ACS OMEGA

http://pubs.acs.org/journal/acsodf

Article

Application of Plant-Based Edible Coatings and Extracts Influences the Postharvest Quality and Shelf Life Potential of "Surahi" Guava Fruits

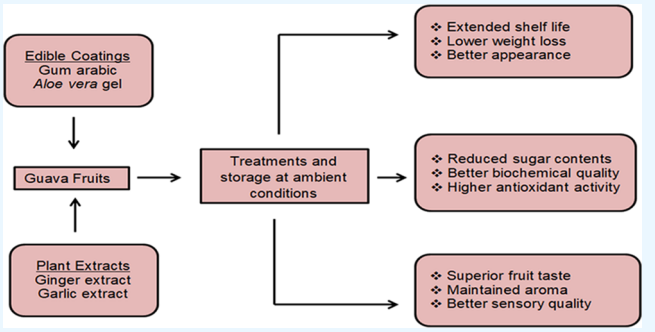
Maryem Zaidi, Arslan Akbar, Sajid Ali, Hira Akram, Sezai Ercisli, Gulce Ilhan, Ebru Sakar, Romina Alina Marc, Duygu Ayvaz Sonmez, Riaz Ullah, Ahmed Bari, and Muhammad Akbar Anjum*

Cite This: *ACS Omega* 2023, 8, 19523−19531

Read Online

ACCESS | Metrics & More | Article Recommendations

ABSTRACT: Guava fruits have a short shelf life due to climacteric nature. The current work was conducted to extend the shelf life of guavas with garlic extract (GRE), ginger extract (GNE), gum arabic (GA), and *Aloe vera* (AV) gel coatings. After coating, fruits of guava were stored at 25 ± 3 °C and RH 85 ± 2% for 15 days. Results showed that guavas treated with plant-based edible coatings and extracts had lower weight loss than that of the control. GRE-treated guavas had the maximum shelf life in contrast to all other treatments including the control. GNE-treated guavas showed the lowest nonreducing sugar content, whereas they had higher antioxidant activity, vitamin C content, and total phenolics compared with all other coating treatments. After the control, antioxidant capacity was the highest in GNE- and GRE-treated fruits. On the other hand, GA-treated guavas had reduced total soluble solids and juice pH (more acidic) and exhibited higher total flavonoids compared with the control, while both GA- and GNE-treated guavas had the highest flavonoid content. GRE-treated fruits exhibited the highest total sugar content and taste and aroma scores. In conclusion, GRE treatment was more effective in conserving the quality and extending the shelf life of guava fruits.



1. INTRODUCTION

The guava fruit is extensively grown in subtropical and tropical areas of the world. It is a rich source of vitamin C. It also possesses medicinal properties and has certain other nutrients considered important for the health of humans.[1−3] However, the harvested guava fruits exhibit fast ripening due to higher respiration and ethylene production rates during postharvest storage.[3] Due to prompt ripening after harvest, it is generally considered difficult to transport guava fruits to long-distance markets and it results in significant losses. Guava fruits can only be stored for about 4−8 days depending upon ambient conditions. Therefore, quick marketing and subsequent consumption of guava fruits are required.[4] Therefore, it is indispensable to find suitable and effective approaches for guava in order to inhibit ripening and to extend the postharvest life of its harvested fruits.

The use of edible coatings for shelf life extension of fruit and vegetable crops has increased much in the recent years. An edible coating acts as a barrier, decreases gas exchange, results in the development of internal modified atmosphere (low O_2 and high CO_2), and reduces loss of water from the treated commodity.[5] Due to the aforementioned beneficial effects, edible coatings are used to conserve the quality and to reduce the mass loss of fruits and vegetables during postharvest storage.[6] Gum arabic (GA) is a plant origin coating. Technically, it is a polysaccharide with film forming ability. GA is considered one of the safe food additives for emulsification, film formation, and encapsulation properties. GA has been used in many fruits and vegetables for storage life extension during postharvest stage.[7] *Aloe vera* (AV) mucilage is also a polysaccharide-based coating. Besides polysaccharides, it also contains certain minerals, vitamins, antioxidants, and sugars. It has the appropriate potential to maintain the quality and has been used to extend the shelf/storage life of fresh horticultural produce.[8,9]

The use of natural products, especially extracts, has took a place as an effective alternate approach for reducing the deterioration and delaying the ripening of harvested fruits and vegetables.[10,11] The extract of *Zingiber officinale* (ginger) is considered to be full of "gingerol." "Gingerol" has antimicrobial

Received: February 12, 2023
Accepted: May 10, 2023
Published: May 23, 2023

properties. In the same way, *Allium sativum* (garlic) is also known for antimicrobial properties. The ginger extract (GNE) has been used on mango, eggplant, papaya, and plantain.[12−14] Similarly, the use of the garlic extract (GRE) has been reported in bananas and mangoes.[15,16] However, the use of GRE and GNE as well as GA and AV gel coatings on guava fruits is still lacking. Therefore, the objective of the current investigation was to explore the effects of GRE and GNE as well as GA and AV gel coatings on shelf life and physicochemical quality of harvested guavas.

2. METHODOLOGY

Physiologically mature green "Surahi" guavas were harvested from a local orchard in the morning around 9.00 a.m. and brought to the laboratory. Fruits were uniform in shape, size, and color and free from injuries, diseases, and bruises. Fruits were thoroughly washed to remove dirt/dust from their surface. After washing, the fruits were placed under a ceiling fan for complete drying for about 5 min, and these dried fruits were used in the experiment. About 3 h elapsed from the time the guavas were harvested until the experiments started. The study was conducted by following completely randomized design under the factorial scheme. There were two factors, i.e., coating treatments and storage times. Each coating treatment had three repeats, and each repeat contained 15 guava fruits. Five different coating treatments, i.e., control, GRE (20%), GNE (20%), AV gel (100%), and GA (10%), were tested in the study. The dipping time of guavas in the treatment solution was 5 min, and the treated fruits were dried at room temperature before storage. After drying, the fruits were kept at 25 ± 3 °C with a relative humidity of 85 ± 2% for a period of 15 days, and the interval of analysis was 3 days. Hence, storage times were 0, 3, 6, 9, 12, and 15 days.

2.1. Preparation of Extracts. *2.1.1. GNE Extract.* Manually peeled ginger rhizomes were sterilized with 70% ethanol. Thereafter, ethanol residues were washed with sterile distilled water, and the sterilized rhizomes were then cut into slices. The resultant slices were then put into a juicer machine (WF-8813, WestPoint, Karachi, Pakistan), and a homogenized paste was obtained. The paste was agitated through a vortex mixer (Orbit 300, Vortexer, Thomas Scientific, New Jersey) for 1−2 min and filtered through a sterilized sheet of muslin cloth.[12] The final GNE concentration was 20%, which was optimized in preliminary work, in which 0, 5, 10, 15, 20, and 25% levels were applied.

