid (AA) on the shelf-life extension of strawberries at $4\pm 1^\circ\text{C}$ was studied. A factorial experiment was performed based on a randomized complete block design with four replications. The treatments included control (distilled water), SA (1%, 2%, 3% w/v), SA in combination with AA (1% w/v) and the storage periods (7 and 14 days). The results showed that lightness (L^*), chroma, firmness, total acidity, vitamin C, phenols, and antioxidant activity decreased during storage, but coating improved them in the sold-stored strawberries. SA2%+AA1% coating was the best treatment in maintaining the fruit quality. Firmness, weight loss, fruit L^* , fruit chroma, sepal L^* , sepal chroma, total phenolics, and polyphenol oxidase activity were decreased by 15%, 1.95%, 16.7%, 2.66%, 10.23%, 16%, 19.47% and 2.5%, respectively for SA2%+AA1% samples at the end of the 14th day, which was lower than the untreated fruits. The results suggested that postharvest application of SA2%+AA1% has the potential to extend the storage life of strawberry fruits by reducing water loss and maintaining fruit quality.

Keywords: Edible coating, fruit decay, postharvest quality, total phenolics.

Abbreviations: AA: Ascorbic acid; PPO: Polyphenol oxidase; SA: Sodium alginate; TAA: Total antioxidant activity; TA: Total acidity; TP: total phenolic; TSS: Total soluble solids.



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Introduction

Strawberry (*Fragaria × ananassa* Duch.) is a non-climacteric fruit with unique and favorable scent and taste. This fruit is extremely perishable with a short postharvest life, mainly because of its high metabolic activity as well as susceptibility to mechanical damage, water loss and infection by phytopathogenic bacteria,

fungi, and viruses (Dong and Wang, 2017). Various techniques including freezing, hot water, controlled atmosphere, UV radiation, gamma radiation, chemical treatments, and edible coatings have been used to preserve the quantitative and qualitative traits of strawberries during storage (Dong and Wang, 2017). Incorporation of edible coatings with antioxidant agents has been promising as a tool to improve the quality

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and to extend the shelf life of strawberry fruit (Sogvar *et al.*, 2016).

Alginate coating is the salt of alginic acid and a polymer of D-mannuronic acid and L-guluronic acid (Guerreiro *et al.*, 2015) that is derived from brown seaweed of the family Phaeophyceae (Nair *et al.*, 2018). The main advantage of alginate is its usage in the production of edible films due to its unique colloidal properties and its ability to form strong gels or insoluble polymers upon reaction with multivalent metal cations such as calcium (Fan *et al.*, 2009). It has been shown that applications of alginate coating on whole fruits enhance shelf-life of strawberry (Peretto *et al.*, 2017), mandarin (Chen *et al.*, 2016), grapes (Aloui *et al.*, 2014), and carambola (Gol *et al.*, 2015) fruits. Furthermore, in guava fruit, application of alginate in combination with pomegranate peel extract and chitosan coatings maintains the fruit qualitative and quantitative traits (Nair *et al.*, 2018). Sodium alginate coating significantly reduces the microbial decay (Fan *et al.*, 2009), decreases the weight loss, maintains the firmness and improves the quality and storage properties of the strawberry fruits (Guerreiro *et al.*, 2015). It is expected that oxygen permeability of edible films can be controlled by using some antioxidants as additives in the film composition. Ascorbic acid (AA) or citric acid (CA) can be used for this purpose (Ayranci and Tunc, 2004). AA is used in many foods as an antioxidant and its derivatives have been studied on fruits, in concentrations ranging from 0.5 to 4% (w/v) (Sogvar *et al.*, 2016). Moreover, AA as an antioxidant reduces vitamin C lost; therefore, it can be added to the edible coating material such as alginate (Tapia *et al.*, 2008). There are numerous studies that reported the beneficial effects of edible coating on the horticultural products. In the following some of those studies are indicated. For instance, effects of an edible coating based on natural *Aloe vera* gel in combination with AA reduces the total aerobic mesophilic, yeast and mold

populations, dampens the weight loss and increases the total soluble solids (TSS) and vitamin C concentrations and titratable acid (Sogvar *et al.*, 2016). The antimicrobial effects of AA have been documented on some fruits such as papayas (Tapia *et al.*, 2008). Responses of 'Fuji' apple slices to AA treatments were reflected by decrease in the browning, ethylene production, and respiration rate during the storage period (Gil *et al.*, 1998). The application of alginate edible coating in conjunction with antibrowning agents (ascorbic acid and citric acid) on mango cubes maintains high color values (L^* and $^{\circ}\text{Hue}$) and increases vitamin C and total phenol contents compared to mango cubes treated only with alginate coating or control (Robles-Sanchez *et al.*, 2013). The addition of AA (1%) to alginate and gellan coatings improves the firmness, preserves the natural vitamin C and maintains the nutritional quality of fresh-cut papaya throughout storage (Tapia *et al.*, 2008). Therefore, pre and postharvest treatments are of great importance in to keep the quality of agricultural products (Abdolmaleki *et al.*, 2015; Bagheri *et al.*, 2015). Due to fast perishable nature of strawberry fruit and the importance of keeping its postharvest quality, the aim of this study was to determine the effect of SA and SA incorporated with AA as coating on the shelf-life extension of strawberry.

