Journal of
Composites Science

MDPI

Article

Composite Coatings of Gellan Gum and Inulin with *Lactobacillus casei*: Enhancing the Post-Harvest Quality of Guava

Rafael Emilio González-Cuello [1,*], Leidy Mendoza-Nova [2], Virginia Consuelo Rodriguez-Rodriguez [2], Joaquín Hernández-Fernández [3,4,5] and Rodrigo Ortega-Toro [1,*]

1 Food Packaging and Shelf-Life Research Group (FP&SL), Food Engineering Program, Universidad de Cartagena, Cartagena de Indias D.T. y C. 130015, Colombia
2 Grupo de Investigaciones Microbiológicas y Biomédicas de Córdoba (GIMBIC), Programa de Bacteriología, Universidad de Córdoba, Carrera 6 #77-305, Montería 230002, Colombia; leidymendozan@correo.unicordoba.edu.co (L.M.-N.); vrodriguez@correo.unicordoba.edu.co (V.C.R.-R.)
3 Chemistry Program, Department of Natural and Exact Sciences, San Pablo Campus, Universidad de Cartagena, Cartagena de Indias D.T. y C. 130015, Colombia; jhernandezf@unicartagena.edu.co
4 Chemical Engineering Program, School of Engineering, Universidad Tecnológica de Bolívar, Parque Industrialy Tecnológico Carlos Vélez Pombo Km 1 Vía Turbaco, Cartagena de Indias 130001, Colombia
5 Department of Natural and Exact Science, Universidad de la Costa, Barranquilla 080002, Colombia
* Correspondence: rgonzalezc1@unicartagena.edu.co (R.E.G.-C.); rortegap1@unicartagena.edu.co (R.O.-T.)

Abstract: Guava is a highly sought-after tropical fruit in the market due to its high content of vitamins, minerals, antioxidants, and other phenolic compounds. However, due to its climacteric nature, it has a short post-harvest shelf life. The aim of this study was to develop coatings based on gellan gum (GG) and inulin (IN) incorporating *Lactobacillus casei*, which were tested for their potential ability to extend the post-harvest shelf life of whole guava fruit. The coatings were prepared using the following formulations: 0.5 GG/1.0 IN (*w*/*v*), 0.8 GG/5.0 IN (*w*/*v*), 0.5 GG/1.0 IN(*w*/*v*), and 0.8 GG/5.0 IN (*w*/*v*). The coated and uncoated (control) fruits were stored at 25 °C for 12 days, and various quality attributes were evaluated (including respiration rate, soluble solids, titratable acidity, weight loss, total phenol content, and color). The results indicated that the application of the coatings reduced weight loss, color change, and respiration rate in the fruits. However, the 0.8 GG/5.0 IN (*w*/*v*) formulation provided the best maintenance of post-harvest quality for the fruit evaluated. The coatings with a higher inulin content showed the highest growth of *L. casei*, which could enhance the antimicrobial effect of the coating. Therefore, the combined application of *L. casei* and inulin in coatings based on gellan gum can be considered an effective treatment to extend the shelf life and preserve the quality of guava fruits.

Keywords: post-harvest quality; gellan gum; guava; coatings; lactic acid bacteria

Citation: González-Cuello, R.E.; Mendoza-Nova, L.; Rodriguez-Rodriguez, V.C.; Hernández-Fernández, J.; Ortega-Toro, R. Composite Coatings of Gellan Gum and Inulin with *Lactobacillus casei*: Enhancing the Post-Harvest Quality of Guava. *J. Compos. Sci.* **2024**, *8*, 353. https://doi.org/10.3390/jcs8090353

Academic Editors: Kuppusamy Kanagaraj, Natesan Thirumalaivasan and Jeevithan Elango

Received: 23 July 2024
Revised: 1 September 2024
Accepted: 5 September 2024
Published: 9 September 2024

1. Introduction

Guava (*Psidium guajava*) is a fruit native to tropical regions with economic importance, particularly in the agro-industrial sector, due to its flavor, aroma, and nutritional characteristics attributed to its content of vitamins (A and C) and bioactive compounds (polyphenols, carotenoids, and oxalic and malic acids) [1]. Physiologically, guava is a climacteric fruit, which means it continues to mature even after being harvested, and has a shorter shelf life under ambient conditions. Due to its climacteric nature, guava fruits exhibit a higher respiration rate, leading to rapid senescence, which reduces the possibility of storing the fruits for long periods [2]. Once harvested, guava fruits have an approximate shelf life of 6 days at 25 °C, making it challenging to transport and market them from production sites to distant places for sale [3]. Hence, the quality of guava fruit after harvest is impacted by several stages, including production, storage, and packaging. To mitigate post-harvest

losses and prolong the quality of guava fruit beyond its natural shelf-life, specific strategies are essential.

