International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Preserving Postharvest Quality of Mango Fruit: The Potential of Xanthan Gum Enriched with *Spirulina platensis*

Mehdi Molaei Moqbeli, Somayeh Rastegar*, Farzin Abdollahi, Leila Jafari

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

ARTICLE INFO

Article history:

Received: 21 September 2024,
Received in revised form: 16 November 2024,
Accepted: 23 November 2024

Article type:

Research paper

Keywords:

Algae
Antioxidant,
Edible coating,
Enzyme,
Shelf life

ABSTRACT

This study investigated the preservation of storage quality in mango (*Mangifera indica*) fruits using an edible coating based on xanthan gum enriched with *Spirulina platensis* (SP). After 50 d of storage (12 ± 1 °C), the fruits were evaluated. Specifically, fruits treated with xanthan 0.2% + SP exhibited the lowest weight loss (29.7%), while the control experienced the most significant weight loss (41.7%). Furthermore, the maximum firmness value (5.7 kg cm^{-2}) was observed in fruits coated with xanthan 0.1% and 0.2% + SP after 50 d of storage. The highest ascorbic acid content (127.5 mg 100 g-1 FW) occurred in fruits treated with xanthan 0.2% + SP 1%, while the control exhibited a lower content (101 mg 100 g^{-1} FW). Furthermore, the maximum flavonoid content, observed in the xanthan 0.2% + SP 1% treatment (1.25 mg QE 100 g^{-1}), was significantly higher than that of the control (0.6 mg QE 100 g^{-1}). Polyphenol oxidase (PPO) activity was significantly lower in xanthan-treated fruits compared to the control. Conversely, peroxidase (POD) and catalase (CAT) activities were higher in xanthan-treated fruits, indicating reduced oxidative stress. In conclusion, applying a xanthan coating (0.2%) enriched with *Spirulina platensis* (1%) is recommended for mango fruit storage and maintenance of freshness and quality in storage conditions.

Introduction

The mango (*Mangifera indica L.*), a member of the Anacardiaceae family, is extensively cultivated in tropical regions globally and is highly regarded for its exceptional nutritional value (Tuo et al., 2020). The postharvest quality attributes and economic value of mangoes are strongly influenced by the efficacy of postharvest management strategies (APEDA, 2022). Evidence from both domestic and international studies highlights significant postharvest losses in mangoes, attributed to factors such as accelerated ripening, microbial spoilage, and mechanical damage. These losses translate into substantial economic burdens for producers (Daisy et al., 2020; Prasad et al., 2022; Kouamé et al., 2020).

Edible coating technology has been proposed as a viable intervention to mitigate postharvest losses and maintain the quality of perishable commodities. These coatings function by creating a barrier that restricts gas and water exchange, thereby modifying the internal environment of the fruit (Pham et al., 2023). As such, edible coatings represent a practical and sustainable approach to minimizing food waste and preserving the economic and nutritional value of agricultural products (Ezati et al., 2022). Natural gums, including xanthan gum, have garnered attention for their utility in formulating edible coatings due to their favorable properties, such as biocompatibility, cost-effectiveness, non-toxicity, and widespread availability (Yun et al., 2022).

Xanthan gum, a microbial polysaccharide widely utilized in the food industry, is known for its stabilizing, emulsifying, and thickening functionalities (Elella et al., 2021). Furthermore, the blue-green microalga *Spirulina platensis* has shown promise as a bioactive additive capable of enhancing crop quality and extending the shelf life of fresh produce (Byantara and Dianursanti, 2021).

Research supports the efficacy of *Spirulina platensis* in improving the postharvest quality of fruits. For instance, Prayoga et al. (2021) demonstrated that a 1% *Spirulina platensis* coating effectively reduced weight loss, preserved pH levels, and enhanced the vitamin C content of strawberries for up to seven days. Similarly, coatings enriched with *Spirulina platensis* were shown to significantly reduce mass loss in guavas during storage (Elny et al., 2018). Additionally, an Aloe vera and xanthan gum-based coating extended the shelf life of guavas to 14 d at ambient conditions and up to one month under refrigeration (Abraham and Banerjee, 2018). The combination of xanthan gum with 0.2% chitosan nanoparticles has also been reported to enhance the overall quality and extend the shelf life of guavas during prolonged refrigeration (Gad and Zagzog, 2017).For other fruits, xanthan gum coatings have demonstrated considerable potential in preserving postharvest quality. Guroo et al. (2021) reported that such coatings maintained higher total phenolic content and antioxidant capacity in fresh kiwifruits, while Rezakhani et al. (2024) documented that xanthan gum-based coatings effectively reduced weight loss and prolonged the shelf life of sapodilla fruits. The growing emphasis on preserving the postharvest quality of fruits and vegetables, coupled with increasing consumer demand for healthier and more sustainable food products, has directed attention toward natural edible coatings as an innovative preservation method. Recent research efforts have primarily focused on integrating bioactive and antioxidant compounds into coating formulations. However, investigations into xanthan gum-based edible coatings enriched with *Spirulina platensis* for mangoes remain limited. The present study aimed to evaluate the effects of a xanthan gum-based edible coating enriched with *Spirulina platensis* on the shelf life and quality retention of mango fruits stored at 12 ± 1 °C for a period of 50 d.

Material and methods

Mango fruits (*Mangifera indica* L.) were harvested from a commercial orchard in Deh Khan village, Kahnouj City, Kerman Province, Iran, during the mature green stage, characterized by a color transition from dark to light green. Harvesting was conducted in accordance with established technical protocols. Fruits selected for the study were uniform in size, free from visible damage, and in overall good condition. Prior to the experiment, the fruits were sanitized by washing in a 0.05% sodium hypochlorite solution for 1 min. The experimental procedures were carried out in 2022 at Hormozgan University.

Preparation of coatings

The preparation of the xanthan gum-based coating involved gradually dissolving xanthan gum in water and stirring the solution for 30 min at ambient temperature. The resulting solution was then refrigerated for 24 h to ensure complete hydration. Coatings were prepared at concentrations of 0.1% and 0.2% xanthan gum, which were subsequently combined with *Spirulina platensis* (SP) extract. The SP extract was prepared using a 10% (w/v) ratio of algae powder in methanol.

The experimental treatments included the following formulations: 0.1% xanthan gum, 0.2% xanthan gum, 1% SP, 0.1% xanthan gum + 1% SP, and 0.2% xanthan gum + 1% SP. To enhance the coating properties, glycerol (0.5% w/v) was added as a plasticizer, and Tween 80 was included as an emulsifier. Both additives were incorporated into the coating solutions at ambient temperature.

Mango fruits were coated using the immersion method, whereby the fruits were submerged in the prepared coating solutions for five min at room temperature. After the coating had completely dried on the fruit surfaces, the mangoes were transferred to baskets and stored for 50 d under controlled conditions of 12 ± 1 °C and 80–90% relative humidity (Khaledian and Momeni, 2021).

Percentage of weight loss

The fruit weight was assessed by a digital scale and the percentage of weight loss was determined using the following formula (Dong and Wang, 2018).

$$WL\ (\%) = \frac{(w1 - w2) \times 100}{w1}$$

WL is the weight loss percentage, Wl is the primary weight in grams, W2 is the secondary weight in grams.

Firmness

To assess the firmness of the mango tissue, the peel was first removed, and the firmness of the fruit flesh was measured using a penetrometer. The results were reported in units of kg cm^{-2}.

Respiration rate

A fixed quantity of fruit was placed in a plastic container. The initial CO_2 level (L1) was recorded at the start, and then after 20 min (L2), using a STEP Respiratory Sensor. The rate of respiration was calculated and expressed in mL kg h^{-1} following the formula below (Xing et al., 2008).

$$CO_2 = \frac{(L2 - L1) \times 10^6 \times Volume\ of\ container}{Time \times Fruit\ weight}$$

Ascorbic acid content

The ascorbic acid content was quantified using a spectrophotometric method as described by O'Grady et al. (2014). To begin, 100 µL of fruit juice was mixed with 10 mL of 1% metaphosphoric acid and homogenized using a vortex mixer. Subsequently, 1000 µL of this mixture was combined with 9 mL of indophenol solution, vortexed thoroughly, and the absorbance was recorded at 510 nm using a microplate reader (Epoch, BioTek Instruments, VT, USA).