Materials and methods

Plant material

Strawberry (*Fragaria anannasa* cv. 'Gaviota') fruits were harvested from a commercial farm in Jiroft, Iran in spring. The fruits were picked based on their healthy, uniform color and their status as commercially mature fruits without bruises or disease and divided randomly into 60 replicates of 150 g of fruits. Four replicates were sampled immediately to assess fruit characteristics at the time of harvest (day 0). The replicates were then divided into seven treatment groups (four replicates for each of the two storage periods). The study

was done as a factorial experiment based on a completely randomized design with four replications. Sources of variation were storage life (7 and 14 days), coating treatments (control, 1% SA, 2% SA, 3% SA, 1% SA + 1% AA, 2% SA + 1% AA and 3% SA + 1% AA) and their interaction. Mean values were calculated and reported as the mean \pm standard error of means (n = 3).

Preparation of the coating

Alginate solution was prepared by dissolving sodium alginate (Sigma-Aldrich Chemic, Steinheim, Germany) powder (1%, 2% and 3% w/v) in distilled water using a magnetic stirrer for one h at a controlled temperature of 70 °C, until the mixtures became clear. To a portion of each mixture, AA (Sigma-Aldrich Chemic, Steinheim, Germany) (1% w/v) was added as an anti-browning agent.

Coating and storage conditions

The fruits were divided into seven groups and were dipped in the following solutions: (1) distilled water as control, (2) 1% SA, (3) 2% SA, (4) 3% SA, (5) 1% SA + 1% AA, (6) 2% SA + 1% AA and (7) 3% SA + 1% AA for 5 min at 20 °C. The treated samples were manually dried and placed in a polystyrene box (about 150 g) and stored at 4 \pm 1 °C with 85 \pm 5% relative humidity. At the end of the storage periods (7 and 14 days), the samples were weighed, and their quantitative and qualitative parameters were measured.

Weight loss

The weight of each replicate was recorded on the first day of the treatment and during its storage. The cumulative weight loss was obtained from the difference between the fruit weight on the first day and its weight during the storage period and was expressed as a percentage of the original fresh weight (Sogvar et al., 2016).

Firmness

Tissue firmness was evaluated using a

Digital Force Tester (Lutron fg5020, Taiwan), fitted with an 11 mm probe. Two different measurements were carried out on two opposite sides of the central zone of strawberries. The values were expressed as kilogram-force (KgF) (Guerreiro et al., 2015).

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

Total acidity was determined using 10 g aliquots of crushed fruit in 90 ml of distilled water that were titrated with 0.1N NaOH to an end-point of pH 8.1. Total acidity was expressed as the percentage of citric acid (%). An Atago digital refractometer (PAL-1 Atago, Japan) was used for TSS measurement. The pH of fruit juice was measured using a pH meter (Germany inolab720, WTW82362).

Vitamin C

The vitamin C content was determined by titration with iodine solution using oxidation-reduction reaction and expressed as mg vitamin C kg⁻¹ fresh weight (Azarakhsh et al., 2014).

Color measurement

strawberry fruits and sepals color values were directly measured using a color meter (Minolta Chroma Meter Model CR-400, Minolta, Japan). The color was measured using the lightness (L^*), red-green (a^*) and blue-yellow (b^*). The chroma value and hue angle were calculated by the following equations (Azarakhsh et al., 2014).

$$\text{Chroma} = \sqrt{(a^*)^2 + (b^*)^2} \quad \text{hue} = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$

Total antioxidant activity (TAA) and total phenolic (TP) concentrations

TAA was determined by the 2,2-diphenyl-1-picryl-hydrazil (DPPH) radical-scavenging method, according to Sanchez-Moreno et al. (1999). The absorbance was measured at 517 nm, using a spectrophotometer (lambda-Elmer Perkin, American). Total antioxidant activity was

expressed as the inhibition percentage of the DPPH radical. TP concentration in the extracts was determined according to the Folin–Ciocalteu procedure (Orthofer and Lamuela-Raventos, 1999), using gallic acid for the standard curve. The results were expressed as mg kg^{-1} of gallic acid on a fresh weight basis.

Panel test

The sensory analysis included a taste panel constituted of ten semi-trained panelists. The panelists evaluated the acceptability of the samples regarding taste, aroma, general acceptance, and browning percentage on the base of a 5-point hedonic scale, where 1 indicated extreme dislike and five indicated extreme like (Sheikhi et al., 2020).

Polyphenol oxidase (PPO) activity

The PPO activity was assayed according to the method of Kochba et al. (1977). The reaction mixture contained 0.1 mL extract, 0.1 mL guaiacol (0.5 g guaiacol/100 mL H₂O) and 1.8 mL of 0.5 mol/L potassium phosphate buffer (pH 6.5). The mixture was read immediately at 410 nm, changes in A₄₁₀ were recorded after 5 min, and expressed as unit/mg protein-min.

Statistical analysis

Data were analyzed by SAS 9.1 statistical software package, and the least significant difference (LSD) test at $P = 0.01$ or 0.05 was used to compare the means among treatments. The tables and graphs were all drawn and interpreted in MS-Excel and MS-Word software packages.

Results

Weight loss

Weight of fruits in all treatments decreased during storage. Weight loss was higher in untreated than treated fruits (Fig.1 A). Weight loss was lower in SA2% + AA1% treatment than the others. At the end of the storage, weight loss in untreated fruits was

2.97%, compared with 1.95 in SA2% + AA1% -treated fruits.

Firmness

Fruit firmness decreased during storage. The uncoated fruits showed loss their firmness after 14 days of storage (37 %), whereas, the firmness loss for coated fruits was less marked, mainly when SA+AA was used (3.9%). Furthermore, strawberries coated with SA2% + AA1% had the highest firmness values among treatments (Fig.1 B).

