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Lead Guest Editor: Amparo L. Rubio
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Editorial Board

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Editorial

Biopolymer-Based Coatings and Packaging Structures for Improved Food Quality

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Biopolymers, that is, polymers derived from bio-based resources, have a central role in keeping or improving food quality. They have mainly been used as structuring or texturizing agents in food, but their potential as edible coatings for increasing postharvest shelf-life of fresh produce and as bio-based packaging structures for substituting petroleum-based polymers is gaining importance. Therefore, the aim of the present special issue was to compile recent developments in these two areas. A substantial number of papers were submitted, highlighting the research interest in these topics and, after a thorough peer review process, four papers were selected to be included in this special issue. Three of them show recent advances in the development of edible coatings for improving postharvest quality of fresh fruits and vegetables, while the other research work deals with the development of a bio-based structure for food packaging applications.

The manuscript of A. Ullah and coworkers reports about the evaluation of three different edible coatings for enhancing quality during storage of the vegetable bell pepper. Their results show that Gum Arabic has an excellent potential as an edible coating for the studied cultivar, as it significantly reduced weight loss, membrane leakage, chilling injury, and decay incidence, without affecting the visual appearance in terms of colour of the fruit.

Another gum with potential as an edible coating is guar gum, as shown in the paper of X. Ruelas-Chacon and coworkers. They evaluated plasticized guar gum coatings on the postharvest and sensorial quality of Roma tomatoes stored at 22°C. Interestingly, it was found that, apart from improving firmness, reducing weight loss, and delaying several decay parameters, the application of guar gum positively affected the sensorial properties of the tomatoes as demonstrated by the results from a trained panel.

The research work of S. Gunaydin and collaborators deals with the development of active composite edible coatings for improving postharvest quality of plums during cold storage. The strategy in this case was to combine hydroxypropyl methylcellulose (HPMC) as the structuring agent of the coating with a beeswax that provided hydrophobicity, thus reducing weight loss and incorporating three different antifungal agents with proven activity. The stability and applicability of the emulsion coatings were improved through the addition of stearic acid and glycerol, respectively. Important quality attributes of the fruits were not adversely affected by the coatings, while their application led to better control of weight and firmness loss and they contributed to a reduction in physiological disorders such as flesh browning and bleeding.

Finally, the research work from Z. Wang and collaborators deals with the development of bio-based hybrid films for food

packaging applications. The authors studied how addition of sodium alginate modified the physical-chemical properties of cast collagen films. They report that incorporation of the carbohydrate polymer improves the thermal stability of the collagen films which also showed increased tensile strength and improved barrier to water vapour, although no differences were observed in the oxygen permeability of the films. Moreover, the components seemed to be compatible as no phase separation was observed in the blends.

We hope that the readers enjoy the reading and that this compilation of papers serves as an inspiring basis for investigation in this exciting and promising research area.

Acknowledgments

We would like to sincerely thank all the authors who contributed to this special issue, as well as the expert reviewers who provided constructive feedback and extremely useful comments.

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Research Article

Scale-Up Preparation and Characterization of Collagen/Sodium Alginate Blend Films

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In an effort to produce scale-up of edible films, collagen-based films including different amounts of sodium alginate (CS) were prepared by casting method. Films were characterized based on their rheological, thermal, and mechanical properties, water vapor permeability (WVP), and oxygen permeability (OP). The microstructures were also evaluated by scanning electron microscopy (SEM), atomic force microscopy (AFM), and Fourier transform-infrared spectroscopy (FTIR). Furthermore, the addition of sodium alginate effectively improved the viscosity and thermal stability, significantly increased TS, and decreased E and WVP ($P < 0.05$), but with no obvious effect on OP ($P > 0.05$). SEM and AFM showed homogeneous matrix, with no signs of phase separation in the blends. Overall, films (CS2) produced using collagen (g) : sodium alginate (g) = 10 : 2 showed suitable rheological property (apparent viscosity was 4.87 m Pa s^{-1}) and better TS (26.49 Mpa), E (64.98%), WVP (1.79×10^{-10} g·cm^{-1}·s^{-1}·Pa^{-1}), and OP (3.77×10^{-5} cm^3·m^{-2}·d^{-1}·Pa^{-1}).

1. Introduction

Food packaging is concerned with the preservation and protection of all types of foods, particularly from oxidative and microbial spoilage, and also extending their shelf-life characteristics. Increased use of synthetic packaging films has led to serious ecological problems due to their total non-biodegradability [1, 2]. Thereby, the use of proper packaging materials and methods to minimize food losses and provide safe and wholesome food products had always been the main interest [3–7].

Indeed, more and more attention has been paid to develop edible films in order to improve food safety and shelf-life [8–10]. Edible films need to possess the appropriate mechanical properties and barrier properties from initial product packing to final consumer usage [11, 12]. Meanwhile, the materials obtained from renewable natural sources that were used to prepare edible films mainly include proteins, lipids, polysaccharides, and their possible combinations [13, 14].

Among them, collagen is one of the renewable natural polymers, which could be widely used as an important industrial raw material [15]. It gained more significance, which offers real potential for applications in the food industry due to its physicochemical properties, short time biodegradability, and nontoxicity. Several authors have developed films or coatings based on collagen to preserve food in laboratory scale [15–20]. Nevertheless, since now, scale-up collagen-based films were not successfully produced, as would limit their application in food preservation field.

Alginate is a salt of alginic acid, a polymer of D-mannuronic acid and L-guluronic acid, and isolated from brown algae, used as an edible coating because of its unique colloidal properties and its ability to form strong gels or insoluble polymers upon reaction with multivalent metal cations, such as calcium [6, 21]. As a stabilizer and a thickener, sodium alginate (SA), the main used form, is applied in various food products including drinks like chocolate milk and deserts like ice cream, jelly, sauces, and soups [22–25]. Particularly, edible films obtained from sodium alginates have obtained good mechanical characteristics and decreased oxygen transfer [26, 27].

Therefore, SA was added to collagen, in order to obtain a suitable rheological behavior for the collagen-based solution, paving the way to a large scale-up preparation for

collagen-based films. More importantly, hydrogen and/or electrostatic interactions between carboxylate groups of SA and hydroxyl groups of collagen can occur, forming a more dense and compact matrix.

The objective of this paper was to prepare and evaluate the properties of different blending ratios of collagen-sodium alginate films in pilot scale. The films were characterized in terms of their rheological behavior, thermal stability, and mechanical properties, as well as their oxygen permeability and water vapor barrier property. Furthermore, their microstructure would be investigated by scanning electron microscopy, Fourier transform-infrared spectroscopy, and atomic force microscopy, respectively.

2. Materials and Methods

2.1. Materials. Fish skin collagen (MW: 2000–3000) was obtained from Shanghai Yuanye Bio-Technology Co., Ltd. Sodium alginate, glycerol, and glutaraldehyde were purchased from Sinopharm Chemical Reagent Co., Ltd. All of them were of analytical grade. Indeed, glutaraldehyde was added as a cross-linking agent, whereas glycerol was added as a plasticizer. The ultrapure water was used as a solvent for the solution preparation.

2.2. Film Preparation. Collagen/sodium alginate blend films were prepared using casting machine. Firstly, a collagen solution (10%, w/v) was prepared by dispersing collagen powder in distilled water at 65°C for 30 min under magnetic stirring. Subsequently, different weight of sodium alginate was added to collagen solution with mechanical stirring for 30 min at 60°C, to obtain the mixed solutions with different ratio of collagen to sodium alginate (10 : 0, 10 : 1, 10 : 2, 10 : 3, and 0 : 2). Then glycerol (20%, based on the content of dried matter) was added as plasticizer, and glutaraldehyde (0.5%, v/v) was added as cross-linking agent. The details could be shown in Table 1.

The film-forming solutions were placed at vacuum condition for 60 min to remove bubbles at room temperature. Finally, the solution was cast onto the steel belt casting machine (TY7000, Zhaoqing Xintai Electromechanical Technology Co., Ltd.) at 60°C for 120 min. As could be presented in Figure 1, the dried films were conditioned for 24 h at 50 ± 5% relative humidity (RH) and 25 ± 1°C before determination.

2.3. Rheological Analysis. Flow properties of film-forming solutions are useful for identifying the most appropriate coating system and optimizing operating conditions [23, 28]. The rheological properties of collagen, SA, and their blended film-forming solutions were characterized by a rheometer (Anton Paar, MCR302, Austria) equipped with a parallel-plate geometry (diameter = 25 mm and a gap = 0.2 mm). All measurements were conducted at 25°C. Before any measurement, samples rested for 2 min, to allow the stresses induced during sample loading to relax.

Rheological characterization was carried out using stationary shear flow and oscillatory tests. The steady shear measurements (flow curves) were performed in an extended shear rate range (1 to 200 s^{-1}).

According to the rheological analysis model [29], the flow (n) and consistency indices (K) were determined after adjusting the empirical data according to the Ostwald de Waele rheological model (a.k.a. the Power-Law Model):

$$\tau = KD^n \quad (1)$$

in which τ is the shear stress (Pa), K is the consistency index (Pa s^n), D is shear rate, and n is the flow-behavior index.

2.4. Films Characterization

2.4.1. Thickness. Thickness of the collagen-sodium alginate films was determined to the nearest 0.01 mm using a micrometer (Mitutoyo Manufacturing, Tokyo, Japan). Measurements were made in at least ten random locations on each film.

2.4.2. Mechanical Properties. Mechanical properties of the films, such as tensile strength (TS, MPa) and elongation at break (E, %), were determined at 25 ± 1°C using a Testometric Machine (PARAM XLW (B) Auto Tensile Tester, Jinan, China) according to the ASTM standard method (D882-01). Films were cut into rectangular strips that were 120 mm long and 15 mm wide. Stripes were equilibrated at 50% RH and 25 ± 1°C for 48 hrs in a desiccator using saturated salt solutions of $MgCl_2$ or $Mg(NO_3)_2$. The films were fixed with an initial grip separation of 80 mm and stretched at a cross-speed of 50 mm/min. A microcomputer was used to record the strength and elongation data. Tensile strength was calculated as the maximum load on the film before failure divided by the cross-sectional area of the specimen. Elongation was defined as the percent change in specimen length compared to the initial length between the grips. For each film, at least five replicate measurements were performed [30].

2.4.3. Water Vapor Permeability (WVP). Water vapor permeability tester (PERME TSY-TIL, Labthink Instruments Co., Ltd., Jinan, China) was used to determine the water vapor permeability (WVP, $\times 10^{-10}$ g·cm^{-1}·s^{-1}·Pa^{-1}) of the films according to the ASTM standard method (D1653). Water vapor transmission rates were determined at 25 ± 1°C and 50% RH using saturated salt solutions of $MgCl_2$ or $Mg(NO_3)_2$. The specimen was fixed to form a sealed environment with 2/3 distilled water in the vessel. The water vapor transmission rate and transmission coefficient were determined by measuring the decreasing weight of distilled water over time. For each film, at least five replicates were performed [30].

2.4.4. Oxygen Permeability (OP). A gas permeability tester (GDP-C) (Brugger Feinmechanik GmbH, Germany) was utilized to test the oxygen permeability (OP, $\times 10^{-5}$ cm^3·m^{-2}·d^{-1}·Pa^{-1}) of the films according to the ASTM standard method (D3985-95). Oxygen transmission rates were determined at 25 ± 1°C and 50% RH using saturated salt solutions of $MgCl_2$ or $Mg(NO_3)_2$. The sample was mounted in a gas transmission cell to form a sealed semibarrier between chambers. One chamber contained O_2 at a specific high pressure and the other lower pressure chamber received the permeating O_2. The lower pressure chamber was initially evacuated

(a) (b) (c)

Figure 1: Casting machine used for films produced: (a) film-forming solution, (b) film drying, and (c) finished film.

and the transmission of the gas through the test specimen was indicated by an increase in pressure [30]. The O_2 stream was set to 100 mL/min and the oxygen transmission rate (OTR) was recorded. The OP was calculated by multiplying the OTR by the film thickness (FT) and then dividing by the partial pressure difference of oxygen (ΔP) as follows:

$$\mathrm{OP} = \frac{\mathrm{OTR} \times \mathrm{FT}}{\Delta P}. \quad (2)$$

For each film, at least five replicates were performed.

2.4.5. Thermal Properties. The thermal properties of samples were characterized as reported previously using differential scanning calorimeter (DSC-Q20, TA Instruments, USA). The samples (3-4 mg) were heated with at 10°C/min in the swept temperature from 10 to 300°C [19].

2.5. Microstructure Characterization

2.5.1. Fourier Transform-Infrared Spectroscopy (FTIR). FT-IR was recorded on a Nicolet 360 spectrometer (Thermo Nicolet Corporation, American) from 400 to 4000 cm^{-1} with the KBr method.

2.5.2. Scanning Electron Microscopy (SEM). The SEM images were acquired on a ZEISS SUPRA 55 (Carl Zeiss, Germany) field-emission scanning electron microscopy. For cross section analysis, samples were cryofractured after immersion in liquid nitrogen. The cryofractured section and film surface were analyzed without further preparation. The images were taken at random positions of the films.

2.5.3. Atomic Force Microscopy (AFM). The surface morphology of collagen-SA films was studied using a Multimode atomic force microscope (Bruker Multimode 8, Bruker, Germany) equipped with a Nanoscope V controller. The equipment was operated in noncontacting mode using etched silicon tip (nominal radius 8 nm and cantilever length of 230 μm) with a resonance frequency of about 267 kHz. AFM images were acquired in air at room temperature.

2.6. Statistical Analysis. All samples were analyzed in triplicate and one-way analysis of variance (ANOVA) was applied on the data followed by Duncan to distinguish the treatments at $P < 0.05$. The statistical analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Rheological Analysis. The flow-behavior of film-forming solutions is an important property because it could affect the spread-ability, thickness, uniformity of the coating layer, the mechanical properties, and the application and processing design [28, 31]. Additionally, flow property modeling of film-forming solutions is useful technologically to identify the most appropriate coating system design and to optimize operating conditions [32].

The variation of viscosity and shear stress of collagen-based film-forming solution could be shown in Figure 2. Pure collagen solution showed Newtonian behavior between 0.1 and 200 s^{-1} shear rate range, whereas collagen/sodium alginate solution exhibited a shear-thinning behavior, confirming that the addition of SA enhanced the elastic behavior (w/v). As mentioned before, shear-thinning behavior is adequate for the production of films by tape casting.

As was presented in Table 1, flow-behavior index (n) increased with increasing SA concentration; accordingly K values primarily increased and then decreased. As expected, higher SA concentration led to a higher apparent viscosity. It suggests that SA was the prime factor affecting apparent viscosity. This may be attributed to the intramolecular interaction of SA which was destroyed; then new hydrogen bonds were formed between collagen and SA. Regardless of this, some researchers have demonstrated that high viscosity

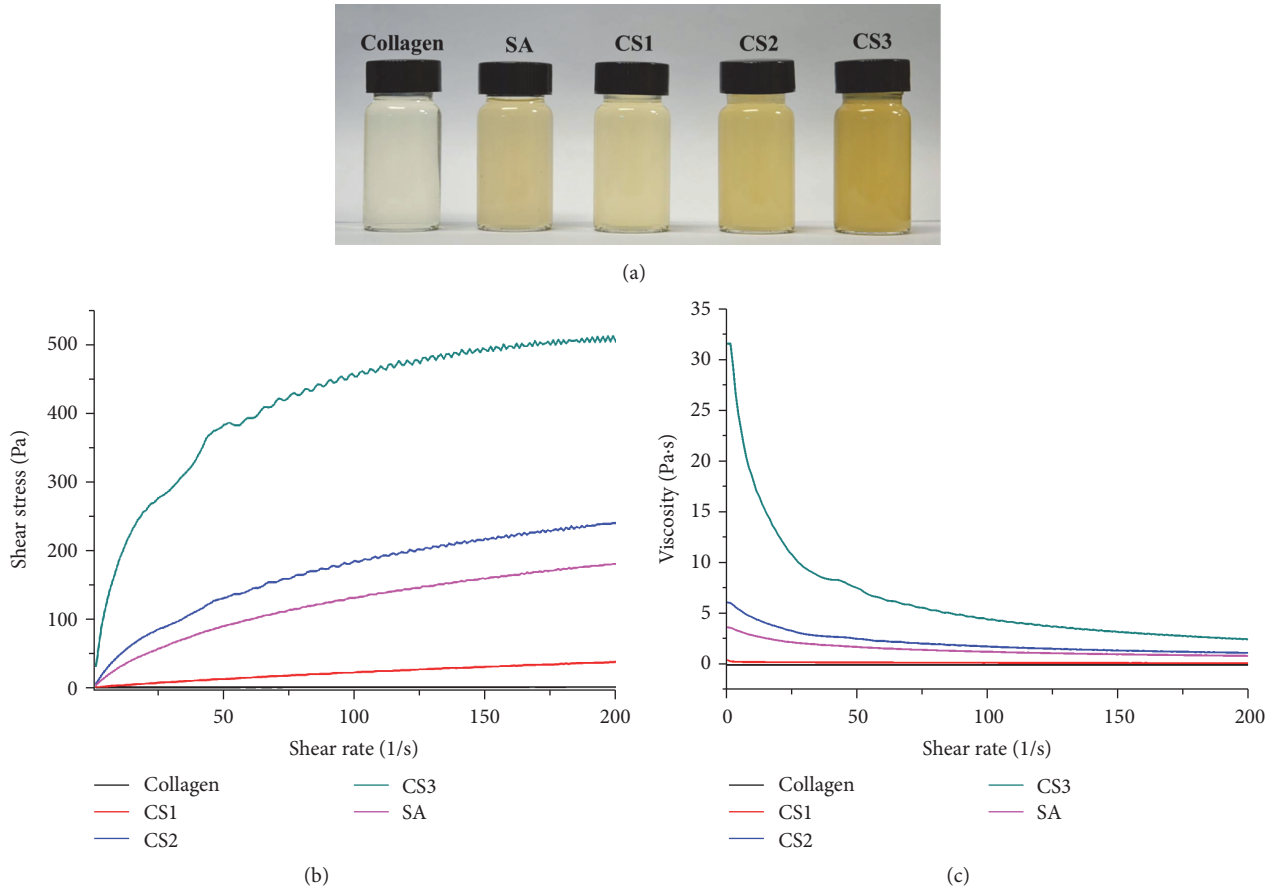

Figure 2: Characterization and rheological property evaluation for the films, (a) film-forming solution macrograph, (b) sheer stress versus shear rate, and (c) viscosity versus shear rate.

makes it difficult to disperse the ingredients and eliminate visible air bubbles during the preparation of liquid films [23, 32, 33], leading to some discontinuities in the final films.

3.2. Films Characterization

3.2.1. Thickness. Indeed, all films were yellowish and flexible and could be easily handled. The surfaces of the films looked very smooth, without visible cracks or pores. Greater details regarding film appearances are described in Table 2.

Thickness of collagen films incorporated with SA at various concentrations is shown in Table 2. Thickness of films incorporated with SA (1–3%, w/v) increased in comparison with the control. It ranged from 0.030 to 0.033 mm. However, no significant difference in thickness was observed between films incorporated with SA ($P > 0.05$). Some authors also reported that the incorporation of SA had no effect on thickness of starch and pectin films [34, 35].

3.2.2. Mechanical Properties. Mechanical properties of biopolymer films are often presented in terms of tensile strength (TS) and elongation at break (E). TS accounts for film's mechanical resistance due to cohesion forces between chains, while E measures its plasticity, which is capacity of a film to extend before breaking [36–38].

All test films showed significant ($P < 0.05$) differences in TS and E (Table 2). Single collagen and SA films exhibited TS and E value of 17.46 and 40.48 MPa and 78.49% and 50.28%, respectively. In general, polysaccharide-based films had better TS compared with protein-based films while protein-based films possessed greater E than polysaccharide-based films [15, 17], agreeing well with the results of this study.

