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Effect of Chitosan–Pullulan Composite Edible Coating Functionalized with Pomegranate Peel Extract on the Shelf Life of Mango (*Mangifera indica*)

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Abstract: The polysaccharide based composite biomaterial (coating) used in preserving fruits and vegetables during storage is attracting increased attention as it is biodegradable material that prolongs shelf life. In the present investigation, chitosan–pullulan (50:50) composite edible coating was prepared with pomegranate peel extract (0.02 g/mL) as an active antioxidant agent. The effect of treatment with pomegranate peel extract enriched chitosan–pullulan composite edible coating on the shelf life of mango fruits during 18 days of storage period at room (23 °C) and cold (4 °C) temperature was evaluated. Results of the present study demonstrated that the application of chitosan–pullulan composite edible coating significantly ($p \leq 0.05$) influences the storage life of mango fruits at both storage temperatures. The chitosan–pullulan composite edible coating reduced the physiological loss in weight (PLW), and maintained total soluble solids (TSS), acidity and pH of coated mango fruits as compared to the control. In addition, fruit sensory quality such as freshness, color, taste and texture were also retained by the treatment. Furthermore, sustained firmness, phenolic content and antioxidant activity confirmed the effectiveness of the pomegranate peel extract enriched chitosan–pullulan composite edible coating on mango fruits. The phenolic, flavonoid and antioxidant activity of coated fruits were retained by pomegranate peel rich edible coating. Therefore, the chitosan–pullulan (50:50) combination with pomegranate peel extract can be used as an alternative preservation method to prolong the shelf life of mango fruits at room and cold storage conditions. However, more in-depth studies are required at farm and transit level without affecting the postharvest quality of mango fruits, providing more revenue for farmers and minimizing postharvest losses.

Keywords: edible coating; pomegranate peel extract; mango fruits; sensory characteristics; quality & shelf life

1. Introduction

Postharvest losses of agricultural produce due to improper handling and storage are one of the major issues of developing countries, which directly impact the agriculture economy [1,2]. Generally, 30–40% of horticulture produces are not acceptable to consumers due to spoilage caused by physical, mechanical and biological reasons [3]. Mango, also known as the king, is a tropical climacteric and highly perishable fruit [4]. It has an excellent nutritious value with a specific taste and appearances. However, 25–40% of postharvest

losses of mango fruits occur due to physical, mechanical and biological factors [5,6]. Mango fruits have a higher deterioration effect and are susceptible to chilling injury during the storage period [7]. The postharvest management of horticulture produce is important to reduce postharvest wastage and improve the food shelf life and security [8,9]. Therefore, the postharvest treatments strategies help minimize microbial contamination and the risk of producing pathogen during the storage period [10]. Various postharvest treatments and technologies have been used to maintain the postharvest quality and nutritional values of horticulture produces [11–13]. Biopolymers-based edible coatings are one of the most important postharvest techniques to protect agro and horticultural produce from environmental and anthropogenic factors during storage period. Edible coating is biodegradable and eco-friendly; it is a suitable alternative to synthetic materials and can be eaten by consumers [14]. Chitosan is the second most abundant natural biopolymer followed by cellulose produce deacetylation of chitin. It is cationic heteropolysaccharides composed of β (1,4)-2-deoxy-2-amino-D-glucopyranose units. It possesses unique nutritional, biochemical and function activities. It is biodegradable, non-toxic and biocompatible in nature with excellent film forming properties and can be used effectively in food packaging applications [15,16]. It has also exhibited good inhibition activity against the growth of microorganism [17]. Pullulan is a non-ionic exo-polysaccharide biopolymer, obtained from the fermentation medium of fungus and yeast. Furthermore, it is a non-toxic, biodegradable, edible, ecofriendly, biocompatible, odor- and tasteless biopolymer with greater efficiency of solubility in hot and cold water. It also has good film forming ability toward application in food packaging sectors [18,19]. Both polymers (chitosan and pullulan) possess good water and oxygen barrier properties.

The biopolymers based edible coating could control the oxidation and migration processes of horticulture produce and give good protection of nutritional content, microbial safety and postharvest characteristics (shelf life, appearance, color, flavor, aroma, moisture loss, etc.) during the storage period [20,21]. Recently, the interest in incorporating natural antioxidant agents within the biopolymers to develop edible coatings and films has been increased. In this context, incorporation of pomegranate peel extract as a natural antioxidant agent into the edible coating formulation can enhance the inhibition rate against loss of vitamins, enzymatic reaction, oxidation and browning of produces due to its excellent properties and phenolic compounds [22,23]. Pomegranate peel is considered an important source of phenolic compounds such as gallic acid, ellagic acid, punicalagin A, punicalagin B and other tannins (Figure 1). This study aimed to evaluate the effect of chitosan–pullulan (50:50) composite edible coating enhanced with pomegranate peel extract on postharvest physicochemical characteristics of *Safeda* mango at room (23 °C, RH-45%) and cold (4 °C, RH-95%) temperature conditions throughout the storage period for 18 days.

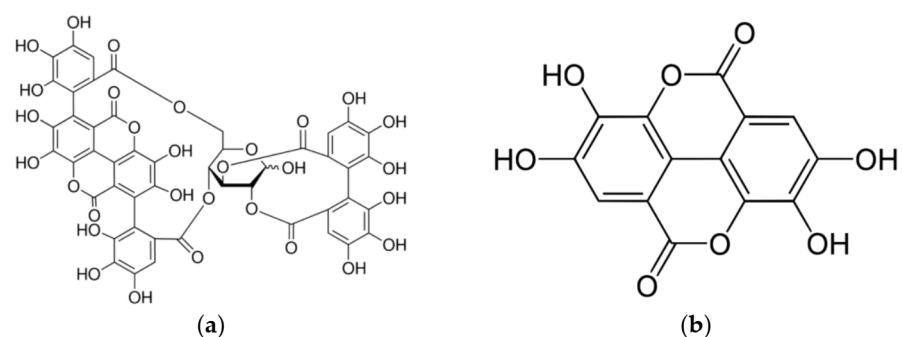


Figure 1. Cont.

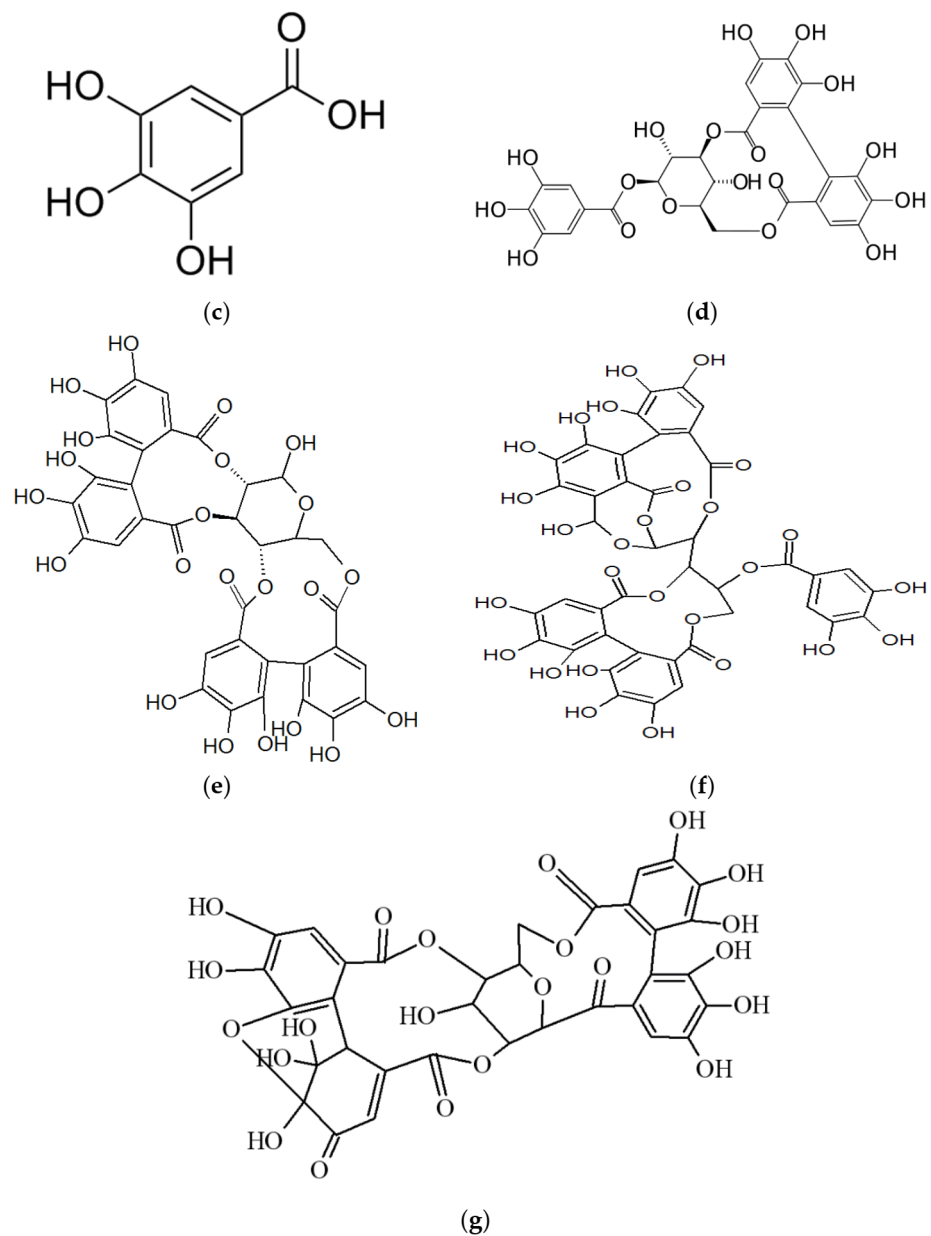


Figure 1. Chemical structure of major bioactive components of pomegranate peel extract: (a) Punicalagin; (b) Ellagic acid; (c) Gallic acid; (d) Corilagin; (e) Pendunculagin; (f) Casuarinin; (g) Granatin A.

2. Materials and Methods

2.1. Materials

The fresh *Safeda* variety of mango fruits and pomegranate (*Cv. Bhagwa*) was procured from agriculture farm Sonipat (Haryana, India) and NRCP, ICAR (Solapur, Maharashtra, India). The biopolymers (chitosan and pullulan) and plasticizer (glycerol) were supplied by Hi-Media and Hi-Tech suppliers (New Delhi, India). The chemical structures of the biopolymers are presented in Figure 2.