Total soluble solids (TSS)

In most cases, TSS increased during storage. There was significant difference among the treatments, as shown in Fig. 1C. In SA2%+AA1% treated fruits the TSS was maintained similar to uncoated fresh fruits.

Total acidity and pH

The initial pH of 3.8 of strawberries increased during storage (Fig. 1D). Still, there were significant differences among the pH values of the variously coated and uncoated fruits. SA2%+AA1% formulation maintain the pH during the storage period. The data from total acidity (TA) of the control and coated strawberries during storage are given in Table 1 and 2. The results of TA, the second most important component of the strawberry flavor, were against the pH values. TA significantly decreased ($p < 0.05$) as a function of the storage time for all coating applications. Samples treated with SA+AA1%, exhibited a slightly higher value for the TA.

Vitamin C

The vitamin C content was gradually decreased till the day 14th (Table 2). The retention of vitamin C content in SA + AA coated samples was significantly ($P < 0.05$) different from SA alone (Table 1). Vitamin C content of SA2%+AA1% coated samples were significantly different as compared to other samples.

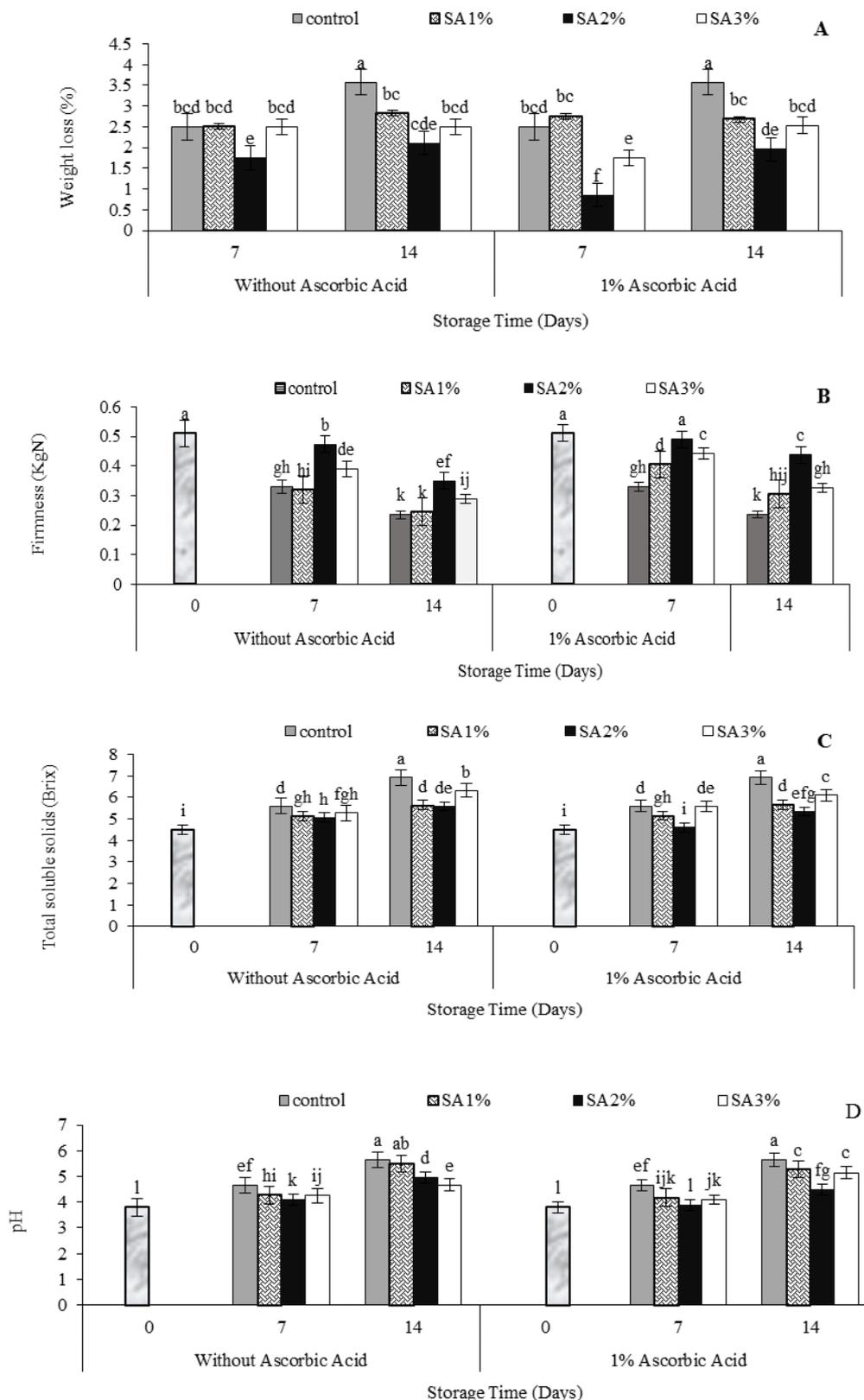


Fig. 1. Weight loss (%) (A), firmness (KgN) (B), Total soluble solids (Brix) (C) and pH (D) in strawberry fruits either untreated or treated with sodium alginate alone or sodium alginate plus different concentrations of ascorbic acid. Fruits were stored at 4±1°C for up to 14 days. Means within columns followed by the same letters, are not significantly different at p<0.05 according to the LSD test. The vertical line on the columns shows means ± standard errors.