Total flavonoid and antioxidant activities

The total flavonoid content was determined following the method described by Chang et al. (2002). To 100 µL of the methanolic extract, 270 µL of 85% methanol, 20 µL of 10% aluminum chloride, 20 µL of potassium acetate, and 560 µL of distilled water were added. The mixture was allowed to stand at room temperature for 30 min before the absorbance was measured at 415 nm using a spectrophotometer.

The antioxidant activity of the fruit juice was assessed using the DPPH radical scavenging method as outlined by Bourtoom (2008). A mixture consisting of 30 µL of the 85% methanolic extract and 600 µL of a 150 mM DPPH solution was prepared and shaken in the dark for 30 min. The absorbance was then measured at 515 nm using a spectrophotometer.

$$DPPH\ \% = \left(\frac{Ablank - Asample}{Ablank}\right) \times 100$$

Peroxidase (POD), polyphenol oxidase (PPO), and catalase (CAT) activities

To prepare the extract, 500 µL of mango juice was mixed with a potassium buffer (pH 7.4) containing 1 M EDTA and 1% polyvinylpyrrolidone (PVP, w/v) at 4 °C. The mixture was centrifuged at 13,000 rpm for 10 min at 4 °C, and the resulting supernatant was used for the assessment of peroxidase (POD) and polyphenol oxidase (PPO) activities.

POD activity was measured using a modified version of the method described by Maehly and Chance (2006). In this procedure, 60 µL of the extract was combined with 1 mL of a peroxidase solution containing 8 mM guaiacol, 4 mM hydrogen peroxide, and 50 mM potassium phosphate buffer in a cuvette. The change in absorbance at 470 nm was recorded over 2 min, and POD activity was expressed as units per milligram of fresh weight (U mg^{-1} FW).

To determine PPO activity, pyrogallol was employed as the substrate following the method of Kar and Mishra (1976). The reaction mixture consisted of 2.5 mL of potassium buffer (50 mM, pH 7), 80 µL of 0.02 M pyrogallol, and 70 µL of the enzyme extract. The absorbance at 420 nm was measured after 3 min, and PPO activity was reported in unit mg^{-1} of fresh weight (U mg^{-1} FW).

Catalase (CAT) activity was determined using the method outlined by Aebi (1984). A reaction mixture was prepared comprising 50 mM sodium phosphate buffer (pH 7), 0.2 mL of the enzyme extract, and 150 µL of 20 mM hydrogen peroxide. The decomposition of hydrogen peroxide by catalase was monitored spectrophotometrically at 240 nm. CAT activity was expressed as units per milligram of fresh weight (U mg^{-1} FW).

Total soluble solids (TSS) and titratable acidity (TA) assessment

The total soluble solids (TSS) of the samples were measured using a digital handheld refractometer (ATAGO PAL-1, Tokyo, Japan) and expressed as % Brix, following a method described by Barry et al. (2004). The titratable acidity (TA) was determined by manually titrating mango juice with 0.1 N NaOH to a pH endpoint of 8.2, using a pH meter (HANA, Romania) and phenolphthalein as an indicator. The results were reported as a percentage of citric acid equivalents.

Statistical analysis

The experiment was conducted using a factorial arrangement in a completely randomized design with three replications. The two factors evaluated were storage time and treatment. Data normality was assessed prior to analysis. Analysis of variance (ANOVA) was performed using the General Linear Model (GLM) procedure in SAS software version 4.9, and mean comparisons

were carried out using the Least Significant Difference (LSD) test ($p \leq 0.05$).

Results

Fruit weight loss

The results demonstrated a progressive increase in fruit weight loss over the storage period. However, the application of edible coatings significantly mitigated weight loss in mangoes compared to the control group. By the end of the experiment, the treatment with 0.2% xanthan gum combined with SP exhibited the lowest weight loss (29.7%), whereas the control group experienced the highest weight loss (41.7%) (Fig. 1a).

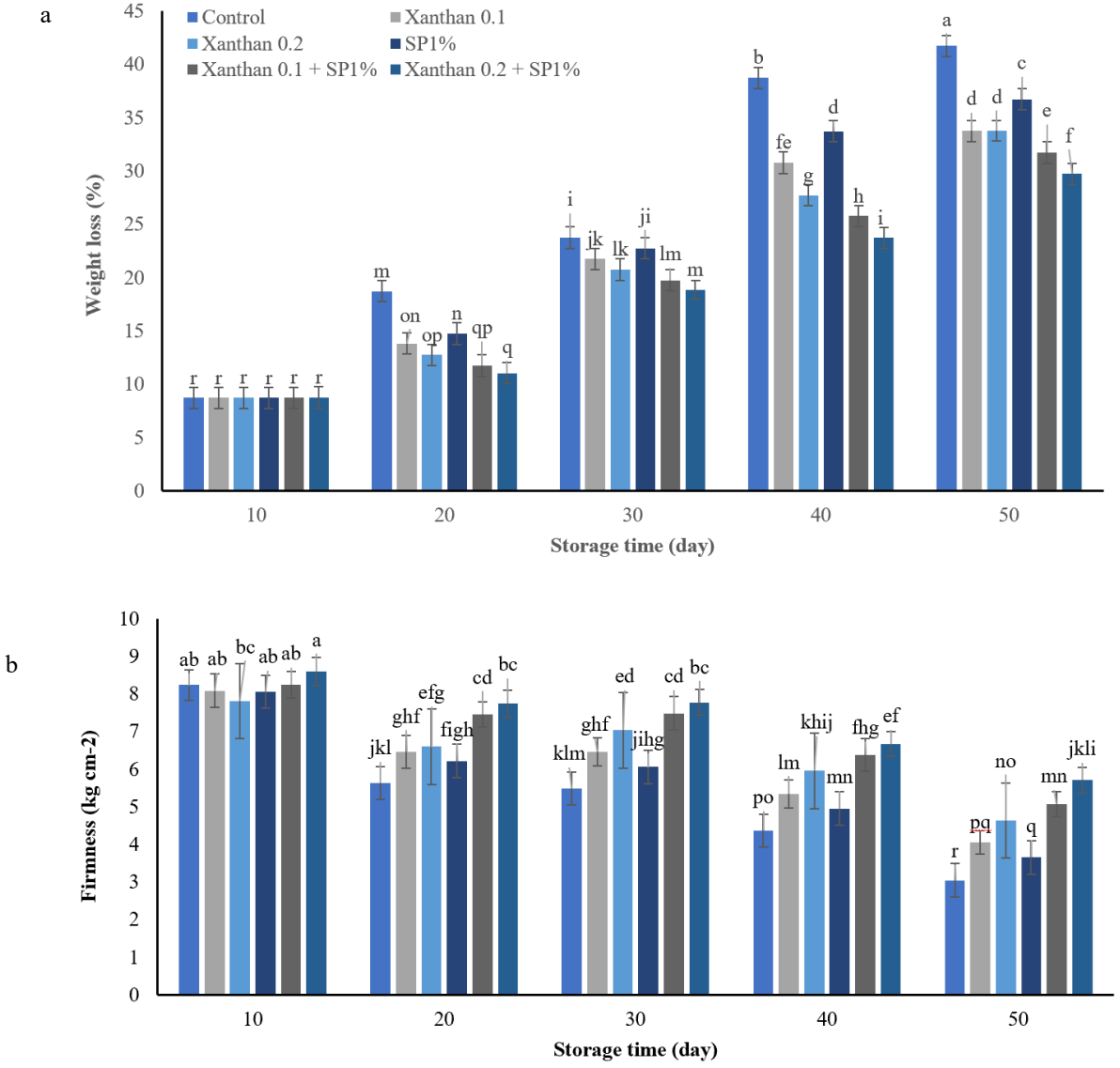

Fig. 1. Interaction effect of edible coating of xanthan gum (control, xanthan gum 0.1%, xanthan gum 0.2%, SP 1%, xanthan gum 0.1% + SP 1% and xanthan gum 0.2% + SP1%), and storage time (10, 20, 30, 40, and 50 d) on a) fruit weight loss and b) firmness. Mangoes were stored for 50 d in cold storage at 12 ± 1 °C. Error bars represent standard errors of the mean values. Similar letters are not significantly different from each other at the probability level of $p \leq 0.05$.