2.1.2. GRE Extract. The peeled (manually) garlic cloves were sterilized with 70% ethanol. Afterward, ethanol residues were washed with sterile distilled water, and the sterilized garlic cloves were cut into pieces of small size. The pieces were ground into paste with a juicer machine (WF-8813, WestPoint, Karachi, Pakistan). After grinding, the paste was agitated through a vortex mixer (Orbit 300, Vortexer, Thomas Scientific, New Jersey) for 1−2 min. After agitation, the homogenate of garlic cloves was filtered with a sterilized muslin cloth sheet.[15] Finally, 20% GRE concentration was obtained by using sterile distilled water, which was selected during preliminary work, in which 0, 5, 10, 15, 20, and 25% concentrations were used.

2.2. Preparation of Coatings. *2.2.1. AV Gel Coating.* Fresh leaves of AV were washed with tap water to remove dust/dirt from their surface. The leaves were then sterilized with 2% NaOCl for 3 min to remove microbes. After surface sterilization, leaves were cut in the longitudinal direction and transparent gel was obtained. A total of 1 L of AV gel was collected after 20−30 s of blending in a blender (WF-8813, WestPoint, Karachi, Pakistan). The gel was filtered through a sieve (80 mesh sieve size) to exclude any leaf fraction.[17] The filtration was done two times to ensure the removal of leaf fractions. Finally, the gel was saved in sterilized glass bottles until it was utilized in the experiment with a final concentration of 100%.

2.2.2. GA Coating. The 100 g powder of GA was solubilized in a small amount of sterile distilled water in a 1 L conical flask; the volume was made up to the mark and constantly heated for 1 h at 40 °C with continuous stirring on a magnetic stirrer.[11] After continuous stirring and boiling, the GA solution turned reddish orange, and it was filtered with a muslin cloth. Therefore, 10% (w/v)-concentrated coating was used in the experiment.

2.3. Data Collection. *2.3.1. Shelf Life.* The guava fruit shelf life was assessed on the basis of deterioration. The shelf life was assumed to be ended when 30% of the fruits lost edible quality, became soft, over-ripened, and started rotting. Finally, it was expressed in days.

2.3.2. Physiological Weight Loss (PWL). The PWL was estimated by subtracting the final weight from the initial weight with the formula PWL (%) = $\frac{(W_i - W_f)}{W_f} \times 100$, where W_i = initial fruit weight and W_f = final weight.[18]

2.3.3. Total Soluble Solids. The juice of guava fruits was extracted and thoroughly homogenized on a magnetic stirrer (MS-300HS, Misung Scientific, South Korea) for 3 min in a beaker. Then, total soluble solids were determined with a hand refractometer (ATAGO) and expressed as °Brix. The same juice was also used for pH and titratable acidity determination.[19]

2.3.4. Titratable Acidity. It was determined from the fruit juice. The juice was titrated against 0.1 N NaOH as reported by Hortwitz[20] and expressed as percent.

2.3.5. Juice pH. Juice pH was assayed with a digital pH meter (Milwaukee Mi 180) at room temperature.[19]

2.3.6. Antioxidant Activity and Antioxidant Capacity. Antioxidant activity and antioxidant capacity were assayed with the protocol of Shimada et al.[21] Concisely, 0.1 mmol L^{-1} DPPH solution was made in MeOH and 1 mL of this solution was collected and guava samples (4 mL) were mixed with it. Then, mixtures of the samples were strongly shaken and left in the dark for 15 min. Lastly, antioxidant activity and capacity were computed after taking absorbance at 571 nm.

2.3.7. Sugar Content. Sugars including nonreducing, reducing, and total sugars in guava fruit juice were assayed with the method of Hortwitz[20] and expressed as percent.

2.3.8. Vitamin C Content. The vitamin C content in guava fruit juice was assayed with the protocol of Ali et al.[19] In brief, 10 mL of juice was taken in a flask and the volume was made 100 mL with 0.4% oxalic acid. An aliquot (5 mL) was collected, and titration was performed with 2,6-dichloroindophenol. Finally, the vitamin C content was derived as mg 100 g^{-1} FW.

2.3.9. Total Flavonoid Content. The total flavonoid content was analyzed by following the assay of ethanolic extraction. Briefly, 1 mL of the extract was reacted with 300 μL of $NaNO_2$ and 4 mL of deionized water and left for 5 min. Later, 300 μL of $AlCl_3$ was incorporated in 2 mL of 1 mol NaOH. Finally, optical density was noted at 510 nm and derived on the basis of quercetin equivalents as mg QE 100 g^{-1} FW.[22]

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

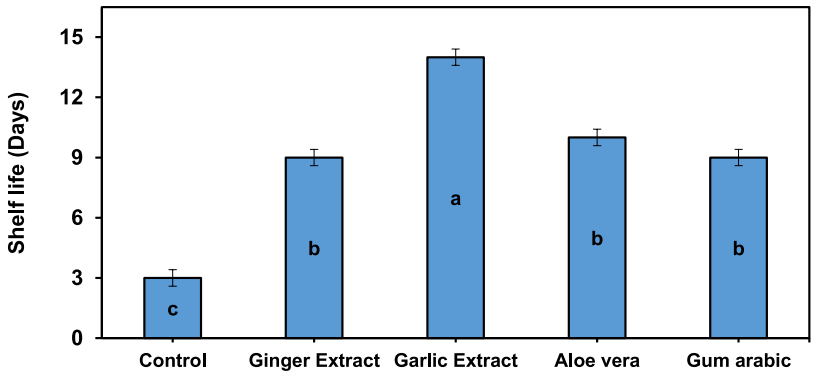


Figure 1. Effect of coating treatments on the shelf life of guava fruits. Vertical bars indicate the standard error of the means. Values are the mean of three replications. LSD ($P \leq 0.05$) value for shelf life: 3.151.