Table 1. Total acidity (%), vitamin C (mg/100ml), and antioxidant activity (%) in strawberry fruits either untreated or treated with sodium alginate plus different concentrations of ascorbic acid. Fruits were stored at 4±1°C for up to 14 days.

		Control	Alginate 1%	Alginate 2%	Alginate 3%
Total acidity	Without Ascorbic Acid	0.434405e	0.449048d	0.483214b	0.436845e
	1% Ascorbic Acid	0.434405e	0.46369c	0.51006a	0.436845e
Vitamin C	Without Ascorbic Acid	58d	59.205d	66b	62.375c
	1% Ascorbic Acid	58d	62.855c	71.25a	62.5c
Antioxidant activity	Without Ascorbic Acid	37.125d	40.25c	42.75b	39c
	1% Ascorbic Acid	37.125d	43.125b	47a	39.875c

Means followed by the same letters, are not significantly different at $p < 0.05$ according to the LSD test.

Table 2. The effect of storage periods on total acidity (%), vitamin C (mg/100ml), and antioxidant activity (%) in strawberry fruits. Fruits were stored at 4±1°C for up to 14 days.

Storage period (days)	Total acidity (%)	Vitamin C (mg/100 ml)	Antioxidant activity (%)
Fruits before the treatment	0.55a	88a	59a
7	0.464375b	66.5775b	46.93b
14	0.442262c	57.5938c	34c

Means followed by the same letters, are not significantly different at $p < 0.05$ according to the LSD test.

Color

The color value of fruits and sepals showed that L^* and chroma decreased during storage (Fig. 2A, B, C and D), but hue angle was not significantly affected by the edible coatings and storage period (data not shown). L^* value of fruits and sepals were decreased during storage, but SA2%+AA1% treatment effectively maintained the L^* values compared to the control. Chroma value of fruits and sepals decreased significantly during storage, while in SA2%+AA1% they were maintained along the storage period. In our study, the fruits coated with SA2%+AA1% exhibited higher chroma than the other treatments.

Total phenolics (TP) and antioxidant activity (AOA)

Figure 3A represents the changes in the

TP content in strawberry fruits subjected to different coating treatments during the storage period. The maximum retention of TP was found in SA2%+AA1% coated samples, followed by SA1%+AA1% and SA3%+AA1% coated samples, at the end of day 14th. In the control, the TP content showed a sharp decline after day 7 (26.45%) of storage, which reached to the value of 46% on day 14th.

Table 1 and 2 show the changes in the antioxidant activity (AOA) of strawberries during storage. The highest AOA was recorded in SA2%+AA1% samples (47%); whereas, the lowest AOA was recorded for the control samples (37.1%). As such, the antioxidant potential was found to be comparatively higher in all the coated samples than the control.

