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Research Article

Assessment of physiochemical and antioxidant characteristics of bell pepper (*Capsicum annuum* L.) using principal component analysis by guar, xanthan gum, and carboxymethyl cellulose as edible coatings

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ABSTRACT- Extending the shelf life of vegetables can be achieved using edible, environmentally friendly coatings. In this study, bell peppers were coated with guar (GU) gum, xanthan (XAN) gum, or carboxymethyl cellulose (CMC) at concentrations of 0.5, 1, and 1.5 %. Uncoated bell peppers served as the control. All samples were stored for 28 days under walk-in storage conditions (8-10 °C, 85% relative humidity, and darkness). Results showed that as storage time increased, signs of disease infection and water loss in the bell pepper fruits also increased. Additionally, levels of organic acids, vitamins, phenols, and antioxidants declined during storage. Overall, the coatings improved key marketability traits, including fruit firmness, total soluble solids (TSS), and organic acid content, all of which contribute to flavor and taste. The extent of fruit skin shrinkage varied depending on the coating type. According to a biplot analysis, carotenoid content, firmness, and TSS were substantially improved by XAN gum at 1 % and CMC at 0.5 and 1 %. In contrast, starch, chlorophyll, phenol, and vitamin C contents increased by XAN gum at 0.5 % and GU gum at 0.5 and 1 %. In conclusion, the GU gum coating at 1 % was the most effective treatment for enhancing postharvest quality and maintaining the shelf life of bell peppers. Toxicological assessment remains essential for the continued development of edible coatings based on natural gums with suitable physical properties.

INTRODUCTION

Pepper (*Capsicum annuum* L.) is among the ten most extensively cultivated vegetables worldwide (Wei et al., 2019). Large quantities of greenhouse-grown peppers are exported globally to meet the growing demand for fresh products, driven by their appealing aroma and notable health benefits (Mahalik and Nambiar, 2010). Bell peppers, in particular, are valued for their high levels of carotenoids and vitamin C, both powerful antioxidants (Villa-Rivera and Ochoa-Alejo, 2020). Despite these advantages, bell peppers have a relatively short shelf life of seven to ten days, which is strongly influenced by handling practices, pre-harvest conditions, and transportation (Maalekuu et al., 2003). Several factors contribute to this limited shelf life, including physical damage, dehydration, rapid biochemical degradation (Bayoumi, 2008), water loss (Díaz-Pérez, 2007), freezing injury, and diseases caused by pathogens (Fallik et al., 2009). Chilling injury, for instance, occurs when peppers are stored below 7 °C and is characterized by pitting, weight loss, calyx darkening, and increased decay (Lim et al., 2007). After harvest, peppers continue to respire and transpire, leading to moisture and metabolite loss. Their high surface area-to-weight ratio makes them particularly prone to water loss, resulting in shriveling and reduced marketability. Additionally, freshly harvested peppers are vulnerable to fungal infections such as *Botrytis cinerea* and *Alternaria alternata* (Edusei et al., 2012), contributing to substantial postharvest losses and economic challenges for producers. Edible coatings have been widely studied as a strategy to extend the shelf life and maintain the quality of fresh products. According to Sharif et al. (2018), certain coating materials effectively reduce decay development and preserve overall freshness even during extended storage. Edible coatings also enhance the appearance of fruits and vegetables by forming a protective barrier that limits oxidation and moisture loss (Ncama et al., 2018). By modifying internal gas composition, often resulting in reduced oxygen levels, they can influence beneficial attributes such as antioxidant activity, microbial growth, color, sensory quality, firmness, ethylene production, and volatile profiles. Extensive research has focused on applying edible coatings to maintain pepper quality during storage and distribution. Studies have demonstrated that materials such as gum tragacanth,

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chitosan, and methylcellulose can significantly enhance the shelf life and quality of coated pepper fruits (Chaple et al., 2017; Kehila et al., 2021; Zare-Bavani et al., 2024).

Xanthan gum (XAN) is a polysaccharide produced by *XANthomonas campestris* and is widely used in the food industry. Its strong resistance to enzymatic degradation makes XAN gum based coatings particularly effective in preserving the quality of fresh-cut and whole fruits (Wani et al., 2021). Kumar and Saini (2021) evaluated XAN gum edible coatings for maintaining the quality of stored tomatoes and reported that the XAN gum treatments performed best overall. Their effectiveness was attributed to their ability to inhibit respiration and reduce the conversion of starch into sugars, processes commonly associated with postharvest quality loss in tomatoes. Guar (GU) gum, obtained from the endosperm of the GU bean (*Cyamopsis tetragonoloba*), also represents a promising material for edible coating applications. Its high molecular weight, long polymeric chains, wide availability, and excellent water solubility make it well-suited for forming protective coatings (Rastegar and Atrash, 2021). The use of GU gum in tomato coatings has been well documented in previous research (Maurizzi et al., 2023). Carboxymethyl cellulose (CMC), a versatile derivative of cellulose, is another strong candidate for edible coatings. This anionic, linear, long-chain, water-soluble polymer is known for its strength and structural stability, which make it suitable for coating various vegetables (Panahirad et al., 2021; Perez-Vazquez et al., 2023). The presence of both hydroxyl and carboxylic groups in its chemical structure gives CMC excellent water-binding and moisture-sorption properties. These characteristics enable CMC -based coatings to improve barriers against moisture, oxygen, carbon dioxide, aroma loss, and oil absorption in coated products (Panahirad et al., 2021; Perez-Vazquez et al., 2023). Additionally, CMC enhances adhesion between the coating material and the surface of the product, increasing its protective capacity. Its anti-senescence effects have been shown to extend the shelf life of climacteric fruits by slowing their ripening processes (Panahirad et al., 2021; Perez-Vazquez et al., 2023). The versatility of CMC is further underscored by its successful use in preserving okra quality, as demonstrated by Gonzales et al. (2023).

Although many studies examined the application of edible coatings to preserve quality and extend the shelf life of fresh products, including bell peppers, further research is needed to determine the optimal coating formulation and concentration specifically for bell peppers. The distinct physiological traits and storage requirements of bell peppers justify a focused investigation to identify the most suitable edible coating approach. Building on existing knowledge, this study evaluates the performance of XAN gum, GU gum, and CMC coatings to generate practical insights for improving the postharvest management of bell peppers, an important export commodity.

MATERIALS AND METHODS

Experimental design

This study was conducted using a completely randomized design with eight replications, each consisting of 20 fruits, resulting in 160 fruits per treatment. The experimental treatments included edible coatings made from XAN gum, GU gum, and CMC, each applied at three concentrations: 0.5, 1, and 1.5 %. Accordingly, the 0.5 % treatments were designated as CMC 1, GU1, and XAN1; the 1 % treatments as CMC2, GU2, and XAN2; and the 1.5 % treatments as CMC3, GU3, and XAN3. An untreated group served as the control. The primary objective of the study was to identify the optimal coating material and concentration for enhancing the postharvest shelf life of bell peppers (*Capsicum annuum* var. 'Orobella').

Preparation of the coating solutions

Separate coating emulsions were prepared using XAN, CMC, and GU. A preliminary experiment was conducted to determine suitable formulations and concentrations for coating *Capsicum annuum* var. 'Orobella' fruits. Following the method of Maftoonazad et al. (2007), nine coating concentrations were initially evaluated. The criteria for selecting the best treatments included the absence of adverse effects such as decay and excessive weight loss. Based on the results of this pre-test, three concentrations, 0.5, 1, and 1.5 %, were selected for the main experiment. These were designated as CMC1, GU1, and XAN1 (0.5 %); CMC2, GU2, and XAN2 (1 %); and CMC3, GU3, and XAN3 (1.5 %). Untreated bell peppers served as the control. For GU gum solutions, GU powder was rehydrated in 100 mL of distilled water for 4 hours at 60 °C. Then, 0.3 mL of glycerol was added as a plasticizer and thoroughly mixed. As noted, the final coating concentrations were chosen based on the preliminary test involving nine levels of each substance (0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, and 2 %). The mixtures were homogenized for 10 minutes to obtain uniformly dispersed emulsions and subsequently cooled. The same procedures and concentrations were applied to prepare XAN gum and CMC solutions.

Fruit sample preparation

Mature fruits of bell pepper (*Capsicum annuum* var. 'Orobella') were harvested from a commercial plastic greenhouse in Ziar, Isfahan. Cultivation was carried out in a soil-based substrate, with seedlings transplanted at the four-leaf stage. Plants were spaced 50 cm apart within rows and 50 cm between rows to ensure adequate air circulation and light penetration. Standard cultural practices for bell pepper production in the region, regular irrigation, integrated pest management, and appropriate nutrient application, were followed. 'Orobella' is a bulky F1 hybrid that transitions from green to yellow at maturity. Fully mature, firm green fruits are typically harvested 60-70 days after planting, with additional harvests occurring at intervals of 5-7 days. Immediately after harvest, fruits were transported to the postharvest laboratory at Isfahan University of Technology. Healthy fruits of uniform shape and size (200-250 g), free from mechanical injury and external defects, were selected for the experiment. The selected fruits were cleaned and disinfected using 0.5% sodium hypochlorite prior to coating.

Fruit fungal inoculation

The selected fruits were divided into two groups (n = 80). Half of the fruits were coated and transferred to storage, while the remaining half were inoculated with 50 mL of an *Alternaria alternata* spore suspension. The fungal inoculum was prepared from infected bell pepper fruits. Spores were obtained by flooding 2-week-old mycelial cultures with 2 mL of distilled water and gently scraping the mycelial surface with a sterile glass rod to dislodge the spores. The resulting suspension was collected using a micropipette, transferred to a 1.5 mL microcentrifuge tube, and adjusted to a concentration of 5×10^5 conidia/mL using a hemocytometer. Bell pepper fruits were first coated as previously described and then inoculated by spraying 50 mL of the *A. alternata* suspension (10^5 spores/mL). Control fruits were not coated but were inoculated with *A. alternata*, following a method by Soliman et al. (2023). Fungal contamination was assessed using standard techniques, including colony counts on selective culture media and microscopic observation of mycelial growth, allowing for a comprehensive evaluation of infection levels.