Table 1. Effect of Treatments and Storage Periods on Physiological Weight Loss and Biochemical Attributes of Guava Fruits[a]

treatments (T)	PWL (%)	TSS (°Brix)	TA (%)	juice pH	antioxidant activity (%)	antioxidant capacity (mM Trolox/100 mL)
control	37.41 a	11.250 a	1.2362 a	3.98 bc	96.82 a	85.14 a
ginger extract	32.28 b	11.306 a	1.2651 a	3.98 bc	95.89 ab	83.60 ab
garlic extract	32.50 b	11.556 a	1.3197 a	4.03 a	95.60 b	83.26 ab
A. vera gel	32.82 b	11.528 a	1.1988 a	3.99 b	95.46 b	82.56 b
gum arabic	32.33 b	10.833 b	1.1752 a	3.96 c	94.82 b	81.63 b
LSD ($P \leq 0.05$)	1.935	0.3601	NS	0.027	1.128	2.069
days (D)						
0		9.667 e	1.9983 a	3.83 c	96.43 ab	84.06 a
3	15.78 e	10.167 d	1.3476 b	3.92 b	96.94 a	85.09 a
6	25.38 d	11.067 c	1.2565 bc	4.06 a	95.23 bc	83.29 a
9	34.10 c	11.933 b	1.2139 c	4.03 a	95.58 b	83.90 a
12	42.53 b	12.333 a	0.7429 e	4.04 a	94.20 c	79.51 a
15	49.56 a	12.600a	0.8747 d	4.04 a	95.93 ab	83.58 a
LSD ($P \leq 0.05$)	1.935	0.3945	0.1229	0.029	1.236	NS
$T \times D$ ($P \leq 0.05$)	NS	0.8820	0.2749	0.067	NS	NS

[a]Means sharing different letter(s) in columns are statistically significant at $P \leq 0.05$ (LSD test). PWL = physiological weight loss, TSS = total soluble solids, TA = titratable acidity, and NS = not significant.

2.3.10. Total Phenolic Content. Total phenolic contents were analyzed by using the assay of Kaushik et al.[23] Blue color was developed with the FC reagent in 20% sodium carbonate; optical density was noted at 750 nm, and the phenolic concentration was expressed as μg GAE g^{-1} FW.

2.3.11. Sensory Quality. Aroma and taste were evaluated on a hedonic scale as proposed by Ali et al.[19] The scale was 9 = like extremely, 5 = neither like nor dislike, and 1 = dislike extremely. There were four persons in the sensory panel; all these were graduate students and were kept blind to the treatments. During the taste evaluation, black tea was served to the panelists between each two samples.

2.4. Data Analysis. Data were processed with analysis of variance (ANOVA). The means of treatment were differentiated with the least significance difference (LSD) test, if the overall treatment effect (F-test) was significant at $P < 0.05$ in the ANOVA. Data are presented in either tabulated or graphical forms. Main effects of coating treatments and storage days are presented in tables, and where the interaction of these two factors was significant, graphs are prepared.

3. RESULTS AND DISCUSSION

3.1. Shelf Life. The effect of different treatments was significant on the shelf life (Figure 1). On an average, the lowest shelf life was noted in the nontreated control, while all treated guava groups had a higher shelf life than that of the control. The maximum shelf life of fruits was noted in the GRE-treated group followed by GNE-, GA-, and AV gel-coated guavas, which were statistically at par with each other (Figure 1). Shelf life is an important indicator of quality in fresh fruits and vegetables.[25] A longer shelf life is critical for storage and marketing of the fruits. The use of plant extract treatments and edible coatings lessens water loss and may have antimicrobial/antifungal properties and thus prolongs the shelf life of a treated commodity with maintained quality.[25,26] Therefore, the shelf life of the treated guavas was enhanced due to the used treatment-based protective effect against deterioration and coating-induced reduction of desiccation.

3.2. PWL of Fruits. The effect of different coating treatments and periods of storage was significant on the PWL. However, their interaction effect was nonsignificant. PWL was significantly greater for the control fruits compared to that of any of the treatments (Table 1). As far as days of storage are concerned, minimum PWL was noted on the 3rd day and the maximum was found on the 15th day of storage period (Table 1). On the whole, PWL was increased with increased period of storage. All of the coating treatments resulted in only modest reductions in PWL throughout the duration of storage. Loss of weight in fruits and vegetables occurs due to desiccation during postharvest.[19] Appropriate treatments which reduce desiccation are practiced worldwide to avoid weight loss of fresh produce. Application of edible