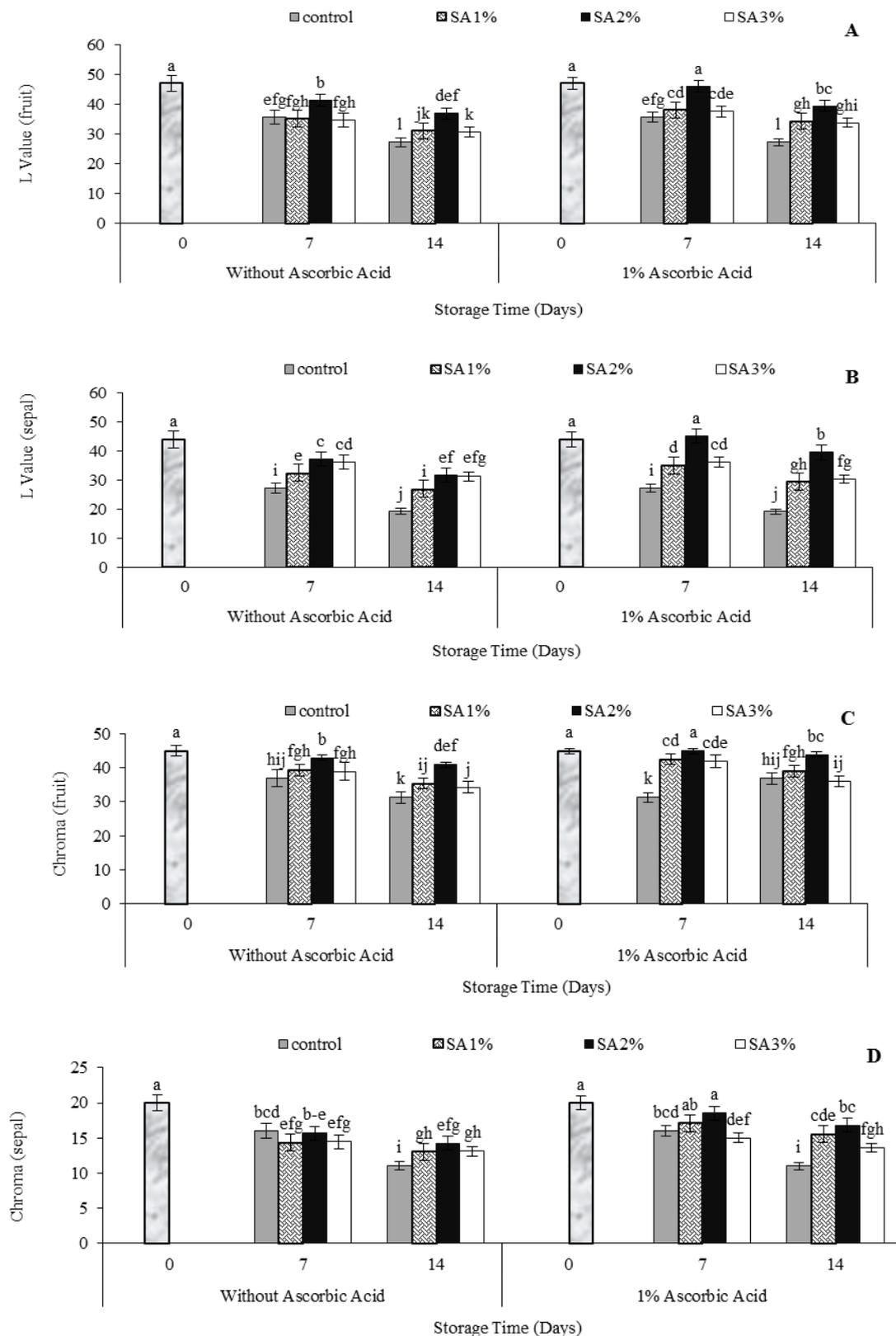


Fig. 2. L Value (fruit and sepal) and chromate index (fruit and sepal) of strawberry either untreated or treated with sodium alginate or sodium alginate plus different concentrations of ascorbic acid. Fruits were stored at 4±1°C for up to 14 days. Means within columns followed by the same letters, are not significantly different at p<0.05 according to the LSD test. The vertical line on the columns show means ± standard errors.

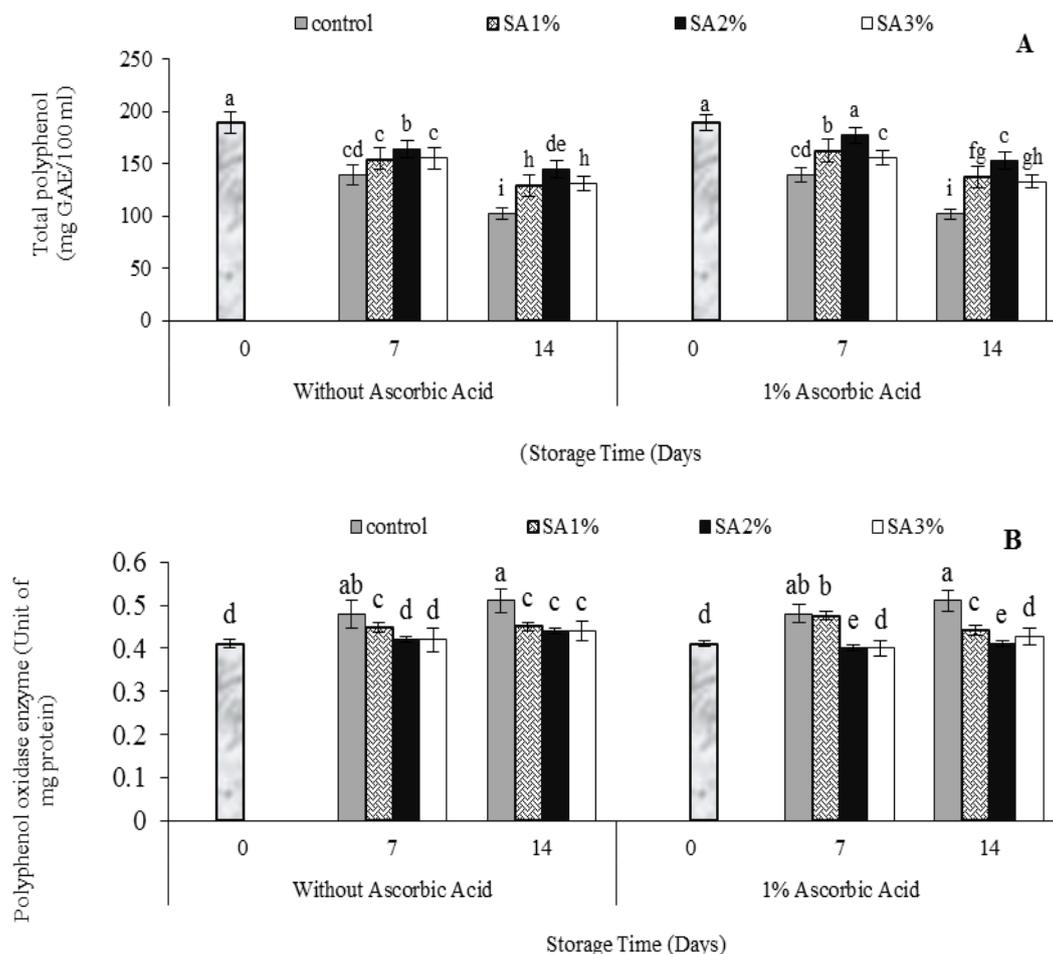


Fig. 3. Total polyphenol (A) and polyphenol oxidase enzymes (B) in strawberry fruit either untreated or treated with sodium alginate plus different concentrations of ascorbic acid. Fruits were stored at $4\pm 1^{\circ}\text{C}$ for up to 14 days. Mean within a column followed by the same letter, are not significantly different at $p < 0.05$ according to the LSD test. The vertical line on the columns show means \pm standard errors.

Polyphenol oxidase (PPO) activity

The activity of PPO in strawberries increased during storage (Fig. 3B). However, SA treatment reduced or delayed the increases in PPO activity. This indicated that combined treatment of SA and AA could inhibit oxidative enzymatic activity during storage.