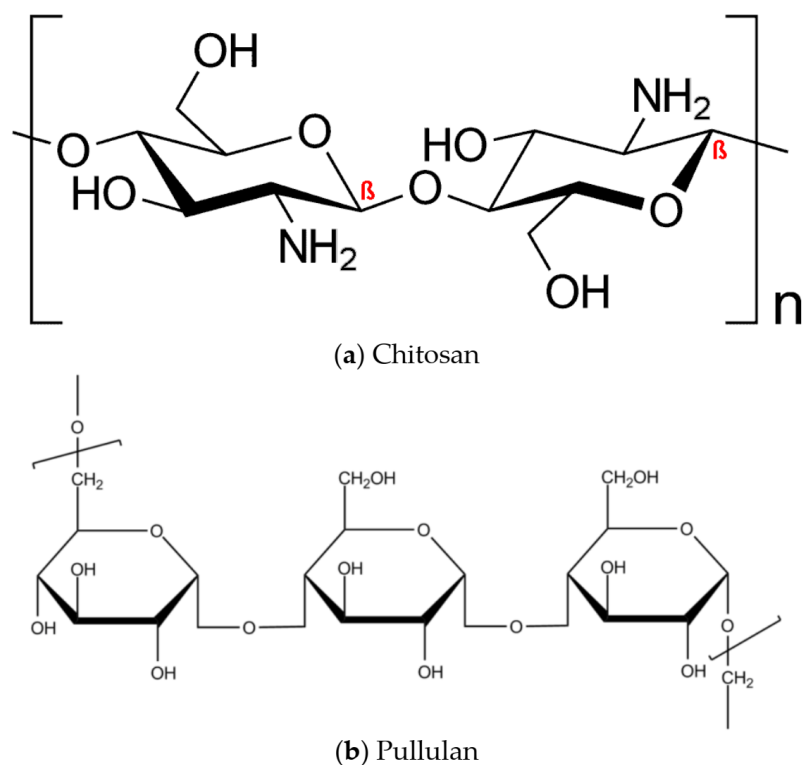


Figure 2. Chemical structure of chitosan and pullulan biopolymers: (a) Chitosan; (b) Pullulan.

2.2. Experimental Methods

2.2.1. Preparation of Pomegranate Peel Extract

The pomegranate peel extract was prepared according to the methodology described by Kumar et al. [24] 0.2 g of freeze dried ($-45\text{ }^{\circ}\text{C}$ for 94 h) pomegranate peel powder was sonicated with 10 mL methanol using an ultrasonic bath (CUB-5, Citizen, 40 kHz, 220–240 V) at $45\text{ }^{\circ}\text{C}$ for 30 min. The solvents from the extract were evaporated through a rotatory evaporator, and the obtained powder was used to prepare aqueous (0.02 g/mL) extract for incorporation in chitosan–pullulan composite edible coating formulation.

2.2.2. Preparation of Chitosan–Pullulan Composite Edible Coating

The 50:50 ratio of chitosan–pullulan biopolymer based edible coating with incorporated pomegranate peel extract was selected for the application based on physicochemical properties investigated by previous studies [24,25]. Chitosan (2%) was prepared in 0.5% citric acid aqueous solution, while pullulan (2%) was prepared in water. The 50:50 ratios of both polymeric solutions were blended and homogenized by mixing at 9000 rpm for 2 min. The prepared blend material again was mixed using a magnetic stirrer for 60 min at room temperature. During this step, 1% plasticizer (glycerol) and 5% of pomegranate peel extract (0.02 g/mL) were added to the coating solution. The prepared solution of chitosan–pullulan composite edible coating enhanced with pomegranate peel extract was used to apply on mango fruits.

2.2.3. Application of Edible Coating on Mango Fruits and their Storage Condition

The prepared chitosan–pullulan composite edible coating solution was applied on the mango by the dipping application method followed by Kumar et al. [9] Approx. 40 kg of mango fruits were washed using 0.01% of sodium hypochlorite to remove the contaminants, fruits wiped with clean cotton clothes and fruits dried for 30 min at room temperature. Four sub lots (control and coated) of 90 mango fruits were prepared. Two sub lots were used as control samples at room and cold temperatures. Two sub lots of mango fruits were dipped in the prepared coating solution for 2 min. The samples were taken out of the

coating formulation and left for drying (15 min) using an air dryer. The control groups of samples were dipped in deionized water. The mango fruits (control and coated) were stored at ambient (23 °C and 45% relative humidity) or 4 °C and 95% RH for 18 days. The physicochemical and postharvest characteristics of control and coated mango fruits during storage were investigated at 3 days intervals within an 18 days storage period (0, 3, 6, 9, 12, 15 and 18 d).

2.2.4. Preparation of Extract of Mango Fruits

The extracts of mango fruit pulp were prepared for the estimation of physicochemical and postharvest shelf life. The extracts of coated and control mangoes were prepared according to the procedure given by Kumar et al. [9] Ten grams of mango pulp were mixed with 40 mL milli-Q-water and homogenized. The obtained aqueous extract was centrifuged and filtered with muslin clothes to estimate acidity and other biochemical parameters such as phenolic and antiradical activity.

2.3. Physiological Responses

Physiological Loss in Weight (PLW)

The physiological weight loss of the stored mango fruits (coated and control) was determined using the mass difference method. In this context, the coated and control mango fruits were weighted every 3 day for up to 18 days of storage period using an analytical weighing balance (BSA224S-CW, Sartorius Analytical Balance, Bangalore, India). The reduction in mass of mango (expressed as percentage loss) was calculated using formula 1 [9]:

$$\text{PLW (\%)} = [(W_1 - W_2) 100]/W_1 \quad (1)$$

where W_1 = Initial mass, W_2 = final mass.

2.4. Physicochemical and Textural Properties

2.4.1. Total Soluble Solids (TSS)

TSS (Brix) of extracted juice from the control and coated mango fruits was measured at intervals using a refractometer (Atago, Tokyo, Japan) at 25 °C [26].

2.4.2. Titratable Acidity (TA)

Titrate acidity of control and coated mango fruits juice was evaluated by titration method [27]. 25 mL of diluted mango fruit juice (10 g diluted with 40 mL milli-Q-water) titrate against 0.1 N of sodium hydroxide (NaOH) to an end point. Phenolphthalein was used as an indicator to note the endpoint of the titration. The results are expressed as citric acid (%CA) and calculated using formula 2:

$$\text{TA (\%)} = \frac{\text{Vol. of NaOH} \times \text{Miliequivalent wt. of acid} \times \text{Normality of NaOH}}{\text{Volume of sample}} \times 100 \quad (2)$$

2.4.3. PH

PH of the fruit samples was evaluated using a digital pH meter (Eu Tech, Thermo Fisher Scientific, Mumbai, India). The mean value of pH is reported [28].

2.4.4. Color

Control and coated mango fruits color was determined in CIELab coordinates (L^* , a^* , b^*) with color difference (ΔE) using a Chroma meter CR-400 (Konica, Tokyo, Japan). Results were expressed as mean \pm S.D. for each interval [29].

2.4.5. Firmness

The firmness of stored control and coated fruits was measured using a texture analyzer (Stable Microsystems, Goldalming, UK): 5 kg load cell with 2 mm diameter probe (aluminum needle) regulated at 10 mm min^{-1} speed of texture analyzer to puncture the

5 equatorial places of the fruits. The results of the firmness of the mangoes are expressed in terms of force (N) [28].

2.5. Phytochemical Analysis

2.5.1. Total Phenolic Content (TPC)

The total phenolic content of the mango fruit was determined using the Folin–Ciocalteu (FC) reagent standard method with some modification [30]. One milliliter of fruit extract was added to 70 mL distilled water and 5 mL of 10 times fold FC reagent. The prepared solution was mixed and added to 15 mL of 20% sodium carbonate (Na_2CO_3) solution, making up a volume of 100 mL. The reaction mixture was allowed to incubate for 2 h before measuring absorbance at 765 nm using a UV spectrophotometer (Sican, Inkar P Pvt. Ltd. Hyderabad, India). Phenolic content was expressed as equivalent gallic acid (mg/g) of mango fruit extract (slurry). Mean values with standard deviation are reported.

2.5.2. Total Flavonoid Content (TFC)

Total flavonoid content of the stored control and coated mango fruits were determined using the standard aluminum chloride spectrophotometric method followed by Kumar et al. [28], Aryal et al. [31]. A measure of 1 mL of mango fruit extract was mixed with 1.5 mL of methanol, to which was added 0.1 mL aluminum chloride (10%) and potassium chloride (1 M), respectively. The prepared mixture was allowed to stand for 40 min at room temperature. The absorbance was recorded at a 430 nm wavelength using a UV spectrophotometer (Sican, 2301, Incarp, Hyderabad, India). Quercetin was used as a standard to calculate the flavonoid content of fruit extract and results are expressed in mg/g of fruit extract.

2.5.3. Radical Scavenging Activity (RSA)

DPPH is a common method based on the transfer electron and estimation of antioxidant activity. It determines the antioxidant activity of organic radicals [32]. The antioxidant activity of the mango fruit was determined using the DPPH 2, 2-diphenyl-1-picryl-hydrazyl) standard assay method with some modification [33]. Mango fruit extract (0.1 mL) mixed with 0.49 mL of methanol of DPPH solution (0.39 mL) was added in the prepared mixture of fruit extract and methanol. The solution was mixed and allowed to stand in the dark for 1 h. The absorbance was recorded at 517 nm using a UV spectrophotometer and calculated using equation 3. Results are expressed as inhibition percentage using.

$$\text{Antioxidant activity (\%)} = [(A \text{ Control} - A \text{ Sample}) / A \text{ Control}] \times 100 \quad (3)$$

2.6. Sensory Evaluation

Sensory evaluation was carried out during the storage period using semi-trained and trained panelists. The samples were given specific codes to distinguish between coated and control samples stored at different temperatures. The nine points hedonic scale was used for the recorded sensory score of control and coated mango fruits on a scale of 1–9 (9 = Extremely like, 8 = Much like, 7 = Moderately like, 6 = Slightly like, 5 = Neither like nor dislike, 4 = Slightly dislike, 3 = Moderately dislike, 2 = Much dislike, and 1 = Extremely dislike [34].

2.7. Experimental Design and Data Analysis

The experiments were laid out in a completely randomized design (CRD) for this study. Statistical analysis of the obtained data were done using IBM SPSS version 24.0. The data are graphically expressed by using Origin 2019b software as Mean \pm SD.

3. Results and Discussion

3.1. Physiological Loss in Weight (PLW)

The physiological mass loss of the fruits happens due to the water transpiration during the storage period [35]. Chitosan–pullulan composite edible coating with pomegranate peel extract significantly reduced the mass loss of mango fruits at room temperature and cold temperature (4 °C) compared to the control group (Figure 3). The uncoated sample has lower quality at room temperature than the coated samples after 9 days of storage at laboratory temperature. The higher physiological mass (weight) loss at room temperature could be attributed to a higher respiration rate, leading to higher transpiration compared to coated samples [36]. The PLW at room temperature was $13.54 \pm 0.36\%$ for control fruits compared to $8.85 \pm 0.12\%$ for coated fruits. During the 18 d storage under cold storage condition, PLW for control was $8.6 \pm 0.50\%$, while coated fruit was $4.76 \pm 0.62\%$. The coated fruits were available for observation for up to 18 d wherein the PLW crossed 10% mark from 12 d onward. The application of the edible coating reduced mango fruit weight loss during storage at room and 4 °C storage conditions. The observed results are supported by the findings of Kumar et al. [9]; Kumar et al. [28]; Kumar et al. [37], who reported the effects of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on litchi, bell pepper and tomatoes. Gol & Rao [38] also found that the application of edible coating controlled the reduction of weight loss in mango fruit during the storage period.

