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Innovative Gelatin-Based Edible Coatings for Preserving Postharvest Quality of Guava (*Psidium guajava* L.) Fruit

Raziyeh Shahsavari, Somayeh Rastegar*

Department of Horticultural Sciences, Faculty of Agriculture and Natural Resources, University of Hormozgan, Bandar Abbas, Iran

*Corresponding author's email: rastegarhort@gmail.com, s.rastegar@hormozgan.ac.ir

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ABSTRACT

Guava (*Psidium guajava* L.) is a climacteric fruit with a short shelf life due to rapid ripening and postharvest decay. This study explored the efficacy of gelatin-based coatings (0.25 and 0. 5%), enriched with pomegranate seed oil (0.05%), in extending the shelf life of guava fruits stored at 5 ± 1 °C (plus 5 d shelf life). Fruit quality parameters were evaluated after 7-, 14-, and 21-d of storage. The results demonstrated that treatments with gelatin and pomegranate seed oil significantly reduced weight loss (4.5%), with the lowest weight loss observed in the oil treatment (2.5%). All treatments effectively maintained fruit firmness and preserved high levels of total phenolic content and titratable acidity compared to the control. Moreover, these treatments lowered the respiration rate (0.4 mL kg^{-1} h^{-1}), enhancing the overall quality and extending the shelf life of guava fruits. This study highlights the usefulness of gelatin-pomegranate seed oil coatings as a novel option to improve guava postharvest treatments.

Introduction

Guava (*Psidium guajava* L.) is a climacteric fruit that undergoes rapid post-harvest ripening, marked by swift skin yellowing, increased respiration, and softening. These physiological changes make the fruit highly susceptible to decay (Francisco et al., 2020). Guava is widely cultivated in India and many other countries, valued both nutritionally and economically. However, its climacteric nature limits its shelf life to approximately 3–4 days at 25 ± 2 °C. The short shelf life is attributed to moisture loss, physical damage, spoilage, and physiological changes, including reduced firmness, premature softening, skin discoloration, and the accumulation of reactive oxygen species (ROS) and polyphenol oxidation. These challenges highlight the importance of effective postharvest management strategies to extend shelf life, enhance marketability, and reduce losses (Singh, 2024).

Recent advances have demonstrated that gelatin-based coatings, particularly when combined with other substances, can significantly delay guava ripening by acting as a barrier to gas exchange, thus reducing physiological and biochemical changes (Omayio et al., 2020). These coatings help maintain fruit weight, firmness, and soluble solids content without compromising texture or flavor, making gelatin an excellent material for food preservation due to its film-forming properties, biodegradability, and biocompatibility. Additionally, gelatin coatings have been shown to retain titratable acidity (TA) and vitamin C levels, reduce total soluble solids (TSS) accumulation, and enhance catalase enzyme activity, contributing to fruit freshness during storage (El-Migeed et al., 2021).

Incorporating cassava starch and chitosan into gelatin-based coatings further extends guava's shelf life by reducing weight loss and delaying ripening, preserving quality and appearance over time (Silva et al., 2021). Chitosan coatings enriched with citronella essential oil have proven effective in maintaining postharvest quality by minimizing firmness loss, delaying color changes, and preserving phenolic compounds during 15 days of storage at 12 ± 1 °C (de Oliveira et al., 2020). Gelatin coatings infused with anise oil have also shown promising results, alleviating surface imperfections and chilling damage in zucchini while prolonging shelf life and maintaining overall quality during storage (Jafari et al., 2022).

Moreover, gelatin-agarose coatings enriched with *Ocimum gratissimum* L. extract have been effective in enhancing avocado quality, reducing weight loss, and slowing respiration over six days of storage at 25 °C and 64% relative humidity (RH). These coatings improved visual appearance, stabilized color, and preserved TSS and pH levels, outperforming both untreated and conventionally treated avocados (Pham et al., 2023). While edible gelatin coatings have demonstrated substantial benefits across various fruits, including guava, opportunities remain to further optimize their protective effects.

Current research primarily focuses on the performance of gelatin coatings at ambient temperatures, with limited exploration at lower storage temperatures. Incorporating pomegranate seed oil, known for its antioxidant properties, into gelatin coatings represents a novel approach that may further enhance fruit shelf life and quality. This study aims to address this research gap by evaluating the efficacy of a gelatin-pomegranate seed oil coating on guava fruits stored at 5 °C. Through this exploration, the study seeks to provide insights into more versatile applications of gelatin-based coatings, offering more effective postharvest solutions for tropical fruits under varying storage conditions.

Materials and Methods

Harvesting and preparation of fruits

White-pulp guava (*Psidium guajava* L.) fruits were harvested from a commercial orchard in Minab City, Hormozgan Province, Iran (Latitude: 27° 07' 51.74" N, Longitude: 57° 05' 13.78" E) at the mature green stage, which is characterized by the transition from dark green to lighter green. The harvested fruits were promptly transported to the laboratory, where they were inspected to ensure they were free from diseases or surface damage. Only healthy fruits were selected for further analysis.

Treatment application

The fruits underwent disinfection by immersion in a 0.05% sodium hypochlorite solution for one minute, followed by rinsing with distilled water. The treatments in this study involved the application of gelatin coatings at two concentrations (0.25% and 0.5%) sourced from Temad Kala, Iran, and a pomegranate seed oil coating at 0.05% concentration. In addition, a combination treatment was applied, where the fruits were immersed in a solution containing xanthan gum and pomegranate seed oil. Each treatment was administered through a 5-min immersion process. After treatment, the fruits were stored in a cold room at 5 ± 1 °C with 85–95% relative humidity (RH) for 21 days. Evaluations were conducted at 7-day intervals (7, 14, and 21 days). At the end of each storage interval, the fruits were held at room temperature for five days before being assessed for various parameters.