Firmness

Fruit firmness declined progressively throughout the storage period in all treatments. However, fruits treated with xanthan (0.1% and 0.2%) + SP displayed a significantly slower rate of firmness reduction compared to the other treatment groups and the control. After 50 d of storage, maximum firmness (5.7 kg cm^{-2}) was observed in fruits treated with the xanthan (0.1% and 0.2%)

+ SP coating, while the control group showed minimal firmness (3.04 kg cm^{-2}) (Fig. 1b).

Respiration rate

The results revealed that a continuous decrease in the respiration rate of mango fruits occurred throughout the storage period across all treatments. After the 50 d storage period, xanthan 0.2% + SP 1% had caused the lowest respiration rate, while the control group caused the highest (Fig. 2a).

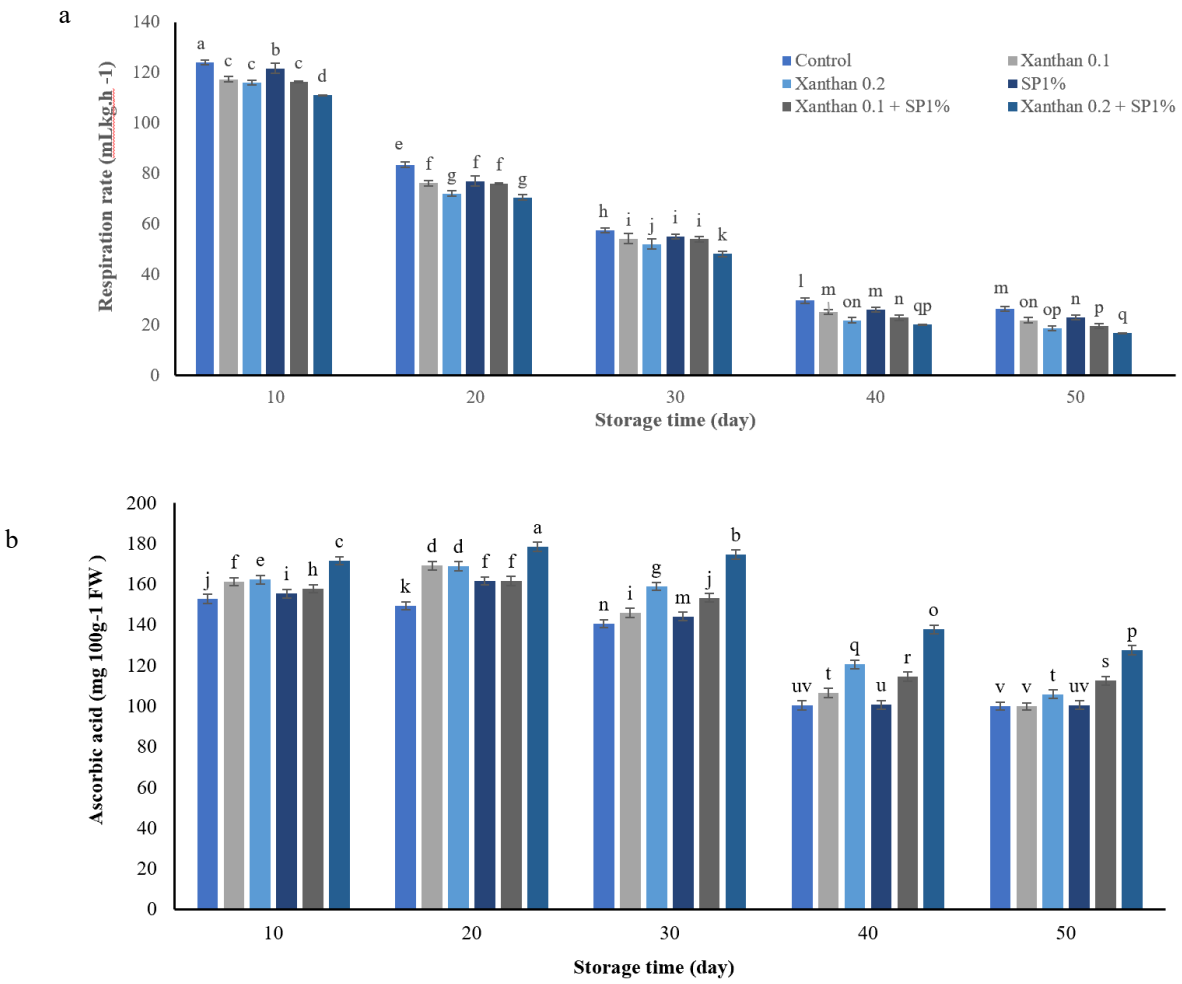

Fig. 2. Interaction effect of edible coating of xanthan gum (control, xanthan gum 0.1%, xanthan gum 0.2%, SP 1%, xanthan gum 0.1% + SP 1% and xanthan gum 0.2% + SP1%) and storage time (10, 20, 30, 40, and 50 d) on a) respiration rate and b) ascorbic acid of mango fruits stored for 50 d in cold storage at 12 ± 1 °C. Error bars indicate standard errors of the mean values. Similar letters are not significantly different from each other at the probability level of p≤0.05.

Ascorbic acid content

As depicted in Figure 2b, ascorbic acid content initially exhibited a slight increase across all treatments, followed by a significant decline after 40 d of storage. By the conclusion of the storage period, fruits treated with xanthan gum combined with SP retained significantly higher levels of ascorbic acid compared to the control and other treatments. The highest ascorbic acid concentration was recorded in fruits treated with 0.2% xanthan gum + 1% SP (127.5 mg 100 g^{-1} FW), whereas the control group exhibited the lowest concentration (101 mg 100 g^{-1} FW).

Total flavonoids and antioxidant capacity

As illustrated in Figure 3a, flavonoid content declined gradually throughout the storage period across all treatments. After 50 d of storage, the highest flavonoid content was recorded in the 0.2% xanthan gum + 1% SP treatment, which showed a statistically significant difference compared to the control and other treatments. Similarly, the antioxidant activity of the samples

initially exhibited a slight increase but subsequently declined by the end of the storage period. After 50 d of storage, the maximum antioxidant activity was observed in samples treated with 0.2% xanthan gum + 1% SP (Fig. 3b).

