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Research Article

Potential of chia seed gum as an edible coating for preserving quality of blood orange fruit (*Citrus sinensis* (L.) cv. 'Moro') under ambient storage conditions

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ABSTRACT- Blood oranges are susceptible to various fungal infections and biochemical changes that contribute to quality deterioration during storage. This study investigated the effect of chia seed gum (CSG) coatings at different concentrations (0.25%, 0.5%, and 0.75%) on weight loss (WL), fruit juice content, total soluble solids (TSS), peel color, browning index (BI), and decay index (DI). The results showed that oranges coated with 0.75% CSG experienced a slower reduction in weight, juice content, and *b** value during storage compared to the other treatment groups. Uncoated samples exhibited higher WL, TSS, *a**, and chroma values than the coated fruits. Moreover, the BI and DI were significantly lower in the coated oranges. The coatings helped reduce moisture and juice loss, thereby maintaining fruit quality during storage. Based on these findings, postharvest treatment with 0.75% CSG is recommended as an effective method to preserve quality and extend the shelf life of blood oranges.

INTRODUCTION

Oranges are widely recognized as health-promoting fruits due to their richness in important antioxidants such as vitamin C, carotenoids, flavonoids, and dietary fiber. Growing consumer awareness of these health benefits has expanded the use of oranges in various food industry applications (Wang et al., 2025). Blood oranges, a group of sweet orange (*Citrus* × *sinensis*) cultivars, are distinguished by their red pigmentation, which results from the presence of anthocyanins in the rind and flesh. The three most common blood orange varieties are Moro, Sanguinello, and Tarocco. Among them, the Moro variety is the most intensely pigmented and is known for its sweet flavor with a hint of raspberry. This variety is particularly valued for its high content of anthocyanins and polyphenolic pigments, which exhibit anti-cancer properties and contribute to overall human health (Grosso et al., 2013). However, blood oranges are vulnerable to various postharvest disorders, including oxidative damage leading to membrane lipid peroxidation, weight loss (WL), senescence, fungal infections, and degradation of pigments such as anthocyanins and carotenoids (Habibi et al., 2021). These biochemical changes during storage can negatively affect the fruit's quality, safety, and marketability (Rovetto et al., 2023). Therefore, managing physiological disorders and identifying effective postharvest treatments to preserve nutritional value are essential (Tahir et al., 2019). Edible coatings can play a key role in reducing postharvest deterioration by forming a protective barrier between the fruit and the external environment, thereby limiting gas exchange (Pandya et al., 2023). Gums are natural polysaccharide polymers commonly derived from plants. They are capable of hydrating in water and forming gels. When used in edible coating formulations, gums can help control postharvest diseases and extend the shelf life of fruits and vegetables (Tahir et al., 2019). Chia (*Salvia hispanica* L.), an annual herb in the Lamiaceae family, is a rich source of fatty acids, protein, vitamins, minerals, and antioxidants (Timilsena et al., 2016). Chia seed gum (CSG), extracted from chia seeds, possesses favorable rheological properties such as viscoelasticity and high water-holding capacity, making it a promising candidate for use in edible coatings (Li et al., 2023). Previous studies have shown that incorporating CSG into edible coatings helps preserve the physicochemical properties of oranges by restricting gas exchange and maintaining sensory attributes during storage (Heidari Krush et al., 2025). Moreover, chia seed mucilage has demonstrated antifungal and antioxidant activities, supporting its potential use as a postharvest coating for fruits and vegetables (Charles-Rodriguez et al., 2020). In another study, CSG-coated strawberries showed reduced activity of oxidative enzymes, effectively maintaining fruit quality and

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extending shelf life (Mousavi et al., 2021). Based on this evidence, the present study investigated the effect of CSG on the storage life and quality maintenance of blood orange fruit (cv. 'Moro').