Determination of weight loss

The weight of the fruits was measured consistently throughout the experiment to assess weight reduction in both treated and control samples. Weight loss was calculated as a percentage of the initial weight following the method outlined by Lo'Ay and Taher (2018).

$$Weight\ loss\ =\ (\frac{W0\ -\ Wf}{W0}) \times 100$$

Where (W0) represents the initial weight and (Wf) the final weight.

Respiration rate

A specific amount of mango was put into a sealed plastic container equipped with a Testo 535 CO_2 sensor. Initial CO_2 levels (D1) were recorded at the start, and then again after 1 h (D_2). The respiration rate was calculated using the formula provided and was expressed in mL kg^{-1} h^{-1}.

$$R\ CO2 = \frac{(D2 - D1)\ \times\ 10^6\ \times\ Volume\ of\ container}{Time\ \times\ Fruit\ weigh}$$

Firmness measurement

The firmness of the guava fruit tissue was evaluated using a manual firmness tester (penetrometer) (SN, 0585, Netherlands) with a piston diameter of one centimeter. Measurements were taken after removing the peel from the equatorial section of the fruit and were recorded in kg cm^{-2}.

Total phenolic content (TPC)

The total phenolic content was determined following the method of Singleton and Rossi (1965), with minor modifications. One g of fruit tissue was homogenized in 10 mL of 80% ethanol (v/v) and centrifuged at 10,000 × g for 15 min at 4 °C. The supernatant was collected, and 100 µL of it was mixed with 1 mL of 10% Folin-Ciocalteu reagent (v/v) and 15% sodium carbonate (v/v). After incubating the mixture at room temperature for 90 min, the absorbance was measured at 765 nm. Gallic acid was used to generate a standard curve for calculating sample concentrations.

Total flavonoid content (TFC)

Total flavonoid content was measured using the method of Chanc et al. (2002) with some modifications. In a volumetric tube, 100 µL of 1 M potassium acetate, 10% aluminum chloride (w/v), and 3 mL of the extract were combined with distilled water. The mixture was incubated in the dark at room temperature for 45 min, and the optical density was measured at 415 nm. Quercetin was used to generate the standard curve for determining flavonoid concentrations.

Antioxidant capacity

The antioxidant capacity was evaluated according to the method of Brand-Williams et al. (1995), with modifications. The test mixture consisted of 3.9 mL of DPPH solution (150 µM) in 95% methanol (v/v) and 0.1 mL of the sample extract. After incubating the mixture for 30 min, the absorbance was measured at 515 nm.

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

TSS was measured using a digital refractometer (DBR95, Thailand) and expressed as a percentage. TA was determined by titrating the guava juice with 0.1 N NaOH until the pH reached 8.2, using a digital pH meter (HANA, Romania) as the endpoint indicator, with results expressed as a percentage of citric acid. The pH of the juice was measured using a calibrated pH meter (model HI93141, HANNA) with standard buffers at pH 4 and 7.

Overall visual acceptability (OVA)

The overall visual acceptability of the fruits was assessed using a 5-point scoring system (excellent, good, average, poor, very poor) adapted from Mohammadi et al. (2024). The evaluation focused on key quality indicators, including freshness, firmness, peel glossiness, and signs of deterioration such as dehydration, shriveling, or discoloration.

Statistical analysis

The experiment followed a completely randomized design with three replications, each treatment consisting of five fruit samples. Factors included storage time and treatment type. Analysis of variance (ANOVA) was performed to determine the statistical significance of the results. Mean comparisons were conducted using the least significant difference (LSD) test at a 5% significance level. Principal component analysis (PCA) was carried out using XLSTAT software version 2020 (Addinsoft SARL, www.xlstat.com), while statistical analyses were conducted with SAS software version 4.9.

Results

Weight loss

The effects of various treatments on the weight loss of guava fruits were monitored over a 21-day storage period. As shown in Figure 1, the percentage of weight loss increased progressively across all treatments over time. Among the treatments, the fruits treated with oil consistently exhibited the lowest weight loss throughout the storage period. On day 7, the treatments involving Gel 0.25% + oil and Gel 0.5% + oil recorded significantly lower weight loss, ranging between 2.5% and 2.9%. This trend persisted throughout the storage period, with both treatments maintaining lower weight loss compared to the control. By day 21, all treatments, except for Gel 0.5%, demonstrated significantly reduced weight loss relative to the control, highlighting the effectiveness of these coating strategies in mitigating moisture loss during cold storage.

Firmness

Regarding firmness (Fig. 2a), all treatments maintained high firmness levels on day 7, with no significant differences among them (approximately 10-9.1 kg cm^{-2}). By day 14, the control treatment showed a notable decline in firmness (around 3.7 kg cm^{-2}), while treated fruits exhibited moderate firmness (approximately 6-9.2 kg cm^{-2}). The Gel 0.5% + oil and Gel 0.25% + oil treatments showed higher firmness (around 9.2 kg cm^{-2}). On day 21, the control treatment had the lowest firmness (approximately 2.2 kg cm^{-2}), followed by Gel 0.25% and Gel 0.5% treatments (around 3.2 kg cm^{-2}). The oil, Gel 0.25% + oil, and Gel 0.25% + oil treatments exhibited the highest firmness (around 4.5 kg cm^{-2}).

Respiration rate

Figure 2b represents the respiration rate across different storage times. The control group showed the highest respiration rate (0.8 mL kg^{-1} h^{-1}), which was significantly reduced in samples treated with gels and oils. Although all the treatments caused lower respiration rates than the control, the least respiration (0.4 mL kg^{-1} h^{-1}) was observed in the oil treatment. This suggests that the treatments effectively slowed down metabolic processes, thus extending the shelf life.