Coating and storage conditions

Coatings were applied on the same day the bell peppers were harvested. Fruits were immersed in their respective coating solutions for 60 seconds, air-dried at room temperature, and then placed in perforated plastic trays. All fruits (coated, inoculated, and control) were stored at 8-10 °C and 85% relative humidity. Analyses were conducted at 7-day intervals over a 28-day storage period.

Quality traits

Baseline quality indices were recorded immediately after harvest. Subsequent measurements were taken every 7 days for one month (days 0, 7, 14, and 21). Quality parameters assessed included marketability, disease incidence and decay, appearance, firmness, total soluble solids (TSS), organic acids, vitamin C, fruit pigments, phenolic content, antioxidant activity, and starch content. Weight loss, marketability, and disease decay were evaluated at the end of the experiment. All fruits within each replication were used for measurements, resulting in 160 fruits analyzed per parameter.

Weight loss of fruit

Fruit weight loss was calculated as percentage of weight loss compared to the initial fruit weight according to the following formula every 4 days from day 0 to 35 (Amiri et al., 2021).

Weight loss (%) = [(W1-W2)/W1] × 100

where, W1 = weight as zero-day, and W2 = weight at sampling times.

Marketable features (MF) of fruit

Color change (%), symptoms of infectious diseases decay, and shiny skin determined the MF. These were evaluated by five professional producers using a scale of 5 (the worst) to 0 (the best) (LeRoux et al., 2010).

Infectious diseases decay (IDD) of fruit

Decay was calculated as a percentage of the total number of infected fruits. The fruit was considered decayed when visible infection was observed on the fruit surface every 4 days from day 0 to 35 (Nasrin et al., 2018).

Fruit firmness

The firmness of the bell pepper fruits was measured from the equatorial zone of the bell pepper fruit using the Penetrometer (model Dual Mass DCP, OSK-I-10576, Northville, USA) in Newton units (Jantra et al., 2018).

TSS of fruit

TSS was determined in all fruits using a hand refractometer, and the results were expressed as °Brix units (Cosmo, K–0032, Kyoto, Japan) calibrated against sucrose (Bernardo et al., 2008).

Organic acids of fruit

Titratable acidity was determined by treating five grams of pericarp with 0.1 N NaOH and 1% phenolphthalein (AOAC, 1995). The results were expressed as a percentage of citric acid.

Vitamin C of fruit

The determination of vitamin C content was carried out according to Tillman's method (AOAC, 1995). Fruit samples (10 mL), 10% KI (5 mL), and 0.3 M H_2SO_4 (1 mL) mixed in a flask. Then, 0.01 M KIO_3 (10 mL) was also added to the flask. The solution was titrated against $Na_2S_2O_3$ (0.01 M) solution. The vitamin C content was presented as mg/g of fresh weight using a standard curve of vitamin C (Perez-Grajales et al., 2019).

Determination of fruit pigments

Chlorophyll and carotenoid contents were determined following a standard method (Arnon, 1967). Fruits were extracted with 80% acetone and centrifuged at 14,000 × g / 5 min at -10 °C. The supernatant absorption was read at 663 nm, 645, and 470 nm by a spectrophotometer (UV160A-Shimadzu Crop., Kyoto-Japan) in mg/100 g FW units.

Chlorophyll = (19.3 × A663 - 0.86 × A645) V/100W + (19.3 × A645 - 3.6 × A663) V/100W

Carotenoids = 100(A470) - 3.27(mg Chl. a) - 104 (mg Chl. b)/227

Phenol determination of fruit

Total phenolic content was measured using the Folin-Ciocalteau reagent. The fruit extract (20 µL) was mixed with Folin-Ciocalteau reagent and sodium bicarbonate solution (7.5%) and incubated at room temperature for 15 min. The reading was set at 730 nm and compared with gallic acid equivalents (GAE) calibration curve and expressed as mg/100 g FW (Shotorbani et al., 2013).

Antioxidant activity of fruit (DPPH)

Chopped fruits were mixed with methanol (5 mL) and 2,2-diphenyl-1-picrylhydrazyl (0.6 mL) (Yu et al., 2002). Then, 0.2 mM DPPH solution in methanol was used as a reference. At 515 nm, the absorbance was measured after 30 minutes. Results were reported in % units.

Starch of fruit

The fruit sample was homogenized in ethanol (80%). Starch was measured by a standard method (Hedge and Hofreiter, 1962). The absorbance was measured at 630 nm, and glucose was used as a standard solution. Results were reported in mg/100 g FW units

Statistical analysis

Analysis of variance (ANOVA) was carried out by Statistix 8 (Tallahassee, USA). Means were compared using the least significant difference ($P < 0.05$). Principal component analysis (PCA) was carried out using Statgraphics Centurion Version XVI. The spider graphs were created using Microsoft Excel 2013. The circular, correlation and Sankey diagrams between traits were created in https://www.chiplot.online/.

RESULTS AND DISCUSSION

Antioxidant activity, phenol, vitamin C, and organic acids of fruit

Based on the circular plot illustrating the effects of coating treatments on antioxidant properties, phenol, vitamin C, and organic acids, the treatments were categorized into two clusters. This separation into clusters suggests that the treatments had distinctly different effects on the measured traits, likely due to the variations in their composition and mechanisms of action. Treatments C, CMC3, CMC2, XAN3, and CMC1 formed one cluster, while the other treatments (GU1, gu3, GU2, XAN2, XAN1) were grouped in a separate cluster. Specifically, the highest antioxidant activity was observed in the CMC2 treatment compared to other treatments. This finding highlights the effectiveness of CMC2 in enhancing antioxidant properties. Additionally, the highest amount of phenol was observed in the XAN1 treatment compared to other treatments, indicating that XAN1 may be particularly effective in promoting phenolic compounds. These results further support the clustering observed in the heat map, as they reflect the unique profiles of each treatment and their corresponding effects on the quality traits measured (Fig. 1A). The treatments had the least effect on vitamin C, while phenol showed the greatest sensitivity. Antioxidants and organic acids displayed relatively uniform changes across the various treatments. The best treatments are those that exhibited minimal changes in antioxidant properties, organic acids, and vitamin C, specifically GU1, GU2, XAN2, and XAN1. These four treatments were grouped together and showed the least variation in organic acids and antioxidants; however, phenol levels were comparatively lower, and vitamin C behaved similarly to other treatments (Fig. 1B).

According to the correlation chart, among antioxidant properties, phenol, vitamin C, and organic acids, the most significant changes were observed in vitamin C and phenol, based on Mantel's plot. As vitamin C decreased, phenol levels increased, indicating a negative correlation between these two traits. In contrast, antioxidants and organic acids showed the least sensitivity. Additionally, vitamin C and phenol showed a positive correlation, meaning that as one increases, the other also tends to increase (Fig. 2).

The antioxidant activity of peppers is influenced by multiple factors, such as genetic variation, environmental conditions, production and management practices, and postharvest handling, similar to other plant species (Zaki et al., 2013). Numerous studies have reported that antioxidant and vitamin C levels may increase, decrease, or remain constant during storage depending on genotype, storage conditions, and temperature. For example, vitamin C and antioxidant contents decreased in pepper (cv. 'Cherry') stored at 10 °C for 10 days and in pepper (cv. 'Zafiro') stored at 10 °C for 12 days, although antioxidant levels remained unchanged in the latter case (Vicente et al., 2005; Avalos Llano et al., 2009). In contrast, peppers stored for 21 days at 7.5 °C showed a slight increase in ascorbic acid concentration (Raffo et al., 2007). Overall phenolic content typically declines during storage, a reduction attributed to increasing polyphenol oxidase activity that accelerates phenolic oxidation. The use of edible coatings may limit oxygen penetration into the fruit, delaying phenol oxidation and thereby reducing the breakdown or transformation of secondary metabolites. As metabolites are continuously consumed during postharvest respiration, a reduced respiration rate can slow their depletion and enhance their retention in coated fruits (Behera et al., 2004). Several studies support the role of edible coatings in enhancing antioxidant properties in peppers and other fruits. For instance, gum arabic has been reported to increase phenolic compounds and pigment content (lycopene, carotenoids, and anthocyanins) in strawberry (Tahir et al., 2018). GU gum has been shown to improve antioxidant activity in cucumbers and tomatoes (Saha et al., 2016; Naeem et al., 2018), while XAN gum enhances antioxidant effects in fresh-cut cantaloupe melon (Chikhala et al., 2024). Vitamin C content is a key indicator of fruit nutritional quality and storage performance (Hu et al., 2011). However, it is unstable and can degrade as a result of factors such as pH, water activity, and enzymatic reactions (Zhang et al., 2013). Chen et al. (2022) observed that vitamin C levels in green bell peppers decreased during storage, but applying a XAN gum coating helped preserve these levels by reducing oxygen diffusion and respiration rates, a finding consistent with Chikhala et al. (2024). The results of the present study align with those reported by Deepa et al. (2006) and Ghasemnezhad et al. (2011) for bell peppers.