MATERIALS AND METHODS

Materials

Blood oranges (*Citrus sinensis* (L.) Osbeck cv. 'Moro') of uniform color and size were harvested from a citrus orchard in Kazerun, located in the northwest of Fars Province, and transported to the laboratory at Shiraz University for postharvest evaluation during storage. For disinfection, the fruits were immersed in a 10% sodium hypochlorite solution for 60 seconds, rinsed with sterile water, and air-dried at room temperature. CSG was obtained from Reyhan Gum Parsian (Tehran, Iran). CSG solutions at concentrations of 0.25%, 0.5%, and 0.75% (w/v) were prepared by dissolving the gum in distilled water using a homogenizer (Heidolph RZR 2102 control, Germany) (Fig. 1A) at 200 rpm for approximately 2 hours. Glycerol, at 50% of the gum's dry weight, was then added as a plasticizer (Fig. 1B). The experiment was conducted using a completely randomized design in a factorial arrangement (four treatments × two storage periods), with three replications and one fruit per replication. Fruits were dipped in the prepared coating solutions for 5 minutes, then allowed to dry completely before being placed on perforated steel trays and stored at 21 ± 1 °C. To better observe postharvest changes, assessments were carried out every 5 days over a 30-day storage period. Uncoated fruits served as the control group.

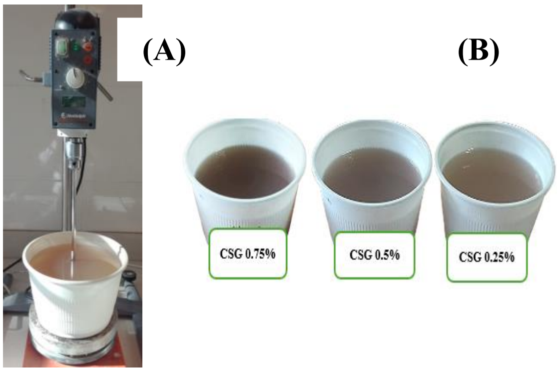

Fig. 1. Preparation of chia seed gum solution, using a homogenizer (A), different concentrations of prepared CSG solution (B).

Weight loss (*WL)*

Initially after the coating dried, the weight of blood oranges was measured. The WL was calculated as a percentage of the initial weight (Ma et al., 2025).

Visual quality

To measure freshness and visual quality, blood oranges were scored from 1 to 4 according to their appearance. In this way, oranges that maintained their freshness, and had the highest quality, received a score of 4, and fruits with lower quality received a lower score (Kowalska et al., 2023).

Fruit juice content

An electric juicer (Pars Khazar, Iran) was used for extracting fruit juice. Juice content was determined as a percentage, based on the initial weight of the fruit (Karki et al., 2024).

Total soluble solids (TSS)

TSS measurement was done using a drop of orange juice by a digital refractometer (Atago, Japan).

Peel color (L, a*, b*, and chroma)*

Colorimeter (CR-400, EC Minolta, Japan) was used to measure peel color changes during storage. Some color parameters such as L^* (blackness to whiteness), a^* (greenish to reddish colors), b^* (bluish to yellowish colors), and chroma ($C = \sqrt{a*^2 + b*^2}$) were evaluated (Pathare et al., 2013).

Browning index (BI)

Based on L^*, a^* and b^* values, BI of blood oranges were evaluated and calculated using Eq. (1) and Eq. (2) (Heidari Krush & Rastegar, 2023).

$$BI = \frac{[100\ (x - 0.31)}{0.17} \quad \text{Eq. (1)}$$

where

$$x = \frac{(a* + 1.75\ L*)}{(5.645\ L* + a* - 3.012\ b*} \quad \text{Eq. (2)}$$

Decay index (DI)

The DI was visually assessed using a scoring decay symptom, as following scale: 0 = no decay symptoms, 1 = less than 1/4 decay, 2 = 1/4–1/2 decay, 3 = 1/2–3/4 decay, and 4 = more than 3/4 decay symptoms (Rasouli et al., 2019). The DI was calculated as a percentage using Eq. (3).

$$DI = 100 \times \sum [(\text{DI scale}) \times (\text{number of fruits at the DI scale})] / (5 \times \text{total number of fruits}) \quad \text{Eq. (3)}$$

Data analysis

The experiment was conducted as a factorial experiment under a completely randomized design. SAS 9.4 (Tallahassee, FL, USA) and GraphPad Prism 10.3.2 (San Diego, CA, USA) were used to data analysis and means were compared by Duncan's multiple-range test at a probability level of $P < 0.05$.