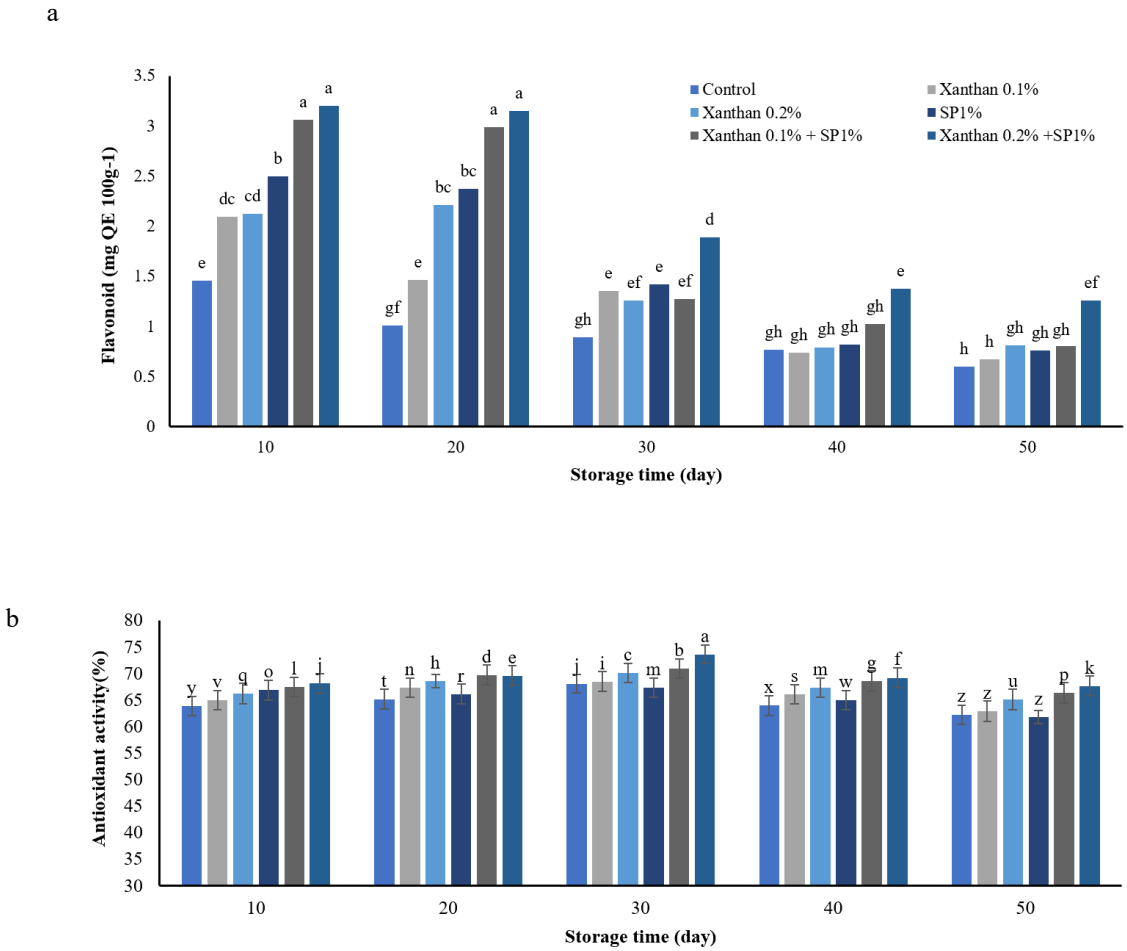

Fig. 3. Interaction effect of edible coating of xanthan gum (control, xanthan gum 0.1%, xanthan gum 0.2%, SP 1%, xanthan gum 0.1% + SP 1% and xanthan gum 0.2% + SP1%) and storage time (10, 20, 30, 40, and 50 d) on a) flavonoid and b) the antioxidant activity of mango fruits stored for 50 d in cold storage at 12 ± 1 °C. Error bars represent the standard error of mean values. Similar letters are not significantly different from each other ($p \leq 0.05$).

POD, PPO, and CAT activity

The findings revealed that the highest POD enzyme activity was observed in the 0.2% xanthan gum + 1% SP treatment, with a value of 43.60 U mg^{-1} FW, whereas the control group exhibited the lowest activity at 15.28 U mg^{-1} FW (Fig. 4a). In contrast, PPO enzyme activity was lowest in the 0.2% xanthan gum + 1% SP treatment (34.4 U mg^{-1} FW) and highest in the control group (51.61 U mg^{-1} FW) (Fig. 4b). Moreover, CAT activity showed a significant increase after 50 d of storage in all treatments. Notably, the 0.1% xanthan gum (40 U mg^{-1} FW) and 0.2% xanthan gum + 1% SP (39.6 U mg^{-1} FW) treatments exhibited significantly higher CAT activity compared to the control group, which recorded 25.3 U mg^{-1} FW(Fig. 4c).

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

As displayed in Figure 5a, the TSS content exhibited a gradual increase throughout the storage period, culminating in a maximum value of 16.7% after 50 d. Fruits subjected to various treatments demonstrated lower TSS levels compared to the control group, with xanthan 0.2% + SP causing the lowest TSS content (14.25%) (Fig. 5b).

A gradual decline in TA was observed during storage (Fig. 5c). Notably, fruits treated with 0.2% xanthan gum + 1% SP exhibited significantly higher TA levels compared to the control and other treatments (Fig. 5d).

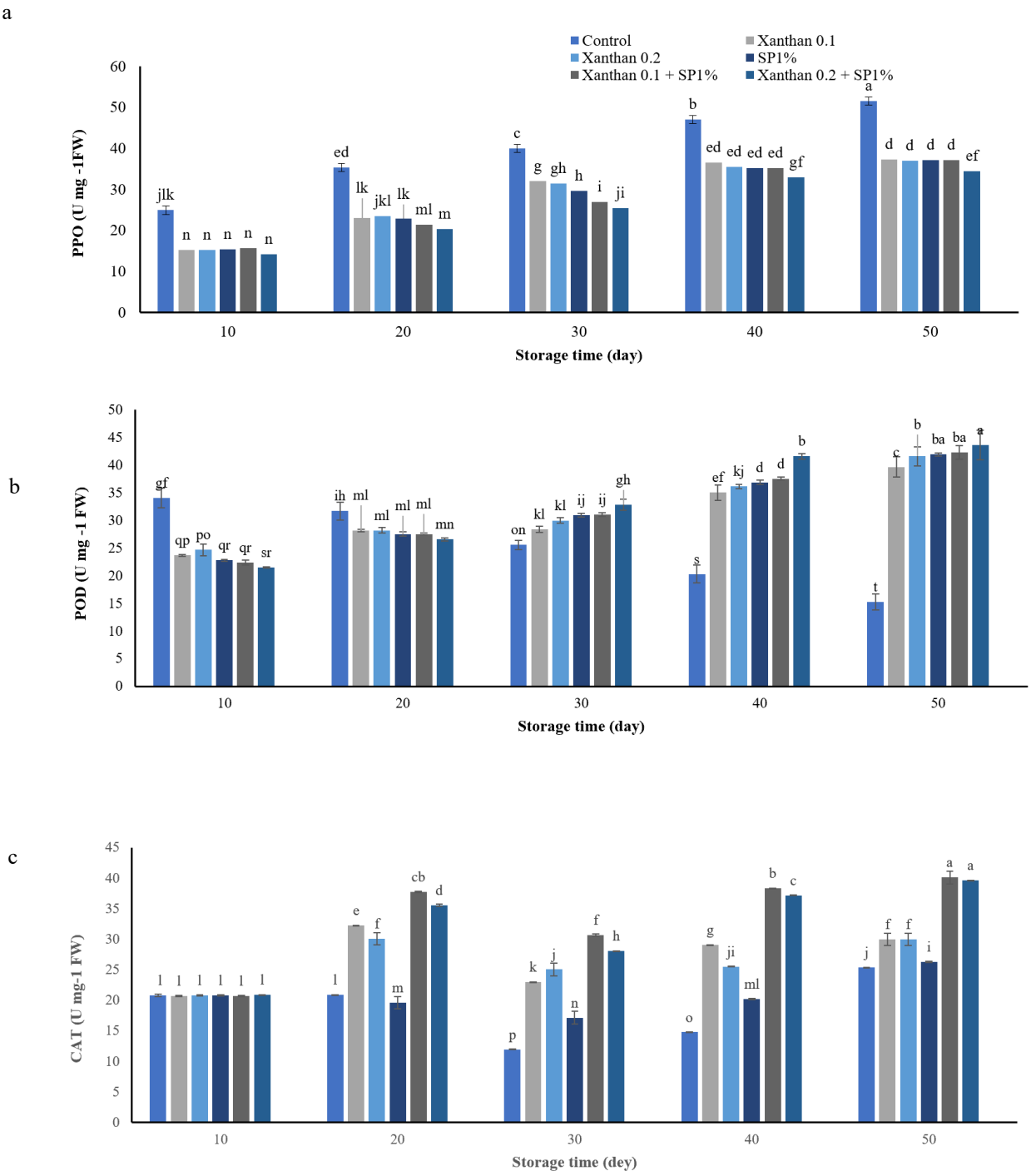

Fig. 4. Interaction effect of edible coating of xanthan gum (control, xanthan gum 0.1%, xanthan gum 0.2%, SP 1%, xanthan gum 0.1% + SP 1% and xanthan gum 0.2% + SP1%) and storage time (10, 20, 30, 40, and 50 d) on a) peroxidase (POD), b) polyphenol oxidase (PPO) and c) CAT enzymes activity of mango fruits stored for 50 d at 12 ± 1 °C. Error bars represent the standard errors of mean values. Similar letters are not significantly different from each other ($p \leq 0.05$).