Panel test

The results from the sensory panel revealed that the highest scores were given to coated strawberry for all the assayed parameters, especially for those fruits coated with SA2%+AA1% (Fig. 4). It was observed that browning percentage of coated fruits was lower than the non-coated. The

browning percentage of the fruits coated with SA2%+AA1% was lower than the other treatments. The overall quality (acceptability by consumers) was in turn significantly higher in coated fruits; the highest scores were given to the fruits coated with SA2%+AA1%. Besides, any presence of 'off-flavor' was detected neither in coated nor in control strawberries at the end of the experiment. Finally, panelists given the highest scores for quality parameters to coated fruits without any detrimental effects on flavor and, or aroma of strawberry with SA2%+AA1% coating.

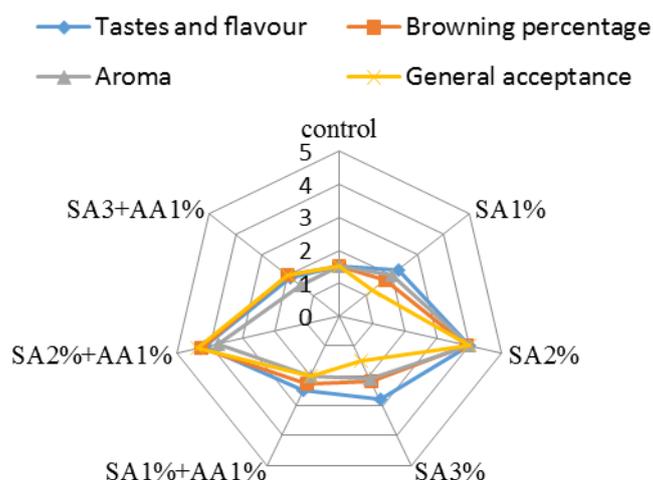


Fig. 4. Tastes and flavor, aroma, general acceptance, and browning percentage in strawberry fruits either untreated or treated with sodium alginate or sodium alginate plus different concentrations of ascorbic acid. Fruits were stored at $4\pm 1^\circ\text{C}$ for up to 14 days.

Discussion

Coating the strawberry fruits with SA+ AA was effective in conferring a physical barrier to moisture loss and therefore retarding dehydration and fruit shriveling (Fig. 1A). Weight loss mainly occurs due to water loss by transpiration and loss of carbon reserves due to respiration (Hernandez-Munoz *et al.*, 2008). The rate at which water is lost depends on the water pressure gradient between the fruit tissue and the surrounding atmosphere. Fan *et al.*, (2009) found that sodium alginate treatment (SA 2%) reduces the water loss in strawberry and extends its shelf-life. This positive effect of edible coatings is based on their hygroscopic properties, which enables the formation of a water barrier between the fruit and the environment (Sogvar *et al.*, 2016). The combinations of SA with AA1%, especially 2% SA, had the most significant effect on reducing weight loss. Similarly, it has been reported that coated strawberry fruits with 0.03% *Aloe vera* (AV) gel + 5% AA (Sogvar *et al.*, 2016), coated apple fruits with 1% chitosan + 2% AA + 0.5% Calcium chloride (Qi *et al.*, 2011) and coated plum fruits with sodium alginate 1% and 3% (Valero *et al.*, 2013) decreased the weight loss compared with uncoated

fruits. The results of some researchers suggest that AA treatments have more than a physical effect, as the addition of AA may not affect the barrier, but fruit physiology as less ripe fruits have lower rates of water loss (Sogvar *et al.*, 2016).

Firmness is an essential factor that influences the consumer acceptability of fresh fruit (Wang and Gao, 2013). Strawberries considerably soften during storage, which results in short postharvest life and susceptibility to fungal contamination. Degradation of the middle lamella of the cell wall of cortical parenchyma cells, cell wall strength, cell to cell contact and cellular turgor may influence the fruit firmness. Strawberry fruit firmness decreased during cold storage in agreement with some reports on 'Parous' (Sogvar *et al.*, 2016). Here, coatings slowed softening (Fig. 1 B), probably due to the effects of SA + AA on fruit, which act as a barrier for O_2 uptake thereby slowing the metabolic activity, and consequently the ripening process. Another reason may be that the film prevented the loss of moisture from the fruit, similar to some previous reports (Sogvar *et al.*, 2016, Fan *et al.*, 2009, Azarakhsh *et al.*, 2014). In a recent study reported by Peretto *et al.*, (2017), the effective gas barrier properties exerted by

the alginate coating could reduce the metabolic activity of strawberries and maintain a better fruit firmness.