RESULTS

Weight loss (*WL)*

As storage progressed, WL in the oranges increased. Analysis of variance (Table 1) indicated that both storage time and treatment had significant effects on WL, while their interaction was not statistically significant. The lowest WL was observed in oranges treated with 0.75% CSG, ranging from 10.6% on day 5 to 33.61% by day 30 of storage (Fig. 2A and Fig. 2B).

Visual quality

After 30 days of storage, the visual quality of the blood oranges was significantly reduced, as shown in Fig. 3. In contrast to uncoated fruits, the treated fruits showed fewer alterations. The 0.75% CSG and 0.5% CSG coated fruits showed a better trend in preserving quality than other groups at the end of storage (Fig. 3).

Fruit juice content

Juice content in all experimental groups decreased during storage (Fig. 4). However, oranges treated with 0.75% CSG maintained significantly higher juice content (51.07%) compared to the untreated control (36.06%) and other treatment groups ($P < 0.05$). Additionally, oranges coated with 0.25% CSG retained more juice than those treated with 0.5% CSG (Fig. 4).

Total soluble solids (TSS)

As shown in Fig. 5, TSS increased over the 30-day storage period. The highest TSS values were observed in uncoated oranges, while the smallest changes occurred in fruits treated with 0.75% CSG. Among the coated samples, oranges treated with 0.5% CSG maintained higher TSS levels during storage compared to those treated with 0.25% CSG (Fig. 5).

Table 1. Analysis of variance of quantitative traits of blood orange fruit

Source of Variation	df	Weight loss (%)	Chroma	L*
Time	1	2823.2^{**}	12.51^{ns}	147.85^{**}
Treatment	3	7.45^{*}	35.74^{**}	5.68^{ns}
Time * Treatment	3	1.080^{ns}	22.69^{*}	9.85^{ns}
CV		5.60	3.94	5.28

Values followed by **, * and ns are significant at the 1% and 5% probability levels, and non-significant, respectively.

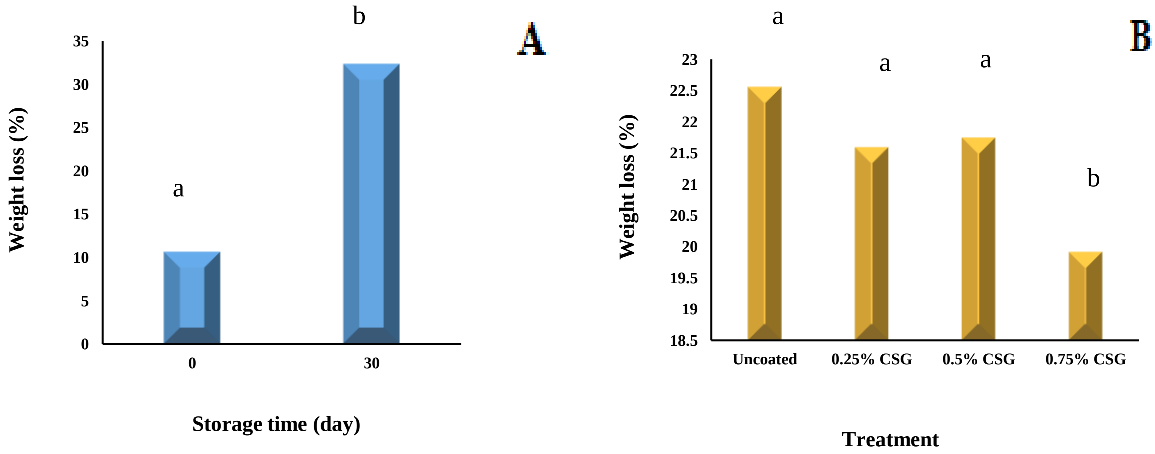

Fig. 2. Comparison of the mean effects of storage time (A) and treatments (B) on weight loss in blood orange fruit, stored for 30 days at 21 °C.