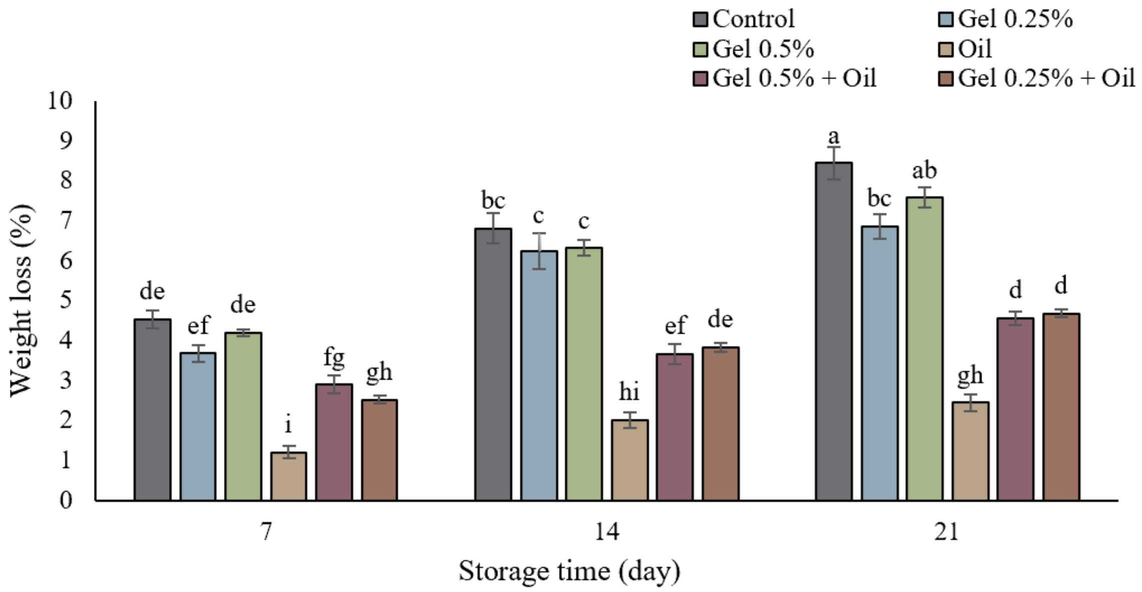

Fig. 1. Effect of xanthan gum enriched with pomegranate seed oil on weight loss of guava fruits stored at 5 ± 2 °C (plus a 5-d shelf life) and 85-95% RH for 21 d. Data represent mean values of n = 3 and the error bars represent standard errors (SE) of the means. Statistical analysis was performed using LSD test at $P \leq 0.05$ level.

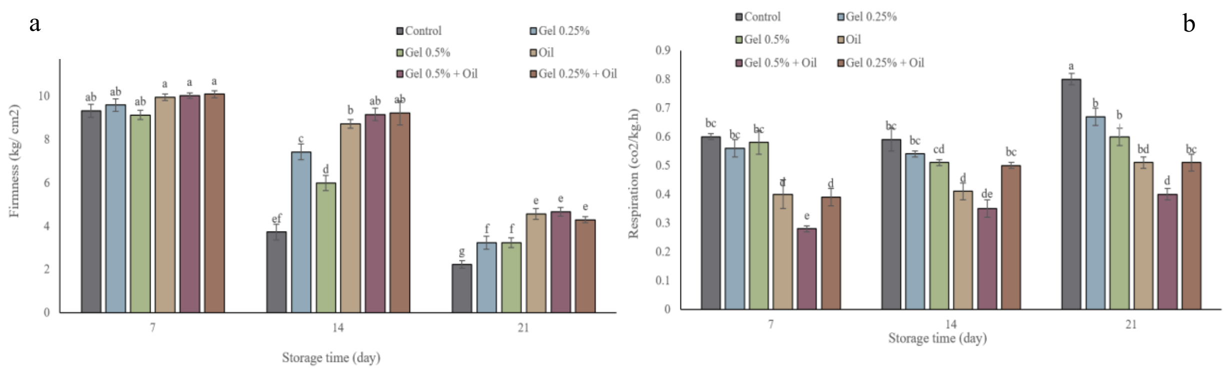

Fig. 2. Effect of gelatin enriched with pomegranate seed oil on a) firmness and b) respiration rate of guava fruits stored at 5 ± 2 °C (plus a 5-d shelf life) and 85-95% RH for 21 d. Data represent mean values of n = 3 and the error bars represent standard errors (SE) of the means. Statistical analysis was performed using LSD test at $P \leq 0.05$ level.

Total phenol and flavonoids

As shown in Figure 1a, on day 7, the Gel 0.5% + oil treatment exhibited the highest phenol content, reaching approximately 145 mg g^{-1}, closely followed by the Gel 0.25% + oil and Gel 0.5% treatments. By day 14, the total phenol content in these treatments remained relatively stable. However, by day 21, a noticeable decline in phenol content was observed across all treatments. Despite the decrease, the Gel 0.25% + oil treatment retained relatively higher phenol levels compared to both the control and the other treatments. Figure 3b illustrates the gradual decline in flavonoid content over the 21-day storage period. The Gel 0.5% + oil treatment consistently maintained significantly higher flavonoid levels (ranging from 16.8 to 13.5 mg g^{-1}) across all evaluation days compared to other treatments. At the end of the storage period, this treatment still exhibited the highest flavonoid content. No significant differences in flavonoid content were observed between the other treatments and the control.