Discussion

The application of edible coatings on fruits provides an additional protective layer that seals surface pores, thereby reducing transpiration and preventing moisture loss. Mangoes treated with a 0.05% xanthan gum coating exhibited significantly reduced weight loss compared to other treatments. Edible coatings like xanthan gum are particularly effective in forming a protective barrier that minimizes dehydration and moisture loss. This observation aligns with the findings of Adetunji et al. (2014), who

reported weight preservation in papaya fruits treated with xanthan gum.

Similarly, coatings derived from microalgae such as *Chlorella sp.*, *Scenedesmus sp.*, and *Spirulina platensis* have been shown to effectively delay ripening in 'Prata Ana' bananas. Oliveira et al. (2018) observed that by the sixth day of storage, bananas coated with *Chlorella sp.* had a mass loss of only 5.89%, while untreated bananas exhibited rapid ripening, significant weight loss, and softening. Bananas coated with microalgae retained superior quality for up to eight d. Further studies have demonstrated that edible coatings formulated from Arabic gum, xanthan gum, and chitosan, combined with pomegranate peel extract, effectively reduce postharvest weight loss, control water loss, and lower respiration rates in fruits such as mangoes, rambutans, and tomatoes under various storage conditions (Daisy et al., 2020; Kumar and Saini, 2021). Similar outcomes were reported for grapes (Golly et al., 2019) and jujube (Naveed et al., 2024) coated with xanthan gum, consistent with the present study's findings.

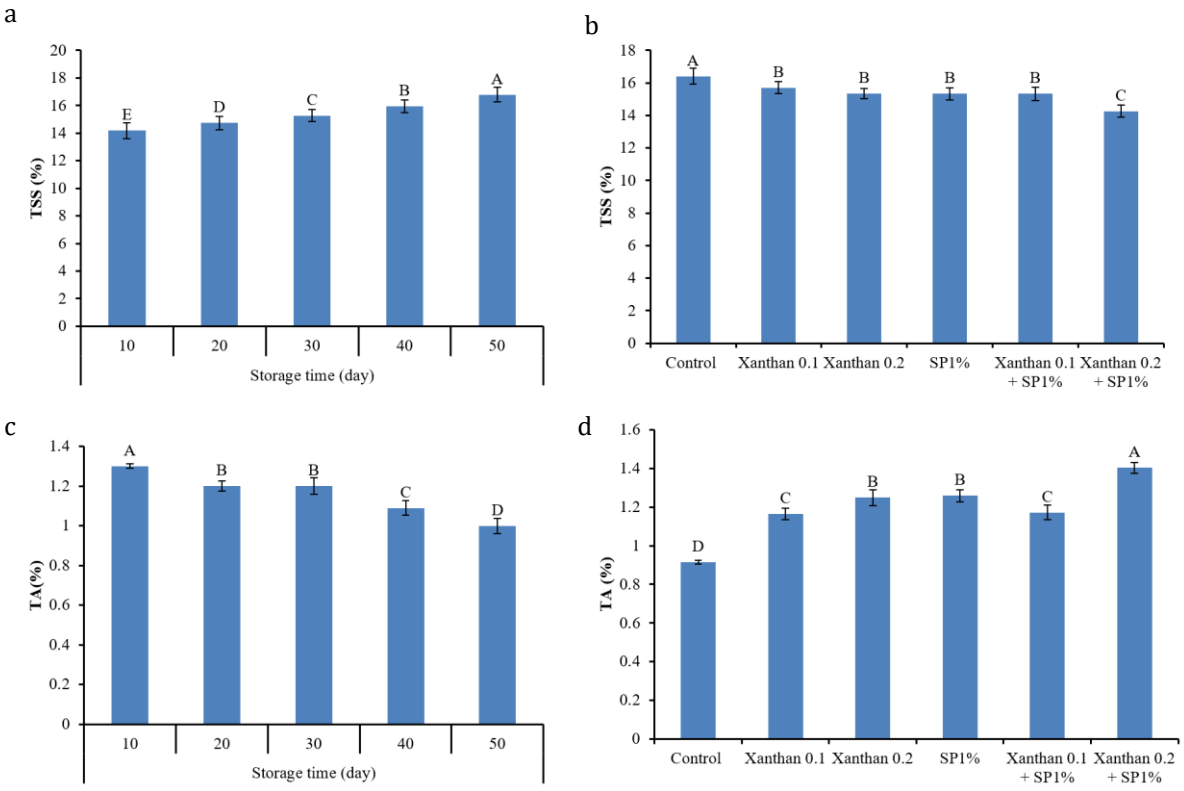

Fig. 5. Effect of xanthan gum edible coating (control, xanthan gum 0.1%, xanthan gum 0.2%, SP 1%, xanthan gum 0.1% + SP 1% and xanthan gum 0.2% + SP1%) and storage time (10, 20, 30, 40, and 50 d) on a) total soluble solids and b) TA of mango fruits stored for 50 d in cold storage at 12 ± 1 °C. Error bars represent the standard errors of mean values. Similar letters are not significantly different from each other ($p \leq 0.05$).

Rahimah et al. (2024) demonstrated that a carboxymethyl cellulose (CMC) edible coating enriched with *Spirulina platensis* significantly reduced weight loss in tomatoes compared to the control. Xanthan gum has been shown to regulate respiration rates, delay ripening, and enhance the firmness and structural integrity of fruit tissue. The softening of fruit during ripening is primarily attributed to the enzymatic activity of polygalacturonase and pectin methylesterase, which degrade the middle lamella between parenchymal cells, weaken the cell wall, and reduce turgor pressure (Harker et al., 2010). The hemicellulose-cellulose network plays a critical role in maintaining cell adhesion and preventing wrinkling (Lahaye et al., 2021). Changes in cell wall composition reduce structural strength, leading to cell detachment and diminished intracellular adhesion, which accelerates fruit softening (Ren et al., 2020). Xanthan gum application has been found to preserve hemicellulose, cellulose, and protopectin within the cell wall, thereby delaying the breakdown and polymerization of polysaccharides. This

preservation enhances cell wall strength and postpones the softening of mango fruits.

By creating a modified atmosphere, edible coatings reduce enzymatic activity and maintain the firmness of fruit tissues, as reported in Washington Navel oranges (Ramezanian et al., 2016). Similarly, Rahimah et al. (2024) observed that tomatoes coated with CMC enriched with *Spirulina platensis* exhibited significantly greater firmness than uncoated tomatoes. Edible coatings also influence fruit respiration rates by forming a semi-permeable barrier that regulates the exchange of gases, such as oxygen and carbon dioxide, between the fruit and its surroundings. This barrier limits oxygen uptake and reduces carbon dioxide release, slowing down respiration and delaying ripening and senescence, thereby extending shelf life and preserving fruit quality (Anjum et al., 2020). Rezakhani et al. (2024) reported that Chico fruits coated with xanthan gum and oleic acid experienced a significant reduction in respiration rates.