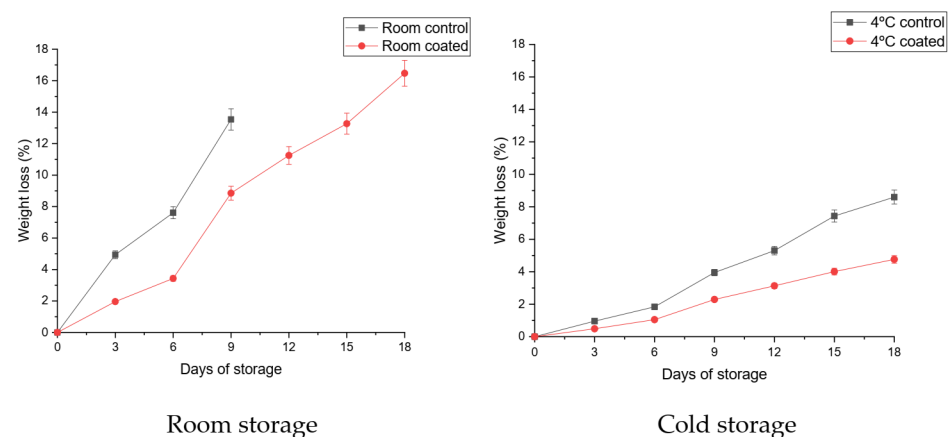


Figure 3. PLW of mango fruits (Mean ± S.D., n = 3).

3.2. Total Soluble Solids (TSS)

TSS has been considered an important biological property of fruits and vegetables produce [39]. The results of the change in the TSS during storage at room temperature and cold temperature are presented in Figure 4. Under both the storage conditions, TSS increased with the increasing storage duration. The change in TSS could be attributed to the breakdown and conversion of sugar molecules [40]. The change in TSS was higher at room temperature compared to cold temperature during the storage. At room temperature, mangoes (control) could be stored for 9 d and exhibited higher TSS (11.52 ± 0.08 °Bx) and were unacceptable; fruits treated with coating were in better condition and had lower TSS (10.24 ± 0.15 °Bx). On 18 d storage of mangoes at cold temperature, the TSS value of 10.93 ± 0.08 °Bx was observed in fruits treated with the edible coating, which was statistically significant ($p < 0.05$) and lower compared to the control (11.54 ± 0.04 °Bx). The results demonstrated that the chitosan–pullulan composite edible coating significantly maintained the TSS of mango fruits during storage at both temperatures. TSS content of fruits stored at room condition was statistically significant ($p < 0.05$) higher in both coated and control than cold storage. Other researchers have investigated the effect of edible coatings (chitosan, pullulan and alginate) on TSS of mango fruits [40–43] and obtained a similar trend of change in TSS during different storage temperatures. Furthermore, Treviño-

Garza et al. [44] explained that the edible coatings based on polysaccharides improved the physical, chemical and sensory properties of strawberries, leading to an increase in their shelf life from 6 to 15 d.

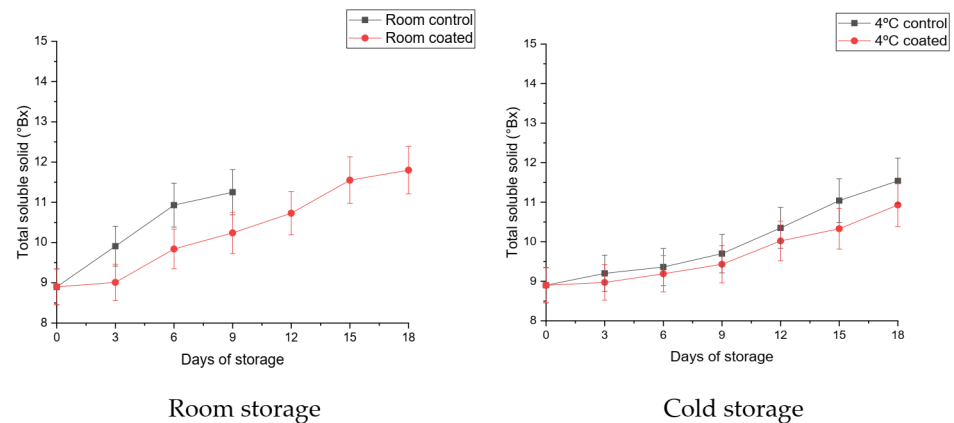


Figure 4. TSS of mango fruits (Mean ± S.D., n = 3).

3.3. Titratable Acidity (%)

Chitosan–pullulan composite edible coating incorporated with pomegranate peel extract had significantly lower titratable acidity at room and cold temperature (4 °C) compared to control. The results of TA are presented in Figure 5. Acidity was increasing with increase of the duration of storage under both temperature conditions. The acidity increased in control samples during storage at both storage temperatures due to accumulation of organic / malic acids and their conversion as respiratory substrates in glycolysis and TCA cycle [45,46]. On 9 d of storage at room temperature, control samples had higher acidity than coated samples. The acidity increased from $0.17 \pm 0.15\%$ (initial) to $1.75 \pm 0.02\%$, which was significantly different. The control samples at room temperature were unacceptable, whereas fruits treated with coating were in a marketable condition. The maximum and significantly increased titratable acidity was recorded in control mango storage at room temperature. After 9 d of storage, the acidity at room temperature was observed at $1.75 \pm 0.02\%$ compared to $1.30 \pm 0.15\%$ in coated fruits, which was significantly lower compared to the control.

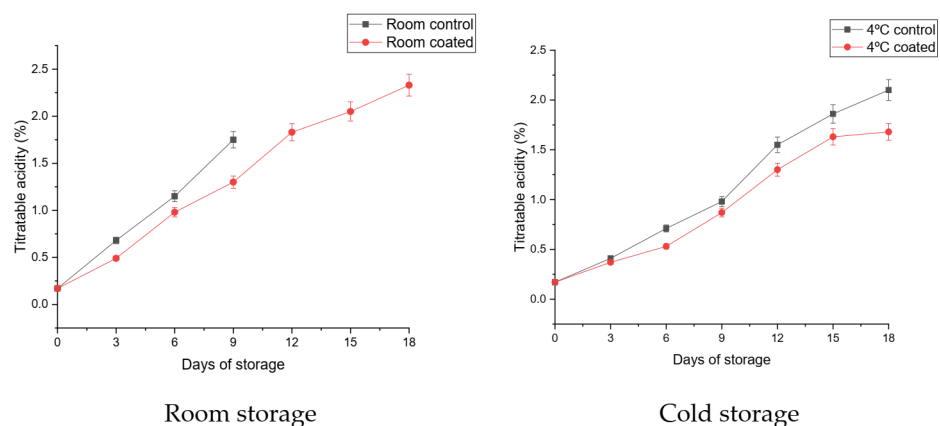


Figure 5. Titratable acidity of mango fruits (Mean ± S.D., n = 3).

During the 18 d storage time of mangoes at cold storage temperature, the acidity was less than 3%, wherein the $1.68 \pm 0.10\%$ acidity was observed in fruits treated with an edible coating which was statistically significant and lower compared to the control ($2.10 \pm 0.06\%$). This observation could be due to the impact of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on fruits. This may be due to applied

edible coating, which significantly ($p < 0.05$) delayed the utilization of respiratory materials such as organic acids. The results of this study are in agreement with the results of previous studies conducted by Eshetu et al. [47], who reported that the titratable acidity of the fruits and vegetables increased with increasing storage duration of both in both control and coated fruits. Tefera et al. [48] also reported that the lower use rate of a respiratory substance such as organic acids could lower fruit acidity due to postharvest treatments that delay respiration. The obtained results indicated that the chitosan–pullulan composite edible coating treatment maintained titratable acidity in fruits and vegetables during the storage period [9,28,37,49]. A similar increasing trend of acidity was reported by Etienne et al. [45] and Sweetman et al. [50] in tomatoes and apples, respectively.

3.4. PH

The pH represents the nature (acid/base) of the fruits & vegetables. The pH of the fruits and vegetables usually decreases with the storage time due to increase of acidity, respiration rate and delayed utilization of organic compounds. The trends of pH change in tested mango fruits are presented in Figure 6. Chitosan–pullulan composite edible coating with incorporated extract of pomegranate peel significantly controls the decreasing pH at room temperature and cold temperature (4 °C) compared to control.

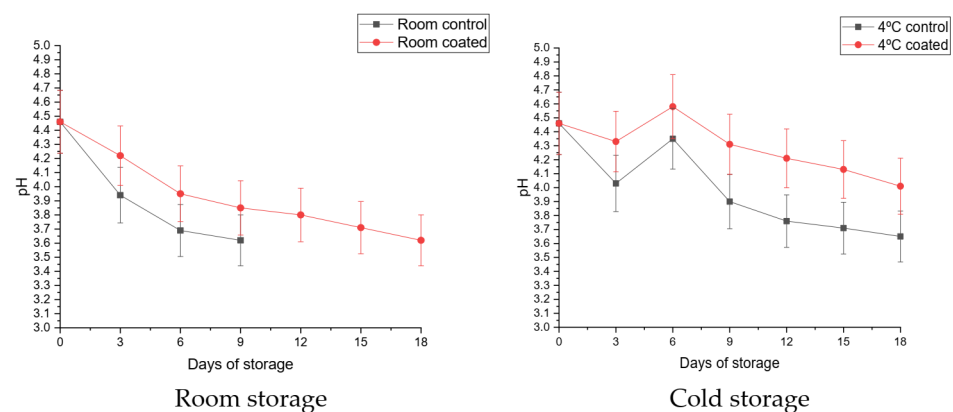


Figure 6. pH of mango fruits (Mean \pm S.D., $n = 3$).

On 9 d of storage at a room temperature condition, the control mango became more acidic and unmarketable, whereas the application of chitosan–pullulan composite edible coating maintained the pH of coated fruits. At 9 d of storage time, the pH at room control was recorded as 3.62 ± 0.03 compared to 3.85 ± 0.10 in coated fruits. At cold temperature on 18 d, the pH was recorded as a higher value than at room temperature fruits, wherein the 4.01 ± 0.04 pH was observed in fruits treated with the edible coating, which was statistically significant and higher than the control (3.65 ± 0.01). The results indicated that uncoated mango fruits at both room temperature and cold temperature significantly showed lower pH than coated mangoes during the storage period. This study agrees with previous studies done by Duan et al. [51] and Sanaa et al. [52]. The authors reported that edible coating controlled the change in pH of fruits and vegetables under storage conditions at 20 °C for 15 d. A similar study was also reported by Kumar et al. [9]; Kumar et al. [28]; Kumar et al. [37], who evaluated the effect of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on litchi, bell peppers and tomatoes.