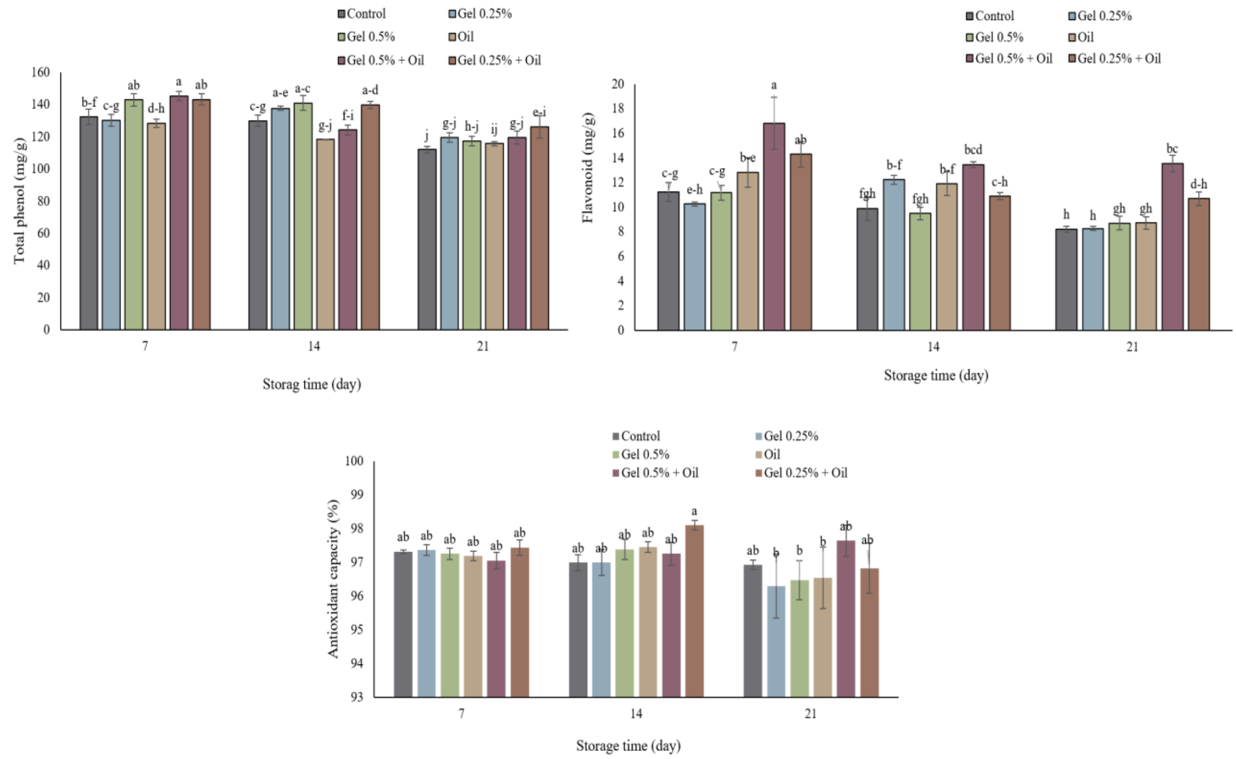

Fig. 3. Effect of gelatin enriched with pomegranate seed oil on a) total phenol and b) flavonoid of guava fruits stored at 5 ± 2 °C (plus a 5-d shelf life) and 85-95% RH for 21 d. Data represent mean values of n = 3 and the error bars represent standard errors (SE) of the means. Statistical analysis was performed using LSD test at $P \leq 0.05$ level.

Antioxidant capacity

As shown in Figure 3c, the antioxidant capacity of the guava fruit remained relatively stable throughout the storage period, with minimal fluctuations. By the end of the experiment, no significant differences were observed between the control group and the treatment groups, indicating that the treatments did not markedly affect the antioxidant capacity.

Total soluble solids (TSS), titratable acidity (TA), pH, and TSS/TA ratio

Figures 4a–d illustrate the trends in TSS, TA, pH, and the TSS/TA ratio over the 21-day storage period. TA decreased steadily across all samples during storage. However, by the end of the storage period, the treatment groups exhibited significantly higher TA levels compared to the control group. TSS levels showed a noticeable increase on day 21, particularly in the control samples, where a significant rise was observed compared to the other treatments.

The pH initially increased during the early stages of storage but later declined. At the end of the experiment, the control group had a significantly higher pH than the treatment groups, indicating that the treatments helped stabilize acidity. The TSS/TA ratio reflected these trends, with the control group displaying higher ratios towards the end of the storage period due to the combined effect of rising TSS and decreasing TA.

Overall visual acceptability

Figure 5 illustrates the superior preservation efficacy of the oil and compound treatments. The control fruits displayed noticeable yellowing compared to the treated groups. In contrast, fruits treated with gelatin (0.25% and 0.5%) + oil retained a predominantly green color and maintained their firmness. The radar chart quantitatively supports these visual observations, demonstrating that the gelatin + oil treatments performed the best across multiple quality parameters, including freshness, firmness, peel glossiness, dehydration, skin shriveling, and discoloration.