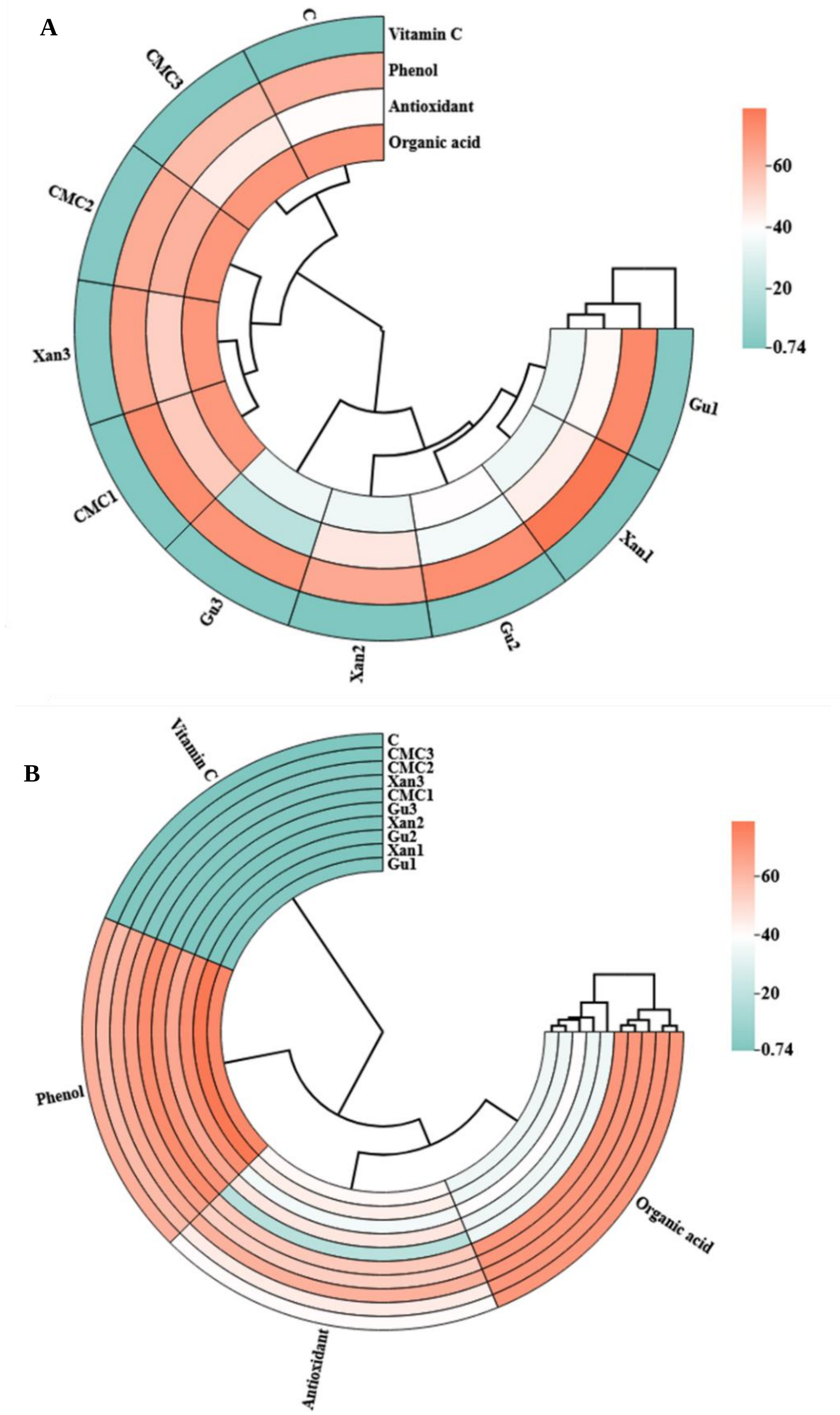

Fig. 1. The circular plots of edible coatings treatments on antioxidant, phenol, vitamin C, and organic acids in bell pepper. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

Chlorophyll and carotenoid contents

Based on the spider chart, the total chlorophyll content decreased over time, with the lowest concentration observed on day 21. The highest levels of chlorophyll were found in the GU1 and GU3 treatments on all days after harvest, while the control treatment consistently showed the lowest chlorophyll levels (Fig. 3A). Similarly, carotenoid concentrations also decreased over the postharvest period. The highest carotenoid levels were recorded on days 0 and 7 in the CMC1 and GU3 treatments, with GU3 maintaining higher carotenoid levels compared to other treatments on days 14 and 21 after harvest (Fig. 3B).

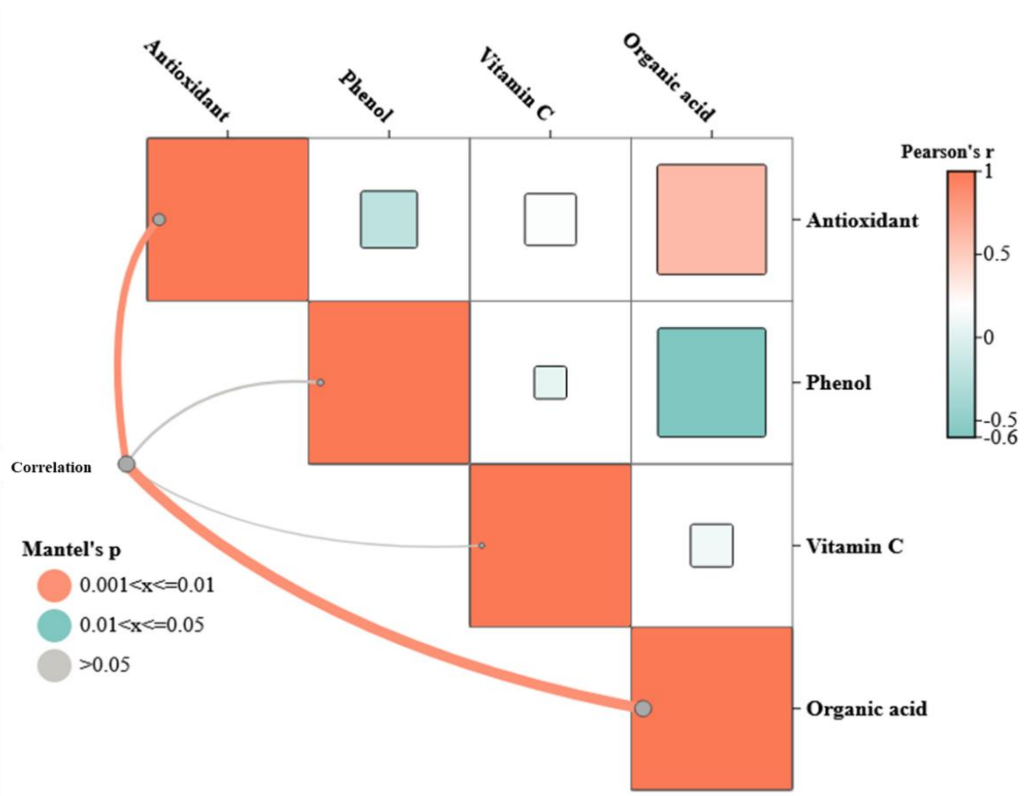

Fig. 2. Correlation between antioxidant, phenol, vitamin C, and organic acids of bell pepper.

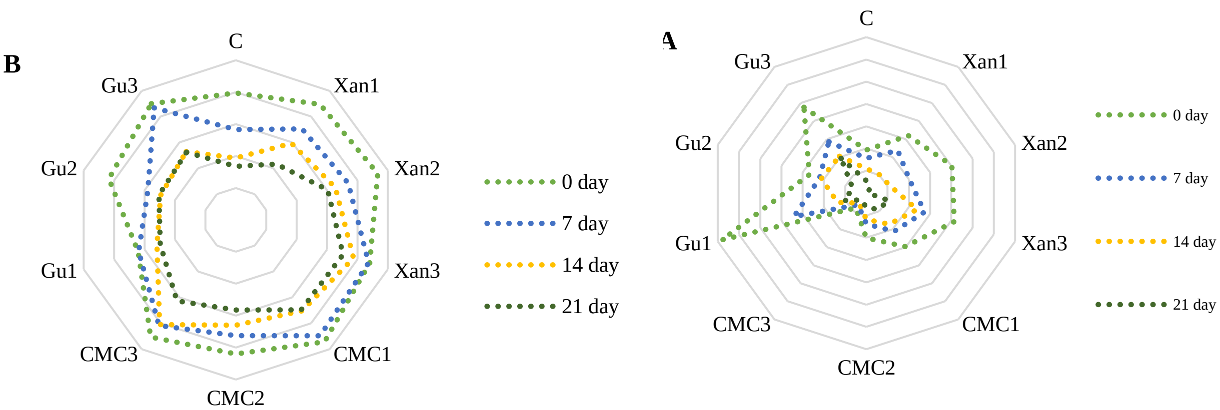

Fig. 3. The spider plots of edible coatings treatments on total chlorophyll (A) and carotenoid (B) in bell pepper. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

Fruit color is a key quality parameter and the main sensory attribute influencing consumer acceptability (Barret et al., 2010). It is governed by pigments that are highly sensitive to storage conditions, such as temperature, packaging, and duration, which can accelerate pigment degradation and alter visual appearance (Gil et al., 2006). Naeem et al. (2018) reported that chlorophyll content in tomatoes declined during storage; however, applying a GU gum coating helped retain higher chlorophyll levels and reduced lycopene accumulation during the first month, thereby delaying ripening. This ripening delay is mainly attributed to the modified atmosphere created around coated fruits, characterized by reduced oxygen and elevated carbon dioxide concentrations, which in turn decreases respiration and ethylene production in climacteric fruits (Daraghmah and Qubbaj, 2021). In addition, Minh et al. (2019) observed that a 5% GU gum coating increased carotenoid content in chili peppers, while Chikhala et al. (2024) found that XAN coatings helped maintain carotenoid levels in cut cantaloupe during storage.

TSS, starch, firmness, and marketable features

According to the circular diagram, the effects of the coating treatments on TSS, starch, firmness, and marketable features of bell peppers show that the treatments GU3, XAN1, and GU2 cluster together, exhibiting the highest levels of starch, TSS, firmness, and marketability. Although there was no significant difference observed between marketable features and firmness across the various treatments, starch was notably more influenced by the treatments than the other three traits. This is highlighted in a separate grouping marked in red, indicating its changes during the postharvest stage due to the treatments (Fig. 4).

In addition, the correlation diagram shows that fruit firmness and TSS had a positive relationship with each other and showed the highest correlation with other traits (Fig. 5). Total and reducing sugars followed close linearity with the TSS content in the bell pepper with an initial increase by coating and decrease by storage time. Along with the conversion of complex polysaccharides and pectic compounds into sugars, the first increase in sugars of the coated fruits was likely caused by water loss from the fruits (i.e., monosaccharides and disaccharides). As opposed to that, a subsequent fall during the later stage of storage can be linked to metabolic breakdown and fruit senescence because of dehydration and decreased fruit firmness. Prior to this, reported comparable observations (Bhardwaj and Sen, 2003; Ochoa-Reyes et al., 2021).