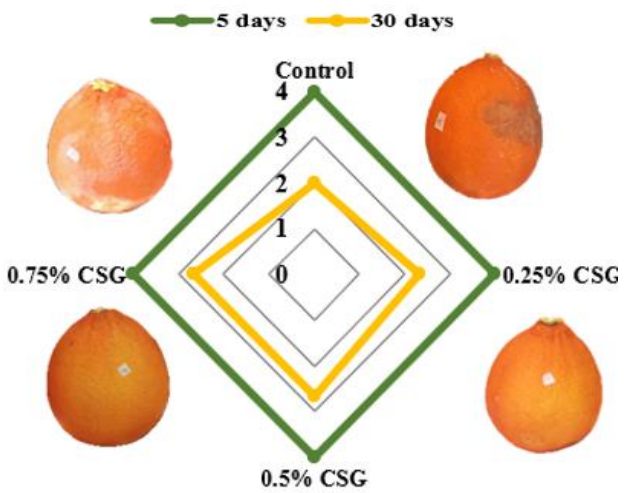

Fig. 3. Visual quality in uncoated and coated orange fruit in uncoated and coated blood orange fruit, stored for 30 days at 21 °C.

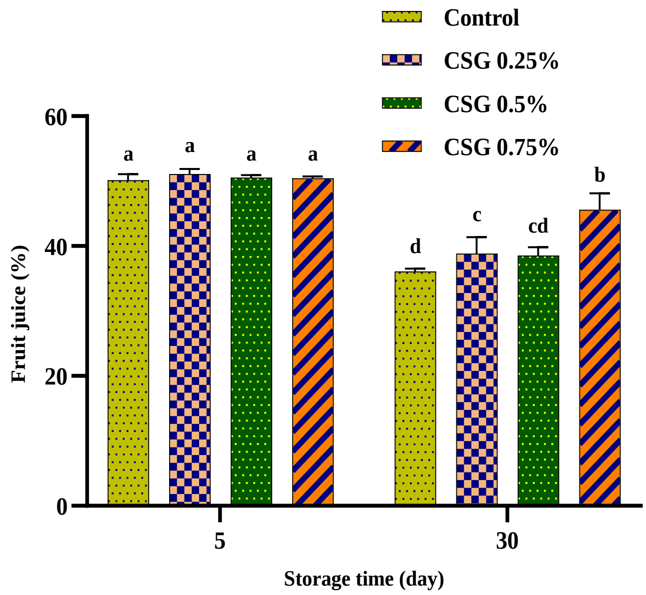

Fig. 4. Fruit juice content in uncoated and coated blood orange fruit, stored for 30 days at 21 °C. The data are the average of three replicates ± standard errors. Different letters in figure represent significant ($P < 0.05$) differences based on the significant difference test (Duncan).