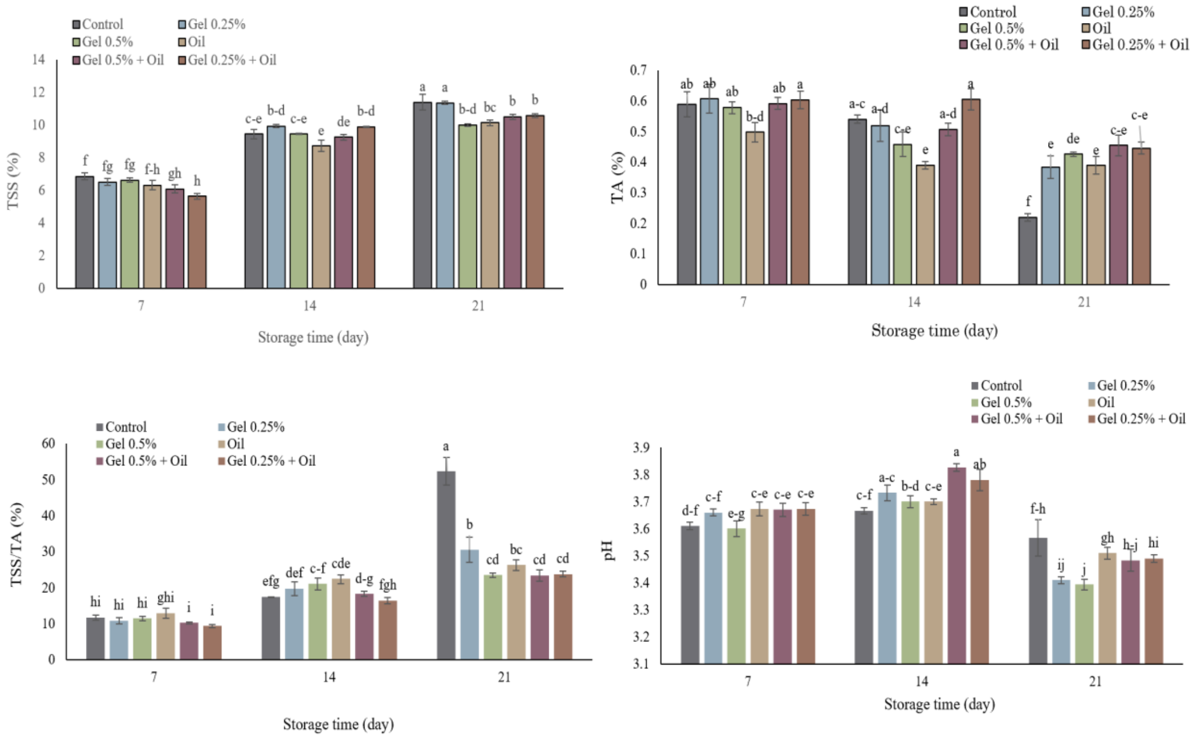

Fig. 4. Effect of gelatin enriched with pomegranate seed oil on a) TSS b) TA, c) TSS/TA and d) pH of guava fruits stored at 5 ± 2 °C (plus a 5-d shelf life) and 85-95% RH for 21 d. Data represent mean values of n = 3 and the error bars represent standard errors (SE) of the means. Statistical analysis was performed using LSD test at $P \leq 0.05$ level.

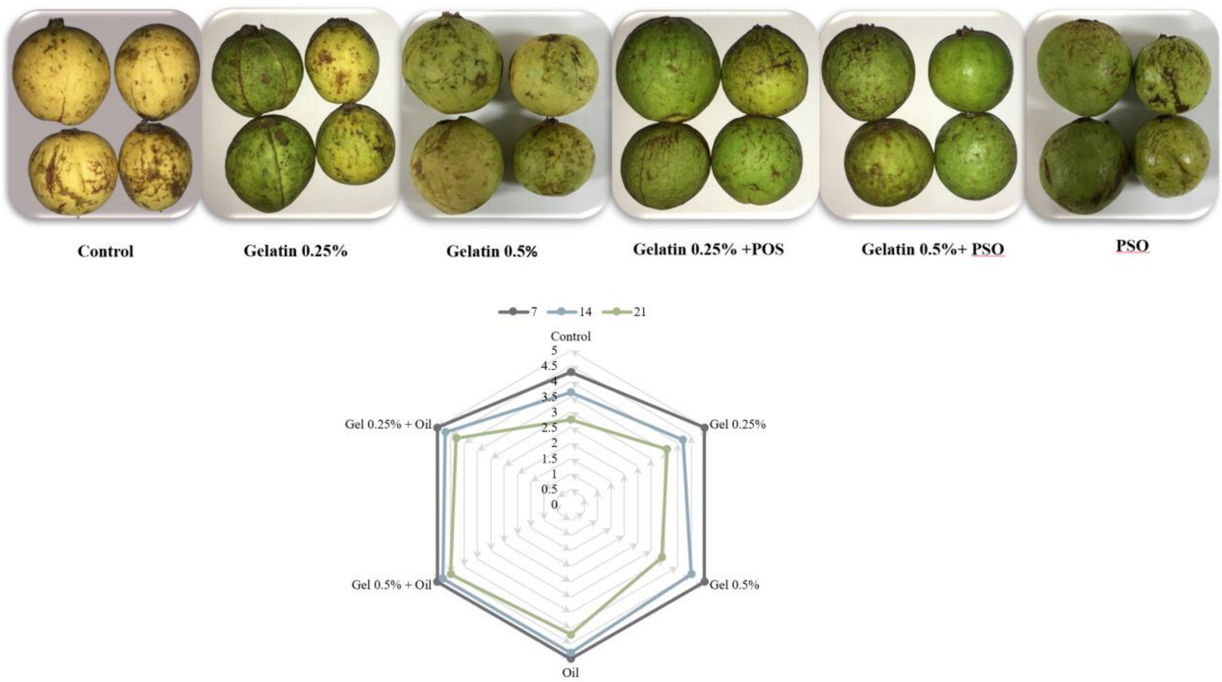

Fig. 5. The effect of gelatin enriched with pomegranate seed oil on overall visual acceptability (OVA) of guava fruits stored at 5 ± 2 °C (plus a 5-d shelf life) and 85-95% RH for 21 d.