3.5. Color (L^* , a^* , b^*)

Color attributes of fruits and vegetables are the most important choice of consumers. The color influences consumer preferences by ensuring the freshness and quality attributes of the fruits and vegetables. The color difference of fruits and vegetables during the storage period was used to determine lycopene and chlorophyll structure [53]. The changes in color scales (L^* , a^* , b^* and ΔE) of the mango fruits during the storage period at room

temperature and cold temperature are presented in Table 1. The color difference (ΔE) of the mango fruit increased with time duration, and the higher difference between the L^* , a^* and b^* values of color was recorded in control samples compared to the coated at both conditions. The results showed that the control (uncoated) sample of mango fruits stored at room temperature and 4 °C temperatures significantly became early yellow, suggesting advanced ripening compared to treated ones. The progressive changes in the chroma values are affected by the chitosan–pullulan composite edible coating on mango fruits during the storage period. On 9 d, lightness (L^*) in control fruits at room temperature was recorded 68.62 ± 0.32 , which was higher than control. The increasing trend of L^* scale indicated the degradation of green color from mango during storage. Color scales a^* and b^* values of the uncoated samples were observed -3.23 ± 0.16 and 48.78 ± 0.18 , respectively. During the 18 d storage of mangoes at cold temperature, the color was recorded (L^* , a^* , b^*), wherein the L^* (64.24 ± 0.33), a^* (-10.17 ± 0.17), b^* (36.39 ± 0.32) with 8.66 ± 0.12 of color difference (ΔE) was observed in fruits treated with chitosan–pullulan composite edible coating incorporated with pomegranate peel extract; which was statistically significant and higher in color scales L^* (67.38 ± 0.13) b^* (39.15 ± 0.10), and ΔE (12.80 ± 0.39) as compared to control. Color scale a^* value of the control fruit at cold temperature was significantly lower (-8.73 ± 0.40) than coated samples. The previous study supports these results. For instance, Ali et al. [54] reported that the application of chitosan-based edible coating could control the color changes of fruits and vegetables during the storage condition due to slowing down the respiration and ethylene production process. The edible coating may decrease the color difference of fruits and vegetables during the storage period due to the control of enzymatic browning and delaying pigmentation [53,55]. A significant difference ($p < 0.05$) was found between the control and coated mango fruits at room temperature and cold temperature.

Table 1. Color (L^* , a^* , b^* and ΔE) of mango fruits during storage conditions.

Samples	Scales	Days of Storage						
		0	3	6	9	12	15	18
Room control	L^*	59.41 ± 0.53^d	62.78 ± 0.09^c	65.18 ± 0.07^b	68.62 ± 0.32^a	N/A	N/A	N/A
Room coated		59.41 ± 0.53^f	61.34 ± 0.27^e	62.23 ± 0.06^d	63.83 ± 0.11^c	65.24 ± 0.20^b	65.90 ± 0.05^b	66.93 ± 0.14^a
4 °C control		59.41 ± 0.53^g	61.28 ± 0.21^f	62.16 ± 0.16^e	62.38 ± 0.10^d	64.40 ± 0.65^c	66.33 ± 0.32^b	67.38 ± 0.13^a
4 °C coated		59.41 ± 0.53^g	60.24 ± 0.11^f	61.03 ± 0.06^e	61.96 ± 0.11^d	62.85 ± 0.36^c	63.74 ± 0.20^b	64.24 ± 0.33^a
Room control	a^*	-16.21 ± 0.03^d	-10.86 ± 0.07^c	-7.08 ± 0.06^b	-3.23 ± 0.16^a	N/A	N/A	N/A
Room coated		-16.21 ± 0.03^g	-14.62 ± 0.31^f	-12.05 ± 0.06^e	-9.14 ± 0.11^d	-5.64 ± 0.19^c	-2.44 ± 0.27^b	1.57 ± 0.10^a
4 °C control		-16.21 ± 0.03^g	-15.26 ± 0.14^f	-14.46 ± 0.40^e	-13.50 ± 0.38^d	-12.45 ± 0.39^c	-11.44 ± 0.14^b	-8.73 ± 0.40^a
4 °C coated		-16.21 ± 0.03^f	-16.19 ± 0.14^f	-15.44 ± 0.22^e	-14.60 ± 0.21^d	-13.40 ± 0.29^c	-12.25 ± 0.17^b	-10.17 ± 0.17^a
Room control	b^*	32.49 ± 0.32^d	38.48 ± 0.26^c	42.52 ± 0.26^b	48.78 ± 0.18^a	N/A	N/A	N/A
Room coated		32.49 ± 0.35^g	35.55 ± 0.33^f	37.77 ± 0.10^e	39.17 ± 0.51^d	44.05 ± 0.48^c	46.46 ± 0.46^b	48.44 ± 0.30^a
4 °C control		32.49 ± 0.32^g	33.43 ± 0.43^f	34.24 ± 0.34^e	35.42 ± 0.35^d	36.54 ± 0.37^c	37.57 ± 0.54^b	39.15 ± 0.10^a
4 °C coated		32.49 ± 0.32^g	33.06 ± 0.05^f	33.70 ± 0.03^e	34.46 ± 0.34^d	35.31 ± 0.19^c	35.96 ± 0.05^b	36.39 ± 0.32^a
Room control	ΔE	0	8.71 ± 0.78^c	14.79 ± 0.91^b	22.77 ± 0.68^a	N/A	N/A	N/A
Room coated		0	3.95 ± 0.34^f	7.29 ± 0.22^e	10.68 ± 0.23^d	16.71 ± 0.30^c	20.66 ± 0.45^b	25.04 ± 0.77^a
4 °C control		0	2.3 ± 0.67^f	3.7 ± 0.25^e	4.97 ± 0.73^d	7.45 ± 0.28^c	9.82 ± 0.34^b	12.8 ± 0.39^a
4 °C coated		0	1.01 ± 0.32^f	2.16 ± 0.02^e	3.6 ± 0.17^d	5.26 ± 0.69^c	6.28 ± 0.26^b	8.66 ± 0.12^a

Mean \pm SD, N/A = Not applicable, L^* (+ = lighter, - = darker), a^* (+ = redder, - = greener), b^* (+ = yellower, - = bluer), ΔE = Color difference. N = 3; Values are represented as mean and standard deviation and different superscripted letter in each row denotes significance difference at $p \leq 0.05$ level.

3.6. Firmness

The firmness of the fruits and vegetables is the main attribute for consumer acceptance. The change of the firmness properties of the fruits and vegetables depends on the loss of water activity and enzymes [56]. Chitosan–pullulan composite edible coating incorporated with pomegranate peel extract significantly controlled the firmness loss of mango fruits at room temperature and 4 °C temperature compared to control. The firmness of the mango fruit was decreased with the advancement of the time storage period at both room temperature and cold storage temperature conditions in control and coated. The results of

the firmness of control and coated fruits are presented in Figure 7. Results have shown a decreasing trend of firmness in both storage conditions. The results indicated the chitosan–pullulan composite edible coating significantly control the loss of firmness in mangoes than control at room and 4 °C temperature storage conditions, probably due to the controlling water and gas transpiration [57]. At room temperature, control mangoes could not be stored beyond 9 d, after which fruit significantly lost firmness and was deemed unacceptable. In contrast, fruits treated with coating were firmer and deemed marketable, suggesting that chitosan–pullulan coating increased cell wall cohesion at the biochemical level during storage. The maximum and significant loss of firmness was recorded in control mangoes stored at room temperature. On 9 d of storage, the firmness at room temperature was observed as $(1125.81 \pm 0.27 \text{ N})$ compared to $(2037.31 \pm 0.84 \text{ N})$ in coated fruits, which was significantly higher than control fruit.

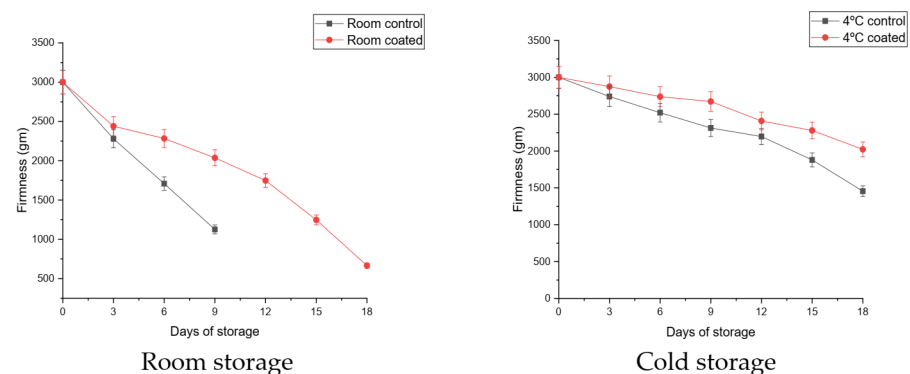


Figure 7. Firmness of mango fruits (Mean \pm S.D., $n = 3$).

At cold storage temperature on 18 d, the firmness $2021.87 \pm 0.4 \text{ N}$ was recorded in fruits treated with the edible coating, which was statistically significant and higher than the control ($1454.84 \pm 0.45 \text{ N}$). This may show the impact of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on fruits. The results demonstrated that the use of chitosan–pullulan composite edible coating was effective to prevent firmness loss of mango fruit during storage period at both room temperature and 4 °C temperature storage condition due to reducing the enzymatic activity (PPO/POD) and barrier property against water and gases [58]. Intalook et al. [59] reported that chitosan-based edible coating retained and enhanced the postharvest quality of the mango fruit during the storage period. The results are in good agreement with the previous study of Zahedi et al. [60], who declared the enhanced shelf life of mango fruit during the storage period using the chitosan-based edible coating. Various studies have reported the effects of chitosan based edible coating on preventing firmness of mango fruits during storage conditions [43,47,58].

3.7. Total Phenolic Content (TPC)

The phenolic compounds are an essential source for antioxidant agents, eliminating the free radicals and protecting the cell damage of fruits and vegetables [61]. Thus, they can be applied in the food industry as a preservative and active agents in edible packaging for food products [62]. Chitosan–pullulan composite edible coating incorporated with pomegranate peel extract significantly controlled the decreasing phenolic content activity of mango fruits at room and 4 °C temperature compared to control. The phenolic activity of the mango fruits was decreased with increasing time of storage period at both room temperature and cold storage temperature conditions in control and coated samples. The total phenolic contents of control and coated mango fruits are presented in Figure 8. Results showed a decreasing trend of phenolic content activity at both storage conditions. The results demonstrated that the mangoes treated with chitosan–pullulan composite edible coating enriched with pomegranate peel extract has significantly reduced the loss of phenolic content at room temperature and cold storage temperature conditions.