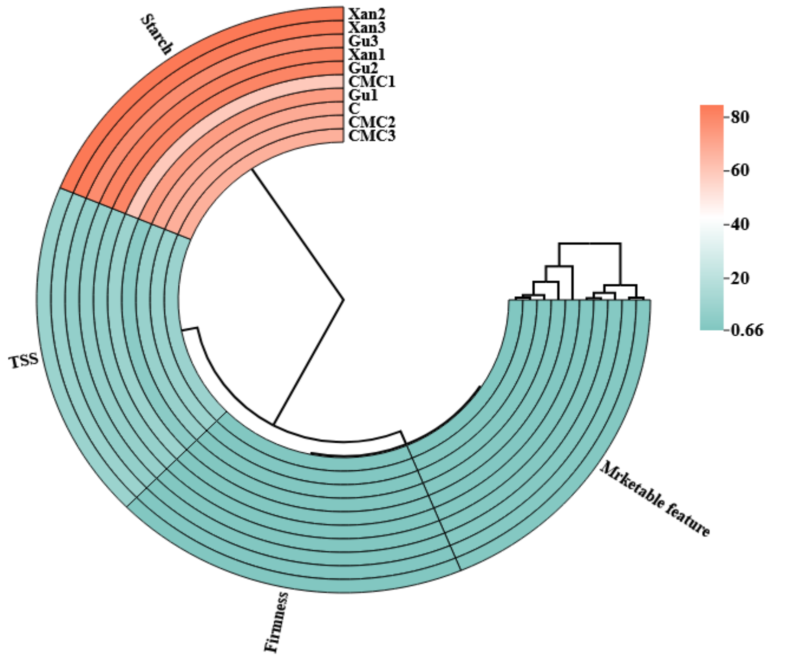

Fig. 4. The circular plots of edible coatings treatments on total soluble solid (TSS), starch, firmness, and marketable features in bell pepper. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

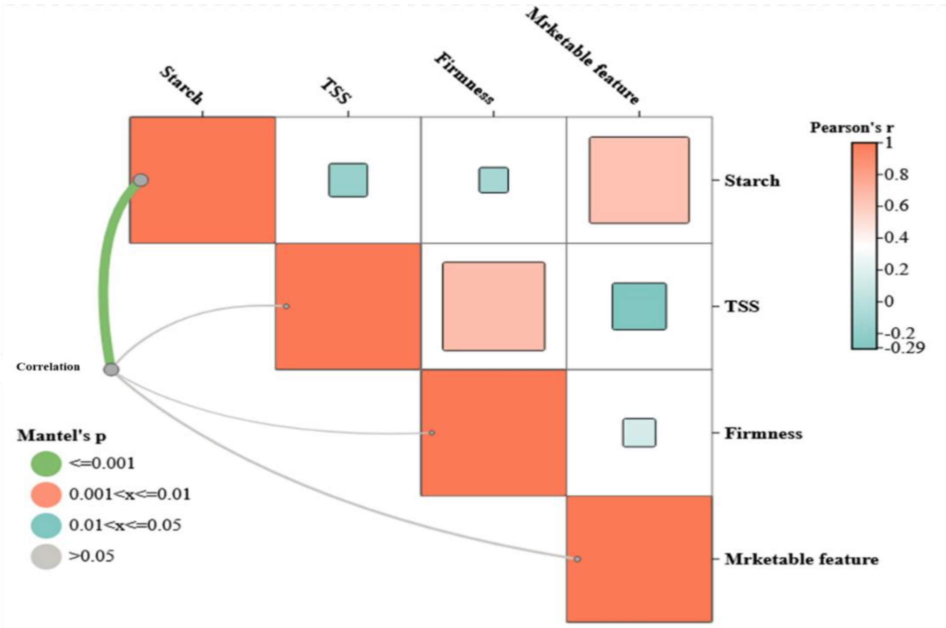

Fig. 5. Correlation between total soluble solid (TSS), starch, firmness, and marketable features of bell pepper.

GU -coated fruits exhibited a greater initial decline in TSS, possibly due to the coating's limited ability to prevent metabolic breakdown. In contrast, CMC and Xanthan treatments appeared to moderate these changes more effectively. Since TSS levels in some treatments were similar to the control, it seems that GU and XAN coatings may regulate the breakdown of complex polysaccharides and pectic substances into sugars and other metabolic products. Thus, while the physiological effects of CMC and XAN on TSS are comparable, they differ from those of GU. Since fresh fruit flavor is largely determined by TSS balance, such variations ultimately influence overall consumer preference (Satish and Thakur, 2017). Water exchange between internal fruit tissues and the surrounding atmosphere is a major cause of weight loss and decay during cold storage, leading to reduced marketability (El-Gioushy et al., 2022). Studies have shown that GU gum coatings improve the marketable quality of tomatoes (Qubbaj and Daraghmah, 2023) and cucumbers (Saha et al., 2016) by forming a protective barrier that reduces respiration, maintains protective enzyme activity, and preserves cell membrane integrity (Ruelas-Chacon et al., 2017). This coating also enhances fruit resistance to microbial attack (Saha et al., 2016). El-Gioushy et al. (2022) further reported that fruit marketability is positively correlated with firmness, acidity, vitamin C content, and total chlorophyll, while negatively correlated with weight loss, decay, TSS, the TSS/acid ratio, total sugars, antioxidant activity, and rot. These physicochemical changes can reduce consumer acceptance and therefore lower marketability. Firmness is a major determinant of consumer acceptability and is influenced by storage duration, treatment type, and their interaction (Kumar and Saini, 2021). It reflects the activity of cell wall–modifying enzymes such as polygalacturonase and pectin methylesterase, which contribute to pectin degradation and softening (Changwal et al., 2021). Hydrolase and pectinase activities can weaken the cell wall matrix, resulting in firmness loss (Saekow et al., 2019). Edible coatings help maintain firmness by lowering respiration and transpiration rates, delaying ripening and senescence, and inhibiting cell wall degradation (Kumar and Saini, 2021). XAN gum has been shown to enhance firmness in tomatoes (Kumar and Saini, 2021) and pumpkins (Survase et al., 2021), while GU gum improves firmness in tomatoes (Maurizzi et al., 2023) and chili peppers (Minh et al., 2019). By regulating gas exchange, edible coatings reduce oxygen uptake and retain carbon dioxide (Yaman and Bayoındırlı, 2002), illustrating the strong relationship between respiration rate, weight loss, and fruit firmness (Klangmuang and Sothornvit, 2018).

Weight loss of fruit and infectious diseases decay

According to the heat map illustrating the effects of edible coating treatments on weight loss in bell pepper fruits across different storage times, substantial weight loss occurred on days 28 and 35. In contrast, days 7, 14, and 21 showed no significant differences from one another. Thus, the greatest weight loss was observed after 28 days, indicating that prolonged storage is economically impractical due to the increased post-harvest weight reduction. In terms of treatment performance, the control and CMC3 treatments clustered together, whereas all other coatings formed a separate cluster. This grouping suggests that treatments such as GU1, XAN1, CMC2, CMC1, GU3, XAN3, XAN2, and GU2 were generally effective in limiting excessive post-harvest weight loss. However, GU3 and XAN3 were less effective, as reflected by their darker color on the heat map. The first- and second-level treatments provided comparatively better protection against weight loss (Fig. 6).

The circular diagram illustrating the impact of edible coating treatments on post-harvest infectious disease decay across different time points shows that XAN1 and XAN3 clustered together, displaying the lowest levels of decay among all treatments. In contrast, the control and GU1 treatments exhibited the highest levels of infectious disease decay, particularly on days 28 and 35. From a temporal perspective, days 28 and 35 formed a cluster, indicating similarly high levels of decay. Days 14 and 21 also grouped together, reflecting comparable levels of infectious disease decay. The lowest decay was observed on days 0 and 7, indicating the absence of contamination up to day 7, with infectious disease decay beginning to appear from day 14 onward (Fig. 7).

Storage duration had a greater influence on pepper fruit firmness than on weight loss. Although XAN and GU coatings contributed to reducing weight loss, the effect of storage time on weight reduction was less pronounced than its impact on firmness. Similar observations have been reported for tomato coatings, which helped preserve firmness and reduce weight loss (Ali et al., 2013). Arabic gum coatings also prevented changes in overall acidity in cherry tomatoes (Li et al., 2017). Compared with uncoated fruit, gum coatings maintained firmness, reduced weight loss, and slowed respiration during cold storage. These benefits are attributed to the modifications in the fruit's internal environment and disruptions in ethylene production, which collectively reduce respiration rates and delay ripening and senescence (del C Robles-Flores et al., 2018). Furthermore, the polysaccharide gum layer acts as a barrier that limits gas exchange and water vapor loss. Formations of hydrogen bonds between polysaccharides and phenolic compounds may also increase skin thickness (Pinzon et al., 2018). Since bell pepper is a non-climacteric fruit, respiration contributes only minimally to water loss; therefore, external factors, such as storage temperature, relative humidity, and coating type, play a significant role in deterioration. Applying appropriate postharvest treatments can therefore reduce losses associated with rot, respiration, and transpiration (Saltveit, 1977). Overall, XAN appeared more effective than GU and CMC in preventing the spread of infection (Fig. 8A and Fig. 8B).