The protective barrier provided by edible coatings also helps preserve ascorbic acid content during storage by limiting exposure to oxygen and moisture, which reduces oxidative degradation (Qiao et al., 2024; Thakur et al., 2019). Ebrahimi and Rastegar (2020) demonstrated that guar gum coatings enriched with *Spirulina platensis* effectively preserved ascorbic acid content in mangoes stored at ambient temperature. Similarly, coatings containing *Spirulina platensis*, chitosan, and gelatin were found to enhance the physicochemical, sensory, and nutritional properties of dried kiwifruit, including ascorbic acid content (Asadi et al., 2020). In addition, Byantara and Dianursanti (2021) reported that strawberries coated with CMC enriched with 1% *Spirulina platensis* experienced minimal weight loss and preserved ascorbic acid content during storage at 4–7 °C. These findings underscore the efficacy of edible coatings in enhancing the postharvest quality and extending the shelf life of fruits.

As fruits ripen, they become increasingly susceptible to oxidative stress. To counteract this, fruits employ non-enzymatic antioxidants such as phenolics and flavonoids (Shi et al., 2021; Zhao et al., 2022). Edible coatings act as a protective barrier, reducing oxygen absorption and minimizing oxidative degradation of these antioxidant compounds (Bonilla et al., 2012). By delaying senescence and ripening, these coatings enhance the fruit's natural defense mechanisms and maintain quality during storage. This is achieved by controlling gas exchange, reducing respiration and transpiration rates, inhibiting senescence-related enzymes, and suppressing microbial growth (Khaliq et al., 2016).

Consistent with the findings of this study, Quoc et al. (2014) reported that xanthan gum coatings effectively preserved the total phenolic content in grapes by forming a protective layer around the fruit. Similarly, Anjam et al. (2020) and Wani et al. (2021) demonstrated higher phenolic retention in fruits treated with edible coatings. These results suggest that coatings effectively delay fruit aging and preserve total phenolic compounds. Xanthan gum-coated mangoes displayed increased levels of phenolics, flavonoids, and antioxidants, which protect the fruit from oxidative damage. These compounds also contribute to antioxidant defense and play regulatory roles in intracellular signaling pathways (Shamloo et al., 2015; Franzoni et al., 2019).

Studies have further highlighted the role of xanthan gum combined with essential oils in preserving fruit quality. For example, Bajaj et al. (2024) showed that coatings containing xanthan gum and lemongrass essential oil helped maintain total flavonoid content and juice quality in Kinnow tangerines. Phenolic compounds, closely linked to antioxidant capacity, decrease in tandem with reductions in antioxidant activity during storage (Shiri et al., 2011).

As fruits experience oxidative stress during ripening, free radical production increases. The fruit's antioxidant system works to neutralize these radicals, mitigating their harmful effects (Asghari and Aghdam, 2010). Treatments that reduce respiration rates, delay ripening, and manage environmental stress are effective in maintaining cellular antioxidants by limiting free radical generation. A decline in antioxidant activity during storage can result from the breakdown of cell structures, which releases oxidative and antioxidant enzymes (Ullah et al., 2017; Shiri et al., 2011).

The accumulation of ROS can cause membrane damage, accelerated ripening, and tissue softening in mango fruits (Yadav et al., 2022). Antioxidant enzymes such as POD, CAT, and APX play crucial roles in neutralizing ROS, thus preventing excessive softening of fruit tissues (Ali et al., 2022). POD, in particular, is integral to the defense system under stress conditions, while PPO mitigates ROS effects and reduces cold damage (Dong and Wang, 2018). The coordinated activity of these enzymes is essential for maintaining the quality and integrity of mango fruits during storage.

The increase in TSS content observed during storage can be attributed to cell wall degradation, the accumulation of dry matter, and reduced juice

volume (Khorram et al., 2017). Edible coatings help prevent excessive increases in TSS by reducing respiration rates and altering the internal atmosphere of the fruit—lowering oxygen and ethylene levels while increasing carbon dioxide (Dong and Wang, 2018).

TA content decreased gradually during storage (Fig. 5c). However, the 0.2% xanthan gum treatment maintained a significantly higher TA (1.4%) compared to the control (0.9%) after 50 d (Fig. 5d). By slowing the ripening process, such treatments effectively reduce the rate of TA changes. TA and TSS are key indicators of fruit maturity and quality. Xanthan gum coatings minimize moisture loss and decelerate ripening, leading to a gradual and limited increase in TSS and the conservation of organic acids (Malmiri et al., 2011).

Consistent with the present findings, Baraiya et al. (2016) demonstrated that xanthan gum combined with olive oil reduced TSS accumulation in grapefruit. In addition, Kumar and Saini (2021) reported that xanthan gum and clove oil coatings effectively slowed the reduction in TA in tomato fruits. These findings emphasize the efficacy of xanthan gum-based coatings in preserving quality attributes such as TSS and TA, thereby extending the shelf life of fruits during storage.

Conclusions

The findings of this study highlight the efficacy of xanthan gum-based edible coatings enriched with *Spirulina platensis* in preserving the postharvest quality of mango fruits. These coatings effectively reduce weight loss, maintain firmness, and slow respiration rates, thereby extending the shelf life of mangoes. Furthermore, the treatments contribute to the retention of vital nutritional components such as ascorbic acid and flavonoids while mitigating oxidative stress during storage. Based on the results, the application of a 0.2% xanthan gum coating enriched with 1% *Spirulina platensis* is recommended for maintaining the freshness and quality of mangoes during postharvest storage. This approach offers a sustainable and eco-friendly strategy to improve postharvest handling and distribution in the mango fruit industry. The study underscores the potential of xanthan gum coatings as a promising method for enhancing postharvest durability, with important implications for sustainable practices in the fruit industry. Future research should focus on exploring the synergistic effects of xanthan gum combined with other natural additives to further enhance preservation outcomes and extend the shelf life of mangoes.

Acknowledgements

The authors are grateful to University of Hormozgan for providing the necessary equipment for the current research and experimental processes.

Conflict of Interest

The authors indicate no conflict of interest in this work.

References

Abraham J, Banerjee A. 2018. Study on the efficacy of *Aloe vera* gel blended with xanthan gum gel in enhancing the shelf life of guava. Universal Review 7, 195-199.

Aebi H. 1984. Catalase in vitro, in: Methods in Enzymology. Elsevier 121–126.

Ali S, Anjum M A, Khan A S, Nawaz A, Ejaz S, Khaliq G, Iqbal S, Ullah S, Rehman R N U, Ali, M M. 2022. Carboxymethyl cellulose coating delays ripening of harvested mango fruits by regulating softening enzymes activities. Food Chemistry 380, 131804.

Anjum M A, Akram H, Zaidi M, Ali S. 2020. Effect of gum arabic and *Aloe vera* gel based edible coatings in combination with plant extracts on postharvest quality and storability of 'Gola'guava fruits. Scientia Horticulturae 271, 109506.

Asadi S Z, Beigmohammadi Z, Mirmajidi Hashtjin A. 2020. The effect of edible coating containing *Spirulina platensis*, chitosan and gelatin on physicochemical, sensory and nutritional properties of dried kiwifruit. Journal of Food Science and Technology (Iran) 17, 53-67.

Asghari M, Aghdam, M S. 2010. Impact of salicylic acid on post-harvest physiology of horticultural crops. Trends in Food Science Technology 21, 502-509.

Bajaj K, Kumar A, Gill P, Jawandha S, Kaur N. 2024. Xanthan gum coatings augmented with lemongrass oil preserve postharvest quality and antioxidant defence system of Kinnow fruit under low-temperature storage. International Journal of Biological Macromolecules 262, 129776.