The preservation of fruits at low temperatures has been explored as a method to extend their shelf life. However, this approach is costly due to the high energy expenses involved and is of limited use, particularly because guava is susceptible to damage from low temperatures. Loss of fruit quality is generally associated with softening and color changes from green to yellow during post-harvest storage. This decay not only affects the quality of the fruit but also its marketability. To maintain the quality of guava fruits, adequate post-harvest technologies have been developed. Recently, new technologies, such as the application of edible coatings, have been developed to increase shelf life in response to consumer demands regarding food safety issues, including the absence of chemical preservatives and environmental friendliness. One such technique is the application of edible coatings. Applying edible coatings or using edible films to modify the internal atmosphere of the fruits is considered an effective and suitable post-harvest technology for preserving the quality of guava [4].

Coatings are thin membranes that are invisible to the human eye and are applied directly to the surface of the fruit. These coatings can be modified by incorporating natural additives to enhance their antimicrobial and barrier properties [5]. From an economic standpoint, the application of coatings is considered a viable alternative to cold storage [2]. Coatings offer numerous advantages, including improved fruit appearance, antimicrobial properties, semipermeable barrier to gases (CO_2 and O_2), good mechanical properties, non-toxicity, biodegradability, and low production cost [6]. Furthermore, coatings help preserve the texture and nutritional value of the fruit by reducing excessive moisture loss [7]. In various studies, coatings based on polymers incorporated with active ingredients have been successfully applied to fruits [8].

Gellan gum, a polymeric material of industrial interest, is commonly used in coating formulations due to its biodegradability, biocompatibility, and ability to form non-toxic gels. It is an anionic linear heteropolysaccharide composed of 1.3-β-D-glucose, 1.4-β-D-glucuronic acid, 1.4-β-D-glucose, and 1.4-α-L-rhamnose [9]. Biopolymers serve as excellent carriers for active compounds, as they can be manipulated to improve controlled release processes. Packaging systems incorporating biological compounds such as antioxidants, antimicrobial agents, nutraceuticals, and other additives have been developed to enhance the quality and integrity of coated products [2], ultimately contributing to improved preservation, distribution, and marketing.

Among the functional components that can be incorporated into edible coatings, lactic acid bacteria (LABs) can also be mentioned. Their growth can inhibit the proliferation of undesirable microorganisms, making LABs a promising approach in the preparation of active coatings due to their ability to produce antimicrobial substances [10]. LABs are considered harmless to human health, as they have a generally recognized safe status and are widely used in the food industry [11]. *Lactobacillus casei* is a bacterium considered probiotic because it can prevent intestinal disorders, regulate the immune system, specifically the cellular immune response, and has potent antidiarrheal action [12]. In addition, this bacterium has applications as an acid-producing starter culture for milk fermentations and especially as a culture for the intensification and acceleration of flavor development in certain varieties of cheeses ripened with bacteria. Inulin is a prebiotic compound frequently used to protect the genus *Lactobacillus* spp. against microencapsulation processes [13]. Taking the above into consideration, the objective of this work was to evaluate the effect of an edible coating based on gellan gum and *Lactobacillus casei* on the quality attributes of post-harvest guava fruits stored at 25 °C.

2. Materials and Methods

2.1. Plant Material and Growth of Lactobacillus casei

Guava fruits, sourced from the Bolívar department in Colombia, were selected based on their color, size, and absence of damage. The guavas were immersed in a solution

of chlorinated water (200 ppm) and then rinsed thoroughly with sterile distilled water to remove any residual chlorine. The *Lactobacillus casei* culture, obtained from the Food Microbiology Laboratory of the University of Cartagena, Colombia, was activated for 48 h and propagated for 24 h on MRS agar. After propagation, the probiotic cells were centrifuged at 6000× *g* for 15 min at 5 °C and washed twice with sterile saline.

2.2. Preparation of Edible Coatings

Gellan gum (GG) (0.5% and 0.8% *w*/*v*) was dissolved in deionized water containing 5.0% (*v*/*v*) glycerol and subjected to constant stirring at 300 rpm at 90 °C for 10 min. Subsequently, the solution was cooled to room temperature, and prebiotic solutions of inulin (IN) (1.0% and 5.0% *w*/*v*) were added. Finally, *L. casei* was incorporated at a concentration of 4.34 Log CFU/mL. The enumeration of *L. casei* was performed using the deep plate count method on MRS agar. Guava fruits were immersed in the following coating solutions for 30 s: distilled water (control) I; II coating with 0.5% GG and 1.0% inulin (0.5 GG/1.0 IN); III coating with 0.8% GG and 5.0% inulin (0.8 GG/5.0 IN); IV coating with 0.5% GG and 5.0% inulin (0.5 GG/5.0 IN); and V coating with 0.8% GG and 1.0% inulin (0.8 GG/1.0 IN). Finally, the coated guavas were placed in polystyrene trays and stored for 12 days at a temperature of 25 °C and a relative humidity of 70%.