The TSS presented in fruits contain important components, especially sugars and organics acids, that are responsible for the taste and consequent consumers' acceptance of the product. Non-climacteric fruits, like strawberries, usually exhibit a reduction in TSS content during storage. The reason is that at harvest time, these fruits present low or no energy source as starch, therefore, they use the sugars present in the fruit as an energy source for respiration, which results in the reduction of TSS content of the fruits. However, in this study TSS increased during storage in most cases. With SA2%+AA1% treatment the TSS was maintained similar to control (Fig. 1C). During storage, some other researchers (Tanada-Palmu and Grosso, 2005; Hernandez-Munoz et al., 2008) observed an increase in the TSS content of strawberries that were covered with a gluten-based and chitosan-based edible coating, respectively. This increase can be explained considering the high water loss observed in these two works, which resulted in TSS concentration. The solubilization of the cell wall polyuronides and hemicelluloses in ripe strawberry might also contribute to the increase in TSS (Tanada-Palmu and Grosso, 2005). Similar results have been reported in the case of guava coated with alginate and chitosan enriched with pomegranate peel extract (Nair et al., 2018), mandarin coated with alginate enriched with *Ficus hirta* fruit extract (Chen et al., 2016), fresh-cut nectarines coated with alginate (Chiabrande and Giacalone, 2016); apples coated with pullulan enriched with sweet basil extract (Synowiec et al., 2014), sweet cherry coated with alginate (Diaz-Mula et al., 2012) and tomatoes coated with alginate and zein (Zapata et al., 2008). These results differ from those reported by Gol et al. (2013) and Velickova et al. (2013) who showed a decrease in the total

soluble solids content in strawberries, at the end of the storage, when using other edible coatings. Duan et al. (2011) approved that blueberries TSS, was not significantly affected by cold storage or sodium alginate and chitosan treatments.

The pH of fruits increased during storage although, SA2%+AA1% kept the initial value of fruit pH (Fig 1D). The increase in pH may be related to the consumption of organic acids by the respiration process during the storage. Opposite to the finding of present study, Velickova et al. (2013) reported that application of chitosan-beeswax edible coatings decreases the pH of fresh strawberries. Total acidity (TA) decreased during storage for all coating applications and samples treated with SA+AA1%, exhibited a slightly higher value (Tables 1 and 2). Usually, TA decreases over storage as the organic acids used during the respiration process (Gol et al., 2015). In this study, SA2%+AA1% treatment could preserve TA and pH as compared to control (Table 1). SA+AA coating could produce a modification of the internal atmosphere, showing similar effects as modified atmosphere packaging (MAP) (Martinez-Romero et al., 2003) and could act as a gas barrier to reduce oxygen uptake by the fruit that in turn slows down the respiration rate. AA reduces the activity of oxidizing enzymes, especially PPO, because of its acidic and antioxidant nature. Then, the consumption of organic acids is postponed in metabolic reactions. These results are in consistent with the studies on fresh-cut apples (Rojas-Graü et al., 2007b).

Vitamin C acts as an antioxidant by scavenging the free radicals produce in fruits and thereby prevents their degradation, which begins during fruit ripening due to the oxidation process (Ayranci and Tunc 2004). Vitamin C decreased throughout the storage period, which may be due to the action of vitamin C oxidase, which converts vitamin C to

dehydroascorbate, and also phenol oxidase (Suseno et al., 2014). The increase in pH by enzymatic activity is another reason for the loss of vitamin C content. Some researchers have blamed the oxidative processes for the degradation of vitamin C in fruit tissues and have found that these processes are accelerated in the presence of light, oxygen, heat, and oxidizing enzymes (Plaza et al., 2004). Edible coating results in lower oxygen permeability followed by reduction in the enzyme activity and thereby, resulting in the reduction of vitamin C oxidation (Wang and Gao, 2013). Use of alginate coating on some fruits such as carambola (Gol et al., 2015), mandarin (Chen et al., 2016), tomato (Zapata et al., 2008), guava (Nair et al., 2018) effectively retain the vitamin C levels during storage. In our study, vitamin C content was preserved in the combined application of alginate with AA (Tables 1 and 2). It was found that vitamin C loss on some fruits such as apricots and green peppers (Ayranci and Tunc, 2004), mango cubes (Robles-Sanchez et al., 2013), apple slices (Rojas-Grau et al., 2007a), and fresh-cut pears (Oms-Oliu et al., 2008) treated with coatings containing AA, is slightly lower than those with coatings containing other antioxidants. Preventing loss of vitamin C in foods with coatings containing antioxidants (AA or CA) can be attributed to the low oxygen permeability of these coatings (Ayranci and Tunc, 2003). AA has a detoxifying property for free radicals of the hydroxyl group, superoxide anion, and hydrogen peroxide through the ascorbate peroxidase reaction. Thus, it prevents oxidative damage in fruits and vegetables (Nair et al., 2018).

Strawberry color is one of the important attributes for consumer acceptance. The changes in the external color was monitored by measuring lightness (L^*), chroma and hue angle. The L^* value is a measure of the lightness of the sample; the chroma value describes its brightness while the hue angle represents a coordinate in a

standardized color space (Guerreiro et al., 2015). As storage time progresses, strawberries undergo a color change so that the fruits become darker and their surface browns (Hernandez-Munoz et al., 2008). A decrease in L^* value is indicative of browning of the tissues. This darkening during storage is related to the increased synthesis of anthocyanins and moisture loss. The advantage of coatings in preserving the color of strawberries arises from their effect on reducing fruit darkening during storage that happens because of the high sensitivity of the fruits to oxidation (Guerreiro et al., 2015). In this study, coating treatments helped maintaining the color of fruits (Fig. 2 A, B, C and D). Other studies have also demonstrated the positive effects of alginate coatings on the color parameters of mangoes (Robles-Sanchez et al., 2013) and pineapples (Azarakhsh et al., 2014), which were related to the decreased activity of PPO enzyme. Besides, antibrowning agents such as ascorbic acid and citric acid inhibit the PPO functioning as a reducing agent (o-quinones to diphenols) and as pH redactor. L^* values of pear juices with 0.20 and 0.24% added AA decreased more slowly than controls lacking AA addition (Jiang et al., 2016). The Robles-Sanchez et al. (2013), proved that the application of sodium alginate in conjunction with AA to mango cubes maintained their color (L^* and Hue). Similarly, Moline et al. (1999) found that the combined treatment of AA and citric acid reduced the browning of bananas. In our study, the SA alone did not delay fruit browning. Thus, along with increased storage time, the fruit became redder and darker.