When the ratio of collagen to SA varied from 10 : 0 (pure collagen film) to 10 : 3 (CS3), TS was enhanced from 17.46 to 34.17 MPa, nearly more than double; however, E decreased from 70.15% to 58.11%. As suggested by [39], usually films with higher TS values show lower E values, due to the structural nature of those attributes. This result was probably induced by a certain degree of cross-linking between the proteins of collagen and SA. As observed in the FTIR analysis, the hydrophobic interactions and hydrogen present bridges in proteins could be demonstrated (Section 3.3.1). It has been proved that lots of hydroxyl groups exist to allow formation of hydrogen bonds between side-by-side polymer chains, resulting in high TS of films made of protein or sodium alginate [6, 21, 40]. Moreover, it has been reported that the mechanical properties of films are greatly associated with distribution and of intra- and intermolecular interactions, depending on the arrangements, and orientation of polymer chains in the network [17]. According to the SEM analysis (Section 3.3.2),

Table 1: Rheological properties of film-forming solutions: index of consistency (K) and flow-behavior (n) calculated by the Ostwald de Waele model. Apparent viscosity values at 10 m S^{-1} shear rate (D).

Sample	Mass ratios of collagen to SA	Parameters of Ostwald de Waele model			Apparent viscosity (m Pa s^{-1})
		K	N	R^2	D = 10 m S^{-1}
Collagen	10 : 0	0.107	0.888	0.947	0.005
CS1	10 : 1	0.354	0.844	0.999	0.33
CS2	10 : 2	1.083	0.582	0.988	4.87
CS3	10 : 3	1.874	0.384	0.964	18.65
SA	0 : 2	0.995	0.538	0.984	2.95

Table 2: Collagen-sodium alginate films properties: tensile strength (TS), elongation at break (E), water vapor permeability (WVP), and oxygen permeability (OP).

Films code	Thickness (μm)	TS (Mpa)	E (%)	WVP $\times 10^{-10}$ g·cm^{-1}·s^{-1}·Pa^{-1}	OP $\times 10^{-5}$ cm^3·m^{-2}·d^{-1}·Pa^{-1}
Collagen	30 ± 2^a	17.46 ± 1.13^a	78.49 ± 3.59^a	3.43 ± 0.38^a	3.87 ± 0.28^a
CS1	31 ± 1^a	20.38 ± 2.24^b	70.15 ± 3.14^b	2.2 ± 0.28^b	3.56 ± 0.57^{ab}
CS2	32 ± 2^a	26.49 ± 2.67^c	64.98 ± 2.69^c	1.7 ± 0.26^{bc}	3.77 ± 0.37^a
CS3	33 ± 2^a	34.17 ± 2.48^d	58.11 ± 2.78^d	2.92 ± 0.22^{ab}	3.85 ± 0.42^a
SA	11 ± 1^b	40.48 ± 1.49^e	50.28 ± 1.38^e	2.74 ± 0.35^{ab}	3.16 ± 0.49^b

Values are expressed as mean ± standard deviation. Different letters in the same column indicate significant differences ($P < 0.05$).

a uniformity appearance for the CS films is obtained, leading to a better mechanical property. Thus, SA could effectively improve the mechanical property of collagen films.

3.2.3. Water Vapor Permeability (WVP). Water vapor permeability (WVP) for the collagen, SA, and their blend films at relative humidity of 50% is shown in Table 2. Obtained values ranged from 1.79 to 3.43 × 10^{-10} g·cm^{-1}·s^{-1}·Pa^{-1}. As it is reported that collagen is a hydrophilic polymer which has hydroxyl groups, thus, the water vapor could easily permeate through the film. In this study, films with lower content of SA showed significantly lower values comparing to the pure collagen films. This was in accordance with the fact that WVP values for blend films produced from protein and polysaccharide mixtures were lower in comparison to the WVP values of those films formed from protein alone [41].

It is perhaps because more hydroxyl groups of SA could form more hydrogen bonds with water; thus water was trapped firmly in the polymer network. Similar results have been reported in the literature for feather keratin and SA blend films [21]. Further, it was discovered that SA could decrease the WVP probably through creating a tortuous pass for crossing water vapor through film, increasing the crystallinity of the biopolymer, or decreasing free hydrophilic groups (OH, NH) in biopolymer matrix [41, 42].

It was also worth noting that further increase in SA (CS3) caused an increase in the WVP of CS films. This may attribute to the fact that both collagen and SA owing to their hydrophilic nature attract water molecules and create mobile regions with larger interchain distances. Additionally, these hydrophilic SA compete with water at the active sites of the polymer matrix causing water clustering which also forms microcavities in the network structure [43, 44]. The absorbed water molecules modify the film matrix, leading to a less dense structure where chain terminals are relatively more mobile, thus increasing water vapor transmission rate [45]. Therefore, the appropriate SA proportion could lead to a better barrier property for the blend films.

3.2.4. Oxygen Permeability (OP). Oxygen is responsible for many degradation processes in foods such as lipid oxidation, microorganism growth, enzymatic browning, and vitamin loss [46]. Consequently, oxygen permeability (OP) is a crucial property in food packaging and it could be used as an index to evaluate the ability to prohibit oxidation reaction [47].

Although the collagen films were hydrophilic and exhibited poor water vapor barrier properties, collagen-based films were hypothesized to be excellent barriers against oxygen, as examined in Table 2. Nevertheless, no significant differences ($P > 0.05$) were obtained between all the estimated values and no specific trends could be observed. The OP value of the pure collagen and SA film was 3.87 and 3.16 × 10^{-5} cm^3·m^{-2}·d^{-1}·Pa^{-1}, indicating that the both films were good oxygen barrier. Similar results were obtained by Bonilla et al. [46]. It was also noted that films made from proteins and carbohydrates are excellent barriers to oxygen, because of their tightly packed, ordered hydrogen bonded network structure [48].

From this result, it appears that the addition of SA slightly changed OP of CS films, but with no obvious effect ($P > 0.05$). When the ratio of collagen to SA varied from 10 : 1 (CS1) to 10 : 3 (CS3), OP varied from 3.56 to 3.85 × 10^{-5} cm^3·m^{-2}·d^{-1}·Pa^{-1}. Among them, the OP for CS1 was found to be lowest, but further increase in SA concentration

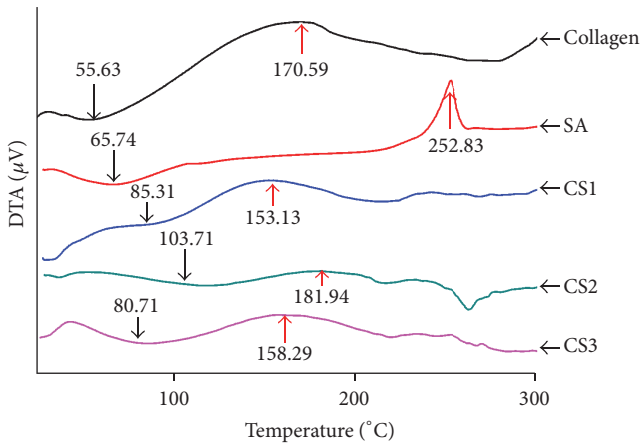

Figure 3: DSC thermograms of collagen, CS1, CS2, CS3, and SA films.

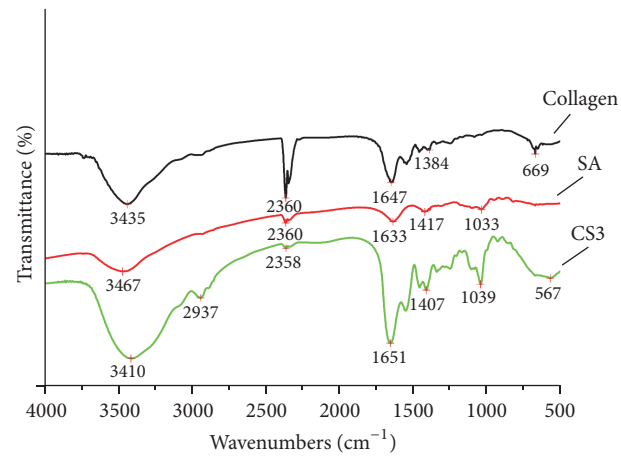

Figure 4: FTIR spectra of the different films (collagen, SA, and CS3) studied in all the range absorption.

led to an increase in OP of CS films. Generally SA possess a film-forming ability, which leads to modest or very good oxygen barrier properties depending on the structure [11]. However, the result was not as good as expected in this study; SA added in the collagen could not decrease the OP values for the blend films.

3.2.5. Thermal Properties. Thermal properties of the samples were estimated using differential scanning calorimeter (DSC). It was known that DSC was a useful and rapid method to measure the interrelated thermodynamic profiles, and it was usually used to determine the temperature and enthalpy during endothermic or exothermic processes for an application in polymer materials [8]. The thermograms of DSC analysis and the related peak temperatures were given and illustrated in Figure 3.

It was reported that the first endothermic events were glass transition, followed by an endotherm associated with the melting of the ordered structures [20, 49]. As observed in Figure 3, the T_g value of the pure collagen film (55.63°C) is inferior to CS1 (85.31°C), CS2 (103.71°C), and CS3 (80.71°C). It suggested that the thermal stability of the CS films has been enhanced, owing to the addition of SA. That may be explained by the increase of interactions provided by SA, stabilizing the collagen structure against unfolding and requiring a higher temperature to degrade collagen [18, 20]. Nevertheless, the T_g value for the CS films initially increased and then decreased, with the SA concentration increase. As reported, T_g value of the collagen film is attributed to the hydrogen bonded networks and mediated by water molecules [50].

Oppositely, as observed, compared to the collagen film (170.59°C), CS1 (153.13°C) and CS3 (158.29°C) presented a decrease in T_c value associated with thermal stability. The lower T_c was related to the reduction in some weak intermolecular forces such as hydrogen bonds between water and the matrix. It could be explained that the hydrophobic feature was imparted into collagen and facilitated evaporation of water with SA added. Totally, the addition of SA effectively improved the thermal property for the CS blend films.

3.3. Microstructure Characterization

3.3.1. FTIR. FTIR spectra of collagen, SA, and their blend films at selected concentrations were depicted in Figure 4. A robust classification of FTIR spectra collagen could be obtained by using a combination of four spectral intervals [ν(C=O) absorption of amide I (1,700–1,600 cm^{-1}), δ(CH2), and δ(CH3) absorptions (1,480–1,350 cm^{-1}), ν(C–N), and δ(N–H) absorptions of amide III (1,300–1,180 cm^{-1}), and (C–O) and (C–O–C) absorptions of carbohydrate moieties (1,100–1,005 cm^{-1})] [51]. Both collagen and CS3 spectra showed similar IR absorbance patterns.

For CS3, the OH stretching and asymmetric COO stretching shift to a lower wavenumber (from 3435 to 3410 cm^{-1}). Generally, the shift to the lower wavenumber indicated the existence of hydrogen bonds in collagen [50]. It also indicated that no other bonds except hydrogen bonds were formatted between collagen and SA.

3.3.2. SEM. Scanning electron microscopy (SEM) observations were carried out to get a better insight into the homogeneity and the microstructure of the blend films (Figure 5). SEM images of the surface of the collagen, SA, CS1, CS2, and CS3 films, and cross section of the CS2 films were presented. It was observed that collagen fiber was arranged in the film matrix, without pores and with excellent structural integrity (Figure 5(a)). SA exhibited rough surfaces with nonporous and heterogeneous morphologies due to some nonfully destructured alginate particles (Figure 5(b)). While more SA was added to the blend, the surface of CS2 and CS3 exhibited rougher and fluctuant matrix morphology (Figures 5(d) and 5(e)). Nevertheless, SEM images revealed that CS films had a smoother surface compared to pure SA films which became rougher upon drying. The cross section of CS2 had a compact and homogeneous structure and no distinct phase separation was observed (Figure 5(f)), indicating the integrity of the blend structure.

The above results lead to the following suggestions about the formation mechanism of the CS blend films. When SA were added to collagen films, the low molecular weight

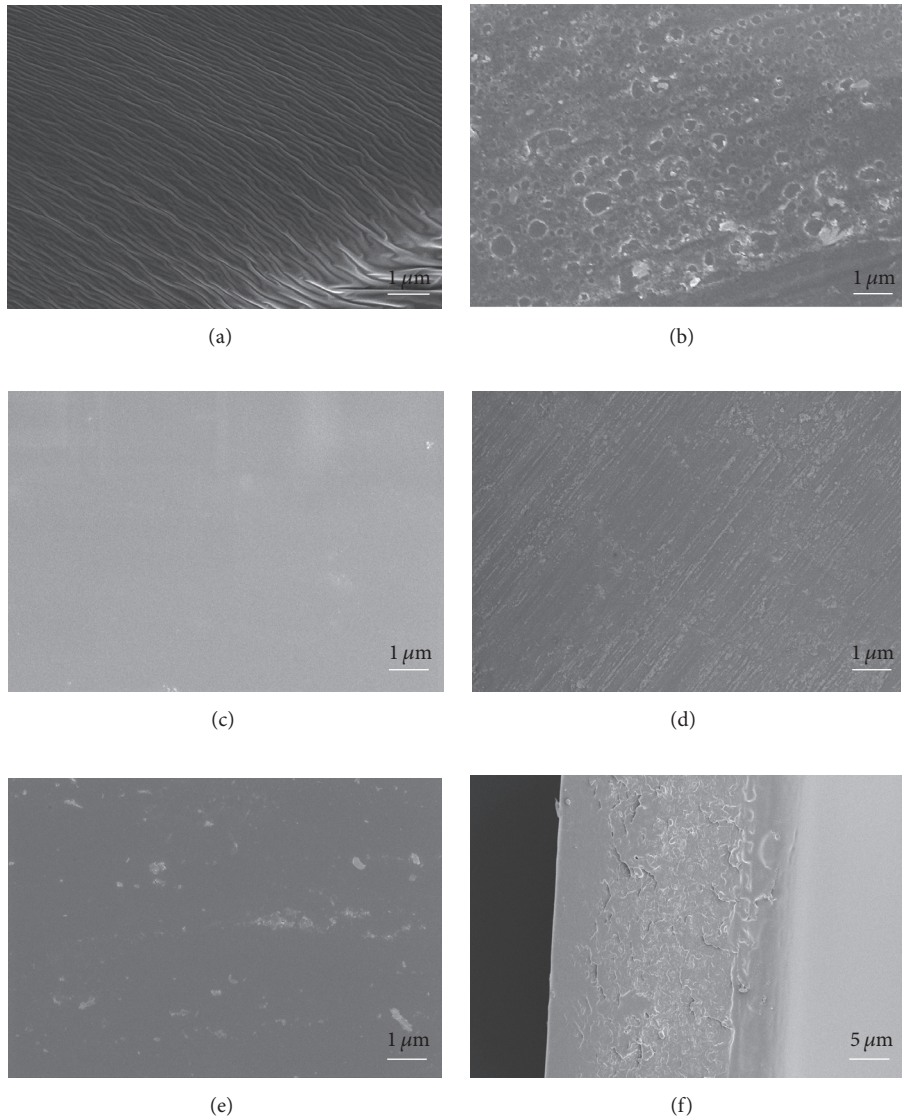

Figure 5: SEM micrographs of the surface of the films based on (a) the pure collagen film, (b) SA film, (c) CS1, (d) CS2, and (e) CS3. SEM micrographs of the cross section appearance of the films based on (f) CS2.

hydrophilic SA molecular movement was depressed by the formed strong cross-linking network structure, resulting in improved mechanical stability.

3.3.3. AFM. AFM images were obtained in order to provide the information of surface morphology and roughness for the sample film. Figure 6 shows surface morphologies and the corresponding results of roughness parameters (*Rq*, root mean square of roughness, and *Ra*, mean value of roughness) of the films. The surface morphology of SA film (Figure 6(a)) showed that bright protuberant parts were obviously observed due to SA molecule self-aggregation. Some significant differences between SA and CS films are exhibited. Obviously, the presence of collagen led to a marked decrease in the roughness of the films, as indicated by lower *Ra* and *Rq* values. The results were accordant with the SEM microstructure observations.

4. Conclusion

Scale-up collagen/sodium alginate (CS) films were successfully prepared and their physical, mechanical, and barrier properties were evaluated. SEM and AFM analysis verified the homogeneity of the blend films while FTIR indicated hydrogen bonds formed between collagen and sodium alginate. Also, DSC suggested that their thermal stability has improved, owing to the addition of SA.

Furthermore, with increasing concentration of SA, TS increased and *E* decreased while WVP initially decreased and then increased. Relatively, no obvious difference on OP for

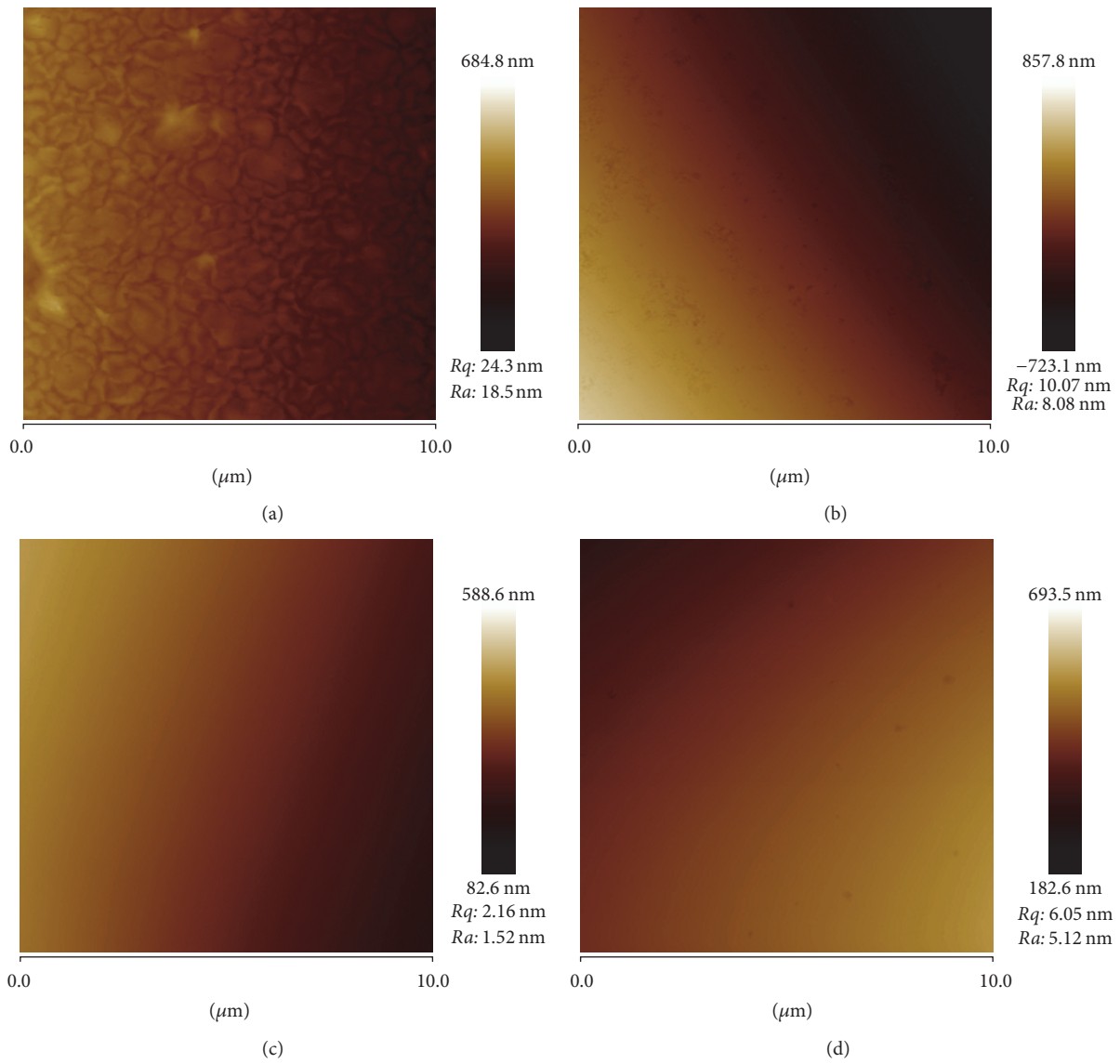

Figure 6: AFM images of the films: (a) SA film, (b) CS1, (c) CS2, and (d) CS3.

the CS films was obtained ($P > 0.05$). Results revealed that CS films with appropriate physical, mechanical, and barrier attributes could be effectively produced and successfully utilized in the food packaging industry.