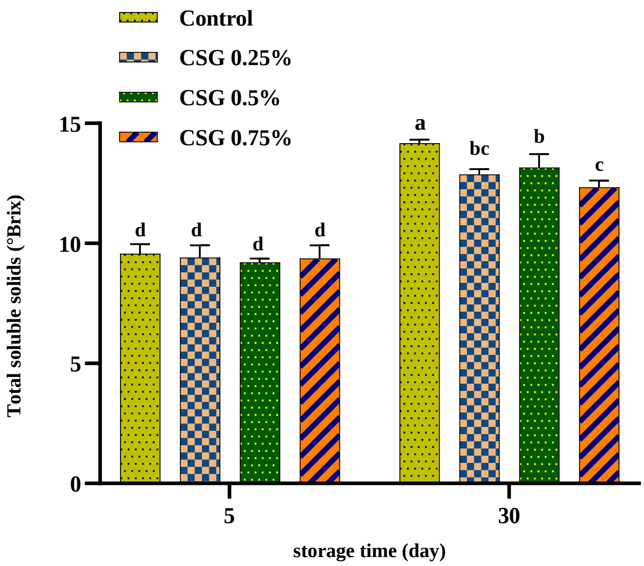

Fig. 5. Total soluble solids in uncoated and coated blood orange fruit, stored for 30 days at 21 °C. The data are the average of three replicates ± standard errors. Different letters in figure represent significant ($P < 0.05$) differences based on the significant difference test (Duncan).

Peel color

After 30 days of storage, the a^* value increased while the b^* value decreased across all experimental groups (Fig. 6A and Fig. 6B). Oranges treated with 0.75% CSG exhibited significantly ($P < 0.05$) smaller changes in both a^* and b^* values compared to the control, 0.25% CSG, and 0.5% CSG treatments. No significant differences in b^* values were observed between the 0.25% and 0.5% CSG treatments (Fig. 6A and Fig. 6B). A significant decrease in L^* value occurred over the storage period, although treatment type had no significant effect on L^* (Table 1). Chroma values did not change significantly over time; however, both the treatment and the interaction between storage time and coating type had a significant effect on chroma ($P < 0.05$). The lowest chroma values were recorded in the 0.75% CSG group throughout the 30-day storage period.

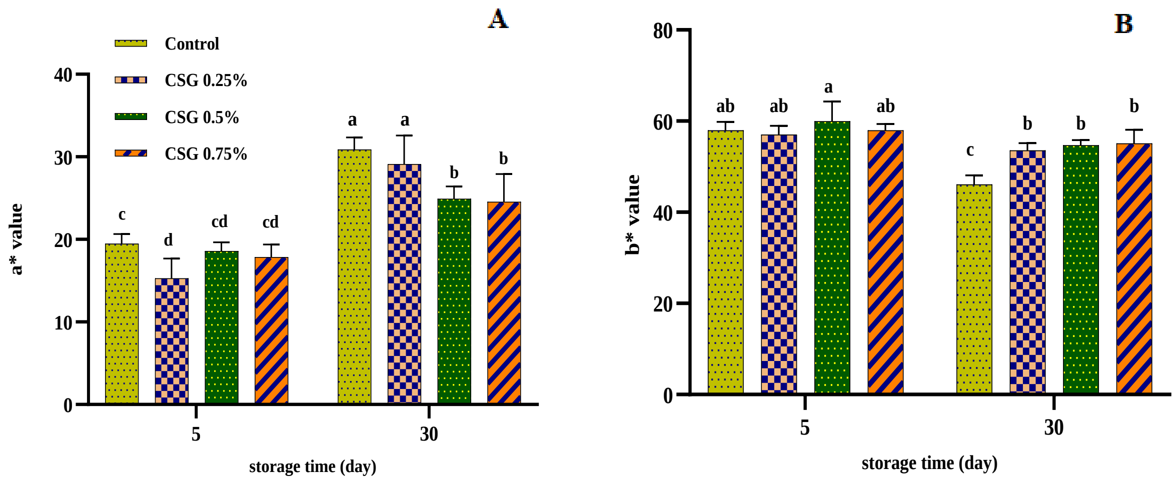

Fig. 6. The *a** and *b** values in uncoated and coated blood orange fruit, stored for 30 days at 21 °C. The data are the average of three replicates ± standard errors. Different letters in figure represent significant (P < 0.05) differences based on the significant difference test (Duncan).