Phenolics are the secondary metabolites present in fruits and vegetables that possess antioxidant activity by capturing free radicals, produced during oxidative stress. They are also capable of auto-oxidation prevention, chelation of metal ions and could cause modulation in the activity of

some enzymes (Peretto et al., 2017). The rapid decline in the TP content in control may be attributed to its higher respiration rate resulting in the breakdown of total phenols and oxidation of the phenols by PPO and peroxidase enzymes (Duan et al., 2011). Our coating treatments were effective in TP retention (Fig. 3 A). Earlier studies have also demonstrated the restricted loss in the TP as the effect of coating in various fruits such as guavas coated with chitosan and alginate based coatings enriched with pomegranate peel extract (Nair et al., 2018), strawberries coated with alginate in combination with carvacrol and methyl cinnamate (Peretto et al., 2014), strawberries coated with *Aloe vera* and ascorbic acid (Sogvar et al., 2016), strawberries coated with chitosan enriched with peony extracts (Pagliarulo et al., 2016), blueberries coated with alginate and chitosan (Chiabrande and Giacalone, 2015) and plums coated with alginate (Valero et al., 2013). It has been reported that the antibrowning activity of ascorbic acid (AA) with sodium alginate could maintain the phenolic concentration and antioxidant activity of fresh-cut mangoes throughout the storage (Robles-Sanchez et al., 2013). Similarly, the use of AA as a reducing agent prevents decrease of the phenolic content in fresh-cut apples (Gil et al., 1998).

Maintaining AOA with alginate coating occurred in the present study on strawberry fruits (Tables 1 and 2), which also has been reported on other fruits such as table grapes (Aloui et al., 2014), mandarin (Chen et al., 2016), mangos (Robles-Sanchez et al., 2013), guavas (Nair et al., 2018), and cherries (Aloui et al., 2014). Edible coatings tend to modify the internal atmosphere resulting in slowing down the metabolism in fresh products. During storage, secondary metabolites such as phenolics and vitamin C accumulate, causing an increase in the antioxidant levels. Nair et al. (2018) reported higher levels of TP content and AOA in chitosan

and alginate coated fruits during storage. Combination of *Aloe vera* coating and AA retarded the loss of antioxidant activity of strawberries. The decline in antioxidant activity in samples might be due to senescence and decay at the storage period. AA has the capacity to retain fruit quality attributes, decrease decay rate, and the inhibition of enzymes that degrade antioxidant compounds (Sogvar et al., 2016).

Another major part of plant antioxidant system is the involvement of antioxidant enzymes. Antioxidant enzymes may reduce the energy of free radicals or cause them to give up some of their electrons, thereby becoming stable. All antioxidant enzymes are essentially catalysts- complex molecules stimulating chemical reactions without becoming consumed or integrated into the response (Shull et al., 1991). Antioxidant enzymes may stop the free radicals from forming, and they may also interrupt an oxidizing chain reaction to minimize the damage caused by free radicals. Therefore, the main function of antioxidant enzymes is neutralizing free radicals (Shull et al., 1991). PPO enzymes catalyze the *o*-hydroxylation of monophenols to *o*-diphenols. PPO can also further catalyze the oxidation of *o*-diphenols to produce *o*-quinones. Rapid polymerization of *o*-quinones produces polyphenols that are the cause of fruit browning. In this study, it was indicated that combined treatment of SA and AA could inhibit PPO activity during storage (Fig. 3 B). A similar result has been previously reported by Chiabrande and Giacalone (2016), on fresh-cut nectarines. Overall, coatings have inhibitory impacts on oxygen, and thereby, they reduce the contact of different parts of the product with the surrounding oxygen. This inhibits the activity of PPO enzyme and mitigates oxidation reactions. AA plays a particular role in reducing PPO activity and can, also, reduce enzymatic browning by reducing pH (He and Luo, 2007). Additionally, the

incorporation of AA into sodium alginate reduces the activity of this enzyme even further by contributing to the preservation of high vitamin C content.

In the case of panel test, the participants of the panel test assigned a score from 1 to 5 to the attributes of tastes, aroma, general acceptance, and browning percentage. Score 5 meant the best and score 1 meant the worst quality. The tastes and aroma are usually detected differently by the panelists, so they have to be assessed by trained sensory panelists to determine the human perception of these attributes. Test panel results revealed that the highest scores are given to coated fruits for all the assayed parameters, especially for those fruits coated with SA2%+AA1% (Fig. 4) without any detrimental effects on flavor or aroma as there was not any off-flavor reported by panelists.

Conclusions

The results of present study showed that the fruits of strawberry undergo changes during cold storage and the use of SA and AA as edible coating exert some beneficial effects on fruits during storage by retarding the ripening process and applying changes triggered by the plant hormones, such as color changes and loss of firmness. It appears that strawberries can be kept for almost two weeks along with preservation of their quantitative and qualitative traits if they are kept at $4\pm 1^{\circ}\text{C}$ and are coated with edible SA and AA. Pre-harvest application of these substances or their combined applications with waxes as better water barriers are issues that need investigation in the future.

Conflict of interest

All authors agree on the content of the paper and have no conflict of interest to disclose.

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