Heatmap and principal component analysis (PCA)

Figure 6 visually represents the effects of various treatments on multiple quality parameters of guava fruits stored at 5 °C for different durations (7, 14, and 21 days). The heat map is divided into four main clusters (I-IV) based on the similarity of treatment effects. Notably, the control groups, particularly at 21 days, exhibited significant weight loss (indicated in blue), while the treatments combining gel and oil showed less weight loss. Furthermore, the control group demonstrated higher respiration rates (indicated in red), in contrast to the treated samples, which exhibited lower rates (indicated in blue), reflecting slowed metabolic processes. Additionally, higher firmness levels (shown in red) were maintained in the gel and oil treatments, indicating superior textural quality. Finally, increased phenol content (indicated in red) was observed in the gel and oil treatments, suggesting better retention of antioxidant compounds.

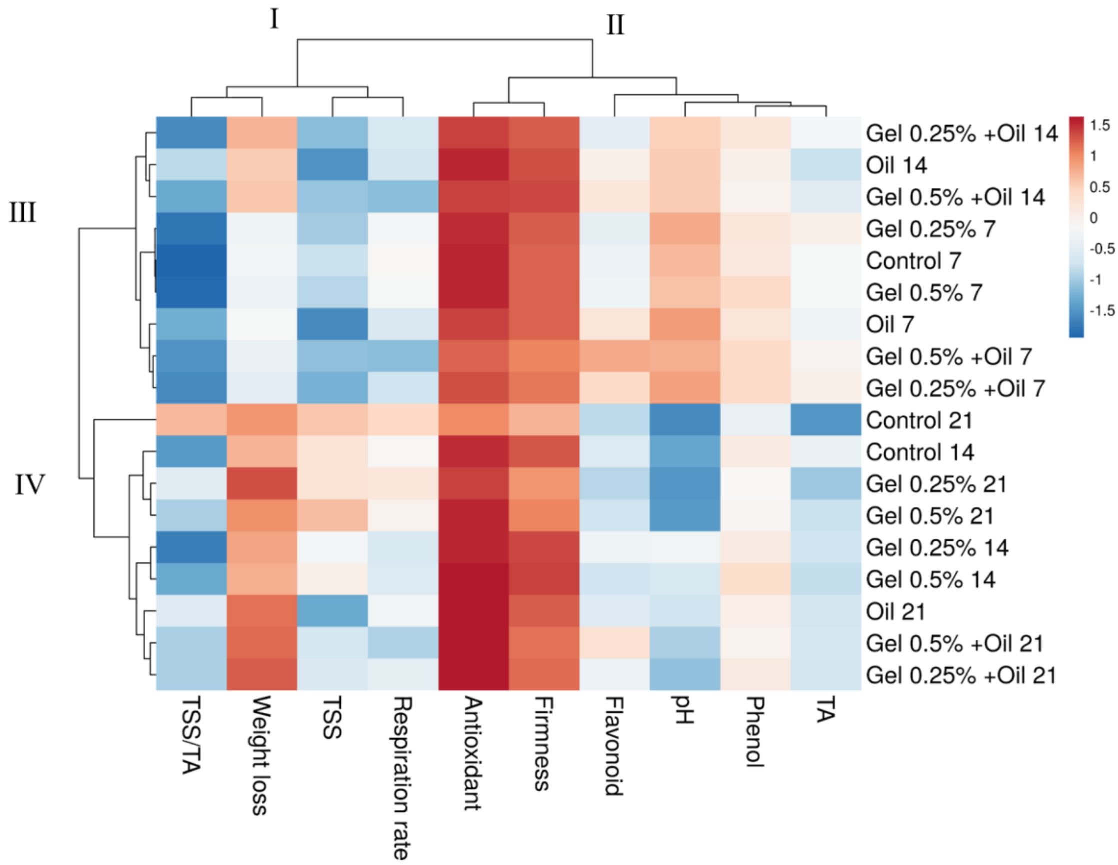

Fig. 6. This heatmap provides a comprehensive visual summary of the effects of different treatments on the shelf life and quality parameters of guava fruit during storage. Rows (y-axis) represent different treatments and storage times for guava fruits. Columns (x-axis) represent different quality parameters of guava fruits. Color gradient represents the relative values of the parameters. Dendrograms are hierarchical clustering of treatments and quality parameters. The horizontal dendrogram (top) shows clusters that are similar in treatments/storage times. The vertical dendrogram (left) shows clusters that are similar in quality parameters.

The PCA biplot provides a visual representation of the relationships between different treatments and quality parameters of guava fruits during storage (Fig. 7). The two principal components (F1 and F2) explain a total of 74.34% of the variance, with F1 accounting for 62.70% and F2 for 11.63%. Treatments involving gels and oils were generally associated with improved quality preservation, as indicated by higher firmness, antioxidant capacity, and TA levels.

In the biplot, respiration rate and TSS correlated strongly and positively while being positioned on the positive side of F2 and the negative side of F1. Conversely, weight loss and the TSS/TA ratio are located on the negative side of both F1 and F2, indicating a strong negative correlation with other parameters. Notably, phenol content and

TA are positioned on the positive side of both F1 and F2, illustrating a strong positive correlation between these two factors.

Firmness and antioxidant capacity cluster on the positive side of F1, indicating a positive correlation between these parameters. The control groups at 21 days and 14 days of storage are positioned on the left side of F1, signifying higher weight loss and TSS/TA ratios. In contrast, the treatments of gelatin 0.25% and 0.5% at 21 days of storage, along with gelatin 0.25% + oil at 21 days, are positioned toward the center-left of the biplot, reflecting moderate weight loss and TSS/TA ratios.