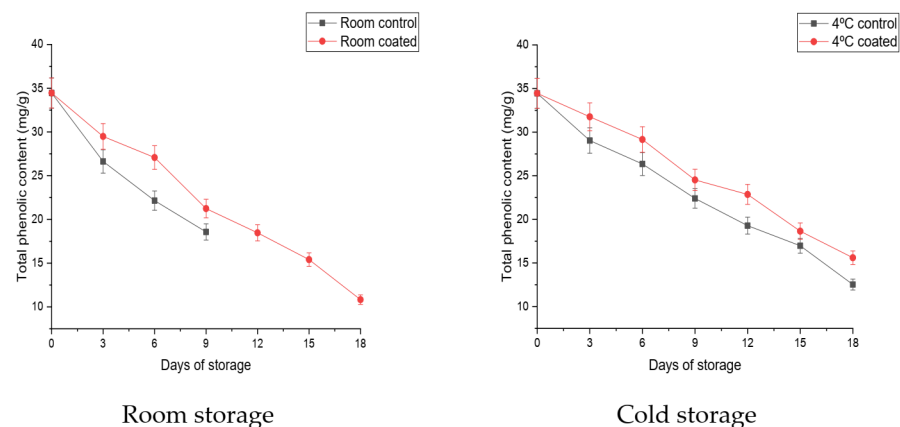


Figure 8. TPC of mango fruits (Mean \pm S.D., $n = 3$).

Mangoes could be kept for 9 days at room temperature as control samples, but the phenolic content greatly decreased and was undesirable, while fruits treated with coating were in much better condition. The maximum and significant loss of phenolic content was recorded in control mango storage at room temperature. On 9 d of storage, the total phenolic content at room temperature was observed (18.57 ± 0.06 mg/g) compared to 21.24 ± 0.28 mg/g in coated fruits that were statistically significantly higher than the control. During the 18 d storage of mangoes at cold storage temperature, the total phenolic content of 15.60 ± 0.39 mg/g was recorded in coated fruits with edible coating, which was statistically significant and higher than those of control samples (12.53 ± 0.50 mg/g). The results indicated that the coated mango fruit at cold storage condition had a statistically significant and minimum loss of phenolic content compared to others. This may show the impact of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on fruits at cold storage conditions. According to previous researchers, incorporating pomegranate peel extracts in edible coating enhances the phenolic activities of material and treated fruits and vegetables [63,64]. This study indicated that the chitosan–pullulan treated mango fruits exhibit lower reducing phenolic activity than control sample at room temperature and 4 °C temperature due to the barrier property of edible coating against moisture and gases losses as well as enzymatic activity [65,66]. A statistically significant difference ($p > 0.05$) was observed between coated and control mangoes at room temperature and cold storage temperature conditions.

3.8. Total Flavonoid Content (TFC)

Flavonoids (C6-C3-C6) are natural water-soluble pigments and are complex phenolics that indicate the ripening stage of fruits [67,68]. Chitosan–pullulan composite edible coating incorporated with pomegranate peel extract significantly controlled the decreasing flavonoid content activity of mango fruits at room and 4 °C temperatures compared to control. The flavonoid content of the mango fruits was decreased with increasing time of storage period at both room temperature and cold storage temperature conditions in control and coated. The results of the total flavonoid content of mango fruits are presented in Figure 9. The results showed a decreasing trend of flavonoid content activity in mangoes at both storage conditions. At room temperature, mangoes could be stored for 9 d as control samples significantly reduced the total flavonoid content compared to coated samples. The decrease in flavonoid content in control may be due to its higher respiration rate, which causes total phenols to be broken down [69]. The statistically significant and higher loss of flavonoid content was recorded in control mango storage at room temperature.

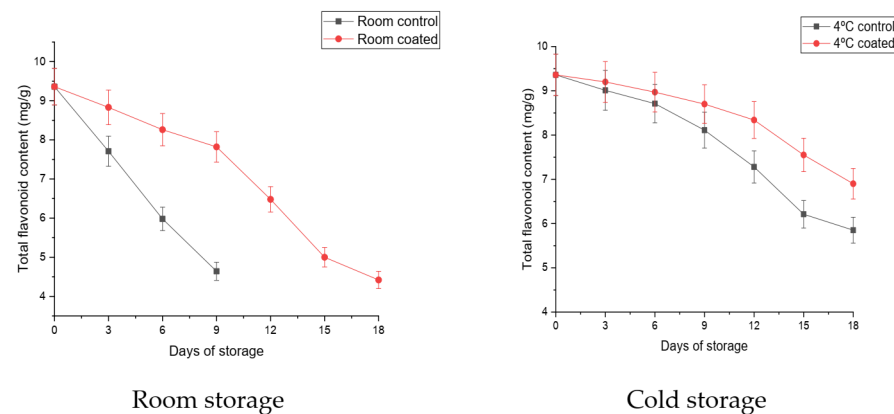


Figure 9. TFC of mango fruits (Mean \pm S.D., n = 3).

On 9 d of storage, the total flavonoid content at room temperature was observed (4.64 ± 0.37 mg/g) compared to 7.82 ± 0.26 mg/g in coated fruits which were statistically significantly higher than control. On the same day, the total flavonoid content activity at cold storage temperature was observed in control (8.11 ± 0.55 mg/g) and coated (8.70 ± 0.10 mg/g) mango fruits, respectively. A significantly ($p < 0.05$) higher loss of flavonoid compounds was recorded in control at room temperature than others. During the 18 d of storage of mangoes at cold storage temperature, the total flavonoid content activity of 6.90 g/g was recorded in coated fruits, which was statistically significant and higher in comparison to control (5.85 ± 0.41 mg/g). The results indicated that the coated mango fruit at cold storage condition had a statistically significant and minimum loss of flavonoid compounds compared to others. This may show the impact of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on fruits at cold storage conditions. Ali et al. [70] reported that the lower value of flavonoid content in fruits and vegetables causes a higher respiration rate. Incorporating pomegranate peel extract in edible coating helped enhance the flavonoid content of fruits and vegetables during the storage period [9]. The results of this study revealed that the mango fruits coated with chitosan–pullulan composite edible coating enriched with pomegranate peel extract exhibited the lower reducing flavonoid activity compared to uncoated sample during the storage period of 18 d at room temperature and cold storage temperature conditions.

3.9. Radical Scavenging Activity (RSA)

Antioxidant agents are the most important plant secondary metabolites, which help eliminate free radical activity due to their hydrogen donating property [71]. Phenolic compounds have an aromatic structure containing one or more hydroxyl groups, which gives them the ability to scavenge free radicals and protect biological tissues from damage related to reactive oxygen species [72]. Chitosan–pullulan composite edible coating with pomegranate peel extract significantly controlled the decreasing antioxidant activity of mango fruits at room temperature and cold temperature (4°C) compared to control. The antioxidant activity (DPPH assay) of the mango fruits was decreased with increasing time of storage period at both room and cold storage temperature conditions in control and coated samples. The results of the antioxidant activity mango fruits are presented in Figure 10. It shows the decreasing trend of antioxidant activity with the advancement of time storage of mangoes at both storage conditions. The results indicate that the application of chitosan–pullulan composite edible coating significantly controlled the loss of free radical scavenging capacity of mango fruits at room and cold storage temperature conditions. At room temperature, mangoes could be stored for 9 d as control samples significantly reduced the antioxidant activity from $83.44 \pm 0.42\%$ to $53.57 \pm 0.69\%$ and were unacceptable for consumption, whereas fruits coated with coating were comparatively in better condition. The statistically significant and higher loss of antioxidant activity was recorded in control mango storage at room temperature. On 9 d of storage, the DPPH antioxidant activity at

room temperature was observed ($53.57 \pm 0.69\%$) compared to $60.44 \pm 0.29\%$ in coated fruits, which was significantly higher compared to control. On the same storage day, the DPPH antioxidant activity at cold storage temperature was observed in control ($65.40 \pm 0.52\%$) and coated ($70.80 \pm 0.66\%$) mangoes, respectively. The DPPH antioxidant activity at cold storage temperature was significantly higher than control and coated at room temperature on 9 d of storage. A significantly ($p < 0.05$) higher loss of DPPH antioxidant activity was recorded in control at room temperature than in others. During the 18 d storage of mangoes at cold storage temperature, the DPPH antioxidant activity of $54.86 \pm 0.22\%$ was recorded in fruits coated with an edible coating which was statistically significant and higher than control ($47.66 \pm 0.63\%$). This study demonstrated that the control sample of mango storage at room temperature reduced higher antioxidant activity during the storage period of 9 days.

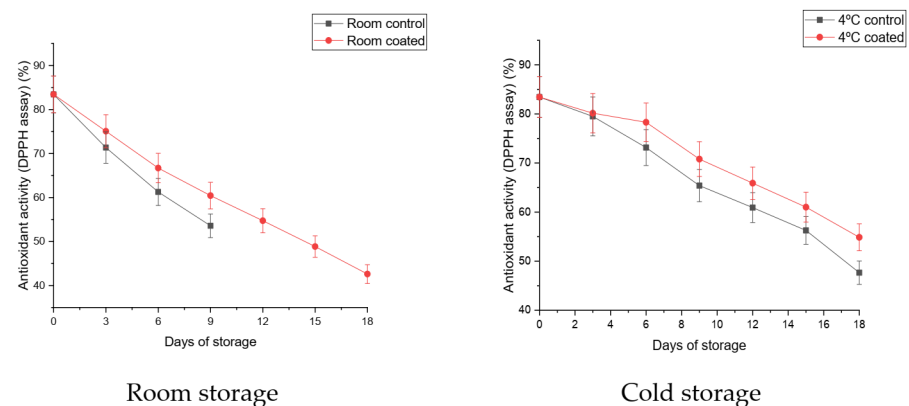


Figure 10. Antioxidant activity of mango fruits (Mean \pm S.D., $n = 3$).

The applied edible coating was effective in controlling the degradation of antioxidant content during storage at room temperature and cold storage temperature compared to control. The results of this study are supported by previous studies by Ma et al. [73], Palafox et al. [74] and Liu et al. [75]; the authors reported that the application of edible coating could be protective against the reduction of antioxidant agents from fruits and vegetables. The previous study done by Tayel et al. [76] reported that plant extract in chitosan-based edible coating enhances the antioxidant activity of citrus fruits during the storage period. Kumar et al. [37] retained the antioxidant property of tomatoes during the storage period using antioxidant rich chitosan–pullulan composite edible coating.