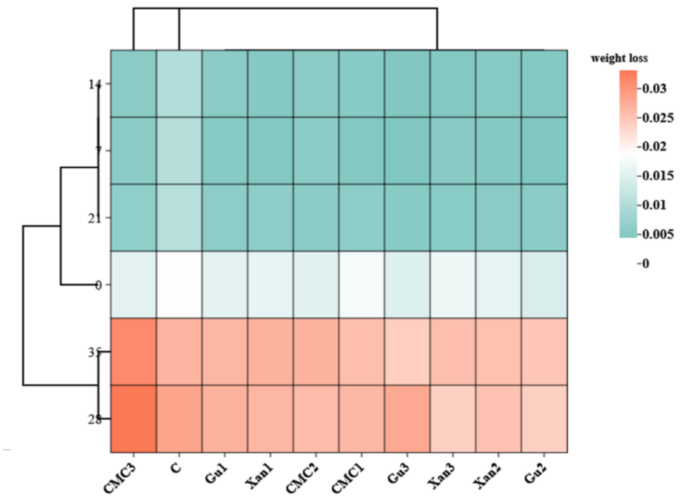

Fig. 6. The heat map of edible coatings treatments on weight loss in bell pepper. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

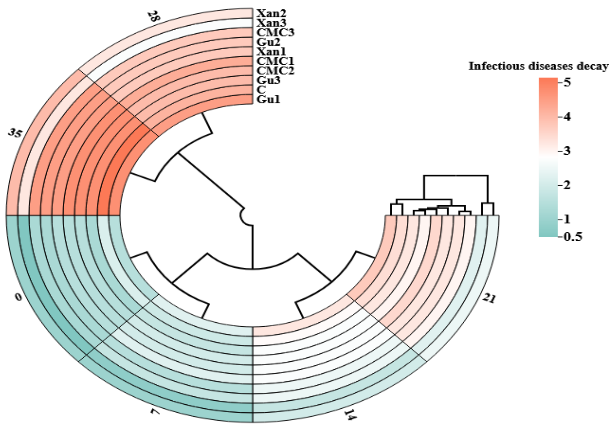

Fig. 7. The circular plots of edible coatings treatments on infectious disease decay in bell pepper. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

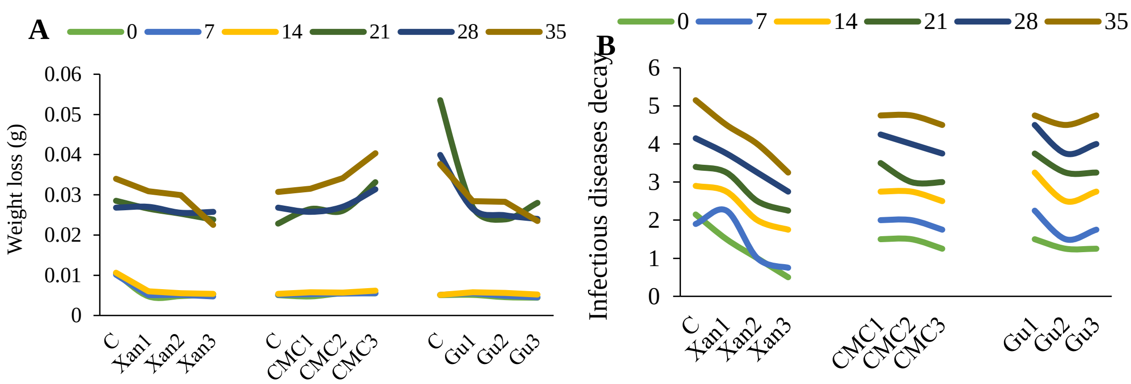

Fig. 8. The interactive effect of different covers over different storage times on infectious diseases decay and weight loss. C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

The most notable qualitative characteristics of the bell pepper fruits included reduced levels of infection and disease, along with lower concentrations of phenols, starch, antioxidants, organic acids, and carotenoids across all coating treatments (Fig. 9A). Among the treatments, GU1 and GU2 were the most effective in maintaining the qualitative attributes of bell peppers during shelf life, followed by XAN2, XAN3, CMC2, and GU1 (Fig. 9B). Texture is a key indicator used by both consumers and the food industry to evaluate the freshness of fruits and vegetables. Microbial contamination of fruits, primarily caused by bacteria, molds, and yeasts, can occur during production, packaging, processing, transportation, distribution, and storage (Ma et al., 2017). Edible gum coatings offer antibacterial properties in addition to serving as mechanical barriers, thereby helping preserve product quality and extend postharvest shelf life (Raffo et al., 2007; Tahir et al., 2018).

Principal component analysis

Biplot analysis revealed that during storage, the XAN2, CMC1, and CMC2 treatments enhanced key consumer-related attributes of bell pepper fruits, including carotenoid content, firmness, and TSS. In contrast, XAN1, GU1, and GU2 were associated with higher nutritional value, particularly with respect to starch, chlorophyll, phenol, and vitamin C levels. Overall, all coating treatments, except the control, CMC3, and GU3, were effective in maintaining bell pepper fruit quality (Fig. 10). Firmness appeared to influence the MF, as it showed a stronger positive correlation with firmness than with weight loss. The coating treatments did not affect visible fruit shriveling (Fig. 11). Loss of firmness is primarily attributed to the pectin degradation mediated by pectin-methylesterase and polygalacturonase (Barbagallo et al., 2012). Related research has shown that phenolic hydroxyl groups in plant polyphenols can interact with the carboxyl groups of polysaccharides (Gao et al., 2013). Such interactions may enhance the antibacterial properties of coatings by slowing the release of bioactive components from edible films and coatings. Although the precise mechanism underlying the antibacterial activity of gum-based edible coatings is not fully understood, several studies indicate that gums serve as rich sources of bioactive compounds, including polyphenols (Al Alawi et al., 2018) and bioactive polysaccharides such as those found in peach gum (Yao et al., 2013). In the present study, all coating treatments successfully reduced symptoms of disease infection.

Sankey plot

Based on the Sankey diagram illustrating the interactions between edible coatings and post-harvest storage time on the physiological traits of bell peppers, the traits most influenced over time, with the greatest to the least impact, were organic acids, starch, antioxidants, phenols, and carotenoids. In contrast, TSS, firmness, weight loss, vitamin C, and correlation were affected to a lesser degree. These findings indicate that treatments capable of stabilizing organic acids and carotenoids, as well as antioxidants and phenols, are particularly beneficial for extending the post-harvest shelf life of bell peppers. Among the most effective treatments in this regard were CMC2, XAN1, and GU2 (Fig. 12).

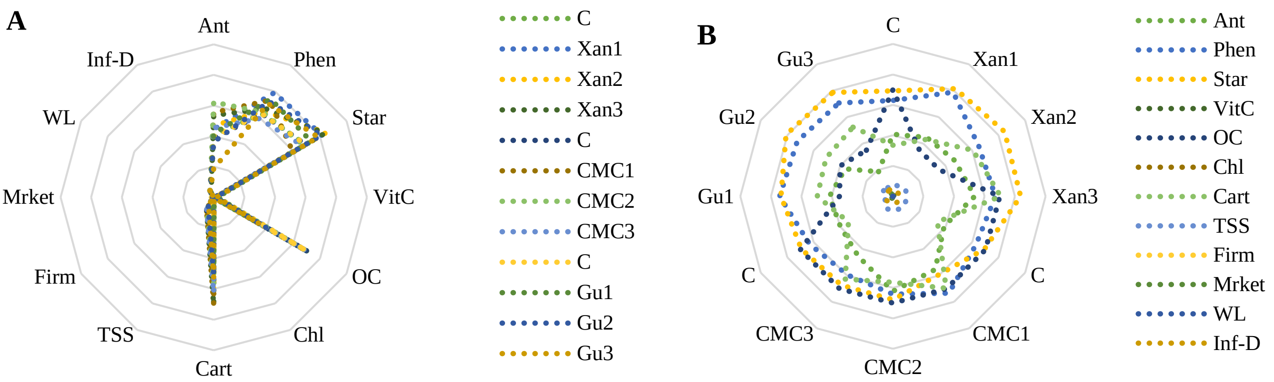

Fig. 9. Rader chart over multiple qualitative changes of pepper by different coatings during storage. (A) Rader chart of the effectiveness of different coatings on some qualitative characteristics of pepper. (B) Star: Starch, VitC: Vitamin C, Cart: Carotenoid, Mrket: Marketable feature, WL: Weight loss, Chl: Chlorophyll, Firm: Firmness, Inf-D: Infectious diseases decay, OC: Organic acids, Phen: Phenol, Ant: Antioxidant, C: Control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC0.5 %, CMC2: CMC1 %, CMC3: CMC1

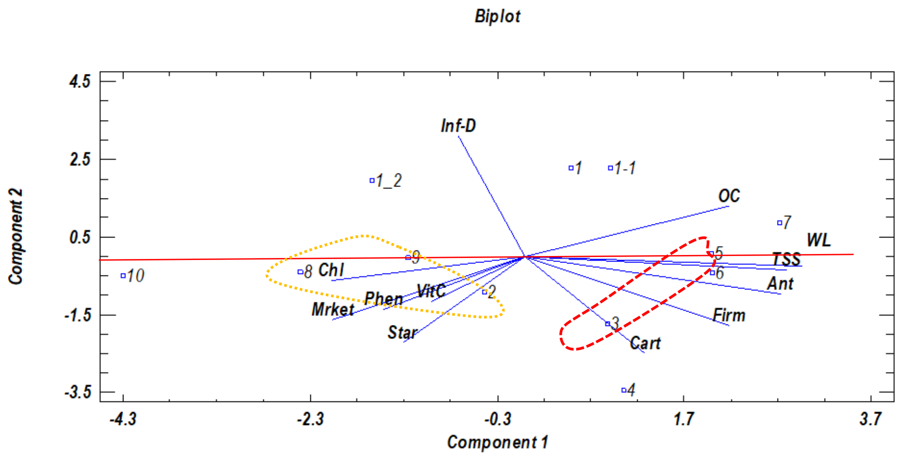

Fig. 10. The biplot analysis of different coatings on some characteristics of bell pepper after storage. Star: Starch, VitC: Vitamin C, Cart: Carotenoid, Mrket: Marketable feature, WL: Weight loss, Chl: Chlorophyll, Firm: Firmness, Inf-D: Infectious diseases decay, OC: Organic acids, Phen: Phenol, Ant: Antioxidant. 1: control, 2: Xanthan 0.5 %, 3: Xanthan 1 %, 4: Xanthan 1.5 %, 1-1: control, 5: CMC 0.5 %, 6: CMC 1 %, 7: CMC 1.5 %, 1-2: control, 8: guar 0.5 %, 9: guar 1 %, and 10: guar 1.5 %.