Baraiya N, Ramana Rao T, Thakkar V. 2016. Composite coating as a carrier of antioxidants improves the postharvest shelf life and quality of table grapes (*Vitis vinifera* L. var. Thompson Seedless). Journal of Agricultural Science and Technology 18, 93-107.

Barry GH, Castle WS, Davies FS. 2004. Juice quality of 'Valencia' sweet oranges borne on different inflorescence types. HortScience 39, 33-

35.

Bonilla J, Atarés L, Vargas M, Chiralt A. 2012. Effect of essential oils and homogenization conditions on properties of chitosan-based films. Food Hydrocolloids 26, 9-16.

Bourtoom T. 2008. Edible films and coatings: characteristics and properties. International Food Research Journal 15, 237-248.

Byantara P, Dianursanti D. 2021. Utilization of *Spirulina platensis* microalgae as edible coating to maintain quality of fresh strawberry (*Fragaria* sp.). In AIP Conference Proceedings, AIP Publishing 2344

Chang CC, Yang MH, Wen HM, Chern JC. 2002. Estimation of total flavonoid content in propolis by two complementary colorimetric methods. Journal of Food and Drug Analysis 10.

Daisy LL, Nduko JM, Joseph WM, Richard SM. 2020. Effect of edible gum Arabic coating on the shelf life and quality of mangoes (*Mangifera indica*) during storage. Journal of Food Science and Technology 57, 79-85.

Dong F, Wang X. 2018. Guar gum and ginseng extract coatings maintain the quality of sweet cherry. Lwt 89, 117-122.

Dotto GL, Vieira ML, Pinto LA. 2015. Use of chitosan solutions for the microbiological shelf life extension of papaya fruits during storage at room temperature. LWT-Food Science and Technology 64, 126-130.

Ebrahimi F, Rastegar S. 2020. Preservation of mango fruit with guar-based edible coatings enriched with *Spirulina platensis* and *Aloe vera* extract during storage at ambient temperature. Scientia Horticulturae 265, 109258.

Elella MHA, Goda ES, Gab-Allah MA, Hong SE, Pandit B, Lee S, Gamal H, ur Rehman A, Yoon K R. 2021. Xanthan gum-derived materials for applications in environment and eco-friendly materials: A review. Journal of Environmental Chemical Engineering 9, 104702.

Elny Alves, Onias, Albert, Einstein, Mathias, de, Medeiros, Teodosio, Marinês, Pereira, Bomfim., Railene, Hérica, Carlos, Rocha, José, F, de, Lima, Maria LS, de Medeiros. 2018. 1. Revestimento biodegradável à base de *Spirulina platensis* na conservação pós-colheita de goiaba Paluma mantidas sob diferentes temperaturas de armazenamento. Revista de Ciências Agrárias. DOI: 10.19084/RCA17201.

Ezati P, Roy S, Rhim JW. 2022. Effect of saffron on the functional property of edible films for active packaging applications. ACS Food Science Technology 2, 1318-1325.

Franzoni G, Trivellini A, Bulgari R, Cocetta, G, Ferrante A. 2019. Bioactive molecules as regulatory signals in plant responses to abiotic stresses. In Plant Signaling Molecules, Elsevier 169-182.

Gad MM, Zagzog OA. 2017. Mixing xanthan gum and chitosan nano particles to form new coating for maintaining storage life and quality of elmamoura guava fruits. International Journal of Current Microbiology and Applied Sciences 6, 1582-1591.

Garcia-Betanzos C, Hernández-Sánchez H, Quintanar-Guerrero D, Galindo-Pérez M, Zambrano-Zaragoza M. 2018. Influence of solid lipid nanoparticle/xanthan gum coatings on compositional and enzymatic changes in guava (*Psidium guajava* L.) during ripening.

Golly MK, Ma H, Sarpong F, Dotse BP, Oteng-Darko P, Dong Y. 2019. Shelf-life extension of grape (*Pinot noir*) by xanthan gum enriched with ascorbic and citric acid during cold temperature storage. Journal of Food Science and Technology 56, 4867-4878.

Gupta DK, Palma JM, Corpas FJ. 2018. Antioxidants and antioxidant enzymes in higher plants. Springer.

Guroo I, Gull A, Wani SM, Wani SA, Al-Huqail AA, Alhaji JH. 2021. Influence of different types of polysaccharide-based coatings on the storage stability of fresh-cut kiwi fruit: Assessing the physicochemical, antioxidant and phytochemical properties. Foods 10, 2806.

Habibi F, Ramezanian A. 2017. Vacuum infiltration of putrescine enhances bioactive compounds and maintains quality of blood orange during cold storage. Food Chemistry 227, 1-8.

Harker FR, Redgwell RJ, Hallett IC, Murray SH, Carter G. 2010. Texture of fresh fruit. Horticultural Reviews 20, 121-224.

Kar M, Mishra D. 1976. Catalase, peroxidase, and polyphenoloxidase activities during rice leaf senescence. Plant Physiology 57, 315-319.

Kazemi M, Aran M, Zamani S. 2011. Effect of salicylic acid treatments on quality characteristics of apple fruits during storage.

Khaledian F, Momeni M. 2021. Measuring the performance of time and quality of project execution under uncertainty. Research in Production and Operations Management 12, 71-

91.

Khaliq G, Mohamed MTM, Ghazali HM, Ding P, Ali A. 2016. Influence of gum arabic coating enriched with calcium chloride on physiological, biochemical and quality responses of mango (*Mangifera indica* L.) fruit stored under low temperature stress. Postharvest Biology and Technology 111, 362-369.

Khorram F, Ramezanian A, Hosseini S M H. 2017. Effect of different edible coatings on postharvest quality of 'Kinnow' mandarin. Journal of Food Measurement and Characterization 11, 1827-1833.

Kouamé M, Kouamé AK, Ouattara L, N'guessan FK, Alloue-Boraud MW, Dje K. 2020. Contraintes liées à la production et à la commercialisation des mangues (*Mangifera indica*) en Côte d'Ivoire: cas des variétés exportées vers l'Europe. Afrique Science 7, 16-27.

Kumar A, Saini C S. 2021. Edible composite bi-layer coating based on whey protein isolate, xanthan gum and clove oil for prolonging shelf life of tomatoes. Measurement: Food 2, 100005.

Lahaye M, Tabi W, Le Bot L, Delaire M, Orsel M, Campoy J A, Garcia J Q, Le Gall S. 2021. Comparison of cell wall chemical evolution during the development of fruits of two contrasting quality from two members of the Rosaceae family: Apple and sweet cherry. Plant Physiology and Biochemistry 168, 93-104.

Liao L, Li S, Li Y, Huang Z, Li J, Xiong B, Zhang M, Sun G, Wang Z. 2022. Pre-or post-harvest treatment with MeJA improves post-harvest storage of lemon fruit by stimulating the antioxidant system and alleviating chilling injury. Plants 11, 2840.

López L, Larrigaudière C, Giné-Bordonaba J, Echeverria G. 2023. Defining key parameters and predictive markers of 'Early Bigi' cherry consumer satisfaction by means of differential storage scenarios. Postharvest Biology and Technology 195, 112117.

MacLean D, Murr D, DeEll J. 2003. A modified total oxyradical scavenging capacity assay for antioxidants in plant tissues. Postharvest Biology and Technology 29, 183-194.

Maehly A, Chance B. 2006. Methods of Biochemical Analytics. In: John Wiley Sons, Inc.

Malmiri JH, Osman A, Tan C, Rahman AR. 2011. Evaluation of effectiveness of three cellulose derivative-based edible coatings on changes of physico-chemical characteristics of 'Berangan' banana (*Musa sapientum* cv. Berangan) during storage at ambient conditions. International Food Research Journal 18, 1381.

Nair MS, Saxena A, Kaur C. 2018. Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). Food Chemistry 240, 245-252.

Naveed F, Nawaz A, Ali S, Ejaz S. 2024. Xanthan gum coating delays ripening and softening of jujube fruit by reducing oxidative stress and suppressing cell wall polysaccharides disassembly. Postharvest Biology and Technology 209, 112689.