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

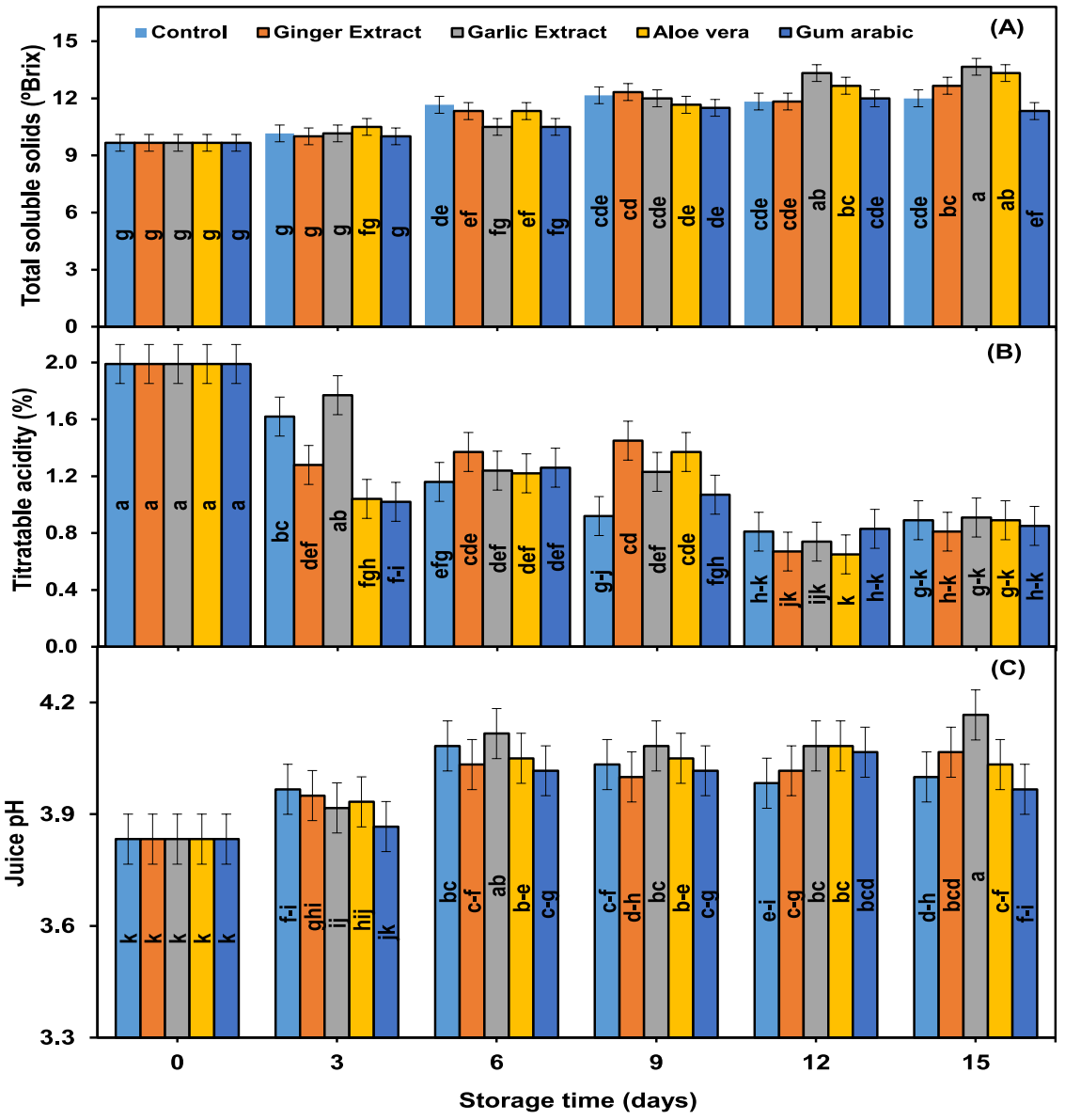


Figure 2. Effect of coating treatments and storage periods on total soluble solids (A), titratable acidity (B), and juice pH (C) of guava fruits. Vertical bars indicate the standard error of the means. Values are the mean of three replications.

coatings and plant extracts reduces weight loss due to inhibition of desiccation.[24] Reduced weight loss was also observed in GRE-treated eggplant[13] as well as GA-treated mango[11] and AV gel-coated litchi fruits.[17]

3.3. Total Soluble Solids. Different storage periods, treatments, and interactions of both these factors had substantial impact on total soluble solids (Table 1). All the fruits had higher total soluble solids, except those coated with GA. The total soluble solid concentration of guavas increased with progressing time of storage (Table 1). The increase was found to be substantially higher in the nontreated control compared with the GNE-, GA-, GRE-, and AV gel-coated guavas. Overall, GRE-treated fruits had the highest total soluble solids on the 12th and 15th days, while GA-coated guavas had the lowest concentration of total soluble solids on the 15th day of storage compared to other treated fruits (Figure 2A). Total soluble solids increase with maturation and senescence of fruits.[19,26] The increase possibly also occurs due to conversion of starch material into sugars.[27] Hence, in our case, GA treatment decreased the increase in total soluble solids probably owing to delayed senescence and reduced increase of sugars in the treated guava fruits.

3.4. Titratable Acidity. Different storage periods and their interaction with treatments had a significant influence on titratable acidity. However, coating treatments have no effect on the parameter. Titratable acidity of guava fruits decreased with progressing time of storage till day 12, and then, it increased (Table 1). Overall, the lowest concentrations of titratable acidity were observed on day 12 in all the treatments (Figure 2B). Acidity of fruits decreases due to advanced maturation and organic acid oxidation.[17] Application of different treatments such as plant extracts and edible coatings reduces organic acid oxidation and maintains higher acidity of the treated fruits.[26] Therefore, acidity of the treated guava fruits was decreased at a lower rate due to lower organic acid oxidation.

3.5. Juice pH. Effects of treatments, periods of storage, and their interaction were significant on pH of juice. The highest

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

Table 2. Effect of Treatments and Storage Periods on the Physiological Sugar Contents of Guava Fruits[a]

treatments (T)	reducing sugars(%)	nonreducing sugars (%)	total sugars (%)	vitamin C (mg 100 g^{-1} FW)	total flavonoids (mg QE g^{-1} FW)	total phenolics (μg GAE g^{-1} FW)
control	3.38 b	1.26 b	4.71 b	148.05 ab	484.64 b	42.33 c
ginger extract	3.54 a	1.22 b	4.82 b	153.72 a	573.92 a	116.61 a
garlic extract	3.48 ab	1.66 a	5.22 a	139.93 cd	473.80 b	108.58 b
A. vera gel	3.17 c	1.67 a	4.88 b	144.54 bc	439.67 b	101.59 b
gum arabic	3.14 c	1.70 a	4.91 b	136.15 d	583.72 a	101.11 b
LSD ($P \leq 0.05$)	0.159	0.270	0.207	6.7931	59.295	7.5773
days (D)						
0	2.73 d	1.43 c	4.20 d	177.36 a	330.97 d	40.62 d
3	3.52 ab	1.01 d	4.57 c	156.61 b	428.01 c	109.76 b
6	3.60 a	1.16 cd	4.78 c	148.46 c	664.27 a	107.11 b
9	3.67 a	1.40 c	5.16 b	131.69 d	605.15 ab	130.44 a
12	3.40 b	1.81 b	5.32 ab	124.76 d	591.46 b	103.71 b
15	3.14 c	2.18 a	5.44 a	128.00 d	447.05 c	72.62 c
LSD ($P \leq 0.05$)	0.174	0.296	0.226	7.4415	64.954	8.3006
$T \times D$ ($P \leq 0.05$)	NS	NS	NS	16.640	145.24	18.561

[a]Means sharing different letter(s) in columns are statistically significant at $P \leq 0.05$ (LSD test). NS = not significant.

juice pH was observed in GRE-treated guavas compared with GNE-, GA-, and AV gel-coated fruits. Juice pH increased till day 6, and then, it became almost stable (Table 1). Overall, GA-treated guavas exhibited the lowest (more acidic) juice pH from the 3rd to the 15th day of storage as compared with the control and AV gel-, GNE-, and GRE-treated fruits (Figure 2C). It has been found that juice pH generally increases due to prolonged storage and advanced maturation of fruits.[28] Overall, during long-term periods of storage, organic acid concentration decreases and pH of juice increases.[29] Therefore, juice pH of GRE-treated fruits and other treatments was increased at a lower rate probably owing to the reduced organic acid concentration reduction and delayed senescence of guavas.

3.6. Antioxidant Activity and Antioxidant Capacity. Different storage periods and treatments had significant impact on antioxidant activity. However, the interaction of these two factors was nonsignificant (Table 1). Overall, greater antioxidant activity was observed in control fruits, followed by GNE-treated guavas. In the case of storage days, antioxidant activity was decreased from the 3rd day to the 12th day but increased on the 15th day of storage (Table 1).

Antioxidant capacity was significantly affected by application of different coating treatments, but statistically, the effects of storage days and interaction of these two factors were nonsignificant. Overall, the highest antioxidant capacity of guavas was noted in the nontreated control. Among the treated ones, GNE- and GRE-treated fruits had higher antioxidant capacity compared with GA- and AV-coated guavas (Table 1).