3.10. Sensory Characteristics

Sensory evaluation of the control and coated mango fruits during the storage period at room temperature and cold storage temperature revealed a statistically significant ($p < 0.05$) difference in freshness, color, texture, taste and overall acceptability. Chitosan–pullulan composite edible coating incorporated with pomegranate peel extract significantly controlled the degradation of sensory characteristics of mango fruits at room temperature and at cold temperature ($4\text{ }^{\circ}\text{C}$) as compared to control. The sensory characteristics of the mango fruits were decreased with increasing storage time at both conditions. The results of sensory evaluation of control and coated mango fruits are presented in Table 2. At room temperature, mangoes could be stored for 9 d as control samples, and they decayed and were unacceptable based on sensory characteristics (freshness, color, texture, taste, and overall acceptability), whereas fruits coated with coating were comparatively in much better condition. At room temperature, mangoes could be stored for 9 d as control samples significantly reduced the sensory attributes. The sensory characteristics at room temperature were observed with the significant lowest sensory score: i.e., freshness (5.2 ± 0.89), color (5.6 ± 0.65), texture (5.8 ± 0.60), taste (5.4 ± 0.69) and overall acceptability (5.5 ± 0.25) as compared to freshness (6.9 ± 0.56), color (7.1 ± 0.40), texture (7.2 ± 0.34), taste

(7.1 ± 0.18) and overall acceptability (7.07 ± 0.12) in coated fruits, which were statistically significantly higher as compared to control. During the 18 d storage of mangoes at cold temperature, the sensory evaluation score was recorded: i.e., freshness (6.8 ± 0.46), color (7.5 ± 0.47), texture (7.2 ± 0.34), taste (6.9 ± 0.71) and overall acceptability (7.1 ± 0.75) in coated fruits, which was statistically significant and higher as compared to control: i.e., freshness (6.2 ± 0.83), color (6.6 ± 0.68), texture (6.2 ± 0.21), taste (6.1 ± 0.47) and overall acceptability (6.27 ± 0.80), respectively. Based on the overall acceptability results, the results demonstrated that the chitosan–pullulan composite edible coating could be a potential technology for the prevention of sensory characteristics of mango fruits during storage at room and cold temperatures.

Table 2. Sensory characteristics of mango fruits during storage.

Samples	Sensory Characteristics	Days of Storage						
		0	3	6	9	12	15	18
Room control	Freshness	8.5 ± 0.91^a	7.9 ± 0.69^b	6.0 ± 0.63^c	5.2 ± 0.89^d	N/A	N/A	N/A
Room coated		8.5 ± 0.91^a	8.1 ± 0.52^a	7.6 ± 0.74^b	6.9 ± 0.56^c	6.1 ± 0.93^c	5.8 ± 0.35^d	5.1 ± 0.42^e
4 °C control		8.5 ± 0.91^a	8.1 ± 0.47^a	7.6 ± 0.56^b	7.0 ± 0.46^c	6.9 ± 0.56^d	6.5 ± 0.47^e	6.2 ± 0.83^f
4 °C coated		8.5 ± 0.91^a	8.2 ± 0.19^a	7.9 ± 0.28^b	7.8 ± 0.31^c	7.4 ± 0.36^d	7.2 ± 0.19^e	6.8 ± 0.46^f
Room control	Color	8.8 ± 0.48^a	7.9 ± 0.41^b	7.1 ± 0.35^c	5.8 ± 0.60^d	N/A	N/A	N/A
Room coated		8.8 ± 0.48^a	8.2 ± 0.53^b	7.8 ± 0.45^c	7.1 ± 0.40^d	6.8 ± 0.27^e	6.1 ± 0.36^f	5.9 ± 0.97^g
4 °C control		8.8 ± 0.48^a	8.4 ± 0.90^a	8.0 ± 0.75^{ab}	7.6 ± 0.14^c	7.3 ± 0.28^c	7.0 ± 0.48^d	6.6 ± 0.68^e
4 °C coated		8.8 ± 0.48^a	8.6 ± 0.23^a	8.4 ± 0.05^{ab}	8.2 ± 0.46^{abc}	8.0 ± 0.86^d	7.8 ± 0.31^e	7.5 ± 0.47^f
Room control	Texture	8.8 ± 0.37^a	8.0 ± 0.45^b	6.5 ± 0.66^c	5.6 ± 0.65^d	N/A	N/A	N/A
Room coated		8.8 ± 0.37^a	8.4 ± 0.58^a	8.0 ± 0.42^b	7.2 ± 0.34^c	6.4 ± 0.35^d	6.0 ± 0.28^e	5.6 ± 0.46^f
4 °C control		8.8 ± 0.37^a	8.6 ± 0.17^a	8.0 ± 0.31^b	7.4 ± 0.39^c	7.0 ± 0.24^d	6.6 ± 0.76^e	6.2 ± 0.21^f
4 °C coated		8.8 ± 0.37^a	8.8 ± 0.36^a	8.4 ± 0.19^b	8.0 ± 0.23^c	7.8 ± 0.18^d	7.5 ± 0.46^e	7.2 ± 0.34^f
Room control	Taste	8.6 ± 0.30^a	8.1 ± 0.48^b	7.0 ± 0.56^c	5.4 ± 0.69^d	N/A	N/A	N/A
Room coated		8.6 ± 0.30^a	8.2 ± 0.26^b	7.6 ± 0.23^c	7.1 ± 0.18^d	6.4 ± 0.23^e	5.9 ± 0.17^f	5.4 ± 0.54^g
4 °C control		8.6 ± 0.30^a	8.4 ± 0.29^b	7.9 ± 0.65^c	7.4 ± 0.57^d	7.1 ± 0.45^e	6.7 ± 0.56^f	6.1 ± 0.47^g
4 °C coated		8.6 ± 0.30^a	8.6 ± 0.31^a	8.2 ± 0.47^b	7.9 ± 0.48^c	7.5 ± 0.24^d	7.1 ± 0.24^e	6.9 ± 0.71^f
Room control	OAA	8.67 ± 0.15^a	7.97 ± 0.09^b	6.65 ± 0.50^c	5.5 ± 0.25^d	N/A	N/A	N/A
Room coated		8.67 ± 0.15^a	8.22 ± 0.12^b	7.75 ± 0.19^c	7.07 ± 0.12^d	6.42 ± 0.65^e	5.95 ± 0.7^f	5.5 ± 0.86^g
4 °C control		8.67 ± 0.15^a	8.37 ± 0.20^b	7.87 ± 0.18^c	7.35 ± 0.25^d	7.07 ± 0.60^e	6.7 ± 0.85^f	6.27 ± 0.80^g
4 °C coated		8.67 ± 0.15^a	8.55 ± 0.25^b	8.22 ± 0.23^c	7.97 ± 0.17^d	7.67 ± 0.55^e	7.4 ± 0.61^f	7.1 ± 0.75^g

N/A = Not available, OAA = Overall acceptability, Mean \pm SD, N = 30; Values are represented as mean and standard deviation and different superscripted letter(s) in each row denotes significance difference at $p \leq 0.05$ level.

The results are in good agreement with the results of previous studies done by Kumar et al. [9] and Kumar et al. [28]; the author reported that the chitosan–pullulan composite edible coating enriched with pomegranate peel extract was effective to prevent the sensory attributes and overall acceptability of litchi fruits and bell pepper, respectively. Krasniewska et al. [77] and Krasniewska et al. [78] incorporated plant extract of *Saturejahortensis* L. with pullulan based edible coating to maintain the apple and pepper quality and sensory characteristics during the storage period, respectively. De Leon-Zapata et al. [79] also applied candelilla wax coating enriched with tarbush (*Flourensiacernua*) extract on apple. The authors reported that the applied material on apples did not cause undesirable changes in the sensorial and appearance during the 8 weeks of the storage period. Guerreiro et al. [80] reported that incorporating the natural antioxidant agents in the edible coating could influence the sensory profiling of the fruits and vegetables. The results demonstrated that the chitosan–pullulan composite edible coating enhanced at least by double the shelf life of mango fruits. At a cold storage temperature, both were acceptable based on sensory evaluation during the 18 d of storage period. The visual appearance of the mango fruits at room temperature and cold storage temperature during 18 d storage are presented in Figure 11.

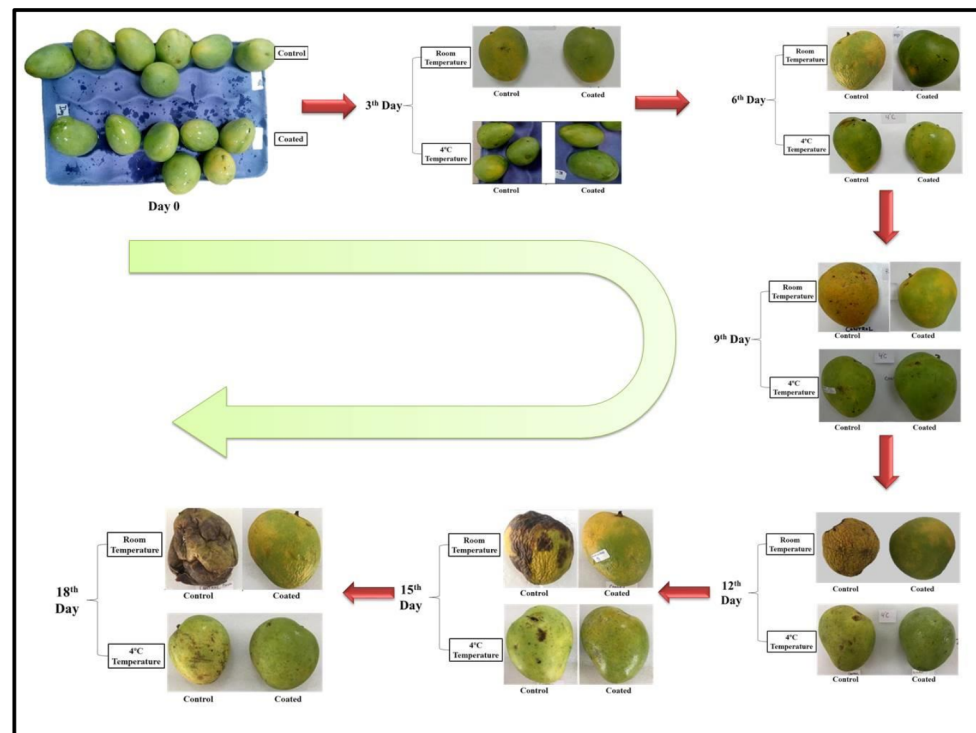


Figure 11. Visual appearance of Mango fruit during storage period at room temperature and 4 °C.

4. Conclusions

Edible coatings and films containing natural plant extracts are commonly used to improve the overall consistency of fruits and vegetables with a long shelf life. The present study investigated the effect of chitosan–pullulan composite edible coating enriched with pomegranate peel extract on mango fruits during the storage time for 18 days at room and 4 °C temperature conditions. The current study revealed that control samples at room temperatures were not available after 9 days of storage duration for the analysis due to unacceptability by the consumers and weight loss. The characterization of mango fruits confirmed the positive impact of edible coating on the postharvest shelf life of mango fruits during storage. The chitosan–pullulan composite edible coating recorded significant retention of postharvest characteristics such as physiological loss in weight (PLW), color, TSS and acidity in the sample compared to the control. Incorporating pomegranate peel extract in the edible coating could enhance the biological activity (phenolic, flavonoid and antioxidant activity) of coated mango fruit during the storage period. Therefore, the technical and scientific investigation indicated that composite edible coating containing chitosan–pullulan (50:50) with pomegranate peel extract could be a promising strategy to improve the postharvest quality of mango fruits during the storage period. Further research should be followed to extend the postharvest shelf life of other fruits and vegetables using the composite formulation of chitosan–pullulan and pomegranate peel extract. The material could be considered at a commercial scale to extend the shelf life of fruits and vegetables.