Conflicts of Interest

The authors declare that the mentioned received funding in the Acknowledgments did not lead to any conflicts of interest regarding the publication of this manuscript.

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Research Article

Influence of Edible Coatings on Biochemical Fruit Quality and Storage Life of Bell Pepper cv. "Yolo Wonder"

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The present study was carried out to investigate the influence of food grade coatings on fruit quality and storage life of bell pepper cv. "Yolo Wonder" at 8 ± 1°C with 90–95% RH for 24 days. Coating treatments were given to bell pepper fruits by dipping in aqueous solutions of gum arabic (6, 9, and 12%), *Aloe vera* gel (4, 5, and 6%), and cinnamon oil (0.5, 0.75, and 1%). Physicochemical characteristics as well as quality of bell pepper fruits improved in all coating treatments. Results revealed that 12% gum arabic coating exhibited significantly reduced weight loss, membrane leakage, chilling injury, and decay incidence with less increase in pH, total soluble solids, and sugar percentage, whereas appealing fruit color (L^*, a^*, and b^*) along with higher values of ascorbic acid (1.84 mg/100 g), titratable acidity (0.19%), and firmness (4 N) was observed in cold storage environment. Our results clearly suggested that coating of bell pepper fruits with 12% gum arabic can maintain postharvest storage quality of bell pepper fruits.

1. Introduction

Bell pepper is the most commonly used fruit of the solanaceous family with excellent nutritive value and a high content of ascorbic acid and vitamins such as vitamins A and E and whole range of vitamin B complex. Its consumption and demand have increased due to the rapid increase of population in current years pertaining to its use in ready-to-eat meals [1]. Bell pepper fruit, due to its short shelf life, is susceptible to flaccidity, wilting, shriveling, fungal diseases, and decay. These problems reduce premium price in market and consumer acceptance after harvest [2]. Postharvest quality of bell pepper is influenced by various factors like moisture loss and chilling injury (CI) that deteriorate the quality of bell pepper fruit during postharvest operations [3].

Fruits are usually stored at low temperature to delay quality deterioration; however, this technique has not proven enough to maintain fruit quality. Therefore, food grade edible coatings combined with certain oils are considered beneficial in improving shelf life to facilitate food consumption [4]. Application of chitosan as an edible coating improved the physical appearance of papaya by creating a barrier against respiration and moisture loss [5]. These coatings develop a modified atmosphere which can induce diverse alterations in fresh and minimally processed foodstuff in some areas such as antioxidant properties, microbial growth inhibition, color, sensory quality, firmness, ethylene production, and volatile compounds as a consequence of anaerobic processes [6].

Previously, the role of different edible coatings has been investigated on many fruit crops. *Aloe vera*, being a plant of tropics, is known for its medicinal value [7] and its main liquid components are clear gel and yellow latex [8]. *Aloe vera* gel has been used in a number of horticultural crops like plum [9], sweet cherries [10], mangoes [11], nectarines [8], and apples [12]. Moreover, *Aloe vera* gel coating application preserves fruit quality by reducing fungal decay in table grapes [7] and sweet cherries under cold storage condition [13]. Raspberry fruits coated with *Aloe vera* gel have an antioxidant capacity with a lower decay incidence [14]. Meanwhile, gum arabic, as a naturally occurring polysaccharide exuded from the stems or branches of the *Acacia* tree, has been widely used in food, textile, and pharmaceutical industry [15]. It is a composite blend of polysaccharides, arabinogalactan oligosaccharides, and glycoproteins [16] and has emulsifying properties [17]. Dipping of an apple fruit in gum arabic substantially delayed ripening in cold storage [18]. Earlier,

tomatoes coated with gum arabic and kept at 20°C up to 20 days showed improved quality without production of any spoilage or off-flavors [19]; meanwhile, gum arabic coating in sweet cherries delayed the ripening process and off-flavor development [20]. In another study, gum arabic coating reduced textural damage and decay of green bell pepper [21], whereas gum arabic in combination with silver nanoparticles inhibited microbial growth and increased shelf life of green bell peppers [22]. A recent report showed that gum arabic along with calcium chloride enhanced low temperature tolerance in mango by improving the antioxidant defense system and reducing oxidative damage of mango fruit [23]. On the other hand, cinnamon, being a natural antimicrobial essential oil, is also known for its antimicrobial properties and reduces decay in fruits [24–26]. It contains antioxidative properties which are mostly derived from phenolic contents [27]. Previously, cinnamon oil in combination with chitosan reduced decay percentage in sweet peppers [28], whereas combined application of cinnamon oil with gum arabic on papaya and banana fruit showed promising control of diseases like anthracnose [29]. Cinnamon oil incorporated with carnauba wax effectively controlled postharvest green and blue mold in citrus fruit [30], whereas cinnamon oil combined with chitosan coating preserved jujube fruit quality under low temperature storage [31].

It appears from the literature that postharvest application of edible coatings like *Aloe vera* gel, gum arabic, and cinnamon oil is useful in maintaining fruit quality under cold storage. However, the comparative role of these edible coatings on fruit quality, chilling injury, and decay of bell pepper cv. "Yolo Wonder" at a low temperature is yet to be explored. Therefore, current research was planned to further probe the ability of *Aloe vera* gel, cinnamon oil, and gum arabic to improve the postharvest quality as well as visual appearance of bell pepper fruit under prolonged cold storage conditions.

2. Materials and Methods

2.1. Plant Material. Bell pepper cv. "Yolo Wonder" was harvested at commercial maturity stage (TSS = 5.66, L = 39.23, a = −18.10, b = 26.51) from a local farm located at Chakwal (32.93°N, 72.86°E), Punjab, Pakistan. Gum arabic in solid form was ground before making further concentrations, whereas *Aloe vera* gel and cinnamon oil were in liquid form. After grinding, 100 g of gum arabic powder was dissolved in 100 ml of water on a heating plate and was further diluted to make 6, 9, and 12% gum arabic concentration. For *Aloe vera* gel, 4, 5, and 6 ml of *Aloe vera gel* were dissolved in 100 ml of distilled water to obtain concentrations of 4, 5, and 6% *Aloe vera* gel. Similarly, 0.5, 0.75, and 1 ml of cinnamon oil were dissolved in 100 ml of distilled water to obtain 0.5, 0.75, and 1% concentrations of cinnamon oil. The harvested fruits were immediately transported to the Postharvest Laboratory of the Department of Horticulture, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi. Pest, disease, and blemish free uniform sized mature fruit were washed with 0.05% solution of sodium hypochlorite (NaClO) for 3 min followed by drying at room temperature. *Aloe vera* gel, cinnamon oil, and gum arabic powder of 100% purity were obtained from a local supplier. Fruits were dipped in different concentrations of *Aloe vera* gel (4, 5, and 6%), gum arabic (6, 9, and 12%), and cinnamon oil (0.5, 0.75, and 1%) for 5 min. The coated fruits were dried, packed in soft board cartons, and stored for 24 days at 8 ± 1°C with 90–95% RH. Fruits were removed from cold storage at a four-day interval to determine weight loss, fruit color, juice, pH, TSS, TA, ascorbic acid, decay incidence, fruit firmness, membrane leakage, and chilling injury (CI).

2.2. Weight Loss. Bell pepper fruits were weighed initially before shifting to a cold storage container, and the amount of weight loss that took place during cold storage was determined using the following formula and expressed as percentage:

$$\text{Weight loss } (\%) = \frac{(W1 - W2)}{W1} \times 100, \quad (1)$$

where

W_1 is the initial weight (g);

W_2 is the weight loss under cold storage (g).

2.3. Fruit Firmness. Fruit firmness was measured using a hedonic scale ranging from 1 to 9, extremely soft and extremely hard, respectively [32].

2.4. Total Soluble Solids (TSS). TSS of the bell pepper was determined by the method described by Dong et al. [33] in °Brix by placing a juice drop on the lens of a handheld refractometer.

2.5. pH. pH from bell pepper fruit juice was expressed by using a digital pH meter (model: Knick 646) [34].

2.6. Titratable Acidity (TA). TA of the bell pepper juice was determined by the method given by AOAC [34] and calculated as a percentage.

2.7. Ascorbic Acid Content. Ascorbic acid contents from extracted juice of bell pepper were recorded according to the procedure described by Hans [35] and measured as mg/100 g of the edible portion.

2.8. Membrane Leakage. Membrane leakage from bell pepper was measured by using a method described by Wang et al. [36] and expressed as a percentage: % membrane leakage = (1 – leakage after 60 min of incubation/total leakage) × 100.

2.9. Decay Incidence. The degree of decay incidence was evaluated as described by Zheng and Zhang [37]. Fruit surface was observed visually by using a scale ranging from 0 to 5, where 0 means no signs and 5 indicates >50% decay. Decay incidence was calculated using the following formula:

$$\text{Decay } (\%) = \frac{(\text{Number of fruits decayed})}{\text{Total number of fruits}} \times 100. \quad (2)$$

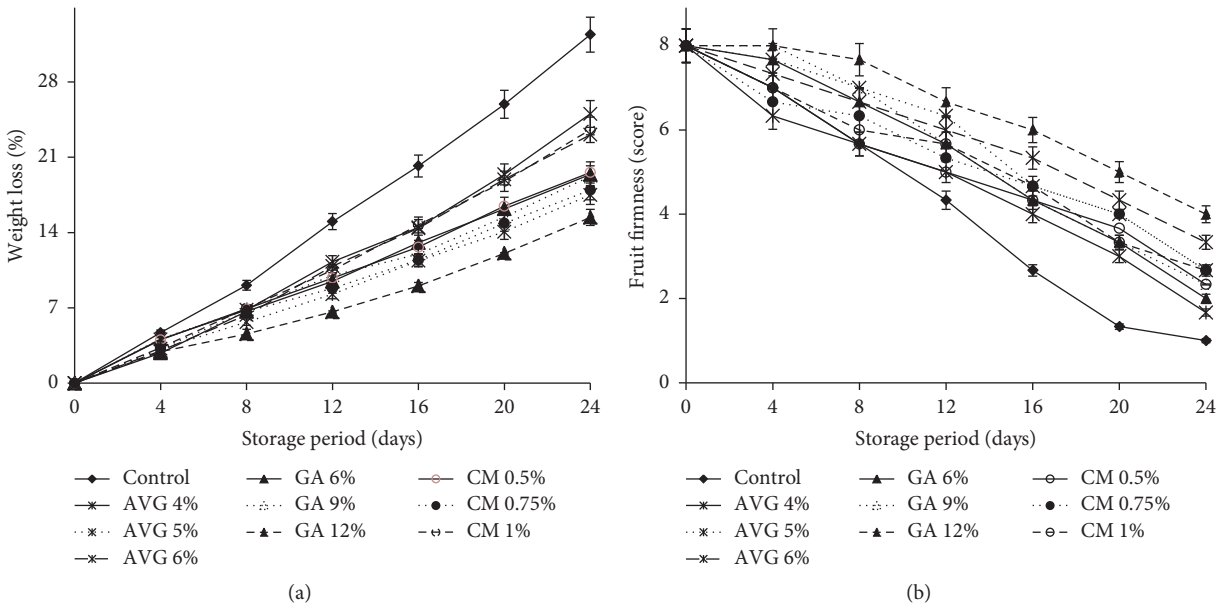

Figure 1: Effect of different coating treatments on the weight loss and fruit firmness of bell pepper during cold storage at 8 ± 1°C for 24 days.

2.10. Chilling Injury (CI). Incidence of CI was calculated based on the method described by Lim et al. [38]. CI symptoms were assessed visually by evaluating marks of pitting on the surface of bell pepper fruits. The following scale was used for CI determination and measured in percentage, that is, 0 = 0%, 1 = 5%, 2 = 6–10%, 3 = 11–15%, 4 = 16–20%, and 5 = more than 21%.

2.11. Fruit Color. Color development of nine randomly selected fruits from each treatment was checked. Fruit color change coordinates including L^* (higher positive values indicate more lightness while negative readings indicate darkness), a^* (greenness is indicated by negative readings while redness is indicated by positive values), and b^* (negative readings are indicative of blueness and higher positive readings are indicative of yellowness) were measured at opposite sides of each fruit by using Chroma Meter CR-400 (Konica Minolta Sensing, Inc., Japan).

2.12. Sugars. Determination of reducing, nonreducing, and total sugars was done by the method reported by Hortwitz [39].

2.13. Statistical Analysis. Completely randomized design (CRD) was used in laying out the postharvest experiment and the data was subjected to analysis of variance (ANOVA) for further analysis, while the least significant difference test (LSD) was used to differentiate the means at 95% confidence level [40].

2.14. Results

2.14.1. Weight Loss and Fruit Firmness. Coating treatments and cold storage period significantly affected weight loss of bell pepper fruits. Weight loss increased with the progression of storage period and reached the maximum on the 24th day. All the coating treatments exhibited less fruit loss than control fruit and the lowest weight loss was observed in 12% gum arabic coated bell pepper fruit. Coating bell pepper with 12% gum arabic exhibited about 2.1-fold less fruit weight loss compared to control (Figure 1(a)). A gradual increase in fruit weight loss decreased fruit firmness throughout the cold storage period. Fruit firmness did not show any significant decrease up to 8 days of storage, but it decreased substantially as storage time increased and was the lowest on the 24th day, irrespective of coating treatments. Coating bell pepper fruit with *Aloe vera* gel, gum arabic, and cinnamon oil significantly delayed loss of firmness. Maximum loss of firmness was observed in control treatment and minimum loss of firmness was observed in 12% gum arabic coated fruit. Bell pepper coated with 12% gum arabic exhibited about 1.5-fold higher firmness after 24 days of cold storage, as compared to the control (Figure 1(b)).

2.14.2. TSS and TA. TSS of bell pepper fruit was significantly affected by coating treatments, storage period, and their interactions. Both edible coated and control fruits showed increased TSS; however, coating treatments significantly delayed increment in TSS of bell pepper fruit during cold storage period. After 24 days of storage, a very little increase in TSS was observed in fruits coated with 12% gum arabic, which was 1.3 times less than the control treatment (Figure 2(a)). Similarly, TA of bell pepper fruit was significantly affected by coating treatments and storage interval. Results showed that TA decreased with increased storage period in both coated and uncoated fruit. However, all coating treatments resulted in higher TA compared to uncoated fruit. Among all coating treatments, 12% gum arabic coated fruit exhibited a lower decrease in TA, while uncoated fruit showed a higher decrease in TA during cold storage (Figure 2(b)). TSS

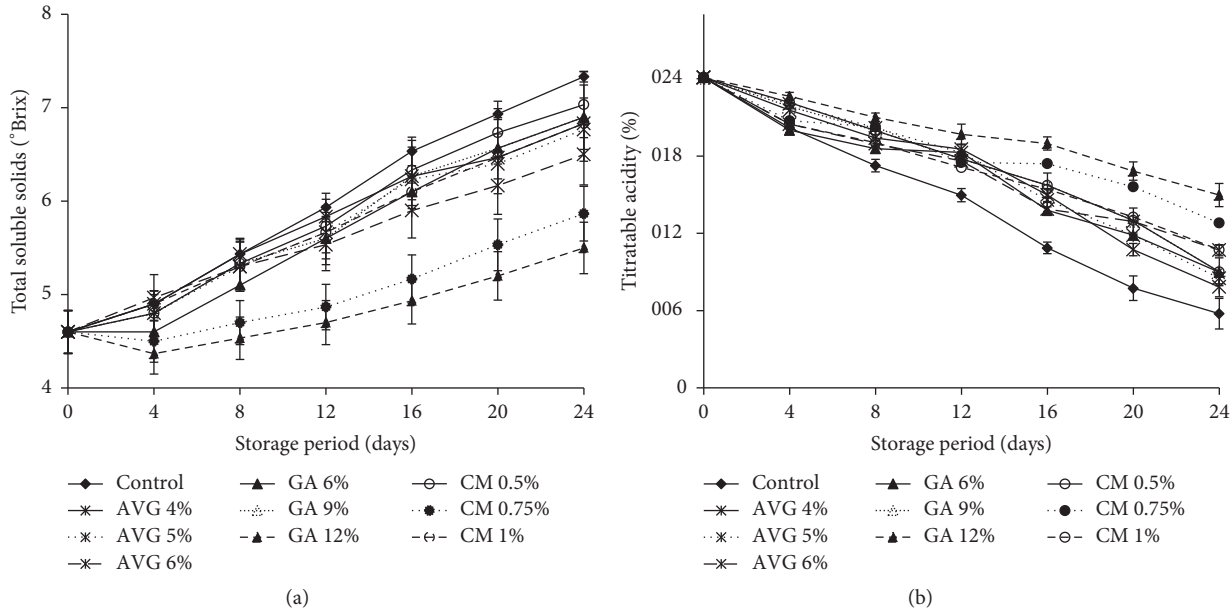

Figure 2: Effect of different coating treatments on the TSS and TA of bell pepper during cold storage at 8 ± 1°C for 24 days.

increased and slower TA reductions indicated the slower ripening process that occurred with 12% gum arabic treatment.

2.14.3. Ascorbic Acid Content, pH, and Membrane Leakage. Coating treatments, storage period, and treatments interactions significantly affected ascorbic acid content of bell pepper fruit. Results revealed that ascorbic acid declined slowly in both coated and uncoated bell pepper fruit with the increase in the storage period. Nevertheless, coating treatments significantly retained higher ascorbic acid contents. After 24 days of cold storage, minimum loss in ascorbic acid contents was recorded in fruits coated with 12% gum arabic which was about 3.2-fold lower as compared to control (Figure 3(a)). Coating treatments and storage period significantly influenced the pH of bell pepper fruit as well. Results revealed that pH increased gradually with the progression in storage. After 24 days of storage, fruit coated with 12% gum arabic showed a smaller increase in pH which was 1.1-fold more in comparison with control fruit (Figure 3(b)). Coating treatments, storage period, and their interaction significantly affected the membrane leakage of bell pepper fruit. However, coating bell pepper fruit with *Aloe vera* gel, gum arabic, and cinnamon oil maintained reduced leakage rate compared with the control; however, membrane leakage was consistent throughout the storage period. After 24 days of storage, fruit coated with 12% gum arabic showed reduced membrane leakage that was about 1.2-fold less as compared to control fruit (Figure 3(c)).

2.14.4. Decay Incidence. Incidence of decay on bell pepper fruit was significantly affected by coating treatments and storage period. Edible coatings significantly controlled decay and symptoms of decay were significantly less in all coated bell pepper fruits. The lowest symptoms of decay were observed in gum arabic coated bell pepper fruit compared with cinnamon oil and *Aloe vera* gel coatings. Fruit coated with 12% gum arabic exhibited the lowest decay incidence which was about 3-fold less as compared to control fruit after 24 days of storage (Figure 4).

2.14.5. Chilling Injury (CI). Fruit coated with different edible coatings exhibited significantly less CI symptoms than control treatment. Gum arabic coated fruit maintained the lowest CI symptoms, whereas maximum symptoms of CI were observed in control fruit. Coating of bell pepper fruit with 12% gum arabic maintained the lowest CI symptoms which were about 5.4-fold less as compared with uncoated fruits (Figure 5)

2.14.6. Color. Coating treatments, cold storage, and interaction of treatments significantly affected the fruit color of bell pepper fruit. Lightness (L^*) of bell pepper was decreased with the advancement in storage duration, irrespective of coating treatments. Bell pepper fruit coated with 12% gum arabic exhibited 1.26-fold higher L^* value than control fruit. Similarly, skin blush value (a^*) increased with the storage period and reached the maximum on the 24th day of cold storage. The lowest value of a^* was noted in fruit coated with 12% gum arabic that was about 1.6-fold less in comparison with control. On the other hand, b^* color value declined in all the treatments with the progression of cold storage period. However, all coating treatments significantly retained higher b^* color value. Uncoated fruit exhibited maximum b^* color value; whereas the lowest value of b^* was observed in 12% gum arabic coated bell pepper fruit. Coating of bell pepper fruit with 12% gum arabic showed 1.1-fold lower b^* *value*, as compared to uncoated fruit (Table 1).