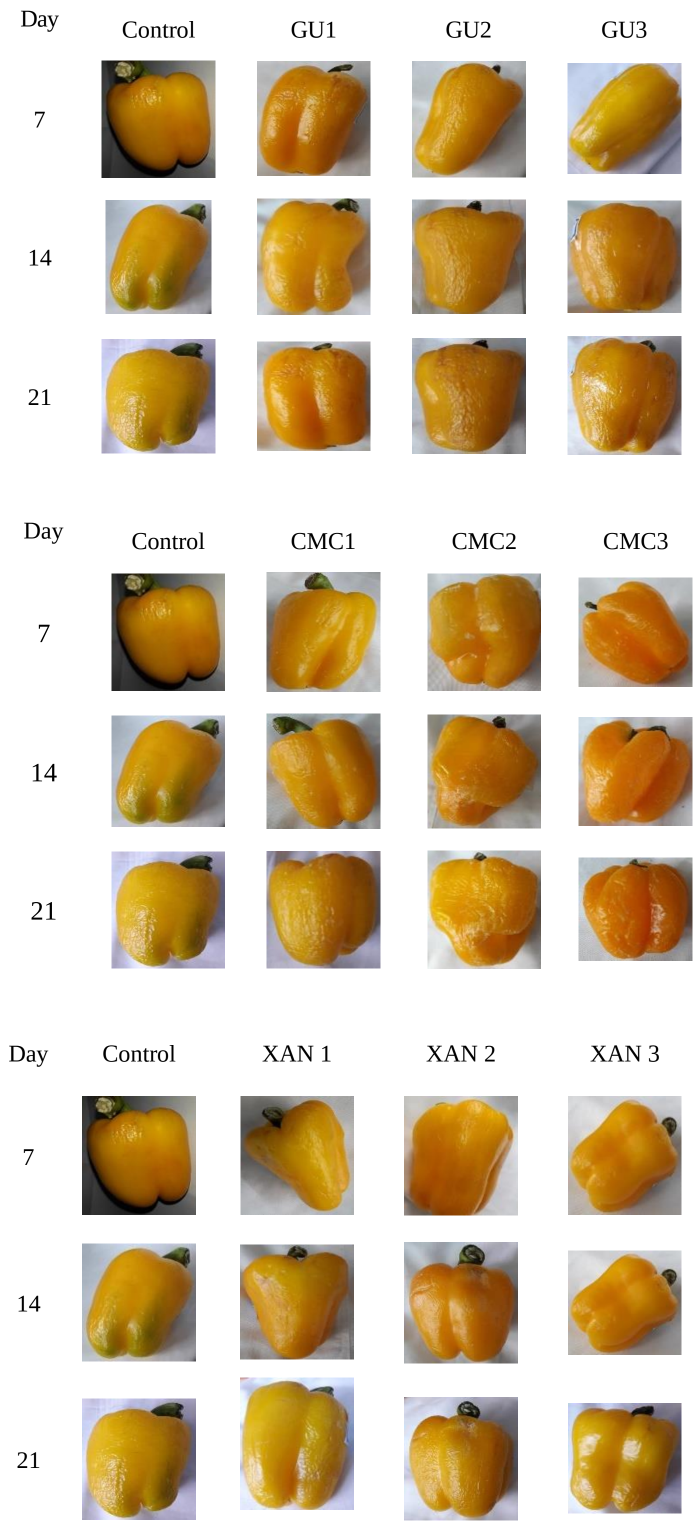

Fig. 11. Fruit appearance covered by guar (GU), Xanthan (xa), and carboxymethyl cellulose (CMC) with different coating concentrations after one month storage. GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %, CMC1: CMC 0.5 %, CMC2: CMC 1 %, CMC3: CMC 1.5 %, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %.

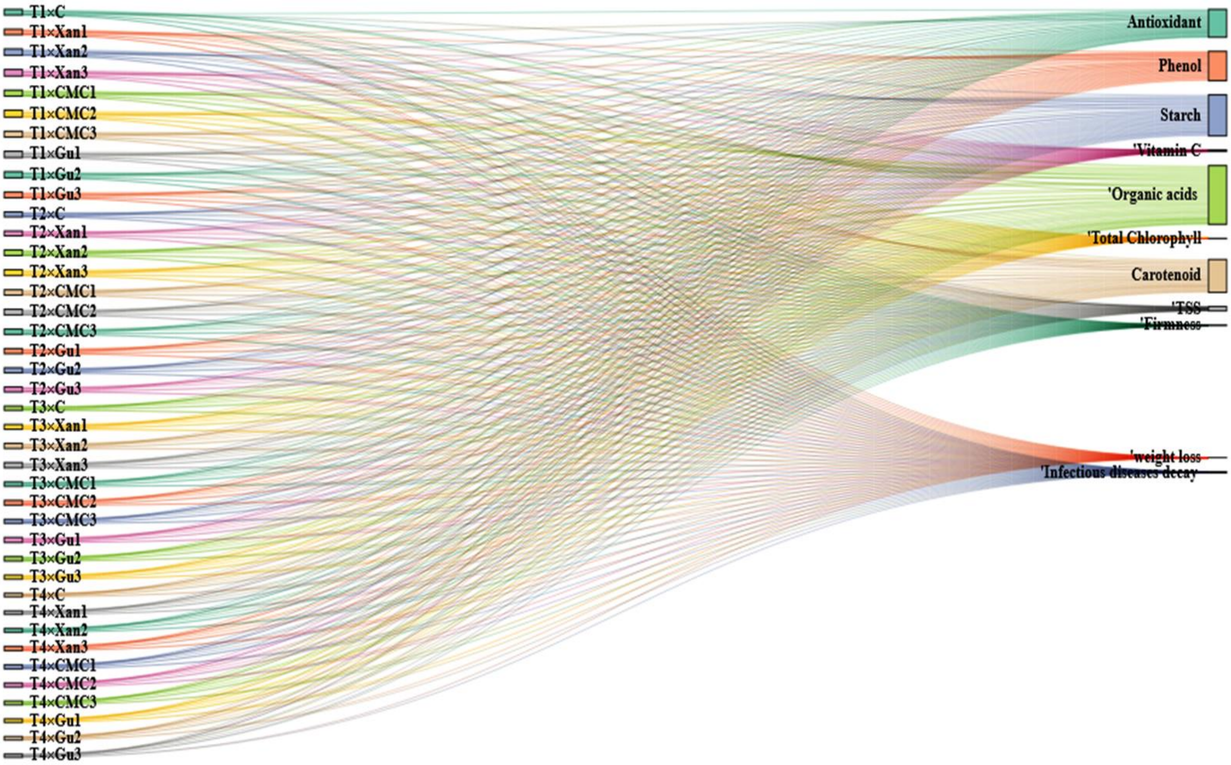

Fig. 12. The sankey plot of different coatings on some characteristics of bell pepper after storage. C: control, XAN1: Xanthan 0.5 %, XAN2: Xanthan 1 %, XAN3: Xanthan 1.5 %, CMC1: CMC 0.5 %, CMC2: CMC 1 %, CMC3: CMC 1.5 %, GU1: guar 0.5 %, GU2: guar 1 %, GU3: guar 1.5 %.

CONCLUSION

This study demonstrated that the nutritional value and marketability of bell peppers declined substantially during storage, largely due to the degradation of key components such as vitamin C, phenols, and antioxidants. The application of edible coatings effectively delayed senescence and helped preserve the postharvest quality of the fruit. Among the treatments evaluated, the GU gum coating at a concentration of 1 % was the most effective in maintaining overall quality. This treatment minimized changes in organic acids and antioxidants, significantly improved firmness, and reduced weight loss, thereby enhancing marketability. Although all coatings contributed positively to quality preservation, the GU gum treatment provided superior protection against microbial decay while maintaining essential nutritional attributes. These findings suggest that GU gum is a promising edible coating for extending bell pepper shelf life and retaining both nutritional value and consumer appeal. Future research should include toxicological assessment and optimization of coating formulations to further improve their safety and effectiveness for commercial application.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Maryam Haghighi; Methodology: Maryam Haghighi; Software: Farinaz Parniani; Validation: Maryam Haghighi; Formal analysis: Maryam Haghighi; Investigation: Farinaz Parniani; Resources: Farinaz Parniani; Data curation: Maryam Haghighi; Writing original draft preparation: Farinaz Parniani; Writing review and editing, Maryam Haghighi; Visualization: Farinaz Parniani; Supervision: Maryam Haghighi; Project administration: Farinaz Parniani; Funding acquisition: Maryam Haghighi.

DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

ETHICAL STATEMENT

Approval was granted by the Ethics Committee of Isfahan University of Technology.

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REFERENCES

Avalos Llano, K. R., Sgroppo, S. C., & Chaves, A. R. (2009). Quality and antioxidant properties of whole and fresh cut 'Cherry' peppers during storage at 10 °C. *Facena*, *25*, 21-32. https://doi.org/10.30972/fac.2503433

Al Alawi, S. M., Hossain, M. A., & Abusham, A. A. (2018). Antimicrobial and cytotoxic comparative study of different extracts of Omani and Sudanese Gum acacia. *Beni-Suef University Journal of Basic and Applied Sciences, 7*, 22-26.
https://doi.org/10.1016/j.bjbas.2017.10.007

Ali, A., Maqbool, M., Alderson, P. G., & Zahid, N. (2013). Effect of gum arabic as an edible coating on antioxidant capacity of tomato (*Solanum lycopersicum* L.) fruit during storage. *Postharvest Biology and Technology*, *76*, 119-124. https://doi.org/10.1016/j.postharvbio.2012.09.011

Amiri, A., Mortazavi, S. M. H., Ramezanian, A., Mahmoodi Sourestani, M., Mottaghipisheh, J., Iriti, M., & Vitalini, S. (2021). Prevention of decay and maintenance of bioactive compounds in strawberry by application of UV-C and essential oils. *Journal of Food Measurement and Characterization*, 15, 5310-5317. Retrieved from: https://link.springer.com/article/10.1007/s11694-021-01095-2

Association of official agricultural chemists (AOAC) (1995). Ascorbic acid in vitamin preparations and juices: 2, 6-dichloroindophenol titrimetric method, OMA, 16-17. Retrieved from: https://vdocuments.site/aoac-method-ascorbic-ac-967-21.html.

Arnon, A. N. (1967). Method of extraction of chlorophyll in the plants. *Journal of Agronomy, 23*, 112-121.