It has been reported that phenolic, ascorbic acid, and flavonoid contents contribute to the antioxidative activity and antioxidative capacity of fruit crops.[30] Reduction of the above-said bioactive contents results in the decline of antioxidative activity and capacity.[31] As application of the GNE and GRE as well as GA and AV coatings inhibited the decline of phenolic, ascorbic acid, and flavonoid contents, antioxidative activity and capacity were maintained in the treated guavas.

3.7. Sugar Content. Application of different treatments and storage intervals significantly affected the concentrations of reducing, nonreducing, and total sugars of guava fruits. However, interactive effects were nonsignificant (Table 2). Overall, the highest level of reducing sugars was noted in GNE- and GRE-treated fruits, whereas the lowest was observed in GA- and AV gel-coated guavas (Table 2). In the case of nonreducing sugar contents, they were found maximum in GA-, AV gel-, and GRE-coated guavas and the minimum concentration of these sugars was noted in GNE-treated and untreated fruits (control). Total sugars were found the highest in GRE-applied guavas as compared to all other coating treatments, which were statistically at par (Table 2). The lowest content of reducing sugars was on day 0, which increased till the 9th day and then decreased till the 15th day of storage (Table 2). On the other hand, the concentration of nonreducing sugars was the lowest on the 3rd day and the highest was noted on the 15th day of storage (Table 2). The total sugar content was the lowest at the time of initiation of the experiment (day 0) and then progressively increased with the passage of time, being maximum on the 15th day of storage (Table 2). Sugar concentration increases due to increased metabolic activity and conversion of the starch into sugars with the passage of time. Application of certain coatings or plant extracts has the ability to suppress starch conversion into sugars.[32,33] Similar with our results, a reduced increase of sugars was also found in GA-coated bell peppers[33] and GRE-treated ripe banana fruits.[15]

3.8. Vitamin C Content. Different storage periods, treatments, and the interaction of both these factors exhibited significant influence on the vitamin C content (Table 2). The vitamin C content of guava fruits decreased in all coating treatments as compared to the control, except in GNE-treated guavas. However, the highest decline was observed in GA-coated guavas compared to all other coating treatments. The vitamin C content decreased till the 9th day of storage and then became almost stable (Table 2). The vitamin C content decreased in all the treatments with the passage of storage time; however, the magnitude was variable. The lowest concentration of vitamin C was noted in GA-coated guavas from the 6th day of storage to the end of the experiment (15th day) as compared with the control and other treatments. Overall, GNE-treated guavas had the highest vitamin C on the 15th day of storage, followed by AV gel-coated fruits (Figure 3A). Oxidation reduces vitamin C in fruits.[34] Coating

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

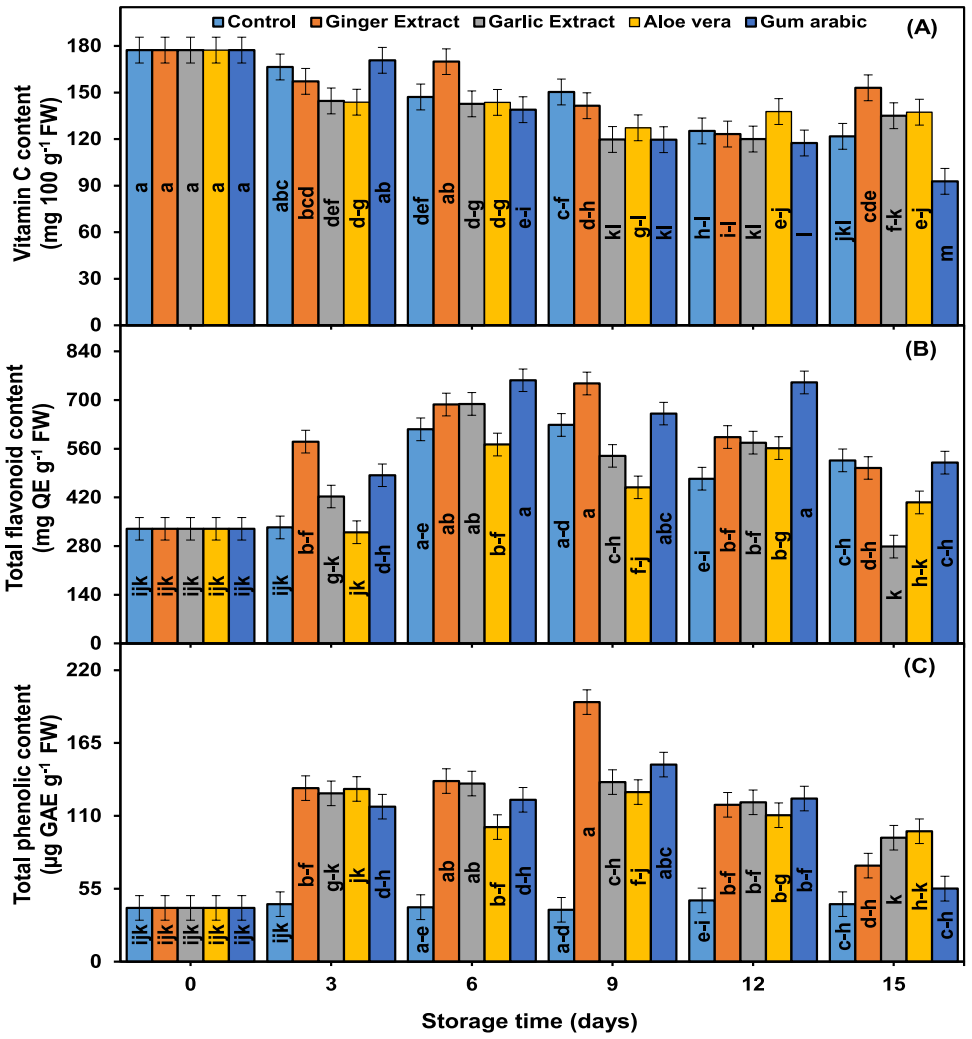


Figure 3. Effect of coating treatments and storage periods on the vitamin c content (A), total flavonoid content (B), and total phenolic content (C) of guava fruits. Vertical bars indicate the standard error of the means. Values are the mean of three replications.

treatment reduces vitamin C degradation owing to suppressed reactions of oxidation.[8] In a previous study, it was observed that GNE and GRE application also reduced vitamin C degradation.[35] Therefore, the vitamin C content was maintained higher probably owing to the lower oxidation reactions in GNE-treated guava fruits.

3.9. Total Flavonoid Content. Effects of treatments, storage days, and their interactions were significant on the total flavonoids of treated guavas (Table 2). GNE- and GA-coated guavas had the highest flavonoid content as compared to controls and AV gel and GRE-coated fruits. Total flavonoids presented a continuous increase up to the 6th day of storage and exhibited a gradual decrease thereafter from the 9th to the 15th day of storage (Table 2). On the 3rd and 9th days of storage, the highest total flavonoid content was noted in GNE-coated guavas in contrast to controls and other treatments. However, on the 6th and 12th days, the concentration of the total flavonoid content was significantly higher in GA-coated guavas compared with the control (Figure 3B).