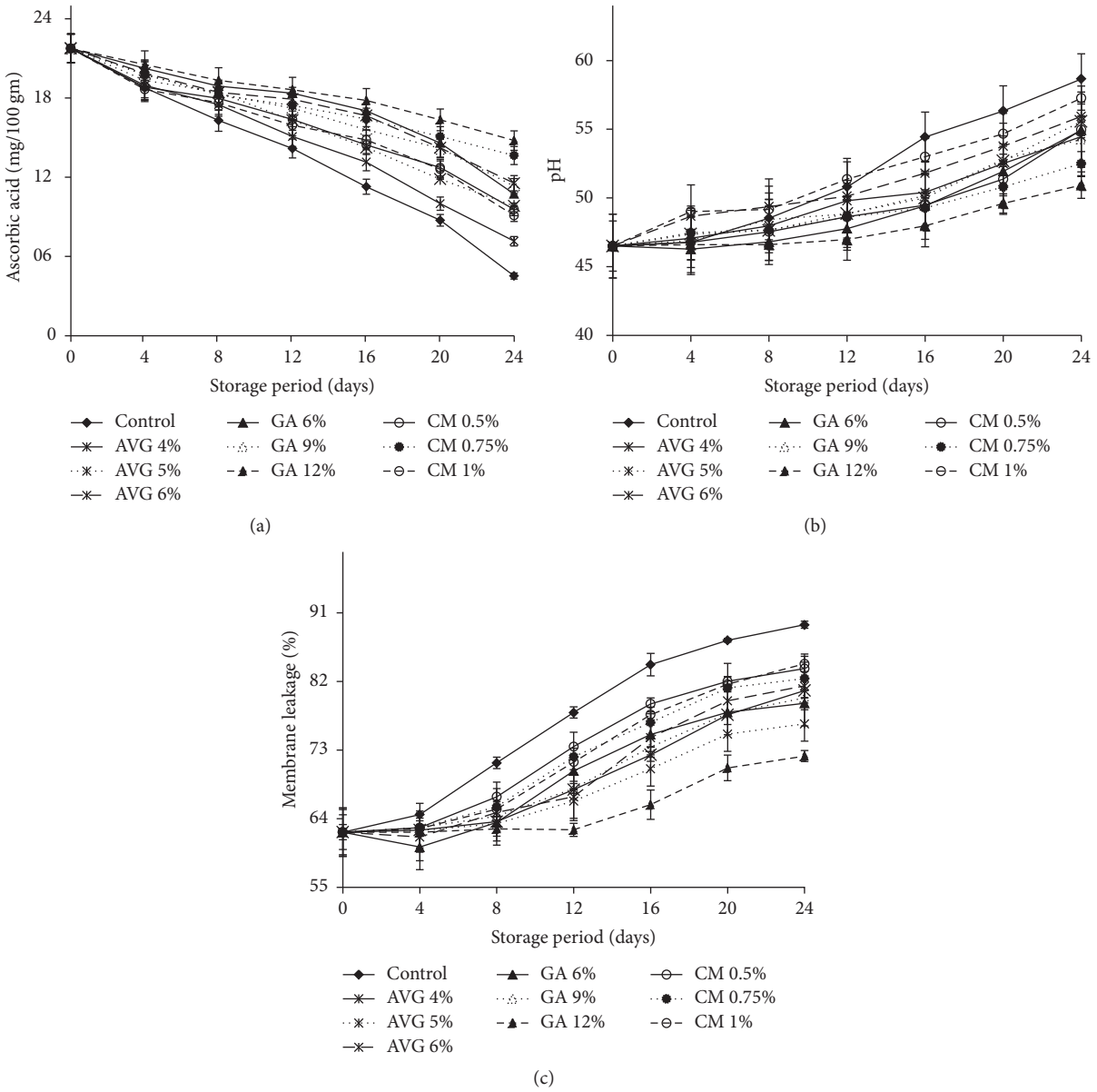

Figure 3: Effect of different coating treatments on the ascorbic acid, pH, and membrane leakage of bell pepper during cold storage at 8 ± 1°C for 24 days.

2.14.7. Reducing, Nonreducing, and Total Sugars. Coating treatments significantly affected sugar content of bell pepper fruit. Irrespective of coating treatments, an increase in reducing sugars was observed with the progression of cold storage. However, fruit coated with 12% gum arabic exhibited 3.1-fold lower increase, as compared to control. On the other hand, nonreducing sugars increased during storage period in both coated and uncoated fruit. However, after 24 days of storage, fruit treated with 4% *Aloe vera* gel coating exhibited 1.8-fold lower increase, as compared to uncoated fruit. Moreover, total sugars showed increasing trends with the advancement of cold storage period. Fruit coated with 12% gum arabic exhibited 1.4-fold lower increment in total sugars than uncoated fruit after 24 days of cold storage (Table 2).

3. Discussion

Weight loss increased gradually throughout the cold storage period irrespective of treatments, which could be due to water loss driven by active metabolic processes, such as transpiration and respiration in the fruit [41]. However, gum arabic coated fruit maintained higher weight throughout the storage period as compared to uncoated fruit. Reduced weight loss in gum arabic coated fruit could be due to the blockage of stomata and guard cells that ultimately slowed down the active metabolic processes and respiration. Moreover, reduced weight loss in gum arabic treated fruit could be attributed to the semipermeable effect of coatings during moisture loss, respiration, and movements of solutes across the membrane. Similar reduction in fruit weight loss has been

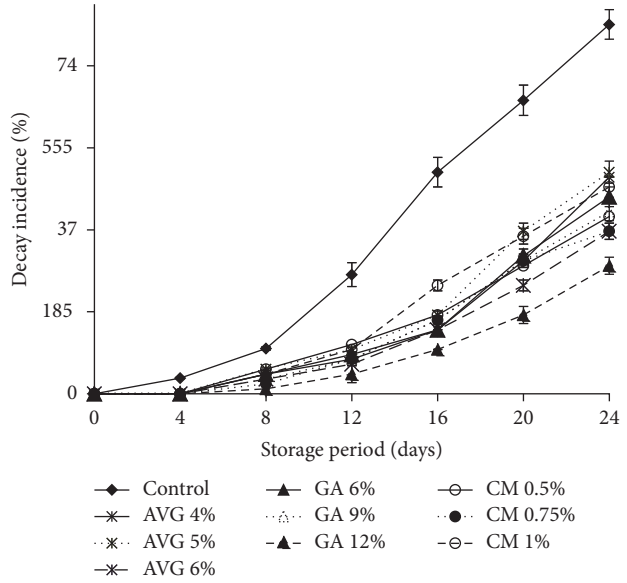

Figure 4: Effect of *Aloe vera* gel, gum arabic, and cinnamon oil coatings on the decay incidence in bell pepper during cold storage. AVG: *Aloe vera* gel; GA: gum arabic; CM: cinnamon oil.

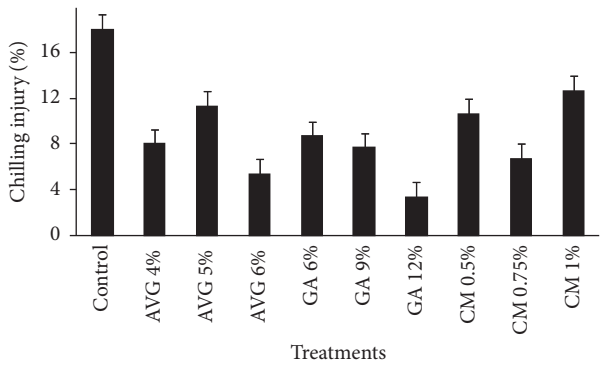

Figure 5: Effect of *Aloe vera* gel, gum arabic, and cinnamon oil coatings on chilling injury percentage of bell pepper during cold storage. AVG: *Aloe vera* gel; GA: gum arabic; CM: cinnamon oil.

reported in banana [25] and apple [18] when coated with different concentrations of gum arabic.

Similarly, bell pepper fruit dipped in edible coatings (*Aloe vera* gel, gum arabic, and cinnamon oil) also exhibited more firmness, as compared to control throughout the cold storage period. Generally, softening of the fruit increases with the progression in ripening due to the depolymerization of pectin substances [42]. Previously, softening enzymes including polygalacturonase and pectin esterase altered the cell wall and caused softening in nectarines [43]. Edible coatings might have inhibited pectin enzyme by slowing down the metabolic processes and kept bell pepper fruit firmer as reported by Mohebbi et al. [44]. Furthermore, coated bell pepper fruits might have developed resistance against compositional changes in cell wall and moisture loss, thereby resulting in reduced softening or more firmness. Our findings are in accordance with Al-Juhaimi et al. [45] who reported that cucumber fruit coated with 20% gum arabic solution notably maintained firmness by acting as a barrier against nutrients and water loss. In another study, Maqbool et al. [29] reported that banana fruit coated with gum arabic combined with chitosan efficiently maintained higher firmness during cold storage.

TSS and TA determine the flavor and nutritional status of fruit. In the current study, TSS showed an increasing trend with the progression of the cold storage period. However, fruit treated with edible coatings showed a lower increase in TSS, as compared to control. Increased TSS in untreated bell pepper fruits could be due to volatility of soluble compounds and water at a faster rate due to lack of protecting barriers [21]. A lower increase in TSS of coated bell pepper fruit might be due to delayed ripening. Our results were in agreement with the findings of Ali et al. [19] who reported that 10% gum arabic coating delayed changes in soluble solids of tomato. On the other hand, postharvest application of edible coatings retained higher TA, as compared to control. Rapid decrease in TA in uncoated fruit could be due to the increased respiration and oxidation of organic acids, whereas higher TA in coated fruit could be the result of less respiration ultimately preventing organic acids from oxidation. Previous findings showed that gum arabic coating resulted in higher TA in tomatoes [46]. Our results are in confirmation with the findings of Khaliq et al. [47] where 10% gum arabic alone or in combination with 3% calcium exhibited higher TA by preventing degradation of organic acids in mango fruit during cold storage.

Ascorbic acid content showed a gradual decline, while pH was increased with the increase in ripening during cold storage. The decrease in ascorbic acid could be attributed to the increased respiration and oxidation of acids into sugars [48]. Coated gum arabic application might have reduced oxidation of acids, thus resulting in higher values of ascorbic acid content [49]. Previously, gum arabic application maintained higher ascorbic acid content in tomato slices [50]. Our results are also in agreement with the findings of Hedayati and Niakousari [22] who reported that gum arabic significantly reduced loss in ascorbic acid contents in green bell pepper. Moreover, the linear increase in pH might be ascribed to biochemical, structural, and physiological alterations taking place during respiration. The increase in pH could be attributed to the accumulation of dry matter content and depolymerization of pepper polysaccharides under cold storage [51]. Meanwhile, membrane leakage was increased with the progression of cold storage period; however, coated bell pepper fruit exhibited reduced membrane leakage compared to the uncoated fruit. Coating treatments might have developed a protective layer around cellular membranes, thus resulting in reduced membrane leakage. Recently, gum arabic coated mango fruits maintained reduced leakage under cold storage conditions [23], whereas our results are also in agreement with the findings of Xing et al. [28] who reported reduced membrane leakage in chitosan coated sweet pepper fruit. Our results are further endorsed. Meanwhile, increased membrane leakage under low temperature storage might be due to changed composition of fatty acids that prompted membrane leakage [52].

Table 1: Effect of *Aloe vera* gel, gum arabic, and cinnamon oil on color L^*, color a^*, and color b^* of bell pepper during cold storage.

Treatments (T)	Storage period (days)							Means*
	0	4	8	12	16	20	24	
				Color L^*				
Control	39.23 a–i	37.56 h–o	34.93 s–y	34.07 w–a	32.87 z–d	31.80 c–e	30.41 e	*34.41 E*
Aloe vera gel 4%	38.83 d–j	38.88 c–j	38.93 b–j	37.31 j–p	36.42 l–t	35.74 o–w	34.92 s–y	*37.29 C*
Aloe vera gel 5%	40.77 ab	40.23 a–e	39.77 a–f	38.93 b–j	37.81 g–m	37.64 g–n	36.08 m–v	*38.75 B*
Aloe vera gel 6%	40.80 a	39.22 a–i	35.79 n–w	35.07 r–y	34.62 t–z	33.96 w–a	33.60 x–z	*36.14 D*
Gum arabic 6%	39.70 a–f	39.31 a–h	36.25 m–u	34.79 s–y	34.36 v–z	33.17 y–d	31.93 b–e	*35.65 D*
Gum arabic 9%	38.89 c–j	38.70 d–k	36.64 l–s	35.10 q–x	34.42 u–z	33.825 x–z	33.21 y–z	*35.83 D*
Gum arabic 12%	40.72 a–c	40.83 a	40.93 a	40.26 a–e	39.71 a–f	39.18 a–i	38.55 e–k	*40.03 A*
Cinnamon oil 0.5%	40.87 a	39.93 a–f	37.39 i–o	36.90 k–q	36.18 m–v	35.31 q–x	34.08 w–a	*37.24 C*
Cinnamon oil 0.75%	41.0 a	40.48 a–d	38.14 f–l	37.64 g–n	36.84 k–r	35.99 m–v	35.34 q–x	*37.92 C*
Cinnamon oil 1%	39.71 a–f	39.50 a–g	36.58 l–s	35.45 p–x	34.32 v–z	32.60 a–d	31.39 d–e	*35.65 D*
Means (T)	*40.05 A*	*39.46 A*	*37.54 B*	*36.54 C*	*35.76 D*	*34.92 E*	*33.95 F*	
				Color a^*				
Control	−18.10 z	−16.59 o	−14.48 f–j	−13.39 c–f	−12.60 b–d	−11.11 ab	−9.74 a	*−13.71 A*
Aloe vera gel 4%	−17.46 u	−16.17 k	−15.50 h–q	−14.27 e–i	−13.67 c–g	−12.70 b–e	−11.72 b	*−14.50 B*
Aloe vera gel 5%	−17.93 x	−17.32 t	−16.91 q–z	−16.28 l–v	−16.31 l–v	−15.76 i–s	−14.79 f–l	*−16.47 E*
Aloe vera gel 6%	−18.39 ab	−17.06 q	−16.29 l–w	−14.84 f–m	−14.59 f–k	−13.52 c–f	−12.45 b–d	*−15.30 C*
Gum arabic 6%	−17.27 t	−16.44 n	−15.62 i–r	−14.29 e–i	−13.53 c–g	−12.61 b–d	−11.70 b	*−14.49 B*
Gum arabic 9%	−18.05 y	−16.98 q	−16.49 n–y	−16.02 j–u	−15.31 h–p	−14.62 f–k	−13.96 d–h	*−15.92 DE*
Gum arabic 12%	−18.12 z	−17.88 w	−17.65 v–z	−17.11 r–z	−16.67 o–y	−16.30 l–u	−16.01 j–s	*−17.11 F*
Cinnamon oil 0.5%	−17.63 v	−17.23 s	−16.42 m–x	−14.94 f–n	−14.30 e–i	−13.48 c–f	−12.1 bc	*−15.17 C*
Cinnamon oil 0.75%	−18.52 b	−16.45 n	−15.98 j–u	−15.64 i–s	−14.73 f–l	−14.48 f–j	−13.51 c–f	*−15.62 CD*
Cinnamon oil 1%	−17.43 u	−16.78 p	−16.15 k–v	−15.64 i–s	−15.12 g–o	−14.26 e–i	−13.40 c–f	*−16.47 DE*
Means (T)	*−17.89 G*	*−16.89 F*	*−16.15 E*	*−15.24 D*	*−14.68 C*	*−13.88 B*	*−12.95 A*	
				Color b^*				
Control	26.51 a	23.33 f	22.98 g	21.75 j	21.43 j	19.62 t–v	19.51 u–w	*22.16 A*
Aloe vera gel 4%	25.69 b	22.61 h	22.08 i	19.93 q–t	19.81 s–u	19.40 v–y	18.44 d–g	*21.14 B*
Aloe vera gel 5%	24.65 c	22.26 i	21.08 k	20.32 n–p	19.49 u–x	19.54 uv	18.70 b–d	*20.86 C*
Aloe vera gel 6%	23.48 ef	20.65 m	19.49 u–x	19.17 x–z	18.46 c–f	17.78 jk	17.06 l	*19.44 H*
Gum arabic 6%	22.93 g	21.05 kl	19.91 r–t	19.22 w–z	19.22 w–z	18.29 f–i	17.64 k	*19.75 G*
Gum arabic 9%	23.73 de	21.61 j	20.64 m-n	20.25 o–q	20.14 p–r	18.93 z–b	18.37 e–i	*20.53 D*
Gum arabic 12%	23.00 g	20.74 lm	20.51 m–o	18.77 a–c	18.13 g–i	17.17 l	16.63 m	*19.28 I*
Cinnamon oil 0.5%	24.60 c	22.58 h	20.51 m–o	19.73 tu	19.09 y–a	18.41 d–h	18.08 ij	*20.43 D*
Cinnamon oil 0.75%	23.41 ef	20.81 k–m	20.13 r–s	19.76 tu	19.20 w–z	18.69 b–e	18.06 ij	*20.01 F*
Cinnamon oil 1%	23.92 d	21.66 j	21.43 j	19.69 t–v	19.05 za	18.09 h–j	17.55 k	*20.20 E*
Means (T)	*24.19 A*	*21.73 B*	*20.88 C*	*19.86 D*	*19.40 E*	*18.59 F*	*18.01 G*	

LSD ($P \leq 0.05$). For color L^*: T = 0.357*, SP = 0.299*, T × SP = 0.945; for color b^*: T = 0.644*, SP = 0.538*, T × SP = 1.704; for color a^*: T = 0.305*, SP = 0.255*, T × SP = 0.808. *Means not sharing the same letter are significantly different at $P \leq 0.05$.

Application of edible coatings significantly reduced decay incidence during cold storage, as compared to uncoated bell pepper fruit. Gum arabic, due to its certain film forming and antimicrobial characteristics, might have prevented pathogen attack, thereby reducing decay incidence. Our results are in line with the findings of Khaliq et al. [47] who had reported a reduced decay incident in gum arabic coated mango fruit. On the other hand, coated fruit exhibited significantly lower CI than untreated (uncoated) bell pepper fruit. Low CI symptoms in coated bell pepper fruit describe the ability of edible coatings to act as a semipermeable barrier, thereby providing extra protection to fruit against low temperature injury. De Reuck et al. [53] successfully alleviated CI in litchi fruit by using chitosan based coatings.

All coating treatments significantly retained the fruit color as compared to uncoated bell pepper fruit. Lower values of a^* and b^* with higher L^* in bell pepper could refer to the changes in epicuticular wax as a result of different coating treatments. Higher L^* value in coated bell pepper fruit describes the ability of edible coatings to delay the breakdown of chlorophyll and synthesis of carotenoids. Green color change in pepper could be due to the conversion

Table 2: Effect of *Aloe vera* gel, gum arabic, and cinnamon oil on reducing sugars (%), nonreducing sugars (%), and total sugars (%) of bell pepper during cold storage.