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References

1. Chauhan, S.; Gupta, K.C.; Agrawal, M. Efficacy of chitosan and calcium chloride on postharvest storage period of mango with the application of hurdle technology. *Int. J. Curr. Microbiol. Appl. Sci.* **2014**, *3*, 731–740.
2. Elik, A.; Yanık, D.; Istanbulu, Y.; Guzelsoy, N.; Yavuz, A.; Gögüs, F. Strategies to reduce post-harvest losses for fruits and vegetables. *Int. J. Sci. Technol. Res.* **2019**, *5*, 29–39.
3. Yahaya, S.M.; Mardiyya, A.Y. Review of post-harvest losses of fruits and vegetables. *Biomed. J. Sci. Tech. Res.* **2019**, *13*, 10192–10200.
4. FAO. *Postharvest Management of Mango for Quality and Safety Assurance. Guidance for Horticultural Supply Chain Stakeholders*; FAO: Rome, Italy, 2018; pp. 1–21.
5. FAO. *The State of Food and Agriculture: Climate Change, Agriculture and Food Security*; FAO: Rome, Italy, 2016; Available online: www.fao.org/publications (accessed on 23 October 2016).
6. Thakur, J.P.; Gothwal, P.P.; Singh, I. Postharvest treatments for extension of mango fruit var. Dashehari (*Mangifera indica* L.). *Int. J. Food Sci. Nutr.* **2017**, *2*, 156–162.
7. Phakawatmongkol, W.; Ketsa, S.; Doorn, W.G. Variation in fruit chilling injury among mango cultivars. *Postharvest Biol. Technol.* **2004**, *32*, 115–118. [[CrossRef](#)]
8. Affognon, H.; Mutungi, C.; Sanginga, P.; Orgemeister, C. Unpacking postharvest losses in sub-Saharan Africa: A meta-analysis. *World Dev.* **2015**, *66*, 49–68. [[CrossRef](#)]
9. Kumar, N.; Pratibha, N.; Singla, M. Enhancement of storage life and quality maintenance of litchi (*Litchi Chinensis* Sonn.) fruit using chitosan: Pullulan blend antimicrobial edible coating. *Int. J. Fruit Sci.* **2020**, *20* (Suppl. 3), S1662–S1680. [[CrossRef](#)]
10. Olaimat, A.N.; Holley, R.A. Factors influencing the microbial safety of fresh produce: A review. *Food Microbiol.* **2012**, *32*, 1–19. [[CrossRef](#)]
11. James, A.; Zikankuba, V. Postharvest management of fruits and vegetable: A potential for reducing poverty, hidden hunger and malnutrition in sub-saharafrica. *Cogent Food Agric.* **2017**, *3*, 1–13. [[CrossRef](#)]
12. Malik, A.U.; Siddiq, F.; Siddiq, M. *Packaging of Fresh Mangoes and Processed Mango Products. Handbook of Mango Fruit: Production, Postharvest Science, Processing Technology and Nutrition*, 1st ed.; Siddiq, M., Jeffrey, K., Sidhu, B.S., Sidhu, J.S., Eds.; John Wiley & Sons Ltd.: Chichester, UK, 2017.
13. Tavassoli-Kafrani, E.; Gamage, M.V.; Dumée, L.F.; Kong, L.; Zhao, Z. Edible films and coatings for shelf life extension of mango: A review. *Crit. Rev. Food Sci. Nutr.* **2020**, 1–29. [[CrossRef](#)]
14. Kumar, N.; Neeraj. Polysaccharide-based component and their relevance in edible film/coating: A review. *Nutr. Food Sci.* **2019**, *49*, 793–823. [[CrossRef](#)]
15. Lazaridou, A.; Biliaderis, C.G. Thermophysical properties of chitosan, chitosan–starch and chitosan–pullulan films near the glass transition. *Carbohydr. Polym.* **2002**, *48*, 179–190. [[CrossRef](#)]
16. Kumar, S.; Mukherjee, A.; Dutta, J. Chitosan based nanocomposite films and coatings: Emerging antimicrobial food packaging alternatives. *Trends Food Sci. Technol.* **2020**, *97*, 196–209. [[CrossRef](#)]
17. Cao, Z.; Sun, Y. Chitosan-based rechargeable long-term antimicrobial and biofilm-controlling systems. *J. Biomed. Mater. Res.* **2009**, *89*, 960–967. [[CrossRef](#)]
18. Farris, S.; Unalan, I.U.; Introzzi, L.; Fuentes-Alventosa, J.M.; Cozzolino, C.A. Pullulan-based films and coatings for food packaging: Present applications, emerging opportunities, and future challenges. *J. Appl. Polym. Sci.* **2014**, *131*. [[CrossRef](#)]
19. Kraśniewska, K.; Pobiega, K.; Gniewosz, M. Pullulan–Biopolymer with potential for use as food packaging. *Int. J. Food Eng.* **2019**, *15*. [[CrossRef](#)]
20. Ghasemnezhad, M.; Zareh, S.; Rassa, M.; Sajedi, R.H. Effect of chitosan coating on maintenance of aril quality, microbial population and PPO activity of pomegranate (*Punica granatum* L. cv. Tarom) at cold storage temperature. *J. Sci. Food Agric.* **2013**, *93*, 368–374. [[CrossRef](#)]
21. Mostafidi, M.; Sanjabi, M.R.; Shir Khan, F.; Zahedi, M.T. A review of recent trends in the development of the microbial safety of fruits and vegetables. *Trends Food Sci. Technol.* **2020**, *103*, 321–332. [[CrossRef](#)]
22. Kumar, N.; Neeraj, P. Functional properties of pomegranate peel in edible coating/film: A review. *Int. J. Post. Technol. Innov.* **2020**, *7*, 205–216. [[CrossRef](#)]
23. Saxena, S.; Sharma, L.; Maity, T. Enrichment of Edible Coatings and Films with Plant Extracts or Essential Oils for the Preservation of Fruits and Vegetables. In *Biopolymer-Based Formulations Biomedical and Food Applications*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 859–880.
24. Kumar, N.; Ojha, A.; Singh, R. Preparation and characterization of chitosan–pullulan blended edible films enrich with pomegranate peel extract. *React. Funct. Polym.* **2019**, *144*, 104350. [[CrossRef](#)]

25. Wu, J.; Zhong, F.; Li, Y.; Shoemaker, C.F.; Xia, W. Preparation and characterization of pullulan-chitosan and pullulan-carboxymethyl chitosan blended films. *Food Hydrocoll.* **2013**, *30*, 82–91. [[CrossRef](#)]
26. Kawhena, T.G.; Opara, U.L.; Fawole, O.A. Optimization of gum arabic and starch-based edible coatings with lemongrass oil using response surface methodology for improving postharvest quality of whole “wonderful” pomegranate fruit. *Coatings* **2021**, *11*, 442. [[CrossRef](#)]
27. Kawhena, T.G.; Tsige, A.A.; Opara, U.L.; Fawole, O.A. Application of gum arabic and methyl cellulose coatings enriched with thyme oil to maintain quality and extend shelf life of “acco” pomegranate arils. *Plants* **2020**, *9*, 1690. [[CrossRef](#)]
28. Kumar, N.; Ojha, A.; Upadhyay, A.; Singh, R.; Kumar, S. Effect of active chitosan-pullulan composite edible coating enrich with pomegranate peel extract on the storage quality of green bell pepper. *LWT* **2021**, *138*, 110435. [[CrossRef](#)]
29. Fawole, O.A.; Riva, S.C.; Opara, U.L. Efficacy of edible coatings in alleviating shrivel and maintaining quality of Japanese plum (*Prunus salicina* Lindl.) during export and shelf life conditions. *Agronomy* **2020**, *10*, 1023. [[CrossRef](#)]
30. Singleton, V.L.; Rossi, J.A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158.
31. Aryal, S.; Baniya, K.M.; Danekhu, K.; Kunwar, P.; Gurung, R.; Koirala, N. Total phenolic content, flavonoid content and antioxidant potential of wild vegetables from western Nepal. *Plants* **2019**, *8*, 96. [[CrossRef](#)] [[PubMed](#)]
32. Pisoschi, A.M.; Negulescu, G.P. Methods for total antioxidant activity determination: A review. *Biochem. Anal. Biochem.* **2011**, *1*, 1–9. [[CrossRef](#)]
33. Brand-Williams, W.; Cuvelier, M.E.; Berset, C.L.W.T. Use of a free radical method to evaluate antioxidant activity. *LWT* **1995**, *28*, 25–30. [[CrossRef](#)]
34. Xing, Y.; Li, X.; Xu, Q.; Yun, J.; Lu, Y.; Tang, Y. Effects of chitosan coating enriched with cinnamon oil on qualitative properties of sweet pepper (*Capsicum annuum* L.). *Food Chem.* **2011**, *124*, 1443–1450. [[CrossRef](#)]
35. Aloui, H.; Khwaldia, K.; Sánchez-González, L.; Muneret, L.; Jeandel, C.; Hamdi, M.; Desobry, S. Alginate coatings containing grapefruit essential oil or grapefruit seed extract for grapes preservation. *Int. J. Food Sci. Tech.* **2014**, *49*, 952–959. [[CrossRef](#)]
36. Maftoonazad, N.; Ramaswamy, S.H. Application and evaluation of a pectin-based edible coating process for quality change kinetics and shelf-life extension of lime fruit (*Citrus aurantifolium*). *Coatings* **2019**, *9*, 285. [[CrossRef](#)]
37. Kumar, N.; Pratibha, N.; Petkoska, T.A. Improved shelf life and quality of tomato (*Solanum lycopersicum* L.) by using chitosan-pullulan composite edible coating enriched with pomegranate peel extract. *ACS Food Sci. Technol.* **2021**. [[CrossRef](#)]
38. Gol, B.N.; Rao, T.V.R. Influence of zein and gelatin coatings on the postharvest quality and shelf life extension of mango (*Mangifera indica* L.). *Fruits* **2013**, *69*, 101–115. [[CrossRef](#)]
39. Abebe, Z.; Tola, B.; Yetenayet, M.A. Effects of edible coating materials and stages of maturity at harvest on storage life and quality of tomato (*Lycopersicon esculentum* Mill.) fruits. *Afr. J. Agric. Res.* **2017**, *12*, 550–565.
40. Yin, C.; Huang, C.; Wang, J.; Liu, Y.; Lu, P.; Huang, L. Effect of chitosan- and alginate-based coatings enriched with cinnamon essential oil microcapsules to improve the postharvest quality of mangoes. *Materials* **2019**, *12*, 2039. [[CrossRef](#)]
41. Diab, T.; Biliaderis, G.C.; Gerasopoulos, D.; Sfakiotakis, E. Physicochemical properties and application of pullulan edible films and coatings in fruit preservation. *J. Sci. Food Agric.* **2001**, *81*, 988–1000. [[CrossRef](#)]
42. Chien, P.J.; Sheu, F.; Yang, F.H. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *J. Food Eng.* **2007**, *78*, 225–229. [[CrossRef](#)]
43. Zhu, X.; Wang, Q.; Cao, J.; Jiang, W. Effects of chitosan coating on postharvest quality of mango (*Mangifera indica* L. cv. Tainong) fruits. *J. Food Process Pres.* **2008**, *32*, 770–784. [[CrossRef](#)]
44. Treviño-Garza, M.Z.; García, S.; Flores-González, M.D.S.; Arévalo-Niño, K. Edible active coatings based on pectin, pullulan, and chitosan increase quality and shelf life of strawberries (*Fragaria ananassa*). *J. Food Sci.* **2015**, *80*, 1823–1830. [[CrossRef](#)]
45. Etienne, A.; Génard, M.; Lobit, P.; Mbéguié-A-Mbéguié, D.; Bugaud, C. What controls fleshy fruit acidity? A review of malate and citrate accumulation in fruit cells. *J. Exp. Bot.* **2013**, *64*, 1451–1469. [[CrossRef](#)]
46. Muñoz, T.; Sanchez-Ballesta, M.T.; Ruiz-Cabello, J.; Escribano, M.I.; Merodio, C. The acid metabolism of annona fruit during ripening. *J. Hortic. Sci. Biotech.* **2004**, *79*, 472–478. [[CrossRef](#)]
47. Eshetu, A.; Ibrahim, M.A.; Forsido, F.S.; Kuyu, G.C. Effect of beeswax and chitosan treatments on quality and shelf life of selected mango (*Mangifera indica* L.) cultivars. *Heliyon* **2019**, *5*, 1–22. [[CrossRef](#)]
48. Tefera, A.; Seyoum, T.; Woldetsadik, K. Effects of disinfection, packaging and evaporatively cooled storage on sugar content of mango. *Afr. J. Biotechnol.* **2008**, *7*, 65–72.
49. Mani, A.; Jain, N.; Singh, K.; Arun, S.M. Effects of aloe vera edible coating on quality and postharvest physiology of ber (*Zizyphus mauritiana* Lamk.) under ambient storage conditions. *Int. J. Pure Appl. Biosci.* **2017**, *5*, 43–53. [[CrossRef](#)]
50. Sweetman, C.; Deluc, L.G.; Cramer, G.R.; Ford, C.M.; Soole, K.L. Regulation of malate metabolism in grape berry and other developing fruits. *Phytochemistry* **2009**, *70*, 1329–1344. [[CrossRef](#)]
51. Duan, J.; Wu, R.; Strik, C.B.; Zhao, Y. Effect of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions. *Postharvest Biol. Technol.* **2011**, *59*, 71–79. [[CrossRef](#)]