Overall, GA and GNE coatings performed significantly better in the conservation of the total flavonoid content than the control in the current study. Flavonoids are important antioxidants in guava fruits.[35,36] Plant extract and edible coating treatment application delays degradation-based loss of flavonoids and maintains their higher concentration in fruits.[3,36]

3.10. Total Phenolic Content. Different treatments, storage times, and their interactions revealed significant impact on total phenolics (Table 2). The total phenolic content was considerably higher in GNE-treated guava fruits than GRE-, AV gel-, and GA-coated fruits and control. A significantly lower phenolic content was determined in untreated fruits (control). The total phenolic content was enhanced till the 9th day and thereafter decreased gradually up to the 15th day of storage (Table 2). The total phenolic content fluctuated among the treatments with the passage of storage time. However, it was the highest in GNE-treated guavas on the 9th day of storage. On the other hand, the control had the lowest total phenolic content throughout the storage (Figure 3C).

The total phenolic content usually decreases with increased fruit maturity and senescence. However, oxidation of phenolics is the leading cause of their reduction under storage.[17] The use of plant extracts and edible coatings may reduce the extent of oxidation and conserve a higher total phenolic content under storage.[26] Therefore, in the current study, the total phenolic content concentration of guavas was possibly reduced at a lower rate in treated fruits owing to less oxidation.

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

3.11. Sensory Quality. Different storage periods, treatments, and interactions of both these factors had a significant influence on the taste and aroma of guavas (Table 3). Overall,

Table 3. Effect of Treatments and Storage Periods on the Sensory Quality of Guava Fruits[a]

treatments (T)	taste	aroma
control	3.5000 d	3.6667 e
ginger extract	6.3889 b	5.8889 c
garlic extract	6.5556 a	7.1667 a
A. vera gel	5.8333 c	6.1111 b
gum arabic	5.7222 c	5.5000 d
LSD ($P \leq 0.05$)	0.1572	0.1217
days (D)		
0	4.0000 e	5.0000 d
3	5.6000 d	6.6000 a
6	6.8000 b	6.6000 a
9	7.2667 a	6.4000 b
12	5.8667 c	5.4667 c
15	4.0667 e	3.9333 e
LSD ($P \leq 0.05$)	0.1722	0.1334
$T \times D$ ($P \leq 0.05$)	0.3850	0.2982

[a]Means sharing different letter(s) in columns are statistically significant at $P \leq 0.05$ (LSD test).

GA and AV gel coatings were not much effective in conserving the taste of the treated guava fruits, but their effect was markedly higher in contrast with the control. The taste score was enhanced up to the 9th day and decreased later up to the 15th day of storage (Table 3). On the 3rd and 6th days, the taste score was the highest in GNE extract-treated guavas compared with the control. However, from the 9th to the 15th day, taste was found the highest in GRE extract-treated guavas than control fruits (Figure 4A).

In the case of aroma, on the whole, the highest rating was noted in GRE-treated guavas. Aroma increased till the 3rd day, remained stable till the 6th day, and later declined from the 9th to the 15th day of storage (Table 3). The score of aroma in GNE-treated guava fruits was significantly higher on the 3rd day of storage as compared to other treatments and became at par with GRE-treated fruits on the 6th day of storage. Nevertheless, from the 9th to the 15th day, the aroma score was substantially higher in GRE extract-treated guavas compared with GNE, AV gel, GA, and control treatments (Figure 4B).

Aroma and taste are imperative sensory-related attributes of fruits. Loss of taste and aroma occurs due to advanced senescence of produce.[37,38] The application of plant extract and coating treatments inhibits senescence as well as leads to higher conservation of taste and aroma of fruits during storage.[37,39] Therefore, different extracts and coatings conserved higher taste and aroma ratings of fruits due to delay in the senescence of guava. In the current study, among the coating treatments, GRE proved to be better at conserving the taste and aroma of guava fruits.

4. CONCLUSIONS

GRE extract application showed the maintained physicochemical quality and extended shelf life of guava fruits. In addition, GNE and GA treatments also conserved nutraceutical compounds. On the other hand, the AV gel coating was less effective than GRE, GNE, and GA treatments. Therefore, plant-based edible coatings and extracts could be used for quality conservation and extending the shelf life of guava fruits.

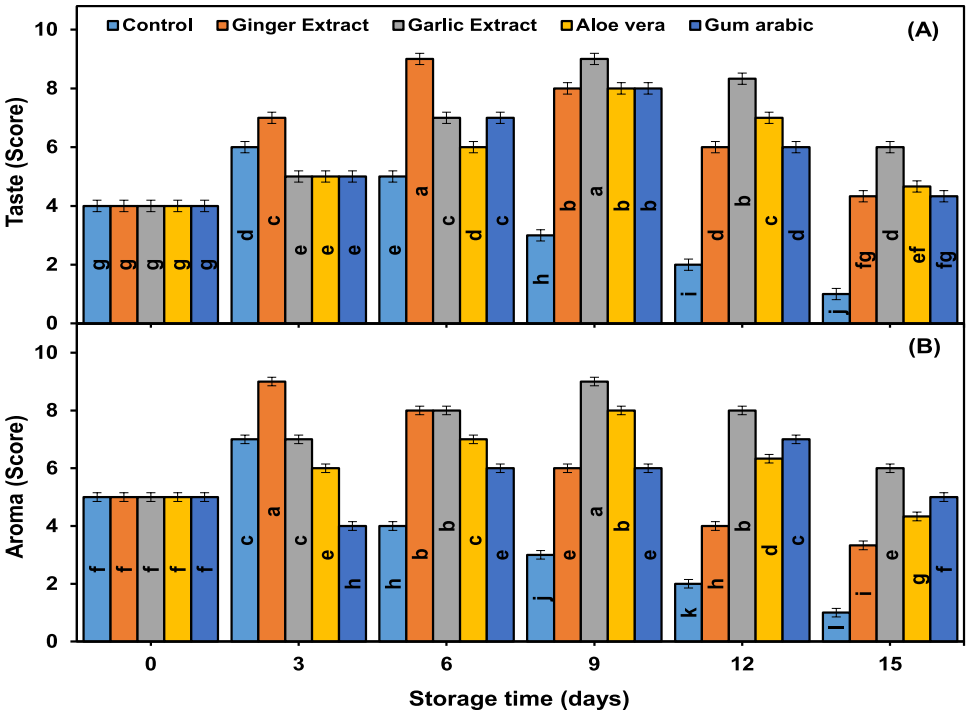


Figure 4. Effect of coating treatments and storage periods on the taste (A) and aroma (B) of guava fruits. Vertical bars indicate the standard error of the means. Values are the mean of three replications.