Treatments (T)	Storage period (days)							Means
	0	4	8	12	16	20	24	
				Reducing sugars (%)				
Control	1.64 c	2.20 y–c	3.92 r–v	6.68 m–o	8.77 h–j	10.98 c–e	13.36 a	*6.79 A*
Aloe vera gel 4%	1.64 c	2.09 z–c	3.56 t–w	4.92 qr	6.34 n–p	8.87 h–j	11.93 bc	*5.62 C*
Aloe vera gel 5%	1.64 c	2.25 x–c	3.85 s–v	5.43 pq	8.01 j–l	10.12 e–g	12.04 b	*6.19 B*
Aloe vera gel 6%	1.64 c	1.98 a–c	2.93 v–a	3.97 r–u	6.20 n–p	8.11 j–l	10.55 d–f	*5.05 D*
Gum arabic 6%	1.64 c	1.90 bc	3.24 t–x	6.06 op	7.70 kl	10.06 e–g	11.50 b–d	*6.01 B*
Gum arabic 9%	1.64 c	2.16 z–c	3.36 t–w	5.55 pq	8.18 i–k	9.90 fg	11.96 bc	*6.11 B*
Gum arabic 12%	1.64 c	1.80 bc	2.32 x–c	3.65 t–w	5.34 pq	7.11 l–n	9.13 g–i	*4.43 E*
Cinnamon oil 0.5%	1.64 c	2.02 z–c	2.75 w–b	3.94 r–u	7.14 l–n	9.37 gh	11.51 b–d	*5.48 C*
Cinnamon oil 0.75%	1.64 c	1.65 c	3.19 t–y	4.14 r–t	5.64 pq	7.68 k–m	9.54 gh	*4.78 DE*
Cinnamon oil 1%	1.64 c	1.86 bc	2.99 u–z	4.66 q–s	7.11 l–n	9.26 gh	11.41 b–d	*5.56 C*
Means (T)	*1.64 G*	*1.99 F*	*3.21 E*	*4.90 D*	*7.04 C*	*9.15 B*	*11.29 A*	
				Nonreducing sugars (%)				
Control	1.30 p–t	1.53 m–t	1.55 l–t	2.06 h–r	3.36 a–d	3.67 a	3.64 a	*2.44 AB*
Aloe vera gel 4%	1.30 p–t	1.45 m–t	0.88 t	2.11 g–r	2.42 d–m	1.71 k–t	1.94 i–s	*1.69 D*
Aloe vera gel 5%	1.30 p–t	1.01 st	0.99 st	2.09 g–r	2.05 h–r	3.03 a–h	2.15 f–p	*1.82 D*
Aloe vera gel 6%	1.30 p–t	1.22 r–t	1.44 m–t	2.28 e–p	2.40 d–m	3.07 a–g	2.08 g–q	*1.97 CD*
Gum arabic 6%	1.30 p–t	1.21 r–t	2.37 d–n	2.60 b–k	3.33 a–d	2.32 e–o	2.43 d–m	*2.22 BC*
Gum arabic 9%	1.30 p–t	1.26 q–t	2.12 f–r	2.54 c–l	3.34 a–d	3.27 a–e	2.89 a–i	*2.39 AB*
Gum arabic 12%	1.30 p–t	1.39 n–t	1.59 l–t	1.72 k–t	2.13 f–p	2.25 f–q	2.29 e–o	*1.81 D*
Cinnamon oil 0.5%	1.30 p–t	0.86 t	1.30 p–t	3.51 a–c	3.55 ab	3.11 a–f	2.81 a–j	*2.35 AB*
Cinnamon oil 0.75%	1.30 p–t	1.35 o–t	1.27 q–t	1.83 j–t	2.70 a–k	2.69 a–k	2.40 d–m	*1.93 CD*
Cinnamon oil 1%	1.30 p–t	1.24 r–t	1.38 n–t	3.08 a	3.41 a	3.47 ab	3.61 a–c	*2.31 A*
Means (T)	*1.30 C*	*1.25 C*	*1.49 C*	*2.44 B*	*2.89 A*	*2.87 A*	*2.61 AB*	
				Total sugars (%)				
Control	3.01 de	3.81 a–e	5.55 v–x	8.86 qr	12.31 h–k	14.85 b–d	17.19 a	*9.37 A*
Aloe vera gel 4%	3.01 de	3.61 a–e	4.49 yz	7.15 tu	8.89 qr	10.68 m–o	13.98 d–f	*7.40 E*
Aloe vera gel 5%	3.01 de	3.32 c–e	4.90 w–z	7.64 st	10.18 op	13.31 e–h	14.30 b–e	*8.09 CD*
Aloe vera gel 6%	3.01 de	3.27 c–e	4.45 y–b	6.38 uv	8.73 qr	11.34 k–n	12.74 g–i	*7.13 E*
Gum arabic 6%	3.01 de	3.18 c–e	5.75 vw	8.80 qr	11.22 l–n	12.51 g–j	14.06 c–e	*8.36 BC*
Gum arabic 9%	3.01 de	3.50 b–e	5.60 w	8.23 rs	11.7 j–m	13.34 e–g	15.01 bc	*8.63 B*
Gum arabic 12%	3.01 de	3.27 c–e	4.01 z–d	5.46 v–y	7.59 st	9.49 pq	11.72 i–l	*6.36 F*
Cinnamon oil 0.5%	3.01 de	2.93 e	4.12 z–c	7.64 st	10.88 l–o	12.65 g–j	14.4 b–d	*7.96 D*
Cinnamon oil 0.75%	3.01 de	3.08 de	4.53 x–z	6.06 v	8.49 q–s	10.52 n–p	13.91 d–f	*7.09 E*
Cinnamon oil 1%	3.01 de	3.17 c–e	4.45 yz	8.55 q–s	10.91 l–o	13.03 f–h	15.10 b	*8.32 B–D*
Means (T)	*3.01 F*	*3.31 F*	*4.78 E*	*7.48 D*	*10.09 C*	*12.17 B*	*14.25 A*	

LSD ($P \leq 0.05$). For reducing sugar: T = 0.192*, SP = 0.160*, T × PS = 0.508; for nonreducing sugar: T = 0.191*, SP = 159*, T × PS = 0.505; for total sugar: T = 0.196*, SP = 0.164*, T × PS = 0.520. Means not sharing the same letter are significantly different at $P \leq 0.05$.

of chloroplasts to chromoplasts pertaining to changes in pigment content of pepper fruit as ripening progresses [54], whereas the increasing trend in a^* value describes the loss of red color and formation of lycopene and β-carotene due to advancement of ripening [55]. These results clearly describe the effectiveness of edible coatings in improving the cosmetic look of bell pepper fruit by maintaining lower values of a^* and b^* with higher L^* values. Our results confirm the findings of Ali et al. [19] who reported that tomatoes coated with gum arabic delayed color change due to reduced respiration. Similarly, Ali et al. [56] illustrated that bell pepper coated with a combination of chitosan and essential oil slowed down the change in color. Furthermore, Al-Juhaimi et al. [45] reported that cucumber coated with 5–20% gum arabic retained a bright green color for 12 days under cold storage conditions.

Sugar content of bell pepper was increased throughout the cold storage period, irrespective of treatments. Higher sugar contents in uncoated bell pepper fruit may be attributed to increased metabolic activities due to which starch was converted to sugars [57]. However, bell pepper coated with

12% gum arabic exhibited a lower increase in sugar content, which may be described due to its ability to slow down the conversion of starch into sugars. Similar observations were also reported by Khan et al. [58] where putrescine treatment delayed the ripening process and maintained lower sugar levels in peach fruit.

4. Conclusions

Coating with gum arabic, *Aloe vera* gel, and cinnamon oil maintained quality and storage life of bell pepper fruit longer than control. Bell pepper coated with 12% gum arabic significantly reduced weight loss; maintained fruit firmness, ascorbic acid content, and TA; retained increment in color, CI, total soluble solids, sugars, membrane leakage, and pH; and delayed decay development. Results suggested that 12% gum arabic could be a promising treatment for extending storage life and maintaining postharvest quality of bell pepper fruit.

Additional Points

Practical Application. Bell pepper is one of the most widely used culinary purpose horticultural crops. It brings about excellent taste and flavor in a variety of foods along with excellent nutritional value. However, bell pepper is highly perishable and loses its freshness and flaccidity soon after harvest, reducing not only the visual appeal of the bell pepper fruit but also the quality. *Aloe vera* gel, cinnamon oil, and gum arabic are naturally occurring food grade edible coatings that not only preserve fruit quality but also play a protective role during cold storage. Hence, the results of this study could be used in bell pepper industry to delay the loss in freshness and improve the storage life of bell pepper fruits during cold storage.

Conflicts of Interest

The authors declare no conflicts of interest regarding the submission of this manuscript.

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Research Article

Effect of Hydroxypropyl Methylcellulose-Beeswax Composite Edible Coatings Formulated with or without Antifungal Agents on Physicochemical Properties of Plums during Cold Storage

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The influence of hydroxypropyl methylcellulose- (HPMC-) beeswax (BW) composite edible coatings formulated with or without food additives with antifungal properties on physicochemical and sensory properties of plums *(Prunus salicina)* cv. "Friar" stored for 11 and 22 d at 1°C followed by a shelf life period of 5 d at 20°C was evaluated. Food preservatives selected from previous research included potassium sorbate (PS), sodium methyl paraben (SMP), and sodium ethyl paraben (SEP). Emulsions had 7% of total solid content and were prepared with glycerol and stearic acid as plasticizer and emulsifier, respectively. All the coatings reduced plum weight and firmness loss and coated fruit showed higher titratable acidity, soluble solids content, and hue angle values at the end of the storage period. In addition, physiological disorders such as flesh browning and bleeding were reduced in coated samples compared to uncoated controls. Paraben-based coatings were the most effective in controlling weight loss and the SMP-based coating was the most effective in maintaining plum firmness. Respiration rate, sensory flavor, off-flavors, and fruit appearance were not adversely affected by the application of antifungal coatings. Overall, these results demonstrated the potential of selected edible coatings containing antifungal food additives to extend the postharvest life of plums, although further studies should focus on improving some properties of the coatings to enhance gas barrier properties and further increase storability.

1. Introduction

Postharvest fruit coating is a common practice used for many years by the industry commercializing different fresh commodities. The main objectives of this practice are extending shelf life by limiting the respiration and water loss rates and improving the visual quality of the product. Traditionally, lipid-based coatings based on waxes and resins are used for this aim since they provide a good moisture barrier and give an additional shine to the fruit [1]. However, lipid-based coatings are brittle and have poor mechanical properties [2]. At present, research efforts on postharvest coating treatments are steadily increasing towards new coating formulations based on biopolymers such as polysaccharides and proteins that can be safely consumed while contributing to meet consumer's interest in health, nutrition, and food safety. These hydrocolloids generally form a continuous structured film with superior mechanical properties and oxygen barrier properties compared to lipid-based coatings but present a low barrier to moisture due to their hydrophilic character [3, 4]. For this reason, composite edible coatings based on matrixes of polysaccharides or proteins and lipids are formulated to obtain coatings with superior mechanical and barrier properties [5]. Besides these main ingredients, several other compounds such as plasticizers, emulsifiers, antimicrobials, texture enhancers, antioxidants, flavoring agents, and nutrients can be included in coating formulations to improve coating integrity and emulsion stability and enhance functionality [6, 7].

In the last decades, the development of antimicrobial edible films and coatings has emerged as a new, effective, and environmentally friendly alternative mean to extend

the shelf life of many products including fresh fruits and vegetables. By protecting fruit from postharvest decay caused by deleterious microorganisms, these coatings provide extra functions beyond retarding fruit dehydration and reducing fruit respiration rate and ethylene production. Compounds as essential oils, organic and inorganic acids and their salts, and other permitted food additives or generally recognized as safe (GRAS) compounds have been preferred as active ingredients of antifungal edible coatings for fruits and vegetables [8–12]. These coatings are of particular interest for fruits that are not peeled for consumption and have emerged as an important alternative to the use of synthetic chemical fungicides for postharvest disease control. For instance, they could substitute synthetic waxes amended with conventional fungicides in the case of commodities such as citrus, pome fruits, stone fruits, or many tropical fruits, and they could also be of use in the case of fresh commodities such as berries, tomato, persimmon, or pomegranate, among others, to which the application of postharvest fungicide treatments is not currently allowed in the vast majority of producing countries [13].

Plums are climacteric fruits with relatively short postharvest life, usually limited by a high susceptibility to internal breakdown, loss in texture, and postharvest diseases caused by a number of fungal pathogens [14–16]. The market life of these fruit varies with the cultivar and storage conditions typically between 1 and 8 weeks [14, 15]. Storage at 0-1°C and 90–95% relative humidity (RH) has been recommended to extend the postharvest life of plums [17], but in some cases cold storage is not sufficient to significantly extend shelf life due to the appearance of chilling injury symptoms. Conversely, storage at higher temperatures can favor the development of fungal infections and increase the incidence of postharvest diseases. Technologies such as controlled and modified atmosphere packaging [18], treatment with chemicals such as oxalic acid [19] and 1-methyl cyclopropene (1-MCP) [20], and the application of edible coatings, all in combination with cold storage, have been tested for prolonging the postharvest life of plums in recent years.

Several works in the literature report that edible coatings based on whey protein [21], hydroxypropyl methylcellulose (HPMC) [2, 14, 22], alginate [23], and chitosan [24–26] preserved the postharvest quality of plums by maintaining fruit firmness and reducing weight loss, internal breakdown and respiration, and decay rates of coated plums. The effect of these coatings on weight loss, firmness, and internal breakdown greatly depended on coating composition. Thus, the addition of beeswax (BW) as a natural lipid was required to improve the moisture barrier on plums treated with HPMC coatings [14, 22], whereas the effect of these coatings on fruit firmness and volatile content greatly depended on HPMC content and plasticizer type and content [2]. Similarly, coatings formulated with essential oils as antimicrobial agents were recently tested on plum fruit and, depending on the type of essential oil and its concentration, successful results and good effects on plum quality attributes were obtained [27, 28]. In other fruits such as citrus and cherry tomatoes, the addition of organic acid salts to HPMC-based coatings to control mold growth affected the gas and moisture barrier of the coatings and the quality of coated fruit during cold storage [29, 30].

In previous studies, we evaluated a wide variety of common food preservatives (mineral salts, organic acid salts, paraben salts, and other GRAS compounds) as ingredients of HPMC-BW edible coatings against brown rot disease caused by *Monilinia fructicola* on artificially inoculated plums [8]. Among all the antifungal agents tested, parabens and potassium sorbate were found to be the best for effective control of disease severity and incidence, respectively. Although several research works on postharvest coating of plums were conducted in the past, the number of studies investigating the effects of coatings containing antimicrobial agents on the physicochemical properties of plums is very limited. Moreover, to the best of our knowledge, there are no previous studies concerning the potential effects of organic acids and their salts incorporated into coating formulations on quality attributes of plums. The objective of this work was to investigate the effect of potassium sorbate and parabens as ingredients of HPMC-BW edible composite coatings on physicochemical and sensory properties of "Friar" plum fruit stored up to 22 days at 1°C, followed by simulated commercialization period of 5 days at 20°C.

2. Materials and Methods

2.1. Edible Coating Formulation. The coatings used in the study consisted of a hydrophilic phase (HPMC; Methocel E15; Dow Chemical Co., Midland, MI, USA) and a hydrophobic phase (BW; Grade 1, Fomesa Fruitech S.L., Valencia, Spain). Glycerol and stearic acid (Panreac-Química S.A., Barcelona, Spain) were added to the formulation to serve as plasticizer and emulsifier, respectively. All the formulations contained 36% BW (dry basis, db), constant ratios of HPMC-glycerol (3 : 1, db) and BW-stearic acid (5 : 1, db), and a total solid content of 7%. For emulsion preparation, an aqueous solution of HPMC (5%, w/w) was prepared by dispersing HPMC in water at 90°C and later hydrating at 20°C. BW, glycerol, stearic acid, and water were added to the HPMC solution and this mixture was heated above 90°C to achieve complete melting of the lipids. Samples were then homogenized using a high-shear mixer (Ultra-Turrax model T25, IKA-Werke, Steufen, Germany) for 1 min at 12,000 rpm followed by 3 min at 22,000 rpm. Emulsions were cooled under agitation to a temperature below 25°C by placing them in a water bath while maintaining agitation for 25 min to ensure complete hydration of HPMC. Finally, potassium sorbate (PS), sodium methylparaben (SMP), or sodium ethylparaben (SEP) (Merck KGaA, Darmstadt, Germany) were added to the emulsions under magnetic agitation to achieve final concentrations of 1% PS or 0.1% SMP or SEP in the coating formulations. These antifungal agents and their concentrations had been previously selected as the most effective in controlling brown rot on inoculated plums [8]. Viscosity and pH values of the emulsions were measured with a viscosimeter (Visco Star Plus R, Fungilab S.A., Barcelona, Spain) and a pH-meter (Consort C830 multiparameter analyzer, Turnhout, Belgium), respectively. Formulations were kept for 24 h at 5°C before use. The emulsions were checked for stability according to the method

described by Valencia-Chamorro et al. [11], observing no phase separation after 24 h at 25°C.

2.2. Fruit and Coating Application. Plums (*Prunus salicina* Lindl.) cv. "Friar" were supplied by Cooperativa del Camp de Llutxent-Otos S.C.V. (Llutxent, Vall d'Albaida, Valencia, Spain). Fruit were commercially grown and no postharvest treatments were applied. After arrival to the laboratory, fruit were examined for various sorts of external damage, surface-sanitized for 4 min with a diluted bleach solution (0.5% sodium hypochlorite), rinsed in tap water, and air-dried for 24 h at room temperature (23–25°C). Then, plums were randomly divided into 10 groups of 50 fruit each, which corresponded to five different treatments and two different storage periods. Uncoated fruit and fruit coated with coatings formulated without the addition of antimicrobial agents were designated as Control A and Control B, respectively. The other three treatments corresponded to coating formulations containing PS, SMP, or SEP as antifungal ingredients. Plums were coated individually as described by Bai et al. [31]. For this aim, 300 μL of emulsion was pipetted onto each fruit and rubbed manually to mimic the application of industrial coating machinery in fresh produce packing-lines. Coated fruit were drained on a mesh screen and allowed to air-dry at room temperature. Coated fruit and control samples were then placed on plastic trays on corrugated cartons and stored up to 22 days at 1°C and 90% RH. In order to simulate industrial storage and retail conditions, physicochemical and sensory analyses were conducted at harvest, after 11 and 22 d of storage at 1°C, and after a shelf life period of 5 d at 20°C.

2.3. Effect of the Coatings on Fruit Quality

2.3.1. Weight Loss. Weight loss during storage was determined by individually weighing 20 fruits per treatment at the beginning and the end of each storage period with an analytical balance. Results were expressed as the percentage of initial weight loss.

2.3.2. Fruit Flesh Firmness. Fruit flesh firmness was measured using an Instron Universal Testing Machine (Model 4301, Instron Limited, Bucks, UK). A thin disk of the skin of about 2 cm in diameter was removed from each of the opposite cheeks of the fruit and firmness was determined as the maximum force in Newtons (N) required to penetrate the fruit flesh with a plunger of 8 mm diameter. Twenty plums were used per treatment and average values were calculated.

2.3.3. Peel Color. Surface color of 20 plums per treatment was measured with a colorimeter (Model CR-400, Minolta, Tokyo, Japan) using the CIELAB color parameters L^*, a^*, b^*, chroma (C^*), and hue angle (h°). Each measurement was taken at three different locations of the fruit. C^* and h° values were calculated according to the formula given below.

$$\text{Chroma}\,(C^*) = \left\lfloor (a^*)^2 + (b^*)^2 \right\rfloor^{1/2},$$
$$\text{Hue}\ \ (h^\circ) = \arctan\left(\frac{b^*}{a^*}\right). \tag{1}$$

2.3.4. Internal Quality. The assessed internal quality attributes were soluble solids content (SSC), titratable acidity (TA), and maturity index (MI) of the plum juice. SSC was measured with a digital refractometer (Model PR1, Atago Co. Ltd., Tokyo, Japan) and values were expressed as g sucrose per 100 mL of juice. TA acidity was determined by titrating 5 mL of juice with 0.1 M sodium hydroxide to an end point of pH 8.1 using an automatic titrator (Model T50, Mettler Toledo, Greifensee, Switzerland) and results were expressed as g malic acid equivalent per 100 mL of juice. MI was calculated as the ratio between SSC and TA. For each treatment, three juice samples from 10 fruit each were prepared and three different readings were performed. Average values were expressed as mean ± standard error of the mean.