O'grady L, Sigge G, Caleb O, Opara UL. 2014. Effects of storage temperature and duration on chemical properties, proximate composition and selected bioactive components of pomegranate (*Punica granatum* L.) arils. LWT-Food Science and Technology 57, 508-515.

Oliveira ÁMFD, Araújo RHCR, Teodosio AEMDM, Lima JFD, Freitas E, Santos JJFD, Oliveira LM. 2018. Postharvest quality of 'prata anã' bananas treated with microalgae coating. Journal of Experimental Agriculture International 27, 1-11.

Ordonez A, Gomez J, Vattuone M. 2006. Antioxidant activities of *Sechium edule* (Jacq.) swartz extracts. Food Chemistry 97, 452-458.

Panigrahi P, Srivastava A. 2017. Water and nutrient management effects on water use and yield of drip irrigated citrus in vertisol under a sub-humid region. Journal of Integrative Agriculture 16, 1184-1194.

Pham TT, Nguyen LLP, Dam MS, Baranyai L. 2023. Application of edible coating in extension of fruit shelf life. AgriEngineering 5, 520-536.

Prasad K, Sharma RR, Asrey R, Sethi S, Srivastav M, Singh D, Arora A. 2022. Hydrocolloid edible coatings extend shelf life, reduce postharvest decay, and maintain keeping quality of mango fruits (*Mangifera indica* L.) under ambient storage. Journal of Food Biochemistry 46, e14481.

Prayoga B, Dianursanti. 2021. Utilization of *Spirulina platensis* microalgae as edible coating to maintain quality of fresh strawberry (*Fragaria* sp.). DOI: 10.1063/5.0047579

Qiao J, Li D, Guo L, Hong X, He S, Huo J. 2024. Enhancing postharvest quality and antioxidant capacity of blue honeysuckle cv. 'Lanjingling' with chitosan and *Aloe vera* gel edible coatings during storage. Foods 13.

Quoc L, Hoa D, Ngoc H, Phi T. 2014. Effect of

xanthan gum solution on the preservation of acerola (*Malpighia glabra* L.).

Ramezanian A, Azadi M, Mostowfizadeh-Ghalamfarsa R, Saharkhiz MJ. 2016. Effect of *Zataria multiflora* Boiss and *Thymus vulgaris* L. essential oils on black rot of 'Washington Navel' orange fruit. Postharvest Biology and Technology 112, 152-158.

Rahimah S, Ghassani D, Martha H, Nurhasanah S, Satya A, Chrismadha T, Mardawati E. 2024. Incorporation of *Spirulina platensis* in edible coating for shelf-life extension of tomatoes (*Lycopersicon esculentum* Mill.) Umagna Variety. In BIO Web of Conferences. EDP Sciences.

Ren Y-y, Sun P-p, Wang X-x, Zhu Z-y. 2020. Degradation of cell wall polysaccharides and change of related enzyme activities with fruit softening in *Annona squamosa* during storage. Postharvest Biology and Technology 166, 111203.

Rezakhani D, Mirzaalian Dastjerdi A, Rastegar S. 2024. The effect of xanthan-based edible coatings enriched with oleic acid on the storage quality and antioxidant properties of sapodilla (*Manilkara zapota*) fruit. Iranian Food Science and Technology Research Journal 20, 1-15.

Santos T. 2018. Men de Sá Filho. MS, Silva, EDO, da Silveira, MR, de Miranda, MRA, Lopes, MM, Azeredo, HM 252-258.

Shamloo M, Sharifani M, Daraei Garmakhany A, Seifi E. 2015. Alternation of secondary metabolites and quality attributes in Valencia Orange fruit (*Citrus sinensis*) as influenced by storage period and edible covers. Journal of Food Science and Technology 52, 1936-1947.

Sharma S, Rao TR. 2015. Xanthan gum based edible coating enriched with cinnamic acid prevents browning and extends the shelf-life of fresh-cut pears. LWT-Food Science and Technology 62, 791-800.

Shi M, Ali MM, He Y, Ma S, Rizwan HM, Yang Q, Li B, Lin Z, Chen F. 2021. Flavonoids accumulation in fruit peel and expression profiling of related genes in purple (*Passiflora edulis* f. edulis) and yellow (*Passiflora edulis* f. flavicarpa) passion fruits. Plants 10, 2240.

Shiri MA, Ghasemnezhad M, Bakhshi D, Dadi M. 2011. Changes in phenolic compounds and antioxidant capacity of fresh-cut table grape ('*Vitis vinifera*') cultivar 'Shahaneh' as influence by fruit preparation methods and packagings. Australian Journal of Crop Science 5, 1515-1520.

Siddiqui MW. 2017. Preharvest modulation of postharvest fruit and vegetable quality. Academic Press.

Thakur R, Pristijono P, Bowyer M, Singh SP, Scarlett CJ, Stathopoulos CE. 2019. A starch edible surface coating delays banana fruit ripening. LWT 100, 341–7

Tuo Y, Coulibaly D, Kone M, Coulibaly N, Koua H. 2020. Optimisation de la production de la mangue dans les villes de karakoro et kolokaha (nord de la côte d'ivoire) par l'installation de rucher dans des vergers de manguiers. Rev. ivoir. sci. technol 36, 11-25.

Ullah A, Abbasi N, Shafique M, Qureshi A. 2017. Influence of edible coatings on biochemical fruit quality and storage life of bell pepper cv."Yolo Wonder". Journal of Food Quality 2142409.

Wani SM, Gull A, Ahad T, Malik A, Ganaie TA, Masoodi FA, Gani A. 2021. Effect of gum Arabic, xanthan and carrageenan coatings containing antimicrobial agent on postharvest quality of strawberry: Assessing the physicochemical, enzyme activity and bioactive properties. International Journal of Biological Macromolecules 183, 2100-2108.

Xing Z, Wang Y, Feng Z, Tan Q. 2008. Effect of different packaging films on postharvest quality and selected enzyme activities of *Hypsizygus marmoreus* mushrooms. Journal of Agricultural and Food Chemistry 56, 11838-11844.

Yadav A, Kumar N, Upadhyay A, Fawole OA, Mahawar MK, Jalgaonkar K, Chandran D, Rajalingam S, Zengin G, Kumar M. 2022. Recent advances in novel packaging technologies for shelf-life extension of guava fruits for retaining health benefits for longer duration. Plants 11, 547.

Yun D, He Y, Zhu H, Hui Y, Li C, Chen D, Liu J. 2022. Smart packaging films based on locust bean gum, polyvinyl alcohol, the crude extract of *Loropetalum chinense* var. rubrum petals and its purified fractions. International Journal of Biological Macromolecules 205, 141-153.

Zambrano-Zaragoza ML, Quintanar-Guerrero D, Del Real A, Piñon-Segundo E, Zambrano-Zaragoza J F. 2017. The release kinetics of β-carotene nanocapsules/xanthan gum coating and quality changes in fresh-cut melon (*cantaloupe*). Carbohydrate Polymers, 157, 1874-1882.

Zhao JC, Miao A, He X-Q, Li WZ, Deng LL, Zeng KF, Jian M. 2022. Changes in phenolic content, composition, and antioxidant activity of blood oranges during cold and on-tree storage. Journal

of Integrative Agriculture 21, 3669-3683.

Zhou L, Li F, Xu H-B, Luo CX, Wu HY, Zhu MM, Lu W, Ji X, Zhou QG, Zhu DY. 2010. Treatment of cerebral ischemia by disrupting ischemia-induced interaction of nNOS with PSD-95. Nature medicine 16(12), 1439-1443.

Zillo RR, da Silva PPM, de Oliveira J, da Glória EM, Spoto MHF. 2018. Carboxymethylcellulose coating associated with essential oil can increase papaya shelf life. Scientia Horticulturae 239, 70-77.