Barbagallo, R. N., Chisari, M., & Caputa, G. (2012). Effects of calcium citrate and ascorbate as inhibitors of browning and softening in minimally processed 'Birgah' eggplants. *Postharvest Biology and Technology, 73,* 107-114. https://doi.org/10.1016/j.postharvbio.2012.06.006

Barret, M., Beaulieu, C., John, C., & Shewfelt, R. (2010). Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: Desirable levels, instrumental and sensory measurement, and the effects of processing. *Critical Reviews in Food Science and Nutrition, 50,* 1040-8398. https://doi.org/10.1080/10408391003626322

Bayoumi, Y. A. (2008). Improvement of postharvest keeping quality of white pepper fruits (*Capsicum annuum*, L.) by hydrogen peroxide treatment under storage conditions. *Acta Biologica Szegediensis, 52,* 7-15. Retrieved from: https://abs.bibl.u-szeged.hu/index.php/abs/article/view/2572

Behera, T. K., Pal, R. K., Nita, S., & Manoj, S. (2004). Effect of maturity at harvest on physicochemical attributes of sweet pepper (*Capsicum annuum* var. grossum) varieties. *The Indian Journal of Agricultural Sciences, 74*, 251-253.

Bernardo, A., Martinez, S., Alvarez, M., Fernandez, A., & Lopez, M. (2008). The composition of two Spanish pepper varieties (Fresno de la Vega and Benavente-Los Valles) in different ripening stages. *Journal of Food Quality, 31,* 701-716. http://dx.doi.org/10.1111/j.1745-4557.2008.00229.x

Bhardwaj, R. L., & Sen, N. L. (2003). Zero energy cool-chamber storage of mandarin (*Citrus reticulata* blanco) cv.'Nagpur Santra'. *Journal of Food Science and Technology, 40,* 669-672.

Changwal, C., Shukla, T., Hussain, Z., Singh, N., Kar, A., Singh, V. P., Abdin, M. Z., & Arora, A. (2021). Regulation of postharvest tomato fruit ripening by endogenous salicylic acid. *Frontiers in Plant Science*, 12, 663943. https://doi.org/10.3389%2Ffpls.2021.663943

Chaple, S., Vishwasrao, C., & Ananthanarayan, L. (2017). Edible composite coating of methyl cellulose for post-harvest extension of shelf-life of finger hot indian pepper (*Pusa jwala*). *Journal of Food Processing and Preservation, 41*, e12807. https://doi.org/10.1111/jfpp.12807

Chen, J., Zheng, M., Tan, K.B., Lin, J., Chen, M., & Zhu, Y. (2022). Development of Xanthan gum/hydroxypropyl methyl cellulose composite films incorporating tea polyphenol and its application on fresh-cut green bell peppers preservation. *International Journal of Biological Macromolecules,* 211, 198-206. https://doi.org/10.1016/j.ijbiomac.2022.05.043

Chikhala, T., Seke, F., Slabbert, R.M., Sultanbawa, Y., & Sivakumar, D. (2024). Utilizing Xanthan gum coatings as probiotic bacteria carriers to enhance postharvest quality and antioxidants in fresh-cut cantaloupe and honeydew (*Cucumis melo* L.) melons. *Foods*, *13*, 940. https://doi.org/10.3390/foods13060940

Daraghmah, F. S., & Qubbaj, T. (2021). Impact of gum arabic and cactus mucilage as potential coating substances combined with calcium chloride treatment on tomato (*Solanum lycopersicum* L.) fruit quality attributes under ambient storage conditions. *Canadian Journal of Plant Science, 102*, 375-384. https://doi.org/10.1139/CJPS-2021-0164

Deepa, N., Kaur, C., Singh, B., & Kapoor, H. C. (2006). Antioxidant activity in some red sweet pepper cultivars. *Journal of Food Composition and Analysis*, *19*, 572-578. https://doi.org/10.1016/j.jfca.2005.03.005

del C Robles-Flores, G., Abud-Archila, M., Ventura-Canseco, L. M. C., Meza-Gordillo, R., Grajales-Lagunes, A., Ruiz-Cabrera, M. A., & Gutiérrez-Miceli, F. A. (2018). Development and evaluation of a film and edible coating obtained from the *Cajanus cajan* seed applied to fresh strawberry fruit. *Food and Bioprocess Technology, 11*, 2172-2181. https://doi.org/10.1007/s11947-018-2175-5

Díaz-Pérez, J. C., Muy-Rangel, M. D., & Mascorro, A. G. (2007). Fruit size and stage of ripeness affect postharvest water loss in bell pepper fruit (*Capsicum annuum* L.). *Journal of the Science of Food and Agriculture,* 87, 68–73. https://doi.org/10.1002/jsfa.2672

Edusei, V. O., Ofosu-Anim, J., & Johnson, P. N. T. (2012). Cornelius EW. Extending postharvest life of green chilli pepper fruits with modified atmosphere packaging. *Ghana Journal of Horticulture, 10*, 131-140.

El-Gioushy, S. F., Abdelkader, M. F., Mahmoud, M. H., Abou El Ghit, H. M., Fikry, M., Bahloul, A. M., Rashwan Ahmed, A., Lo'ay, A., Abdelaziz, A., Al-Haithloul, H., Hikal, D., Abdein, M., Hassan, K., & Gawish, M. (2022). The effects of a gum arabic-based edible coating on guava fruit characteristics during storage. *Coatings, 12*, 90. https://doi.org/10.3390/coatings12010090

Fallik, E., Bar-Yosef, A., Alkalai-Tuvia, S., Aharon, Z., Perzelan, Y., Ilić, Z., & Lurie, S. (2009). Prevention of chilling injury in sweet bell pepper stored at 1.5ºC by heat treatments and individual shrink packaging. *Folia Horticulturae, 21*, 87-97. https://doi.org/10.2478/fhort-2013-0141

Gao, P., Zhu, Z., & Zhang, P. (2013). Effects of chitosan–glucose complex coating on postharvest quality and shelf life of table grapes. *Carbohydrate Polymers, 95*, 371-378. https://doi.org/10.1016/j.carbpol.2013.03.029

Ghasemnezhad, M., Sherafati, M., & Payvast, G. A. (2011). Variation in phenolic compounds, ascorbic acid and antioxidant activity of five coloured bell pepper (*Capsicum annum*) fruits at two different harvest times. *Journal of Functional Foods, 3*, 44-49. https://doi.org/10.1016/j.jff.2011.02.002

Gil, M. I., Aguayo, E., & Kader, A. A. (2006). Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. *Journal of Agricultural and Food Chemistry, 54*, 4284-4296. https://doi.org/10.1021/jf060303y

Gonzales, L. M. R., & Benitez, M. M. (2023). Physicochemical and physiological properties of okra [*Abelmoschus esculentus* (L.) moench] fruits coated with polysaccharide-based edible coatings. *Mindanao Journal of Science and Technology, 21*. https://doi.org/10.61310/mjst.v21i2.1717

Hedge, J. E., & Hofreiter, B. T. (1962). Carbohydrates. In Whistler, R. L. & Be Miller, J. N. (Ed.), *Methods in carbohydrate chemistry* (pp. 17-22). New York: Academic Press.

Hu, Q., Fang, Y., Yang, Y., Ma, N., & Zhao, L. (2011). Effect of nanocomposite-based packaging on postharvest quality of ethylene-treated kiwifruit (*Actinidia deliciosa*) during cold storage. *Food Research International, 44*, 1589-1596. https://doi.org/10.1016/j. foodres.2011.04.018

Jantra, C., Slaughter, D. C., Roach, J., & Pathaveerat, S. (2018). Development of a handheld precision penetrometer system for fruit firmness measurement. *Postharvest Biology and Technology, 144*, 1-8. https://doi.org/10.1016/j.postharvbio.2018.05.009

Kehila, S., Alkalai-Tuvia, S., Chalupowicz, D., Poverenov, E., & Fallik, E. (2021). Can edible coatings maintain sweet pepper quality after prolonged storage at sub-optimal temperatures? *Horticulturae, 7*, 387. https://doi.org/10.3390/horticulturae7100387

Klangmuang, P., & Sothornvit, R. (2018). Active coating from hydroxypropyl methylcellulose-based nanocomposite incorporated with Thai essential oils on mango (cv. Namdokmai Sithong). *Food Bioscience,* 23, 9-15. https://doi.org/10.1016/j.fbio.2018.02.012

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. https://doi.org/10.1016/j.meafoo.2021.100005

LeRoux, M. N., Schmit, T. M., Roth, M., & Streeter, D. H. (2010). Evaluating marketing channel options for small-scale fruit and vegetable producers. Renewable Agriculture and Food Systems, 25, 16-23.

Li, C., Tao, J., & Zhang, H. (2017). Peach gum polysaccharides-based edible coatings extend shelf life of cherry tomatoes. *3 Biotech,* 7, 1-5. https://doi.org/10.1007%2Fs13205-017-0845-z

Lim, C. S., Kang, S. M., Cho, J. L., Gross, K. C., & Woolf, A. B. (2007). Bell pepper (*Capsicum annuum* L.) fruits are susceptible to chilling injury at the breaker stage of ripeness. *HortScience, 42*, 1659-1664. https://doi.org/10.21273/HORTSCI.42.7.1659

Ma, L., Zhang, M., Bhandari, B., & Gao, Z. (2017). Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables. *Trends in Food Science and Technology, 64*, 23-38. https://doi.org/10.1016/j.tifs.2017.03.005

Maalekuu, K., Elkind, Y., Fallik, E., Shalom, Y., & Tuvia-Alkalai, S. (2003). Quality evaluation of three sweet pepper cultivars after prolonged storage. *Advances in Horticultural Science, 17*, 187-191. https://www.jstor.org/stable/42883362

Mahalik, N.P., & Nambiar, A.N. (2010). Trends in food packaging and manufacturing systems and technology. *Trends in Food Science & Technology,* 21, 117–128. https://doi.org/10.1016/j.tifs.2009.12.006

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2007). Evaluation of factors affecting barrier, mechanical and optical properties of pectin-based films using response surface methodology. *Journal of Food Process Engineering, 30*, 539-563. https://doi.org/10.1111/j.1745-4530.2007.00123.x

Maurizzi, E., Bigi, F., Volpelli, L. A., & Pulvirenti, A. (2023). Improving the post-harvest quality of fruits during storage through edible packaging based on guar gum and hydroxypropyl methylcellulose. *Food Packaging and Shelf Life, 40*, 101178. http://dx.doi.org/10.1016/j.fpsl.2023.101178

Minh, N. P., Van Tuan, T., Tuyen, T. T., & Mai, D. K. (2019). Application of guar gum as edible coating to prolong shelf life of red chilli pepper (*Capsicum frutescens* L.) fruit during preservation. *Journal of Pharmaceutical Sciences, 11*, 1474-1478.