Fig. 7. Principal component analysis (PCA) biplot analysis for treated guava fruit during storage. The PCA biplot includes vectors representing quality parameters and points representing different treatments and storage durations. The direction and length of the vectors indicate the influence of each parameter on the principal components.

Discussion

In this study, it was observed that the weight loss of guava fruits increased over a 21-day storage period. The highest percentage of weight loss was recorded in the control group, while the lowest occurred in the treatment with pomegranate seed oil. The decrease in mass observed in the uncoated fruits throughout the storage period can be attributed to elevated rates of transpiration and respiration, intrinsic aspects of the fruit's physiological metabolism. This process is compounded by diminished water retention capabilities, ultimately culminating in a notable reduction in mass and the emergence of surface wrinkling (Moreira et al., 2021).

Pomegranate seed oil can effectively prevent moisture loss in fruits. Upon harvesting, fruits contain natural moisture, which can diminish over time, leading to weight reduction. The application of edible coatings, along with pomegranate seed oil, protects the moisture in the fruits, thereby mitigating weight loss and contributing to an increase in their weight (Lufu, 2020). Additionally, the application of CMC-Gel-MT coating resulted in a significant reduction in weight loss and an increase in respiration rate during extended cold storage (Venkatachalam et al., 2024). The utilization of gelatin coatings enriched with plant extracts notably extended the shelf life of strawberries by efficiently reducing weight loss, delaying softening and color changes, and hindering fungal development (Vargas-Torrico et al., 2022).

Biochemical reactions in fruits are closely related to their respiration rates, which significantly impact fruit quality. Respiration contributes to water loss, leading to weight reduction and shriveling (Chen et al., 2019). Managing the respiration rate through appropriate treatments plays a crucial role in determining postharvest life and overall fruit quality. In the present study, the lowest respiration rate was observed in the gelatin + oil treatment, aligning with previous research that examined the influence of edible coatings on respiration rates during storage. Coatings create a barrier that limits oxygen access to the fruit's interior, resulting in a decrease in respiration rates and associated enzyme processes. This inhibition slows the decomposition of organic acids such as tartaric and ascorbic acid (Zhang et al., 2021).

The coatings modify the permeability properties of the fruit, leading to lower respiration rates in coated samples compared to control samples (Kingwascharapong et al., 2020). Initially, respiration rates may increase but subsequently decrease in all samples, possibly due to reduced cellular integrity as the fruit transitions into the post-climacteric stage. Coating treatments, such as edible coatings made from a gelatin-pectin composite with garlic essential oil, have been shown to reduce the respiration rate of red chili during storage by limiting oxygen access and delaying the utilization of organic acids (Heristika et al., 2023).

The efficacy of using gelatin to slow down the ripening of fruits has been substantiated through its ability to decrease both respiration rates and weight loss. Specifically, increasing the gelatin concentration in the coating has been demonstrated to extend the period before bananas ripen (Pham et al., 2022).

In this study, at the conclusion of the experiment, treatments involving pomegranate seed oil, gelatin 0.5% + oil, and gelatin 0.25% + oil significantly preserved the firmness of guava fruit compared to the control group. The preservation of firmness in produce fundamentally relies on factors such as tissue turgor and cell wall degradation (Fagundes et al., 2015). Fruit firmness serves as a reliable indicator for evaluating the ripening status and plays a pivotal role in determining both shelf life and market appeal. This attribute is also crucial for consumers when making purchasing decisions (Chen et al., 2019; Hong et al., 2012).

The observed decrease in firmness in uncoated fruits can be attributed to heightened metabolic activity, rapid degradation of the cell wall, softening of the pulp, and disintegration of starch and cell wall components such as cellulose, hemicellulose, and pectin. These processes are facilitated by enzymes associated with the cell wall, including pectin methylesterase, polygalacturonase, and cellulase (Soradech et al., 2017; Li et al., 2014). The application of edible coatings leads to a low internal O_2 concentration, which reduces metabolic rates and cell wall degradation processes, including the dissolution of pectins, thereby preserving the firmness of fruit tissue. In a related study, fruits coated with algae and pomegranate seed oil exhibited the highest firmness values due to the structural protection provided by the coating, which maintained quality and enhanced preservation during storage (Teodosio et al., 2021), consistent with findings from Oliveira et al. (2018).

Moreover, the loss of firmness can occur due to increased carbohydrate metabolism, resulting in heightened activity of cell wall enzymes that break down pectin, causing cell loosening, regulated by ethylene (Maldonado-Astudillo et al., 2014). Pomegranate seed oil has been reported to prevent water loss in fruits (Kawhena et al., 2022), which is crucial for maintaining fruit firmness. Moisture increases internal cell pressure and preserves the structure of various substances within the fruit (Paniagua et al., 2013). By applying pomegranate seed oil, moisture is protected, thereby preventing drying and loss, which helps maintain fruit firmness (Khedr, 2022).

Phenols and flavonoids are natural antioxidants in fruits that help maintain cell health and prevent oxidative damage (Khan et al., 2021). Coated fruits generally contain higher levels of phenols and flavonoids compared to the control group, with the highest levels observed in the treatment with gelatin 0.5% and pomegranate seed oil. During storage, the phenolic concentration in coated fruits decreased less, indicating the positive effect of coatings in preserving the nutritional value of guava. Pomegranate seed oil can protect fruits against oxidation by forming a barrier that reduces contact with oxygen, thereby preserving phenol levels (Chavan et al., 2023). Additionally, gelatin coatings may help maintain the antioxidant activity of flavonoids by regulating the activity of enzymes that lead to their oxidation (Yan et al., 2023).