2.3.5. Physiological Disorders. A total of 30 samples per treatment, which corresponded to 3 replicates of 10 fruit each, were examined for the main postharvest physiological disorders of plums. These are caused by chilling injury and their main symptoms are flesh browning and/or bleeding [32]. Fruit were halved and the mesocarp and the area around the pit were visually inspected for browning and bleeding at the end of storage periods at 20°C. Samples were rated on a scale ranging from 1 (none) to 5 (severe) for browning and a scale from 1 (none) to 3 (severe) for bleeding [32]. The severity for each disorder was calculated as an average index of the three replicates. For each replicate, the severity index was calculated as follows:

$$\text{Index} = \frac{\sum (\text{number of fruits with each scale} * \text{scale})}{\text{Total number of fruits}}. \tag{2}$$

2.3.6. Respiration Rate. The effect of coating application on plum respiration rate was measured through a closed system. Five fruits were individually analyzed for each treatment. Samples were weighed and placed in 250 mL glass jars. Then, the jars were sealed and incubated at 20°C for 2 h. After the incubation period, 1 mL of the gas in the headspace of the jar was withdrawn using a microsyringe and injected into a gas chromatograph (GC) (Thermo Trace, Thermo Fisher Scientific, Inc., Waltham, MA, USA). The GC was equipped with a thermal conductivity detector (TCD) and fitted with a Poropack QS 80/100 column (1.2 m × 0.32 cm i.d.). Temperatures were 35, 115, and 150°C for the oven, injector, and TCD, respectively. The carrier gas was helium with a flow rate of 22 mL/min. A standard gas mixture of oxygen (O_2) and carbon dioxide (CO_2) (15.0 : 2.5%) was used and the CO_2 concentration in the samples was calculated according to the peak areas of the samples and the standard. Results were expressed as mg CO_2/kg h.

2.3.7. Ethanol and Acetaldehyde Contents. Ethanol and acetaldehyde concentrations were determined from the headspace of the juice samples by GC. Juice samples (5 mL) were transferred into glass vials with crimp-top caps and PTFE/silicone septum seals. Samples were frozen and stored at −18°C till analysis. At the time of analysis, the equilibrium

in the headspace of the vials was achieved by placing them in a water bath at 20°C for 1 h, followed by 10 min at 60°C. One mL of the gas in the headspace of the vial was withdrawn using a microsyringe and injected to the GC. The GC was equipped with a flame ionization detector (FID), fitted with a Poropack QS 80/100 (1.2 m × 0.32 cm i.d.), and used helium as carrier gas at a flow rate of 28 mL/min. Temperatures were 150, 175, and 200°C for the oven, injector, and FID, respectively. Analytical standards of ethanol and acetaldehyde were used and their concentrations in the headspace of the juice samples were calculated according to the areas under their peaks. Three replicates of 10 fruit per treatment were analyzed and results were expressed as mg of volatile compounds per L of juice.

2.3.8. Sensory Analyses. Sensory analysis was conducted by 10 trained panelists according to the general guidance of ISO 8586:2012 [33] at the end of each storage period. For each treatment, samples from various fruit were portioned, coded with randomly chosen 3-digit numbers, and served on plastic plates at room temperature. Panelists were requested to use different qualitative scales to rate flavor (from very poor = 1 to optimum = 9), off-flavors (from absence = 1 to high presence = 5), and firmness (from very low = 1 to very high = 5) of the samples. The judges had to taste various segments of each sample in order to compensate, as far as possible, for biological variation of the material. Spring water was provided for palate rinsing between samples. External aspect of the fruit was also evaluated using a 3-point scale (bad = 1, acceptable = 2, and good = 3).

2.4. Statistical Analysis. Experimental data were subjected to analysis of variance (ANOVA) to determine the significant differences among treatments. Duncan's multiple range test, at a significance level of $P = 0.05$, was used to separate means from different treatments. All analyses were performed with the software Statgraphics Plus 5.1 (Statpoint Technologies Inc., Warrenton, VA, USA).

3. Results and Discussion

3.1. Fruit Weight Loss. The effect of the different coatings on plum weight loss is shown in Figure 1. As expected, weight loss increased with storage time, reaching a maximum value of 2.48% in uncoated control samples stored for 22 d at 1°C plus 5 d at 20°C. The HPMC-BW coatings, with or without antifungal agents, significantly reduced weight loss compared to control samples, being the coatings containing paraben salts more effective than those containing PS. In previous studies conducted with plums [22, 28] and other fruits [34, 35], cellulose-lipid coatings were also reported to reduce weight loss probably due to the moisture barrier exerted by the lipid ingredients of the coating formulation. In plums, which are in general naturally covered with a continuous wax layer that provides high resistance to water movement across the cuticle, Navarro-Tarazaga et al. [22] reported no differences on weight loss between uncoated and HPMC-coated plums with no lipids, which indicated that, in order to improve moisture barrier of plums, coatings must contain a hydrophobic compound.

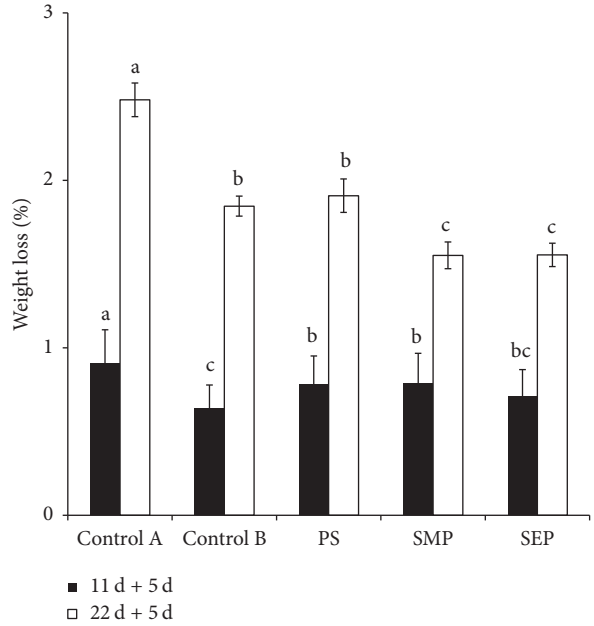

Figure 1: Weight loss of "Friar" plums uncoated or coated with hydroxypropyl methylcellulose-beeswax edible coatings containing potassium sorbate (PS), sodium methyl paraben (SMP), or sodium ethyl paraben (SEP) and stored for 11 and 22 d at 1°C followed by 5 d at 20°C. Control A: uncoated; Control B: coating without antifungal agent. For each storage time, bars with different letters are significantly different according to Duncan's range test ($P < 0.05$) ($n = 20$).

On the other hand, Valencia-Chamorro et al. [11] reported that the presence of minor ingredients such as food preservatives or GRAS salts in HPMC-lipid edible films had an important effect on their barrier properties, which was attributed to changes in the network structure of the polymer matrix. In that study, HPMC-BW films formulated with paraben salts had lower water vapor permeability than films with organic acid salts like for instance PS. In the present work, the addition of the paraben salts SMP or SEP to the coating matrix had a positive effect for the reduction of weight loss of coated plums, whereas the addition of PS did not modify the moisture barrier properties of the HPMC-BW coating formulated without food preservative (Control B). These observations are in agreement with permeability results reported by Valencia-Chamorro et al. [11]. However, other research works conducted with fresh fruits indicated that the coating performance reducing weight loss did not always correlate with the water vapor permeability of stand-alone films, because physical, physiological, and biochemical properties of the skin and/or the flesh of the fruit have a crucial effect in the coating final performance and they typically show important differences among fruit species and even among cultivars. Thus, for instance, Fagundes et al. [29] observed higher weight loss values on cherry tomatoes coated with HPMC-BW emulsions containing parabens than on fruit

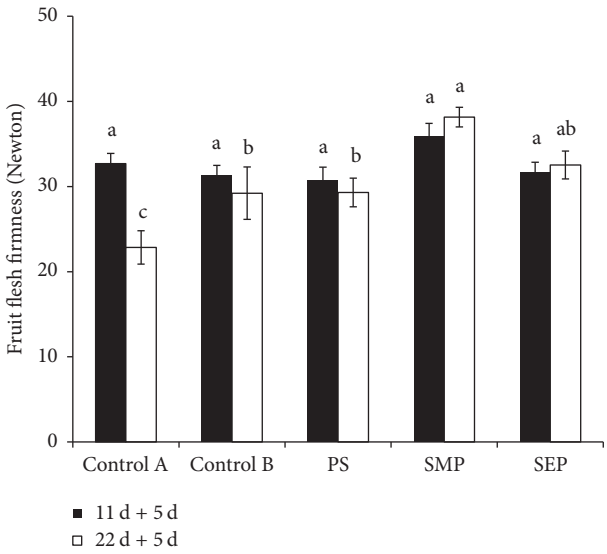

Figure 2: Fruit flesh firmness of "Friar" plums uncoated or coated with hydroxypropyl methylcellulose-beeswax edible coatings containing potassium sorbate (PS), sodium methyl paraben (SMP), or sodium ethyl paraben (SEP) and stored for 11 and 22 d at 1°C followed by 5 d at 20°C. Firmness at harvest was 47.08 ± 1.61 N. Control A: uncoated; Control B: coating without antifungal agent. For each storage time, bars with different letters are significantly different according to Duncan's range test ($P < 0.05$) ($n = 20$).

coated with other antifungals such as sodium benzoate. In other works, the influence of HPMC-based coatings containing PS on weight loss of citrus fruits greatly depended on fruit cultivar, and the performance of the coatings was significantly enhanced when PS was used in combination with other organic salts [30, 36].

3.2. Fruit Flesh Firmness. Flesh firmness of coated and uncoated samples is shown in Figure 2. Softening is a quality defect that compromises the shelf life and commercialization of many fruits and particularly of plums. For this reason, plums destined for cold storage and/or long-distance transportation are picked with high levels of firmness. In the present work, "Friar" plums were very firm at harvest (47.08 ± 1.61 N), but their firmness significantly decreased during storage to values in the range of 30–38 N for coated plums and 22 N for uncoated plums. It is known that polysaccharides present in the cell wall such as pectin, starch, and hemicellulose mainly contribute to the firmness of the fruit. Degradation of these compounds by hydrolyzing enzymes like pectin methylesterase and polygalacturonase causes softening of the fruit during ripening and storage [15]. The capacity of edible coatings to modify the internal gas composition of the fruit in terms of O_2 and CO_2 concentrations might influence the activities of the cell wall degrading enzymes, reducing fruit softening. In the present study, there were no significant differences among firmness values of uncoated (Control A) and coated samples stored for 11 d at 1°C plus 5 d at 20°C ($P > 0.05$). However, firmness of coated samples (with and without antifungal agents) was significantly higher than that of the uncoated Control A after storage for 22 d at 1°C plus 5 d at 20°C ($P < 0.05$), revealing the beneficial effect of coating application to reduce plum softening. The following order SMP > SEP > PS was observed for coatings containing antifungal agents in terms of fruit firmness control on coated plums, although the difference between coatings containing SEP and PS was not statistically significant ($P > 0.05$). HPMC-based coatings amended with PS and paraben salts had been previously reported as effective in reducing firmness loss of coated "Clemenules" mandarins [30]. According to those findings, parabens were the best agents not only for fruit firmness maintenance but also for weight loss control. This behavior is also confirmed in the present work. Therefore, it can be suggested that, in the case of plums and mandarins, the application of coatings containing parabens positively affects the relationship between fruit firmness and weight loss, leading to a significant extension of postharvest life. On the contrary, Fagundes et al. [29] reported that HPMC-BW coatings containing SMP or SEP failed to control both firmness and weight loss of cherry tomatoes.

3.3. Peel Color. Color values for coated and uncoated samples after 22 d at 1°C plus 5 d of storage at 20°C are given in Table 1. All the color parameters evaluated (L^*, a^*, b^*, C^*, and h°) significantly decreased from those at harvest, indicating less vivid colors and a peel color change from green to red due to the ongoing ripening process during the storage period [37]. At the end of storage, coated plums maintained higher b^* and h° values than uncoated samples (Control A) and no differences among treatments were observed in a^* and C^* values. On the other hand, the highest and the lowest L^* values were recorded for the samples coated with coatings containing PS and SEP, respectively. Coatings containing parabens and PS were also tested for peel color maintenance of strawberries [38] and tomatoes [29], with relatively successful results. The differences in lightness observed in our work could be an indication of the effect of the coatings in fruit gloss. The decrease of b^* and h° (which indicates more reddish tonalities) from the initial values at harvest was higher for uncoated (Control A) than for coated samples, demonstrating that coating applications may delay fruit ripening by creating an inner modified atmosphere in the fruit. In a similar way, Choi et al. [28] reported relative lower decreases in h° values on coated than on uncoated plums.

3.4. Internal Quality. The initial TA, SSC, and MI values of plum (values at harvest) were 1.83 ± 0.09 g malic acid/100 mL, 13.67 ± 0.19 g sucrose/100 mL, and 7.5 ± 0.29, respectively. During storage, TA decreased and MI increased consequently, whereas SSC was maintained practically constant (Table 2). Decrease in TA of plums typically occurs during postharvest storage and depends on cultivar and maturity stage at harvest. This has been attributed to the use of organic acids as substrates in the respiratory metabolism [23]. Coating application delayed acidity losses in plums compared to uncoated controls, which could be related to a decrease in weight loss and a slow-down in respiration rate and metabolic activity [39]. The higher TA of coated samples translated into

Table 1: Color values of "Friar" plums uncoated or coated with hydroxypropyl methylcellulose-beeswax edible coatings containing potassium sorbate (PS), sodium methyl paraben (SMP), or sodium ethyl paraben (SEP) and stored for 22 d at 1°C followed by 5 d at 20°C.

Food preservative	L^*	a^*	b^*	C^*	h°
Control A[i]	25.43 ± 0.43^{ab}	6.82 ± 0.74^{a}	0.32 ± 0.26^{b}	6.90 ± 0.74^{a}	3.17 ± 1.84^{b}
Control B[i]	24.59 ± 0.45^{bc}	7.34 ± 0.85^{a}	1.98 ± 0.34^{a}	7.61 ± 0.91^{a}	13.61 ± 0.76^{a}
PS	26.07 ± 0.39^{a}	7.13 ± 0.76^{a}	1.70 ± 0.29^{a}	7.35 ± 0.80^{a}	12.30 ± 0.85^{a}
SMP	24.86 ± 0.40^{ab}	6.59 ± 0.69^{a}	1.54 ± 0.24^{a}	6.78 ± 0.73^{a}	13.19 ± 0.98^{a}
SEP	23.53 ± 0.27^{c}	6.59 ± 0.74^{a}	1.66 ± 0.28^{a}	6.81 ± 0.79^{a}	12.96 ± 0.77^{a}

Values at harvest: $L^* = 32.64 \pm 0.67$; $a^* = 11.66 \pm 0.57$; $b^* = 6.10 \pm 0.88$; $C^* = 13.49 \pm 0.55$; $h^\circ = 23.03 \pm 2.59$; [i]Control A: uncoated; Control B: coating without antifungal agent. Mean values with different letters within the same column are significantly different according to Duncan's multiple range test ($P < 0.05$) (mean ± SE; $n = 20$).

Table 2: Titratable acidity (TA), soluble solid content (SSC), and maturity index (MI) of "Friar" plums uncoated or coated with hydroxypropyl methylcellulose-beeswax edible coatings containing potassium sorbate (PS), sodium methyl paraben (SMP), or sodium ethyl paraben (SEP) and stored for 22 d at 1°C followed by 5 d at 20°C.

Food preservative	TA (g malic acid 100 mL^{-1})	SSC (g sucrose 100 mL^{-1})	MI
Control A[i]	1.04 ± 0.03^{c}	13.23 ± 0.07^{a}	12.69 ± 0.28^{a}
Control B[i]	1.40 ± 0.06^{a}	13.52 ± 0.03^{a}	9.60 ± 0.41^{c}
PS	1.38 ± 0.05^{a}	13.68 ± 0.12^{a}	9.97 ± 0.41^{bc}
SMP	1.38 ± 0.02^{a}	13.40 ± 0.13^{a}	9.74 ± 0.24^{c}
SEP	1.25 ± 0.03^{b}	13.50 ± 0.03^{a}	10.78 ± 0.22^{b}

Values at harvest: TA = 1.83 ± 0.09 g malic acid/100 mL; SSC = 13.67 ± 0.19 g sucrose/100 mL; MI = 7.5 ± 0.29; [i]Control A: uncoated; Control B: coating without antifungal agent. Mean values with different letters within the same column are significantly different according to Duncan's multiple range test ($P < 0.05$) (mean ± SE; $n = 3$).

MI values lower than those of control fruit, and SEP-coated samples had the highest MI. On the other hand, there were no significant differences in SSC among the different treatments.

3.5. Physiological Disorders. Physiological disorders reported for plums include mealiness, flesh browning, black pit cavity, translucency, lack of juiciness, and flesh bleeding (red pigment accumulation). These physiological disorders are reported as chilling injury symptoms (internal breakdown) and the degree of incidence depends majorly on cultivar, physiological stage at harvest, and storage conditions [32]. In this work, flesh bleeding and browning were the main symptoms observed on "Friar" plums at the end of the evaluated storage period. Both symptoms were significantly reduced by HPMC-based coatings and no significant differences were observed among coating treatments (data not shown). Severity of flesh browning was light (value of 2 within a scale from 1 = none to 5 = severe) and practically negligible (value of 1) in control and coated plums, respectively. Fruit flesh bleeding typically occurs as a result of anthocyanins diffusion from their original locations in the cells near the skin and/or the stone to the rest of plum flesh, and it has been attributed to tissue senescence or abnormal ripening due to chilling injury [22]. In this work, uncoated "Friar" plums showed a moderate level of flesh bleeding after storage (value of 2 within a scale from 1 = none to 3 = severe), whereas coated samples showed no flesh bleeding (index of 1). Similar results were reported for "Autumn Giant" and "Angeleno" plums [14, 22]. These authors observed that internal physiological disorders after prolonged cold storage at 1°C followed by a shelf life period at 20°C were significantly reduced by coating application, which was attributed to the gas barrier provided by the coatings and the consequent creation of a modified atmosphere in the fruit.

3.6. Respiration Rate. The effect of the application of coatings on CO_2 production rate of "Friar" plums during cold storage plus shelf life at 20°C is given in Table 3. CO_2 production rates of uncoated plums (Control A) increased when compared with the initial value in samples stored for 11 d at 1°C plus 5 d at 20°C, probably coinciding with the climacteric peak. After this storage period, CO_2 production of coated samples was significantly lower than that of uncoated ones (Control A), indicating that the coatings reduced the respiration peak of the plums. On the other hand, in samples stored for 22 d at 1°C plus 5 d at 20°C, although coated samples had lower CO_2 production rates than uncoated plums, the differences were not significant ($P > 0.05$). As reported above in agreement with other workers, the effect of edible coatings on delaying changes related to fruit ripening, such as softening, color change, decrease in acidity, or some physiological disorders has been associated with the gas barrier exerted on the fruit surface leading to reductions in respiration rate and/or weight loss [23, 29]. In the present work, HPMC-BW coatings significantly reduced weight loss and seemed to retard the natural physiological ripening process by reducing the initial respiration peak of "Friar" plums, which could explain their effect

Table 3: CO_2 production rate and ethanol and acetaldehyde content in the juice of "Friar" plums uncoated or coated with hydroxypropyl methylcellulose-beeswax edible coatings containing potassium sorbate (PS), sodium methyl paraben (SMP), or sodium ethyl paraben (SEP) and stored at 1°C for 11 or 22 d followed by 5 d at 20°C.