Naeem, A., Abbas, T., Ali, T. M., & Hasnain, A. (2018). Effect of antioxidant and antibacterial properties of guar gum coating containing spice extracts and its application on tomatoes (*Solanum lycopersicum* L.). *Measurement: Food, 12*, 2725-2734. https://doi.org/10.1007/s11694-018-9890-5

Nasrin, T. A. A., Rahman, M. A., Islam, M. N., Arfin, M. S., & Akter, L. (2018). Effect of edible coating on postharvest quality of bell pepper. *41*, 73-83. Bulletin of the Institute of Tropical Agriculture Kyushu University, http://dx.doi.org/10.11189/bita.41.73

Ncama, K., Magwaza, L. S., Mditshwa, A., & Tesfay, S. Z. (2018). Plant-based edible coatings for managing postharvest quality of fresh horticultural produce: A review. *Food Packaging and Shelf Life, 16*, 157-167. https://doi.org/10.1016/j.fpsl.2018.03.011

Ochoa-Reyes, E., Martínez-Vazquez, G., Saucedo-Pompa, S., Montañez, J., Rojas-Molina, R., de Leon-Zapata, M. A., & Aguilar, C. N. (2021). Improvement of shelf life quality of green bell peppers using edible coating formulations. *Journal of Microbiology, Biotechnology and Food Sciences, 2*, 2448–2451.

Qubbaj, T., & Daraghmah, F. S. (2023). Postharvest guar gum coating modulates fruit ripening, storage life, and quality of tomato fruits kept in ambient or cold storage conditions. *Journal of Agricultural Science and Technology, 25*, 963-974. https://doi.org/10.22034/jast.25.4.14

Panahirad, S., Dadpour, M., Peighambardoust, S. H., Soltanzadeh, M., Gullón, B., Alirezalu, K., & Lorenzo, J. M. (2021). Applications of carboxymethyl cellulose- and pectin-based active edible coatings in preservation of fruits and vegetables: A review. *Trends in Food Science & Technology, 110*, 663-673. https://doi.org/10.1016/j.tifs.2021.02.025

Perez-Grajales, M., MartíNez-DamiáN, M. T., Oscar, C. A., Potrero-Andrade, S. M., Aureliano, P. L., GonzáLez-HernáNdez, V. A., & Villegas-Monter, A. (2019). Content of capsaicinoids and physicochemical characteristics of Manzano hot pepper grown in greenhouse. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 47*, 119-127. https://doi.org/10.15835/nbha47111241

Perez-Vazquez, A., Barciela, P., Carpena, M., & Prieto, M.A. (2023). Edible coatings as a natural packaging system to improve fruit and vegetable shelf life and quality. *Foods, 12*, 3570. https://doi.org/10.3390/foods12193570

Pinzon, M. I., Garcia, O. R., & Villa, C. C. (2018). The influence of Aloe vera gel incorporation on the physicochemical and mechanical properties of banana starch-chitosan edible films. *Journal of the Science of Food and Agriculture, 98*, 4042-4049. https://doi.org/10.1002/jsfa.8915

Raffo, A., Baiamonte, I., Nardo, N., & Paoletti, F. (2007). Internal quality and antioxidants content of cold-stored red sweet peppers as affected by polyethylene bag packaging and hot water treatment. *European Food Research and Technology, 225*, 395-405. https://doi.org/10.1007/s00217-006-0430-x

Rastegar, S., & Atrash, S. (2021). Effect of alginate coating incorporated with Spirulina, Aloe vera and guar gum on physicochemical, respiration rate and color changes of mango fruits during cold storage. *Measurement: Food, 15*, 265-275. https://doi.org/10.1007/s11694-020-00635-6

Ruelas-Chacon, X., Contreras-Esquivel, J. C., Montañez, J., Aguilera-Carbo, A. F., Reyes-Vega, M. L., Peralta-Rodriguez, R. D., & Sanchéz-Brambila, G. (2017). Guar gum as an edible coating for enhancing shelf-life and improving postharvest quality of roma tomato (*Solanum lycopersicum* L). *Journal of Food Quality, 2017*, 1-9. http://dx.doi.org/10.1155/2017/8608304

Saekow, M., Naradisorn, M., Tongdeesoontorn, W., & Hamauzu, Y. (2019). Effect of carboxymethyl cellulose coating containing ZnO-nanoparticles for prolonging shelf life of persimmon and tomato fruit. *Journal of Food Science and Technology, 5*, 41-48.

Saha, A., Tyagi, S., Gupta, R.K., & Tyagi, Y. K. (2016). Guar gum based edible coating on cucumber (*Cucumis sativus* L.). *European Journal of Pharmaceutical and Medical Research, 3*, 558-570.

Saltveit Jr, M. E. (1977). Carbon dioxide, ethylene, and color development in ripening mature green bell peppers. *Journal of the American Society for Horticultural Science, 102*, 523-525. https://doi.org/10.21273/JASHS.102.5.523

Satish, K., & Thakur, K. S. (2017). Effect of starlight fruit conserve wax emulsion and CFB packaging on storage quality of pear. *Indian Journal of Ecology, 44*, 744–750.

Sharif, M., Mujtaba, M., Rahman, M. U., Shalmani, A., Ahmad, H., Anwar, T., Tianchan, D., & Wang, X. (2018). The multifunctional role of chitosan in horticultural crops: A review. *Molecules, 23*, 872. https://doi.org/10.3390%2Fmolecules23040872.

Shotorbani, N. Y., Jamei, R., & Heidari, R. (2013). Antioxidant activities of two sweet pepper *Capsicum annuum* L. varieties phenolic extracts and the effects of thermal treatment. *Avicenna Journal of Phytomedicine, 3*, 25-34.

Soliman, S. A., Abdelhameed, R. E., & Metwally, R. A. (2023). In vivo and in vitro evaluation of the antifungal activity of the pgpr *Bacillus amyloliquefaciens* RaSh1 (MZ945930) against *Alternaria alternata* with growth promotion influences on *Capsicum annuum* L. plants. *Microbial Cell Factories, 22*, 70. https://doi.org/10.1186/s12934-023-02080-8

Survase, S. S., Garande, V. K., Pawar, R. D., & Sonawane. PN. (2021). Effect of different edible coatings on Physico-chemical composition and sensorial qualities of fresh cut red pumpkin. *Journal of Pharmaceutical Innovation, 10*, 2535-2540.

Tahir, H. E., Xiaobo, Z., Jiyong, S., Mahunu, G. K., Zhai, X., & Mariod, A. A. (2018). Quality and postharvest-shelf life of cold-stored strawberry fruit as affected by gum arabic (*Acacia senegal)* edible coating. *Journal of Food Biochemistry, 42*, e12527. https://doi.org/10.1111/jfbc.12527

Vicente, A. R., Pineda, C., Lemoine, L., Civello, P. M., Martinez, G. A., & Chaves, A. R. (2005). UV-C treatments reduce decay, retain quality and alleviate chilling injury in pepper. *Postharvest Biology and Technology, 35*, 69-78. https://doi.org/10.1016/j.postharvbio.2004.06.001

Villa-Rivera, M. G., & Ochoa-Alejo, N. (2020). Chili pepper carotenoids: Nutraceutical properties and mechanisms of action. *Molecules, 25*, 5573. https://doi.org/10.3390%2Fmolecules25235573

Wani, S. M., Gull, A., Ahad, T., Malik, A. R., Ganaie, T. A., Masoodi, F. A., & 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. https://doi.org/10.1016/j.ijbiomac.2021.06.008

Wei, J., Zheng, J., Yu, J., Zhao, D., Cheng, Y., Ruan, M., & Zhou, G. (2019). Production and identification of interspecific hybrids between pepper (*Capsicum annuum* L.) and the wild relative (*Capsicum frutescens* L.). *Journal of Agricultural Science and Technology, 21*, 761-769. https://dor.isc.ac/dor/20.1001.1.16807073.2019.21.3.6.9

Yaman, O., & Bayoındırlı, L. (2002). Effects of an edible coating and cold storage on shelf-life and quality of cherries. *LWT-Food Science and Technology, 35*, 146-150. https://doi.org/10.1006/fstl.2001.0827

Yao, X. C., Cao, Y., & Wu, S. J. (2013). Antioxidant activity and antibacterial activity of peach gum derived oligosaccharides. *International Journal of Biological Macromolecules, 62*, 1-3. https://doi.org/10.1016/j.ijbiomac.2013.08.022

Yu, L., Haley, S., Perret, J., Harris, M., Wilson, J., & Qian, M. (2002). Free radical scavenging properties of wheat extracts. *Journal of Agricultural and Food Chemistry,* 50, 1619-1624. https://doi.org/10.1021/jf010964p

Zaki, N., Hakmaoui, A., Ouatmane, A., Hasib, A., & Fernández-Trujillo, J. P. (2013). Bioactive components and antioxidant activity of Moroccan Paprika (*Capsicum annuum* L.) at different period of harvesting and processing. *Journal of Biology Agriculture and Healthcare, 3*, 1-8.

Zhang, L. P., Xie, J., Wang, T., & Xiong, Q. (2013). Study of physicochemical properties of chinese small cabbage *(Brassica chinensis* L.) stored at four temperatures. *Advanced Materials Research*, 2384, 1275-1281. http://dx.doi.org/10.4028/www.scientific.net/AMR.690-693.1275

Zare-Bavani, M. R., Rahmati-Joneidabad, M., & Jooyandeh, H. (2024). Gum tragacanth, a novel edible coating, maintains biochemical quality, antioxidant capacity, and storage life in bell pepper fruits. *Food Science & Nutrition, 12*, 3935-3948. https://doi.org/10.1002/fsn3.40