Browning index (BI)

As shown in Fig. 7, BI increased during storage in all treatments, especially control samples, which demonstrated the most significant increase after 30 days of storage. At the end of the storage, the lowest BI values were observed in the 0.75% CSG treatment, followed by the 0.5% CSG treatment.

Decay index (DI)

Fig. 8 indicates that 0.75% CSG significantly decreased the percentage DI in blood oranges compared to other groups. Whereas the highest percentage of decay was observed in control samples. Higher DI was recorded in 0.25% CSG coated oranges than 0.5% CSG treated samples (Fig. 8).

Heatmap analysis

The correlation coefficient values between experimental groups and physiological parameters of blood orange fruit over a 30-days storage period are shown in Fig. 8. The results indicated that increased WL, TSS along with higher *a** value, BI, and DI (green color spectrum), corresponded with reduction in fruit juice content, *L** value, *b** value, and chroma (yellow color spectrum), indicating a negative correlation between these factors (Fig. 9). The least changes after 30 days were observed in the 0.75% CSG group, as shown by paler colors in Fig. 9.

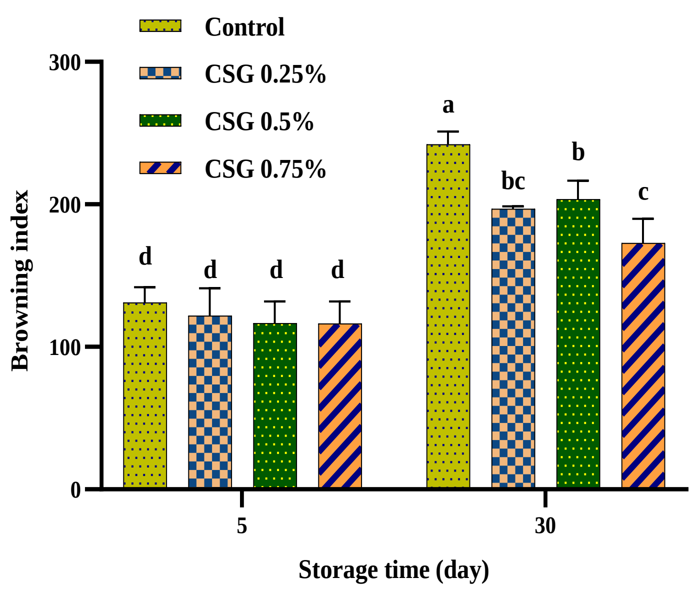

Fig. 7. Browning index in uncoated and coated blood orange fruit, stored for 30 days at 21 °C. The data are the average of three replicates ± standard errors. Different letters in figure represent significant (P < 0.05) differences based on the significant difference test (Duncan).

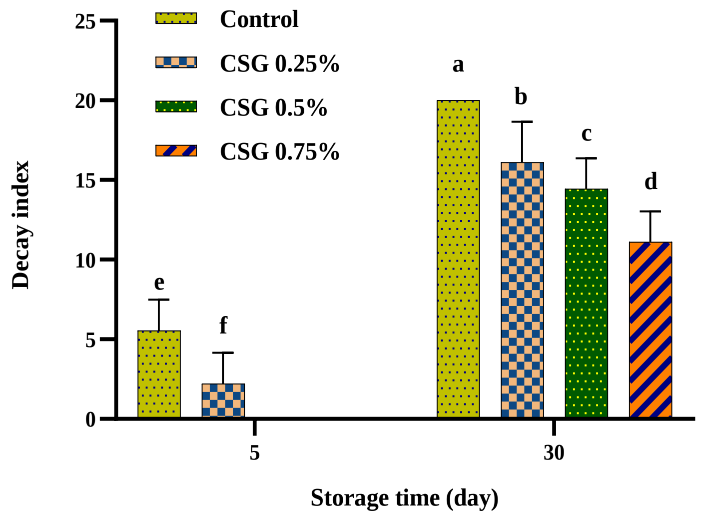

Fig. 8. Decay index in uncoated and coated blood orange fruit, stored for 30 days at 21 °C. The data are the average of three replicates ± standard errors. Different letters in figure represent significant (P < 0.05) differences based on the significant difference test (Duncan).