Food preservative	11 d at 1°C + 5 d at 20°C			22 d at 1°C + 5 d at 20°C		
	CO_2 (mL kg^{-1} h^{-1})	Ethanol (mg L^{-1})	Acetaldehyde (mg L^{-1})	CO_2 (mL kg^{-1} h^{-1})	Ethanol (mg L^{-1})	Acetaldehyde (mg L^{-1})
Control A[i]	29.47 ± 4.24[a]	0.29 ± 0.02[c]	0.18 ± 0.01[b]	20.34 ± 1.40[a]	2.14 ± 0.23[b]	0.55 ± 0.06[a]
Control B[i]	20.40 ± 0.15[b]	0.98 ± 0.05[b]	0.18 ± 0.01[b]	18.74 ± 1.46[a]	1.13 ± 0.11[cd]	0.28 ± 0.02[b]
PS	24.75 ± 2.58[ab]	1.46 ± 0.16[ab]	0.22 ± 0.02[a]	18.64 ± 1.17[a]	4.26 ± 0.36[a]	0.33 ± 0.03[b]
SMP	18.46 ± 1.00[b]	1.40 ± 0.16[b]	0.21 ± 0.01[a]	14.53 ± 1.17[a]	0.58 ± 0.02[cd]	0.24 ± 0.02[b]
SEP	17.04 ± 1.21[b]	1.56 ± 0.14[a]	0.24 ± 0.01[a]	18.06 ± 1.52[a]	1.39 ± 0.26[c]	0.25 ± 0.02[b]

At harvest: CO_2 production rate = 20.02 ± 0.71 mL/kg∗h; ethanol content = 0.36 ± 0.12 mg/L; acetaldehyde content = 0.10 ± 0.02 mg/L; [i]Control A: uncoated; Control B: coating without antifungal agent. Mean values with different letters within the same column are significantly different according to Duncan's multiple range test ($P < 0.05$) (mean ± SE; $n = 3$).

on the reduction of firmness loss, color change, or physiological disorders at the end of the evaluated storage period. In any case, these effects were limited and it could be expected that an improvement in the gas barrier properties of these coatings would have a greater effect on the physiological response of the fruit. Overall, the coatings containing paraben salts resulted in the lowest CO_2 production rates after both storage periods tested, showing the potential of these coatings as gas barriers on plums, although the formulations might be optimized to improve the gas barrier properties. In contrast, Valencia-Chamorro et al. [11] reported an increase in O_2 permeability of HPMC-lipid edible films amended with SEP and Fagundes et al. [29], working with similar coatings amended with a variety of antifungal agents, observed the highest respiration rates in cherry tomatoes coated with emulsions containing SEP. This confirms that the capacity of an edible coating to create an effective gas barrier depends not only on the coating composition and properties, but also on the commodity, cultivar, and storage conditions.

3.7. Ethanol and Acetaldehyde Contents. Fresh fruit coatings constitute a gas barrier on the surface of the fruit that reduces internal O_2 and increases internal CO_2 concentrations. This typically translates in an increase in ethanol and acetaldehyde volatiles that depends on the barrier properties of the coating, the commodity, and the storage conditions (basically temperature and duration). In this work, the results confirmed the creation of a modified atmosphere in coated plums stored for 11 d at 1°C plus 5 d at 20°C, with higher ethanol and acetaldehyde contents than in uncoated samples ($P < 0.05$; Table 3). After this storage period, treatments with HPMC-BW coatings formulated with antifungal agents generally induced higher ethanol contents than coatings formulated with no agents (Control B). However, the effect of coatings on the increase of ethanol and acetaldehyde contents in the fruit was not observed at the end of the storage period, after 22 d at 1°C plus 5 d at 20°C. At this time, coated samples presented lower ethanol and acetaldehyde contents than uncoated plums, with the exception of the coating containing PS, which induced higher ethanol level. These results could be related to the limited gas barrier of the coatings observed at the end of the storage period and the lack of influence of the coatings on the plum CO_2 production rate (Table 3). In general, ethanol and acetaldehyde contents of uncoated "Friar" plums after 22 d at 1°C plus 5°C at 20°C were low, indicating that this cultivar does not accumulate anaerobic metabolites if proper storage conditions are used. Similar values were reported for "Angeleno" and "Autumn Giant" plums after 2 and 4 weeks of storage at 1°C plus a 3–5 d period of shelf life at 20°C [2, 14]. In these works, the application of HPMC-BW coatings significantly increased the ethanol and acetaldehyde contents in juice, but only for those coatings that had higher HPMC content (i.e., lower BW content), whereas an increase in BW content above 20% (db), with the consequence reduction of HPMC, significantly decreased the gas barrier of the coatings and the accumulation of these volatiles in the fruit juice to levels that were not significantly different from those of uncoated samples. However, in other fruits such as mandarins and cherry tomatoes, the use of similar HPMC-BW coatings resulted in an increase up to tenfold of ethanol in juice [29, 40].

3.8. Sensory Properties. Trained panelists performed a sensory evaluation to assess coating influence on external appearance, flavor (overall flavor and induction of off-flavors), and firmness of plums. At harvest, plums were evaluated as having a good external appearance (2.0 ± 0.2 in a qualitative scale from 1 = bad to 3 = very good), a medium overall flavor (4.8 ± 0.4 in scale from 1 = bad to 9 = excellent) that was associated with the high acidity of the fruit, absence of off-flavors (value of 1 in a scale from 1 = absence to 5 = high presence), and a very high firmness (4.6 ± 0.2 in scale from 1 = very soft to 5 = very firm). At the end of the storage period of 22 d at 1°C plus 5 d at 20°C, these sensory quality attributes were scored in the range from 1.5–2.9, 4.6–5.4, 1.2–1.4, and 3.6–3.8 for appearance, overall flavor, off-flavors, and firmness, respectively. Statistical analysis showed no significant differences among treatments or storage times ($P > 0.05$) for off-flavors, firmness, and flavor of plums (data not shown). The results for flavor are in agreement with the low volatile levels detected in the fruit juice after coating application. With regard to firmness, the high values at harvest possibly contributed to maintaining high fruit firmness during storage, which could probably explain why

the differences observed instrumentally between coated and uncoated plums were not detected by the sensory panel (Figure 2). On the other hand, plums treated with the PS-based coating were scored with the highest appearance values among all tested samples, which correlated with the highest L^* values of these samples. In general, HPMC-BW emulsion coatings are not characterized for providing significant gloss to coated fruits such as citrus or tomatoes, mainly due to the macroemulsion character of the coating formulation [29, 30, 36]. In the case of many plum cultivars, the epicuticular wax of the fruit surface usually forms a whitish film that reduces the natural gloss of the fruit. Therefore, differences in external appearance by the application of emulsion edible coatings were not generally significant compared to uncoated samples.

4. Conclusion

HPMC-BW coatings containing the food additives SEP, SMP, or PS, selected from previous research as effective coatings to reduce brown rot of plums caused by *M. fructicola*, could be of use as nonpolluting postharvest treatments to maintain fruit quality of "Friar" plums during cold storage at 1°C followed by a shelf life period at 20°C. These coatings delayed the postharvest ripening process, reduced weight and firmness loss, and minimized color change and physiological disorders of the fruit. The lowest weight loss was achieved with the use of paraben salts and the highest L^* values were obtained with the use of PS in the coating formulations. Further research is required to improve the gas barrier properties of these coatings, as well as to determine the effect of different concentrations of the food preservatives used in the present study and optimize coating composition for the best postharvest performance and maximum fruit shelf life extension. In addition, the effect of these antifungal coatings should be tested for other plum cultivars in order to broaden the spectrum of action and facilitate the commercial adoption by the industry of these coating formulations as sustainable and environmentally safe means for enhanced postharvest fruit preservation.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Guar Gum as an Edible Coating for Enhancing Shelf-Life and Improving Postharvest Quality of Roma Tomato (*Solanum lycopersicum* L.)

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There exists an increasing interest from consumers and scientific community in developing edible-natural-biodegradable coatings to replace commercial wax-based coatings for maintaining postharvest quality of vegetables. In this work, the effectiveness of guar gum coating on various quality characteristics of Roma tomato at 22 ± 2°C over a 20 d storage period was investigated. Tomatoes were covered with a 1.5% guar gum coating plasticized with glycerol at 30% and stored at 22 ± 2°C and 40% RH for 20-d. Tomatoes covered with edible coating significantly enhanced firmness and reduced weight loss, delayed changes on soluble-solids-content, retarded loss of total acidity, and decreased respiration rate compared with uncoated-control fruit. Sensory analysis by trained panelists revealed that the use of the edible coating influenced the acceptability of tomatoes. There were significant differences on the scores given by panelists when comparing the coated and uncoated tomatoes. It was concluded that guar gum affected favorably the physicochemical, microbial, and sensorial quality properties of Roma tomato and therefore could be beneficial in delaying the ripening process at 22 ± 2°C.

1. Introduction

Tomatoes *(Solanum lycopersicum L.)* have become essential ingredients in the cuisine of many countries. This fruit has limited marketability because of its high moisture content and high degree of perishability which leads to extensive postharvest losses. Storage life is limited by several factors, for example, transpiration, postharvest diseases, increased ripening, and senescence [1]. Of all these factors, the most important is respiration rate, due to its association with tomato postharvest shelf-life, fruit ripening, and deterioration of tomato quality [2].

One way to control tomato ripening is through the manipulation of ambient temperature, gas, and humidity. At low storage temperature, it is possible to maintain freshness and extend shelf-life as the respiration rate and thermal

decomposition are reduced [3, 4]. Controlled atmosphere and hypobaric storage can extend shelf-life of tomatoes but these processes are costly. An alternative to extend postharvest life and keep production costs low is the use of edible coatings [5].

Edible coatings generate a modified atmosphere by creating a semipermeable barrier against O_2, CO_2, moisture, and solute movement, thus reducing respiration, water loss, and oxidation reaction rates [2]. Different materials have been used as edible coatings and are commonly based on proteins, lipids, or polysaccharides [6]. The great benefit conferred by edible coatings is that these are natural biodegradable products [7, 8].

Guar gum is a galactomannan rich flour, water soluble polysaccharide obtained from the leguminous Indian cluster bean *Cyamopsis tetragonoloba* (L.) *Taub.* The backbone of this hydrocolloid is a linear chain of D-mannopyranose units connected to each other by β-1,4-bonds linked to galactose residues by 1,6- bonds forming short side-branches [9–11]. Guar gum is one of the most important thickeners and is a versatile material for many food applications due to its different physicochemical properties as well as its high availability, low cost, and biodegradability. This galactomannan has similar properties as carrageenan, alginate, xanthan gum, and gum arabic as an edible coating but guar gum has the advantage of being cheaper than all the others. Moreover, the availability of guar gum is not a problem since it is produced in the north of Mexico by a Mexican company, Guar Growers Mexico.

The aim of the present study was to evaluate the potential of the guar gum edible coating on the extension of shelf-life and maintaining the quality of Roma tomato fruit during a 20-day storage period at 22 ± 2°C. This temperature was selected because there are several studies about postharvest with tomato using room temperature between 20 and 25°C [2, 8, 12, 13].

2. Materials and Methods

2.1. Plant Material. Freshly harvested tomato *(Solanum lycopersicum L. vc Pyriform)* fruit at light red stage of ripening according to the USDA standard tomato color classification chart [14] were obtained from a commercial supplier in Saltillo, Mexico. The fruits with an average weight of 14.55 g were visually sorted for uniformity in size, color, absence of blemishes, and fungal infection. Tomatoes were transported to the laboratory within 1 h of purchase. Before treatment, fruits were washed with sodium hypochlorite solution (200 mg kg^{-1}) for 2 minutes and air-dried at ambient temperature (22 ± 2°C).

2.2. Coating Treatment. Guar gum (G4129-500G) was from Sigma-Aldrich (St. Louis, MO, USA) and glycerol was from Jalmek Co. (Monterrey, Mexico). Guar gum coating solution was prepared using 1.5% (w/v) guar gum and 30% (v/v) glycerol; 0.3 mL of glycerol and 1.5 g of guar gum were dissolved in 100 mL distilled water, formulation selected according to previous research reported by Ruelas-Chacón et al. (2017). The solution was stirred at 800 rpm at 60°C during 30 minutes on a magnetic stirrer/hot plate (Talboys, Thorofare, New Jersey, USA) [15].

A total of 108 tomato fruits were randomly allotted to two groups: uncoated (UC) and coated (C). Tomatoes in the UC group were immersed in distilled water for 1 minute and the C group was immersed in the guar gum coating solution for 1 minute. Fruits were air-dried for 5 h at 22 ± 2°C. All samples were left in a chamber at ambient temperature and 40% RH for 20 days.

2.3. Weight Loss Percentage. The tomato samples, UC and C, (three samples per repetition) were weighted at days 0, 4, 8, 12, 16, and 20 during the storage period. The difference between initial and final fruit weight (to the nearest 0.001 g) was considered as total weight loss during the storage intervals and calculated as percentages on a fresh weight basis [16].

2.4. Color. The color characteristics were assessed using a Minolta Chroma Meter CR-400 (Minolta Corp, Ramsey, New Jersey, USA) to measure L (lightness of brightness), a^* and b^* values. Three measurements were taken for each treatment and the averages of L, a^*, and b^* values were obtained following the procedure described by Maftoonazad et al. [17].

2.5. Firmness. The firmness of tomatoes in each treatment group was determined using a digital Force Gauge penetrometer (PCE-PTR 200, PCE group, Albacete, Castilla la Mancha, Spain), equipped with an 8 mm plunger tip, at the equator of the fruit where a section of rid (4 cm × 4 cm, approximately) had been removed. Results were expressed in newtons (N). Three readings were taken for each tomato [4].

2.6. Soluble Solid Concentration (SSC). Three tomatoes per treatment were analyzed at each sampling day (0, 4, 8, 12, 16, and 20). Each tomato was ground with a Master Craft processor (Blender 9 in 1 EC51034, Soriana Stores S.A. de CV, Monterrey, Mexico) during 1 min. SSC of the ground tomatoes was measured following the AOAC (1984) method using an ATAGO refractometer (ATAGO, USA Inc., Bellevue, WA, USA) at ambient temperature (22 ± 2°C). The SSC concentration was expressed as percentage on the Brix scale.

2.7. Total Acidity (TA). Two milliliters of ground tomato was diluted with 30 mL of distilled water. The titration of the samples was done with NaOH 0.01 N at pH 8.3. Three readings for each treatment were recorded per sampled day and the means of these measurements were expressed as citric acid and then used for statistical analyzes [18, 19].

2.8. Microbial Analysis. Surface skin (2 cm^2) of UC and C tomatoes at 0, 4, 8, 12, 16, and 20 days of storage at ambient temperature was peeled off with a sterile scalpel. Ten grams of skin samples was immersed in 90 mL of peptone water and vortexed for 2 min (Vortex-Genie 2, Scientific Industries, Inc., Bohemia, NY, USA). The microbial analysis consisted of a plate count method for aerobic mesophilic bacteria at 30°C in

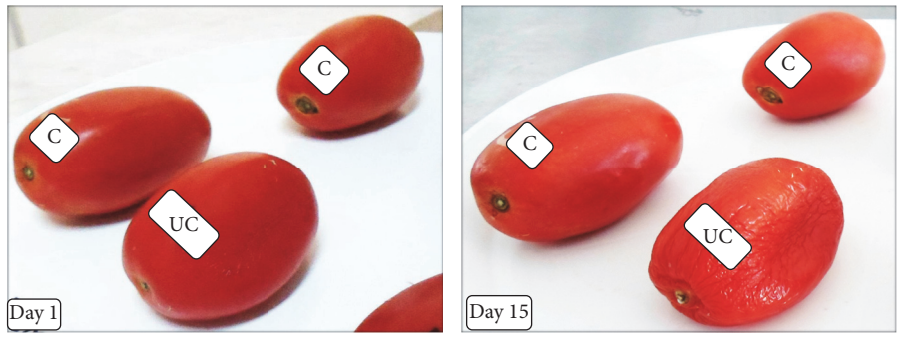

Figure 1: Effect of storage period (day 1 and day 15) on Roma tomatoes coated with guar gum (C) and uncoated (UC), under ambient temperature conditions (22 ± 2°C).

plate count agar (PCA) over 48 h and yeast and molds at 25°C in potato dextrose agar (PDA) over 72 h. Visible colonies were counted and CFU/g calculated [8, 20].

2.9. Respiration Rate. Respiration of samples was analyzed periodically in a closed and hermetic system. The samples (three tomatoes per jar) were randomly distributed in the glass containers with a capacity of 1.80 liter at ambient temperature (22 ± 2°C). The ratio between container capacity and amount of tomato was 600 : 100 (v-w, mL-g). Gas samples were taken from the jar with a needle inserted through a septum fixed at the center of the jar lid. The needle was connected to CO_2/O_2 gas analyzer (PBI Dansensor Gas Analyzer, Checkmate II, Denmark). The results in percentage a CO_2 were used for calculation of the respiration rate ($mL\,kg^{-1}h^{-1}$), using the following equation:

$$\text{Respiration rate is} = \frac{\%CO_2}{(\text{Mass of sample in kg} * \text{hours incubated} * \text{volume jar})} \quad (1)$$

2.10. Sensory Evaluation. A panel of 15 trained judges analyzed visual appearance, flavor (taste), and firmness during days 1, 5, and 10 of the storage period. Evaluations were scored based on a nine-point scale (1 = extremely poor, 3 = poor, 5 = acceptable, limit of marketability, 7 = good, and 9 = excellent [20]). The overall appreciation of the sample was measured on the same scale and referred to as overall quality [21].

2.11. Statistical Analysis. Data were subjected to one-way analysis of variance (ANOVA) with three replications, using the JMP 5.0.1 software (SAS Institute Inc. Cary, NC, USA), including a Least Significant Difference Test. The Tukey test was used to compare the mean values in different storage intervals. Statistical differences were declared at $p < 0.05$.

3. Results and Discussion

The guar gum coating adhered well to the Roma tomato surface and exhibited a transparent appearance. All tomato fruits shrank during the 20-day storage period; coated treatment shrank less rapidly than the uncoated one.

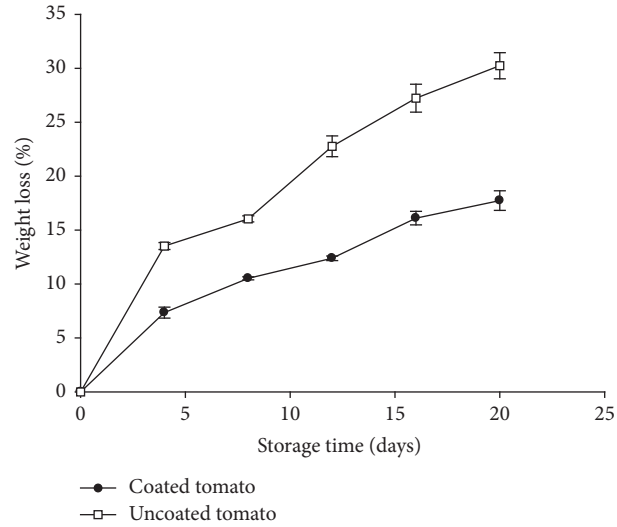

Figure 2: Effect of guar gum coating on weight loss of Roma tomatoes during a 20-day storage period (22 ± 2°C).

3.1. Weight Loss. Figure 1 shows changes on tomato fruits (UC and C) from day 1 and day 15 during storage time. UC tomato from day 15 lost weight and shrank, and C tomatoes, at the same time of storage, look different compared to the UC fruits. Visually the difference is evident, so the application of guar gum coating retarded the weight loss of tomato fruit during the storage period.

Figure 2 shows the weight loss of the UC and C tomatoes. The fruits exhibited significant difference ($p \leq 0.05$): the C tomatoes exhibited comparatively lower weight loss than the UC fruits. It can be inferred that the guar gum coating formed a semipermeable layer, which allows passage of certain small molecules but acts as a barrier to others, and acted as protective barrier to reduce respiration and transpiration on the fruit surface and conferred a physical barrier against O_2, CO_2, moisture, and solute movement, reducing water loss [12, 22].