It has been reported that pomegranate seed oil can prevent the oxidation and degradation of flavonoids in post-harvest fruits (Kawhena et al., 2022; Singh et al., 2022). Mohammadi et al. (2024) noted that the combination of gelatin and pomegranate seed oil increased the phenol and flavonoid content in *Citrus aurantifolia*. This combination could serve as an effective method for preserving the quality of fruits after harvest, as gelatin acts as a thickening and lubricating agent, forming a protective layer on the fruit surface (Kocira et al., 2021). Pomegranate seed oil functions as an antioxidant, preventing nutrient oxidation, moisture loss, and color changes, thereby helping to maintain fruit quality and longevity (Drinić et al., 2020; Ghoshal and Chopra, 2022).

Overall, the combination of gelatin and pomegranate seed oil presents a promising method for preserving the quality and extending the shelf life of postharvest fruits. Additionally, the application of CMC-Gel-MT coating led to increased phenylalanine ammonia-lyase activity, resulting in enhanced phenolic content within the fruit. Consequently, the treated longkong fruit exhibited improved antioxidant capacity to neutralize free radicals (Venkatachalam et al., 2024).

The findings of this research demonstrated a significant increase in the TSS of guava fruits at the end of the experiment (21 d), with the minimum TSS level associated with the gelatin 0.5% treatment and the maximum corresponding to the control. The increase in soluble solids in fruits primarily results from biosynthesis and the breakdown of polysaccharides, which is further intensified as water content decreases. This process is corroborated by a reduction in acidity during storage. As fruits ripen, their acidity quickly diminishes, contributing to an increase in sweetness (Rodrigues et al., 2020). The control fruits exhibited the highest concentrations of soluble solids, showing a marked rise throughout the storage duration due to accelerated ripening. These levels were notably distinct from those observed in fruits treated with a combination of algae and pomegranate seed oil (Teodosio et al., 2021).

Coatings can potentially reduce fruit respiration (Rodrigues et al., 2018), which aids in preserving TSS in coated fruits. Pomegranate seed oil plays a crucial role in preventing moisture loss in fruits. Moisture is essential for maintaining nutrients in fruits, such as TSS (Opara et al., 2015). By preserving the moisture content of the fruits, the coatings prevent the loss of nutrients due to drying, discoloration, and alterations in taste and flavor, thereby aiding in the maintenance of the fruits' sugar content (Hasan et al., 2019).

In this study, fruits coated with gelatin 0.25% and pomegranate seed oil treatments exhibited higher TA levels, which can be attributed to the inhibitory effects of these coatings that delay fruit ripening. In contrast, the control fruits showed a reduction in TA levels. TA is commonly used to evaluate the quality of fruits because it reflects the level of organic acids, which are crucial for various physiological processes, including cellular respiration, the formation of phenolic compounds, and the generation of volatile compounds that contribute to aroma. As fruits mature, there is a notable decrease in the concentration of these organic acids (Batista-Silva et al., 2018; Formiga et al., 2019).

In climacteric fruits like guava, which ripen post-harvest, there is a simultaneous process of organic acid oxidation and TSS increase, typically associated with the fruit's respiration cycle. This leads to a reduction in fruit acidity throughout the storage period (Yahia and Carrillo-Lopez, 2018). However, the application of post-harvest treatments, such as the natural coatings explored in this research, has the potential to decelerate the ripening process. This is achieved by mitigating the rise in fruit acidity, thus preserving the fruit's quality for a longer period (Thakur et al., 2019).

The higher levels of TA detected in fruits coated with algae and pomegranate seed oil during ripening might be attributed to the release of galacturonic acid from the breakdown of cell wall components (Germano et al., 2019). Additionally, pomegranate seed oil can function as a natural antioxidant, preventing the degradation of acids present in the fruits (Boroushaki et al., 2016). By applying pomegranate seed oil, oxidative degradation of acids can be inhibited, which helps to preserve the acidity and flavor compounds of the fruits (Kaseke et al., 2020).

The appearance and quality of fruits and vegetables are critical factors that influence consumer preferences and drive economic outcomes. The overall visual appeal is particularly important, encompassing aspects such as color, texture, and shape. Research has indicated that if water loss in fruit exceeds 5% of its original weight, it can adversely affect its appearance, leading to symptoms such as wilting, dry peels, damaged membranes, and the onset of senescence and decay. These factors can significantly reduce the product's marketability and result in economic losses (Lufu et al., 2020).

In this study, treatments with gelatin (0.25% and 0.5%) combined with oil, as well as oil alone, significantly improved the appearance of the fruits compared to the control group. The maintenance of a green color in the treated fruits is a critical indicator of chlorophyll retention, suggesting that the treatments effectively inhibited chlorophyll degradation. Edible coatings play a crucial role in enhancing the overall visual appeal and maintaining fruit quality by providing a protective layer that reduces water loss, controls ripening, delays spoilage, and inhibits microbial growth (Rajial et al., 2024).

Conclusions

Gelatin-based coatings enriched with pomegranate seed oil effectively preserved the postharvest quality of guava fruits. These coatings significantly reduced weight loss, maintained firmness, preserved phenolic content and titratable acidity, and lowered the respiration rate, thereby enhancing the overall quality of the fruit during cold storage for 21 days. These findings underscore the potential of this novel treatment to minimize postharvest losses and extend the market life of guava.

Future research should focus on optimizing the concentrations of the coating components and exploring their application on a broader range of tropical fruits under varied storage conditions. Utilizing natural compounds like gelatin and pomegranate seed oil can contribute to a more sustainable agricultural system by reducing the reliance on synthetic chemicals in postharvest treatments. Additionally, minimizing food waste while maintaining guava fruit quality can improve supply chain efficiency and provide economic benefits for both growers and consumers.

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Conflict of Interest

The authors indicate no conflict of interest in this work.

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