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531

■ ASSOCIATED CONTENT

Data Availability Statement

All associated data are available in the article. Additional information will be made available upon reasonable request from the corresponding author.

■ AUTHOR INFORMATION

Corresponding Author

Muhammad Akbar Anjum − *Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, 60800 Multan, Pakistan;* orcid.org/0000-0003-3483-345X; Email: akbaranjum@bzu.edu.pk

Authors

Maryem Zaidi − *Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, 60800 Multan, Pakistan*

Arslan Akbar − *Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, 60800 Multan, Pakistan*

Sajid Ali − *Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, 60800 Multan, Pakistan*

Hira Akram − *Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, 60800 Multan, Pakistan*

Sezai Ercisli − *Department of Horticulture, Agricultural Faculty, Ataturk University, 25240 Erzurum, Türkiye; HGF Agro, Ata Teknokent, Erzurum TR-25240, Türkiye*

Gulce Ilhan − *Department of Horticulture, Agricultural Faculty, Ataturk University, 25240 Erzurum, Türkiye*

Ebru Sakar − *Department of Horticulture, Faculty of Agriculture, Harran University, 63290 Şanlıurfa, Türkiye*

Romina Alina Marc − *Food Engineering Department, Faculty of Food Science and Technology, University of Agricultural Sciences and Veterinary Medicine, 400372 Cluj-Napoca, Romania;* orcid.org/0000-0002-6409-6019

Duygu Ayvaz Sonmez − *Yaltır Agricultural Products Inc., 01355 Adana, Türkiye*

Riaz Ullah − *Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia;* orcid.org/0000-0002-2860-467X

Ahmed Bari − *Department of Pharmaceutical Chemistry, College of Pharmacy, King Saud University, Riyadh 11451, Saudi Arabia*

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.3c00930

Author Contributions

M.A.A.: conceptualization, writing, review, and editing; M.Z.: methodology, data curation, formal analysis, and investigation; S.A. and A.A.: writing, original draft preparation, writing, review, and editing; H.A., S.E., G.I., E.S., R.A.M., R.U., and A.B.: writing, review, and editing; S.E., G.I., and E.S.: visualization; and D.A.S., R.A.M., R.U., and A.B.: project administration and funding acquisition.

Funding

The research work was supported by researchers supporting project Number (RSP2023R110) King Saud University, Riyadh, Saudi Arabia.

Notes

The authors declare no competing financial interest.

All authors have read and agreed to publish the article.

■ ACKNOWLEDGMENTS

Authors wish to thanks researchers supporting project Number (RSP2023R110) King Saud University Riyadh Saudi Arabia for financial support. The authors are also thankful to the Department of Horticulture, B.Z. University, Multan, for the technical support and facilities during the conduct of this work.

■ ABBREVIATIONS

AV *Aloe vera*
GA gum arabic
GNE ginger extract
GRE garlic extract
PWL physiological weight loss
FW fresh weight
DPPH 2,2-diphenyl-1-picrylhydrazyl
MeOH methanol
QE quercetin equivalent
GAE gallic acid equivalent

■ REFERENCES

(1) Sanda, K. A.; Grema, H. A.; Geidam, Y.; Bukar-Kolo, Y. M. Pharmacological aspects of *Psidium guajava*: An update. *Int. J. Pharmacol.* **2011**, *7*, 316−324.

(2) Hong, K.; Xie, J.; Zhang, L.; Sun, D.; Gong, D. Effects of chitosan coating on postharvest life and quality of guava (*Psidium guajava* L.) fruit during cold storage. *Sci. Hortic.* **2012**, *144*, 172−178.

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

(4) Mohamed, H.; Alamri, S. The biocontrol of postharvest disease (*Botryodiplodia theobromae*) of guava (*Psidium guajava* L.) by the application of yeast strains. *Postharvest Biol. Technol.* **2009**, *53*, 123−130.

(5) Baldwin, E. A.; Burns, J. K.; Kazokas, W.; Brecht, J. K.; Hagenmaier, R. D.; Bender, R. J.; Pesis, E. Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. *Postharvest Biol. Technol.* **1999**, *17*, 215−226.

(6) Campos, C. A.; Gerschenson, L. N.; Flores, S. K. Development of edible films and coatings with antimicrobial activity. *Food Bioprocess Technol.* **2011**, *4*, 849−875.

(7) Tahir, H. E.; Xiaobo, Z.; Mahunu, G. K.; Arslan, M.; Abdalhai, M.; Zhihua, L. Recent developments in gum edible coating applications for fruits and vegetables preservation: A review. *Carbohydr. Polym.* **2019**, *224*, No. 115141.

(8) Rasouli, M.; Saba, M. K.; Ramezanian, A. Inhibitory effect of salicylic acid and *Aloe vera* gel edible coating on microbial load and chilling injury of orange fruit. *Sci. Hortic.* **2019**, *247*, 27−34.

(9) Khatri, D.; Panigrahi, J.; Prajapati, A.; Bariya, H. Attributes of *Aloe vera* gel and chitosan treatments on the quality and biochemical traits of post-harvest tomatoes. *Sci. Hortic.* **2020**, *259*, No. 108837.

(10) Tripathi, P.; Dubey, N. K. Exploitation of natural products as an alternative strategy to control postharvest fungal rotting of fruit and vegetables. *Postharvest Biol. Technol.* **2004**, *32*, 235−245.

(11) Khaliq, G.; Mohamed, M. T. M.; Ghazali, H. M.; Ding, P.; Ali, A. Influence of gum arabic coating enriched with calcium chloride on physiological, biochemical and quality responses of mango (*Mangifera indica* L.) fruit stored under low temperature stress. *Postharvest Biol. Technol.* **2016**, *111*, 362−369.

(12) Adams, A. A.; Salifu, A. W.; Chonga, J.; Bayuo, T. Effect of ginger extracts and storage temperature on shelf life of Kent mango fruits. *J. Postharvest Technol. Innov.* **2016**, *4*, 75−82.