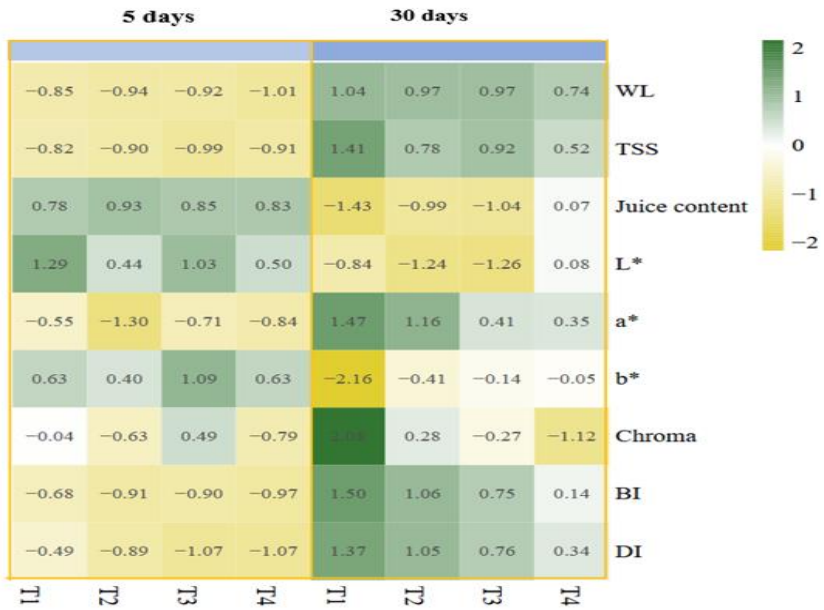

Fig. 9. Heatmap analysis of blood orange fruit characteristics according to various coatings (T1= uncoated, T2= 0.25% CSG, T3= 0.5% CSG, and T4= 0.75% CSG) and storage times (0 and 30 days). The color scale from yellow to green indicates the minimum to maximum values for each attribute.

DISCUSSION

Turgor pressure refers to the internal pressure generated by water entering cells through osmosis, filling the vacuole, and thereby helping maintain the freshness and firmness of fruits (Kumar et al., 2025). During storage, as fruit moisture declines, cellular turgor pressure decreases, leading to reduced juice content and accelerated WL. This is followed by desiccation and shriveling, i.e., visible signs of excessive water loss and diminished turgor pressure (Valero, 2013). Edible coatings form a barrier over the fruit peel, filling surface pores and slowing down water vapor transmission, thereby delaying both WL and juice loss during storage (Heidari Krush et al., 2025; Rasouli et al., 2019). A reduction in juice content may lead to an increased concentration of soluble sugars such as glucose, fructose, and sucrose, which could explain the higher TSS observed in uncoated blood oranges compared to the coated ones. In the present study, CSG coatings likely acted as a protective barrier by restricting gas exchange, preserving juice content and TSS, and thus mitigating WL and quality degradation. These findings are consistent with previous studies on oranges, which demonstrated that CSG in the coating solution improved water-resistance properties, reduced moisture transfer, prevented dehydration, and helped maintain quality characteristics (Heidari Krush et al., 2025). Peel color is a critical quality attribute that strongly influences consumer preference and serves as a key indicator of external quality. To assess changes in peel color during storage, an instrumental method was used to generate quantifiable color measurements in terms of L* (lightness), *a** (negative for green, positive for red), and *b** (negative for blue, positive for yellow) values (Pathare et al., 2013). Color changes during storage are associated with senescence, spoilage, and decay, resulting from physiological and biochemical processes. Postharvest metabolism may trigger increased respiration and water loss via transpiration, leading to chemical alterations, pigment degradation, and a decrease in overall brightness (Tahir et al., 2019). Chroma, a measurable color attribute, indicates the purity or intensity of color and plays a significant role in the visual appeal and freshness perception of fruits (Pathare et al., 2013). Carotenoids, which contribute to the yellow, orange, and red hues in citrus, are affected by these storage-related changes. Although citrus fruits are non-climacteric, the peel behaves differently; previous studies have shown that ethylene can activate carotenogenic gene expression and accelerate peel reddening in citrus (Sun et al., 2025). It appears that CSG, particularly at the 0.75% concentration, may form an effective surface barrier that reduces moisture loss, enzymatic activity, and ethylene production, i.e., factors involved in fruit color and quality changes. This protective effect likely contributed to the preservation of color-related parameters in blood oranges. These results align with findings reported for coated strawberries (Mousavi et al., 2021) and oranges (Heidari Krush et al., 2025).