52. Sanaa, S.H.; Aly, E.N.M.; Entsar, S.A. Effect of edible coating on extending the shelf life and quality of fresh cut taro. *Am. J. Food Technol.* **2017**, *12*, 124–131.
53. Sharma, L.; Saini, S.C.; Sharma, K.H. Biocomposite edible coatings based on cross linked-sesame protein and mango puree for the shelf life stability of fresh-cut mango fruit. *J. Food Process Eng.* **2019**, *42*, 1–9. [\[CrossRef\]](#)
54. Ali, A.; Mohamed, T.M.M.; Muhammad, M.; Sijam, K.; Siddiqui, Y. Effect of chitosan coating on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. *Food Chem.* **2011**, *124*, 620–626. [\[CrossRef\]](#)
55. Dilmacunal, T.; Koyunchu, M.A.; Aktas, H.; Bayindir, D. The effect of several postharvest treatments on shelf life, quality of bunch tomatoes. *Not. Bot. Horti Agrobot.* **2011**, *39*, 209–213. [\[CrossRef\]](#)
56. Paniagua, A.; East, A.; Hindmarsh, J.; Heyes, J.A. Moisture loss is the major cause of firmness change during postharvest storage of blueberry. *Postharvest Biol. Technol.* **2013**, *79*, 13–19. [\[CrossRef\]](#)
57. Mebratie, M.A.; Woldetsadik, K.; Ayalew, A.; Haji, J. Comparative study of different banana ripening methods. *Sci. Technol. Arts Res. J.* **2015**, *4*, 32–38. [\[CrossRef\]](#)
58. Mandal, D.; Sailo, A.; Hazarika, K.T.; Shukla, C.A. Effect of edible coating on shelf life and quality of local mango cv. Rangkuai of Mizoram. *Res. Crops* **2018**, *19*, 419–424.
59. Intalook, W.; Huber, J.; Sargent, S.A. Coating material effect on postharvest quality changes of mango fruit. *Postharvest Biol. Technol.* **2006**, *28*, 247–257.
60. Zahedi, M.S.; Hosseini, S.M.; Karimi, M.; Ebrahimzadeh, A. Effects of postharvest polyamine application and edible coating on maintaining quality of mango (*Mangifera indica* L.) cv. Langra during cold storage. *Food Sci. Nutr.* **2019**, *7*, 433–441. [\[CrossRef\]](#)
61. Toor, R.K.; Savage, G.P. Antioxidant activity in different fractions of tomatoes. *Food Res. Int.* **2005**, *38*, 487–494. [\[CrossRef\]](#)
62. Lourenço, S.C.; Moldão-Martins, M.; Alves, V.D. Antioxidants of natural plant origins: From sources to food industry applications. *Molecules* **2019**, *24*, 4132. [\[CrossRef\]](#)
63. Kharchoufi, S.; Parafati, L.; Licciardello, F.; Muratore, G.; Hamdi, M.; Cirvilleri, G.; Cristina, R. Edible coatings incorporating pomegranate peel extract and biocontrol yeast to reduce *Penicillium digitatum* postharvest decay of oranges. *Food Microbiol.* **2018**, *74*, 107–112. [\[CrossRef\]](#)
64. Taberner, V.; Sanchís, E.; Mateos, M.; Palou, L.; Pérez-Gago, M.B. Pectin-based edible coatings formulated with pomegranate peel extracts and other antibrowning agents to extend shelf life of fresh-cut ‘RojoBrillante’. *Acta. Hort.* **2018**, *1194*, 887–894. [\[CrossRef\]](#)
65. Wang, S.Y.; Gao, H. Effect of chitosan-based edible coating on antioxidants, antioxidant enzyme system, and postharvest fruit quality of strawberries (*Fragaria x aranassa* Duch.). *LWT Food Sci. Technol.* **2013**, *52*, 71–79. [\[CrossRef\]](#)
66. Zam, W. Effect of alginate and chitosan edible coating enriched with olive leaves extract on the shelf life of sweet cherries (*Prunusavium* L.). *J. Food Qual.* **2019**, *2019*, 1–7. [\[CrossRef\]](#)
67. Serradilla, M.J.; Lozano, M.; Bernalte, M.J.; Ayuso, M.C.; López-Corrales, M.; González-Gómez, D. Physicochemical and bioactive properties evolution during ripening of “Ambrunés” sweet cherry cultivar. *LWT Food Sci. Technol.* **2011**, *44*, 199–205. [\[CrossRef\]](#)
68. Alyson, E.M.; Robertson, D.; Koh, E. Optimizing the extraction of procyanidins oligomers through decamer. *Nutr. Food Sci.* **2017**, *4*, 555–559.
69. Howard, L.R.; Talcott, S.T.; Brenes, C.H.; Villalon, B. Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. *J. Agric. Food Chem.* **2020**, *48*, 1713–1720. [\[CrossRef\]](#)
70. Ali, A.; Maqbool, M.; Alderson, G.P.; Zahid, N. Effect of gum arabic as an edible coating on antioxidant capacity of tomato (*Solanum lycopersicum* L.) fruit during storage. *Postharvest Biol. Technol.* **2013**, *76*, 119–124. [\[CrossRef\]](#)
71. Lobo, V.; Patil, A.; Phatak, A.; Chandra, N. Free radicals, antioxidants and functional foods: Impact on human health. *Pharmacogn. Rev.* **2010**, *4*, 118–126. [\[CrossRef\]](#)
72. Kafkas, N.B.; Kosar, M.; Oz, A.T.; Mitchell, A.E. Advanced analytical methods for phenolics in fruits. *J. Food Qual.* **2018**, *26*, 1–6. [\[CrossRef\]](#)
73. Ma, X.; Wu, H.; Liu, L.; Yao, Q.; Wang, S.; Zhan, R. Polyphenolic compounds and antioxidant properties in mango fruits. *Sci. Hort.* **2011**, *129*, 102–107. [\[CrossRef\]](#)
74. Palafox-Carlos, H.; Yahia, E.M.; Gonzalez-Aguilar, G.A. Identification and quantification of major phenolic compounds from mango (*Mangifera indica*, cv. Ataulfo) fruit by HPLC-DAD-MS/MS-ESI and their individual contribution to the antioxidant activity during ripening. *Food Chem.* **2012**, *135*, 105–111. [\[CrossRef\]](#)
75. Liu, F.; Fu, S.; Bi, X.; Chen, F.; Liao, X.; Hu, X.; Wu, J. Physico-Chemical and antioxidant properties of four mango (*Mangifera indica*) cultivars in China. *Food Chem.* **2013**, *138*, 396–405. [\[CrossRef\]](#)
76. Tayel, A.A.; Moussa, S.H.; Salem, M.F.; Mazrou, K.E.; El-Tras, W.F. Control of citrus molds using bioactive coatings incorporated with fungal chitosan/plant extracts composite. *J. Sci. Food Agric.* **2015**, *96*, 1306–1312. [\[CrossRef\]](#)
77. Krasniewska, K.; Gniewosz, M.; Synowiec, A.; Przybyl, J.L.; Baczek, K.; Weglarz, Z. The use of pullulan coating enriched with plant extracts from *Satureja hortensis* L. to maintain pepper and apple quality and safety. *Postharvest Biol. Technol.* **2014**, *90*, 63–72. [\[CrossRef\]](#)
78. Krasniewska, K.; Gniewosz, M.; Synowiec, A.; Przybyl, J.L.; Baczek, K.; Weglarz, Z. The application of pullulan coating enriched with extracts from *Bergenia crassifolia* to control the growth of food microorganisms and improve the quality of peppers and apples. *Food Bioprod. Process.* **2015**, *94*, 422–433. [\[CrossRef\]](#)

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79. Leon-Zapata, M.A.D.; Saenz-Galindo, A.; Rojas-Molina, R.; Rodriguez-Herrera, R.; Jasso-Cantu, D.; Aguilar, C.N. Edible candelilla wax coating with fermented extract of tarbush improves the shelf life and quality of apples. *Food Packag Shelf Life* **2015**, *3*, 70–75. [[CrossRef](#)]
 80. Guerreiro, A.C.; Gago, C.M.; Faleiro, M.L.; Miguel, M.G.; Antunes, M.D. The effect of alginate-based edible coatings enriched with essential oils constituents on *Arbutus unedo* L. fresh fruit storage. *Postharvest Biol. Technol.* **2015**, *100*, 226–233. [[CrossRef](#)]