(13) Ogbuehi, H. C.; Emeribe, E. O.; Asagwara, J. O. Potential of ginger (*Zingiber officinale*) extracts on shelf life of eggplant (*Solanum melogena* L.). *Int. J. Appl. Pure Sci. Agric.* **2016**, *2*, 171−178.
(14) Ali, A.; Hei, G. K.; Keat, Y. W. Efficacy of ginger oil and extract combined with gum Arabic on anthracnose and quality of papaya fruit during cold storage. *Int. J. Food Sci. Technol.* **2016**, *53*, 1435−1444.
(15) Sanwal, G. G.; Payasi, A. Garlic extract plus sodium metabisulphite enhances shelf life of ripe banana fruit. *Int. J. Food Sci. Technol.* **2007**, *42*, 303−311.
(16) Ashwini, M.; Desai, N. Biopreservative effect of plant extracts on the shelf life of mango cv Raspuri. *J. Pharmacogn. Phytochem.* **2018**, *7*, 2245−2248.
(17) Ali, S.; Khan, A. S.; Nawaz, A.; Anjum, M. A.; Naz, S.; Ejaz, S.; Hussain, S. *Aloe vera* gel coating delays postharvest browning and maintains quality of harvested litchi fruit. *Postharvest Biol. Technol.* **2019**, *157*, No. 110960.
(18) Ali, S.; Khan, A. S.; Malik, A. U. Postharvest L-cysteine application delayed pericarp browning, suppressed lipid peroxidation and maintained antioxidative activities of litchi fruit. *Postharvest Biol. Technol.* **2016**, *121*, 135−142.
(19) Ali, S.; Khan, A. S.; Malik, A. U.; Shahid, M. Effect of controlled atmosphere storage on pericarp browning, bioactive compounds and antioxidant enzymes of litchi fruits. *Food Chem.* **2016**, *206*, 18−29.
(20) Hortwitz, W. *Official and Tentative Methods of Analysis.*; Association of Official Analytical Chemists: Washington DC, USA, 1960; pp 314−320.
(21) Shimada, K.; Fujikawa, K.; Yahara, K.; Nakamura, T. Antioxidative properties of xanthan on the autoxidation of soybean oil in cyclodextrin emulsion. *J. Agric. Food Chem.* **1992**, *40*, 945−948.
(22) Kaushik, N.; Srinivasa, R. P.; Mishra, H. N. Process optimization for thermal-assisted high-pressure processing of mango (*Mangifera indica* L.) pulp using response surface methodology. *LWT–Food Sci. Technol.* **2016**, *69*, 372−381.
(23) Kaushik, N.; Kaur, B. P.; Rao, P. S.; Mishra, H. N. Effect of high pressure processing on color, biochemical and microbiological characteristics of mango pulp (*Mangifera indica* cv. Amrapali). *Innov. Food Sci. Emerg. Technol.* **2014**, *22*, 40−50.
(24) Fan, X. J.; Zhang, B.; Yan, H.; Feng, J. T.; Ma, Z. Q.; Zhang, X. Effect of lotus leaf extract incorporated composite coating on the postharvest quality of fresh goji (*Lycium barbarum* L.) fruit. *Postharvest Biol. Technol.* **2019**, *148*, 132−140.
(25) Ali, A.; Maqbool, M.; Ramachandran, S.; Alderson, P. G. Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biol. Technol.* **2010**, *58*, 42−47.
(26) de Jesús Salas-Méndez, E.; Vicente, A.; Pinheiro, A. C.; Ballesteros, L. F.; Silva, P.; Rodríguez-García, R.; et al. Application of edible nanolaminate coatings with antimicrobial extract of *Flourensia cernua* to extend the shelf-life of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biol. Technol.* **2019**, *150*, 19−27.
(27) Pandey, S. K.; Joshua, J. E. Influence of gamma-irradiation, growth retardants and coatings on the shelf life of winter guava fruits (*Psidium guajava* L.). *J. Food Sci. Technol.* **2010**, *47*, 124−127.
(28) Fernández-Ruiz, V.; Sánchez-Mata, M. C.; Cámara, M.; Torija, M. E.; Chaya, C.; Galiana-Balaguer, L.; Roselló, S.; Nuez, F. Internal quality characterization of fresh tomato fruits. *HortScience* **2004**, *39*, 339−345.
(29) Machado, F. L. C.; Cajazeira, J. P.; da Costa, J. M. C. Color change and quality response of 'Lane late' orange submitted to degreening process. *Eng. Agríc.* **2015**, *35*, 144−153.
(30) Shahnawaz, M.; Sheikh, S. A.; Bhangar, M. I.; Ahmed, E. Total phenolic compounds and antioxidant activity of jamun fruit (*Eugenia jambolana*) products. *Pak. J. Food Sci.* **2010**, *20*, 31−41.
(31) Maqbool, M.; Ali, A.; Alderson, P. G.; Mohamed, M. T. M.; Siddiqui, Y.; Zahid, N. Postharvest application of gum arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage. *Postharvest Biol. Technol.* **2011**, *62*, 71−76.
(32) Gupta, N.; Jain, S. K. Storage behavior of mango as affected by post-harvest application of plant extracts and storage conditions. *J. Food Sci. Technol.* **2014**, *51*, 2499−2507.
(33) Ullah, A.; Abbasi, N. A.; Shafique, M.; Qureshi, A. A. Influence of edible coatings on biochemical fruit quality and storage life of bell pepper cv. "Yolo Wonder". *J. Food Qual.* **2017**, *3*, No. 2142409.
(34) Lee, S. K.; Kader, A. A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **2000**, *20*, 207−220.
(35) Anjum, M. A.; Akram, H.; Zaidi, M.; Ali, S. Effect of gum arabic and *Aloe vera* gel based edible coatings in combination with plant extracts on postharvest quality and storability of 'Gola' guava fruits. *Sci. Hortic.* **2020**, *271*, No. 109506.
(36) Kumar, A.; Singh, O.; Kohli, K. Post-harvest changes in functional and sensory properties of guava (*Psidium guajava* L. cv. Pant Prabhat) fruits as influenced by different edible coating treatments. *J. Pharmacogn. Phytochem.* **2017**, *6*, 1109−1116.
(37) Khaliq, G.; Ramzan, M.; Baloch, A. H. Effect of *Aloe vera* gel coating enriched with *Fagonia indica* plant extract on physicochemical and antioxidant activity of sapodilla fruit during postharvest storage. *Food Chem.* **2019**, *286*, 346−353.
(38) Chen, H.; Sun, Z.; Yang, H. Effect of carnauba wax-based coating containing glycerol monolaurate on the quality maintenance and shelf-life of Indian jujube (*Zizyphus mauritiana* Lamk.) fruit during storage. *Sci. Hortic.* **2019**, *244*, 157−164.
(39) Radi, M.; Firouzi, E.; Akhavan, H.; Amiri, S. Effect of gelatin-based edible coatings incorporated with *Aloe vera* and black and green tea extracts on the shelf life of fresh-cut oranges. *J Food Qual.* **2017**, *2017*, No. 9764650.

https://doi.org/10.1021/acsomega.3c00930
ACS Omega 2023, 8, 19523−19531