Postharvest quality of fruits refers to desirable attributes such as visual appearance, juiciness, texture, and flavor that must be maintained until the point of consumption. During storage, increases in WL, dehydration, shriveling, loss of surface gloss, and fungal infection contribute to a decline in fruit quality and marketability. These deteriorations are often caused by metabolic activity, enzymatic browning, moisture loss through the fruit peel, and microbial contamination (Elbarbary et al., 2023). Enzymatic browning is a biological process primarily initiated by the activity of polyphenol oxidase (PPO), an enzyme that catalyzes the oxidation of phenolic compounds. PPO first hydroxylates monophenols to form o-diphenols, which are then oxidized to reactive o-quinones. These o-quinones undergo polymerization to form melanin in the presence of oxygen, resulting in visible browning. This browning is accompanied by tissue breakdown, which facilitates microbial infestation and accelerates fruit decay. Decayed fruits are typically dry and dark in appearance (Tilley et al., 2023). In the present study, CSG coatings may have contributed to visual quality maintenance by slowing the processes of browning and decay in coated fruits, thereby improving consumer acceptance. This finding is consistent with a previous study in which a composite coating of chitosan, chia mucilage, and levan effectively preserved the quality of sweet cherries by minimizing WL and reducing fungal deterioration (Mujtaba et al., 2023).

CONCLUSION

It can be concluded that the application of CSG edible coating, particularly at a concentration of 0.75%, acts as an effective protective barrier over the fruit surface, reducing gas exchange and moisture loss. This treatment significantly improved the storability and marketability of blood oranges by maintaining key quality parameters such as TSS, juice content, and peel color attributes (*a**, *b**, and chroma), while also reducing WL, BI, and DI over a 30-day storage period compared to the uncoated fruit. These findings suggest that 0.75% CSG can be recommended as a suitable postharvest coating to preserve the quality and extend the shelf life of blood oranges. By forming a layer on the peel surface that minimizes moisture loss and gas exchange, this coating reduces decay and enhances fruit longevity. Moreover, its natural and biodegradable composition may increase consumer acceptance and offer a financially viable alternative to conventional packaging methods.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Somayeh Rastegar, Asghar Ramezanian, and Hadi Hashemi; Methodology: Asghar Ramezanian and Somayeh Rastegar; Software: Golrokh Heidari Krush; Investigation: Somayeh Rastegar, Asghar Ramezanian, and Hadi Hashemi; Data curation: Golrokh Heidari Krush; Writing-original draft: Golrokh Heidari Krush; Preparation: Somayeh Rastegar, Asghar Ramezanian, and Hadi Hashemi, Writing—review and editing: Somayeh Rastegar, Asghar Ramezanian, and Hadi Hashemi; Supervision: Somayeh Rastegar, Asghar Ramezanian, and Hadi Hashemi; Project administration: Somayeh Rastegar, Asghar Ramezanian.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL STATEMENT

This study did not involve any experiments on humans or animals. All experimental procedures complied with institutional, national, and international guidelines for research ethics.

DATA AVAILABILITY

All data are available upon reasonable request.

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