Our results are in agreement with findings of Ali et al. [2], where water loss of tomato fruit was reduced by coating with gum arabic. Rice starch-based coating has been effective in controlling weight loss in tomatoes stored at room temperature [8]. Ahmed et al. [20] used delactosed whey

Table 1: Changes in L, a^*, b^*, and chroma (C^*) color values of guar gum coated tomatoes at different storage time intervals.

Color parameter	Storage time (days)	Uncoated	Coated
L	0	42.59 ± 0.51^b	43.49 ± 0.55^a
	4	44.89 ± 0.61^b	46.05 ± 0.31^a
	8	39.43 ± 0.14^b	41.63 ± 0.89^a
	12	44.46 ± 0.25^b	49.24 ± 0.30^a
	16	44.82 ± 0.21^b	44.81 ± 0.26^a
	20	43.52 ± 0.28^b	45.08 ± 0.39^a
a^*	0	22.33 ± 0.26^a	20.46 ± 0.56^b
	4	24.66 ± 0.24^a	20.81 ± 0.74^b
	8	26.00 ± 0.89^a	19.77 ± 0.61^b
	12	26.74 ± 0.68^a	20.90 ± 0.73^b
	16	27.78 ± 0.89^a	22.77 ± 0.77^b
	20	28.91 ± 0.55^a	23.76 ± 0.91^b
b^*	0	21.39 ± 0.73^a	19.46 ± 0.94^a
	4	18.18 ± 0.89^a	18.78 ± 0.86^a
	8	20.38 ± 0.93^a	20.00 ± 0.75^a
	12	23.24 ± 0.34^a	18.91 ± 0.23^a
	16	13.17 ± 0.36^a	17.64 ± 0.95^a
	20	20.32 ± 0.16^a	17.41 ± 0.94^a
C^*	0	30.92 ± 0.83^a	28.24 ± 0.66^b
	4	30.64 ± 0.79^a	28.03 ± 0.79^b
	8	33.03 ± 0.43^a	28.12 ± 0.84^b
	12	35.43 ± 0.89^a	28.19 ± 0.27^b
	16	33.19 ± 0.76^a	29.42 ± 0.67^b
	20	35.34 ± 0.20^a	29.46 ± 0.38^b

[ab]Means in the same raw followed by a different superscript differ by Tuckey's test at $p \leq 0.05$.

coating on tomatoes and reduced weight loss during storage period, the application of protein-phenolic based coating on tomatoes also retarded weight loss [12], and El-Ghaouth et al. [23] using chitosan on tomatoes extended shelf-life by reducing weight loss and other quality postharvest parameters.

Chitosan coatings have been effective in controlling weight loss from other vegetables, including papaya [24], cucumber and pepper [23], longan fruit [25], and strawberry fruit [26]. The obtained results are also in good agreement with the findings by Bai et al. [27] who reported that an efficient reduction in weight loss was found in coated "Delicious" apples.

3.2. Color. The changes on CIELAB parameters of C and UC tomatoes during the storage time at ambient temperature ($22 \pm 2^{\circ}$C) are shown in Table 1. There was a significant difference in L values when comparing the treated and untreated tomatoes. C tomatoes presented a higher visual brightness compared to the UC samples. It is important to say that there were not significant differences between fruits during the storage period.

These results agree with findings of Athmaselvi et al. [28] and Santoso and Rahmat [29], where L values were higher for tomatoes treated with *Aloe vera* based edible coating. Parameter a^* was different ($p \leq 0.05$) between treatments during the 20-day trial; a^* values change from light red reading to red color [30]. The a^* values (red color) for UC tomatoes were higher ($p \leq 0.05$) than for the C ones, whereas no differences were observed on b^* values between the UC and the C fruits. This could be attributed to the modified atmosphere in the fruit created by the guar gum coating which influenced the respiration rate delaying color variation between treatments more than on the storage period itself.

The chroma (C^*) values were maintained during storage on C tomatoes (Table 1) and they significantly increase in UC samples after storage. The higher C^* values on UC samples indicated higher saturation related to the redness stage of ripening.

During ripening, the green pigment chlorophyll degrades and carotenoids are synthesized [31] from colorless precursor (phytoene) to carotene (pale yellow), lycopene (red), β-carotene (orange), xanthophylls, and hydroxylated carotenoids (yellow) [5, 32] given the variation in the values of color parameters.

3.3. Firmness. In this study, firmness of fruit decreased ($p \leq 0.05$) with storage time in both C and UC fruit (Figure 3). The firmness of UC tomatoes decreased ($p \leq 0.05$) more rapidly than C tomatoes. After the fourth day, deterioration of firmness increased substantially and steadily, being more accentuated in UC fruits. Reduction of firmness in the UC sample was 72% compared to 46% of the C tomatoes after 20 days of storage (Figure 3). Firmness data were correlated versus respiration rate and the Pearson correlation

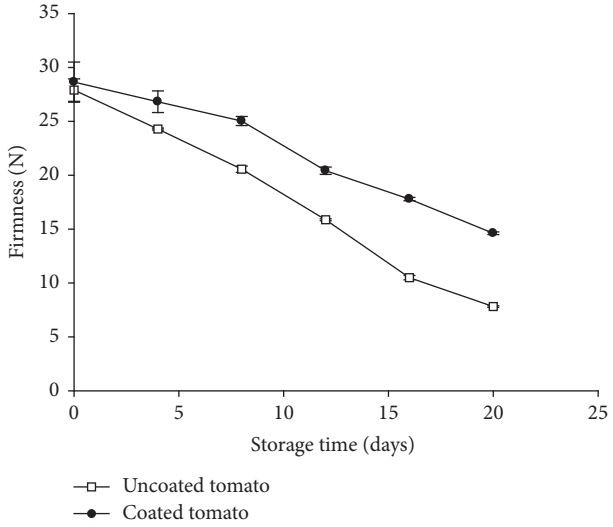

Figure 3: Effect of guar gum coating on the firmness of Roma tomatoes during a 20-day storage period (22 ± 2°C).

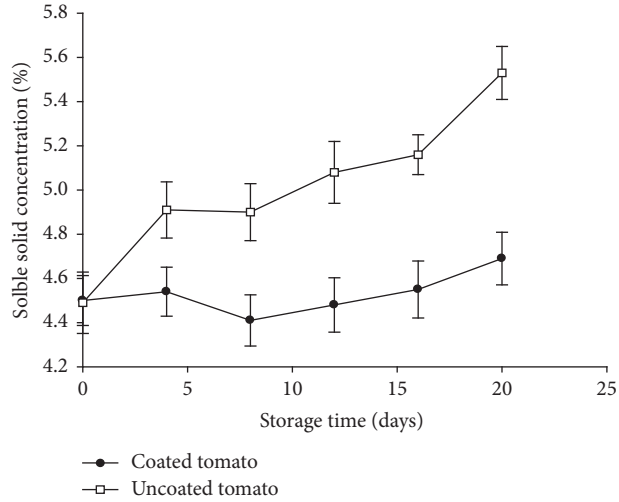

Figure 4: Influence of guar gum coating on the soluble solid concentration of Roma tomatoes during a 20-day storage period (22 ± 2°C).

coefficient was −0.763, meaning that if values of respiration rate increased the values for firmness decreased, probably due to the enzymatic activities during the ripening process [29, 33, 34]. Softening of fruits is due to deterioration in the cell wall composition [33] and it is a biochemical process involving the hydrolysis of pectin and starch by enzymes such as hydrolases, pectinesterase, and polygalacturonase [34]. High levels of CO_2 propitiated by coating on the fruit can limit the activity of these enzymes which allows maintenance of firmness during storage.

3.4. Soluble Solids Concentration. In general, there was a gradual increase in SSC during the complete storage period (Figure 4). For UC samples were 18.2% whereas for C fruits were only 4.26% (Figure 4). The SSC at 20 days of storage was higher ($p \leq 0.05$) in UC (5.5%) compared to C fruits (4.7%) from the initial SSC which was 4.5% for UC and C tomatoes.

The lowest SSC at the end of the storage period was recorded in fruit coated with guar gum and showed that the coatings provided a good semipermeable barrier around the fruit, modifying the internal atmosphere by reducing or elevating CO_2 production. As a result, decreased respiration rates slowed down the synthesis and use of metabolites resulting in lower SSC [2, 18, 34]. Variations in SSC are correlated with hydrolytic changes in polysaccharides (hemicellulose and pectin) with ripening in postharvest storage. The degradation of the cell wall polysaccharides that occur during storage period in tomatoes leads to the release of oligosaccharins which can affect fruit ripening [8].

3.5. Total Acidity. In the present trial, total acidity values of C and UC fruit during storage decreased with storage time (Figure 5) and the values were higher ($p \leq 0.05$) in UC fruit (0.41%) compared to the C samples (0.35%). This response occurs because the citric acid content increases with maturity and stage of ripening [3, 22]; however, once fruit reach the full ripe stage, citric acid content starts to decline [35]. The guar

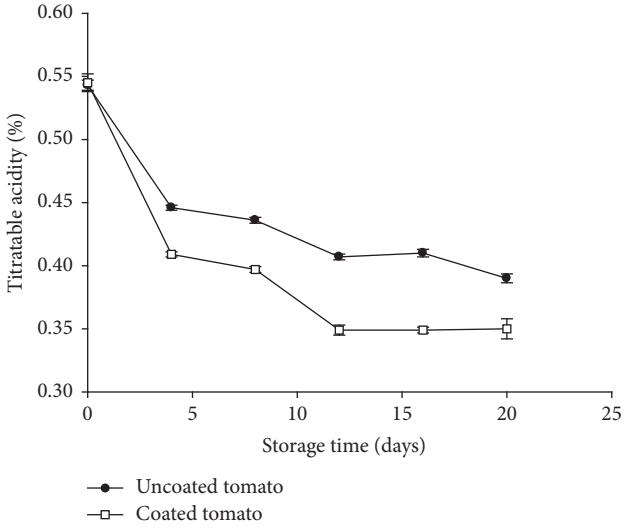

Figure 5: Total acidity response of tomatoes coated with guar gum during a 20-day storage period at ambient temperature (22 ± 2°C).

gum coating slowed down the synthesis of citric acid during ripening; this effect is shown in Figure 5. The higher TA level in control fruit suggests that coating delayed ripening by providing a barrier against O_2 uptake around the fruit [33, 36, 37].

The acidity of tomato is very important for the taste of the fruit. The effect of coating on internal quality parameters is dependent on coating type, fruit cultivar, and storage conditions. In tomato, Das et al. [8] found greater values for TA in uncoated fruit than in fruit coated with rice starch-based coatings. This was attributed to higher ethylene production and respiration rate in uncoated fruit during ripening. In the same trial, higher values of TA were also reported in uncoated than in coated tomatoes. The higher TA values on uncoated samples than on coated ones were attributed to the loss of citric acid in tomatoes as fruit ripened [13, 38].

Table 2: Microbial plate counts of uncoated and coated (edible guar gum) Roma tomatoes.

	Uncoated		Coated	
Storage time (days)	0	20	0	20
Mesophilic bacteria (CFU/g)	480[a]	1460[a]	480[b]	960[b]
Yeast and molds (CFU/g)	520[a]	1580[a]	530[b]	1030[b]

Means followed by different letters in the same column are significantly different by Tuckey's test $p \leq 0.05$.

3.6. Microbial Analysis. Microbial count for mesophilic bacteria and yeast and molds increased as storage time increased for both treatments (Table 2). The colony forming units (CFU/g) for mesophilic bacteria were different ($p \leq 0.05$) for UC tomatoes from days 0 to 20 (480 and 1460 CFU/g). In C tomatoes, there was also a significant difference from days 0 to 20 (480 and 960 CFU/g) but the CFU/g on UC samples were higher than in C ones. The CFU/g values for yeast and molds showed significant differences ($p \leq 0.05$) between treatments. The CFU/g for UC samples were 520 and 1580 CFU/g for days 0 and 20, respectively. Regarding the C fruits, the CFU/g were 530 for day 0 and 1030 for day 20. Pearson's correlation coefficient for mesophilic bacteria versus respiration rate was 0.978 and for yeast and molds versus respiration rate was 0.980; these are strong correlations between variables. As the respiration rate of the fruits increased the deterioration of the fruit does too, given the conditions such as nutrient availability for the microorganisms to develop. The protective effect provided by the edible guar gum coating seems to reduce the rate of development of microorganisms that affect the quality of tomatoes, because the coating acts as a barrier of gases and other substances such as water or other nutrients needed for the growth of microorganisms [39]. Further, protective coating offers an additional barrier to microorganism contamination during storage. This is also evident from results reported here.

3.7. Respiration Rate. The effect of coatings on respiration rate of Roma tomatoes stored at ambient temperature (22 ± 2°C) is shown in Figure 6. All samples increased the respiration rate during storage, which indicates an increase in the fruit metabolic activity. After 20 d, the C tomatoes had the lowest CO_2 production (2.8, mL kg^{-1}h^{-1}) compared with the UC tomatoes (10.7, mL kg^{-1}h^{-1}), indicating that coating might have modified the internal atmosphere and significantly delayed respiration rate of Roma tomatoes. Respiration rate in fresh fruit and vegetables is considered good index for determination of storage life [38]. The effect of polysaccharide-based coatings on respiration of horticultural products is related to their ability to create a barrier to oxygen diffusion through the coating [40]. In tomatoes, coatings based on gum arabic [38], alginate or zein [41], and hydroxyl propyl methyl cellulose (HPMC) also reduced the fruit respiration rate during storage [7, 42].

A reduction in respiration rate as a result of coating has also been reported by many researchers in various fruit, such as papaya, grapes, mango, strawberries, and tomatoes [23, 24, 29, 39, 43].

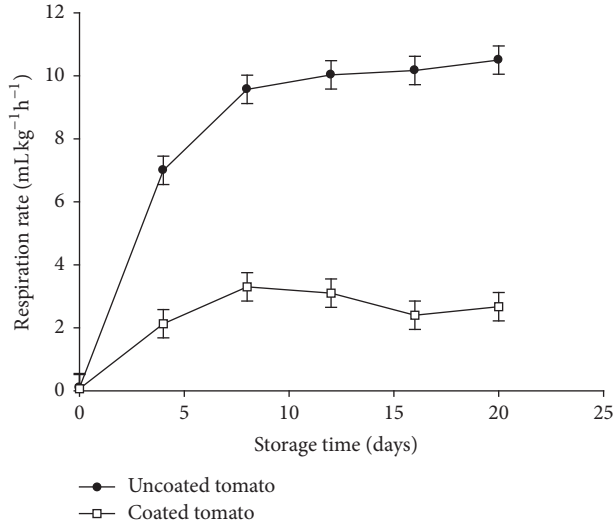

Figure 6: Influence of guar gum coating on the respiration rate of Roma tomatoes during a 20-day storage period at ambient temperature (22 ± 2°C).

3.8. Sensory Evaluation. Sensory evaluation of C and UC fruit at the end of the storage period revealed differences ($p \leq 0.05$) in appearance, flavor, firmness, and overall acceptability (Figure 7). On day 0, there were no significant differences ($p \leq 0.05$) detected for all the attributes evaluated. As storage time increased (Figure 7; days 5 and 10), there were significant differences ($p \leq 0.05$) detected by the panelists in favor of the C tomatoes on appearance, flavor, firmness, and overall acceptability. The effect of guar gum coating on tomatoes helps to slow down the ripening process [29, 39] that influence the quality attributes of the samples evaluated. On Figure 7, it can be seen that there were significant differences on appearance, flavor, firmness, and overall acceptability of C and UC tomatoes. Other authors report similar findings: the application of a coating helps maintain texture firmness [13, 29, 39], color, and flavor changes [2, 13, 38, 39], on different products such as apples, and tomatoes, using several types of coatings at ambient temperature (22 ± 2°C).

The scores given by the panelists to all the attributes were between 9 and 7, which is interpreted as "excellent" to "good." These results suggest that the guar gum coating can be used to prolong the shelf-life and improve tomato quality during storage at ambient temperature (22 ± 2°C). C and UC Roma tomato were not sensory analyzed after 10 days of storage based on the microbiological results.

4. Conclusions

The present study shows that coating Roma tomatoes with guar gum delayed the ripening process by inhibiting the respiration rate of this fruit. This suggests that guar gum coating not only maintained firmness but also improved the postharvest quality during storage at ambient temperature.

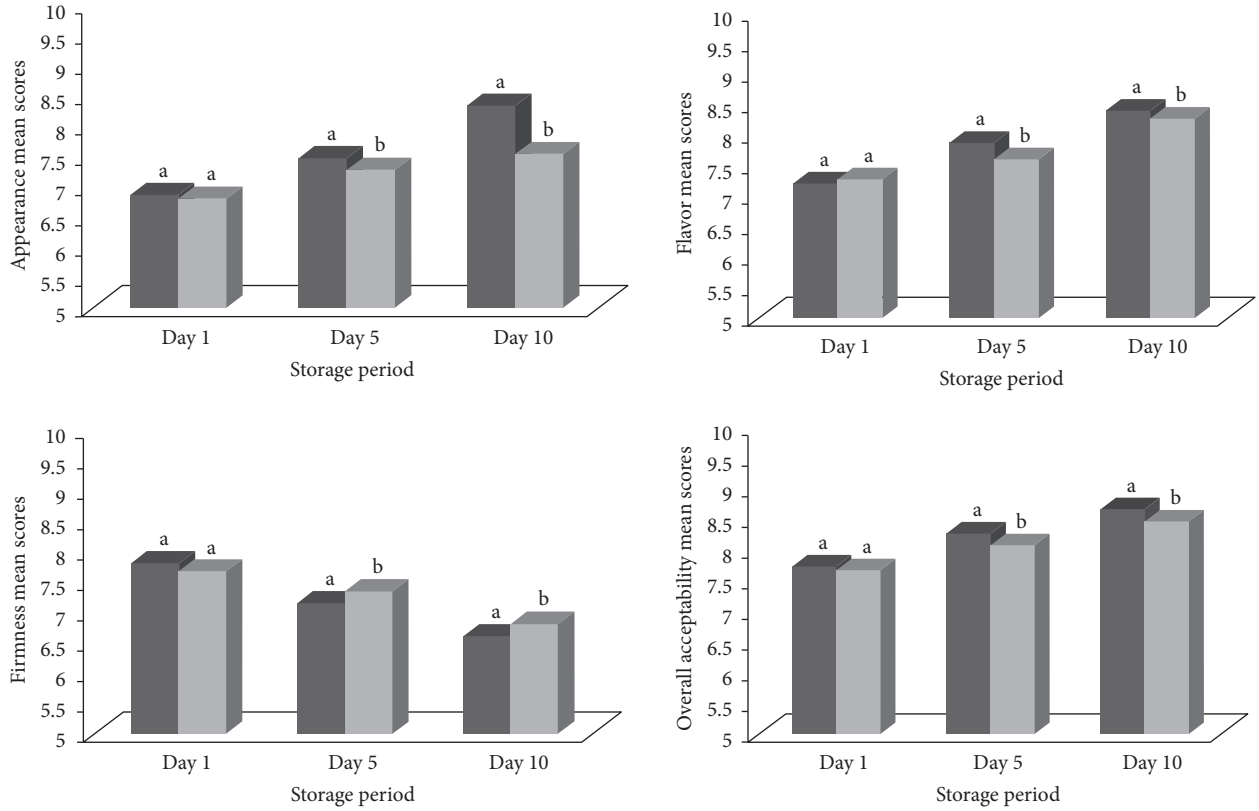

Figure 7: Sensory evaluation of uncoated (dark gray) and coated (light gray) tomatoes stored at 22 ± 2°C for 10 days. Scores designated by different letters are significantly different ($p \leq 0.05$) for each attribute. Three different trials were carried out in triplicate. The scale corresponds to 9 = excellent and 1 = extremely poor.

The guar gum coating is biodegradable, easily applied, and less expensive (compared with other hydrocolloids and commercial waxes) and it can be used commercially to prolong the storage life of Roma tomatoes.

For future studies, it is still necessary to improve its water vapor barrier properties, perhaps by adding specific lipid components in order to increase the postharvest storage quality at ambient temperature and cold storage.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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