2.3. Respiration Rate, Soluble Solids, and Titratable Acidity

Coated and control guavas were stored in an airtight plastic jar for one hour, after which a gas analyzer (F-950, Felix Instruments, QA Supplies LLC, Norfolk, UK, EEUU) was used. The respiration rate is expressed as mmol CO_2/kg/h. For the determination of soluble solids and titratable acidity, the fruits were macerated in a mortar. To determine soluble solids (SS), four drops of the macerate were placed on the prism of a refractometer (Extech Model 2132, Extech Instruments, Nashua, NH, USA, EEUU). The results were expressed as °Brix. Titratable acidity was determined by titration with a 0.1 N NaOH solution until reaching a pH of 8.2. The results were expressed as a percentage of citric acid.

2.4. Weight Loss

The coated and control fruits were weighed using an analytical balance. The weights were recorded on days 0, 3, 6, 9, and 12. Weight loss was calculated as the difference between the initial weight and the final weight of each fruit divided by the initial weight, as shown in Equation (1).

$$\textbf{\textit{Weight loss}}\ (\%) = \frac{\boldsymbol{W_0 - W_t}}{\boldsymbol{W_0}} \cdot \mathbf{100} \quad (1)$$

where $\boldsymbol{W_0}$ is the initial weight in grams of the fruit and $\boldsymbol{W_t}$ represents the weight in grams at each sampling time.

2.5. Total Phenol Content

A total of 0.5 g of guava fruits was macerated, and 15 µL of the extract was transferred to a tube containing 75 µL of Folin-Ciocalteu reagent diluted with water (1:10). After 3 min of incubation at room temperature, 60 µL of Na_2CO_3 was added, and the mixture was incubated again for a period of 120 min. After incubation, the absorbance of each sample at 765 nm was determined using a spectrophotometer. Gallic acid was used to create the calibration curve. The results were expressed as milligrams of gallic acid equivalents per 100 g of fresh fruit.

2.6. Measurement of Color in Guava Fruits

Color changes in the coated and control guava fruits were measured at equidistant points on their surfaces using a colorimeter (CR-20 Konica Minolta, Tokyo, Japan). The color parameters used to estimate the color change were as follows: L^* for lightness, a^* for the red/green co-ordinates (+a indicates red, −a indicates green), and b^* for the yellow/blue

co-ordinates (+b indicates yellow, −b indicates blue). The color change (ΔE) was calculated using Equation (2).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

The chromaticity (C^*) was calculated by means of Equation (3):

$$C^* = \left[(a^*)^2 + (b^*)^2\right]^{1/2} \quad (3)$$

2.7. Primary Modeling of Lactobacillus casei

The content of *L. casei* incorporated into the edible coatings was studied during the storage of the coated fruits at 25 °C and 70% relative humidity. At different time points (0, 1, 5, 9, 12, and 15 days) during storage, 11 g of the coated fruit was taken and transferred aseptically to a sterile container with 99 mL of peptone water (10^{-1} dilution). Subsequent consecutive serial dilutions were performed. Colony counting was carried out on Petri dishes with MRS agar after incubating for 48 h at 35 °C. The results were expressed as log colony-forming units per gram of fruit (CFU/g). Finally, the Baranyi model (Equation (4)) was fitted to the growth curve data.

$$(t) = y_0 + \mu_{max}t + \frac{1}{\mu_{max}}\ln\left(e^{-vt} + e^{-h_0} - e^{-vt-h_0}\right) - \frac{1}{m}\ln\left[1 + \frac{e^{m\mu_{max}t + \frac{1}{\mu_{max}}\ln(e^{-vt}+e^{-h_0}-e^{-vt-h_0})} - 1}{e^{m(y_{max}-y_0)}}\right] \quad (4)$$

where y(t) is the cell concentration or colony diameter, y_0 is the initial concentration or diameter, μ_{max} is the specific growth rate (1/h), m is a curvature parameter to characterize the phase transition exponential, v is a curvature parameter to characterize the transition to the exponential phase, and ho is a dimensionless parameter that quantifies the initial physiological state of the cells.

2.8. Statistical Analysis

All analyses were performed in triplicate, and the results are presented as the arithmetic mean ± standard deviation. To determine significant differences between the samples, a normal one-way analysis of variance (ANOVA) was conducted using the SPSS computer program (version 23) for Windows.

3. Results and Discussion

3.1. Respiration Rate, Soluble Solids, and Titratable Acidity

The respiration rate of the evaluated fruits increased during storage, as shown in Figure 1a. In the control samples, the highest average rates were obtained with a value of 67.51 CO_2/kg/h, followed by the samples coated with 0.5 GG/1.0 IN with 60.97 CO_2/kg/h. The samples coated with 0.8 GG/5.0 IN and 0.8 GG/1.0 IN had the lowest average rates at 56.38 and 56.99 CO_2/kg/h, respectively. Similar results were published by Gull et al. [14], where the respiration rate of coated guavas was lower than that of uncoated fruits. However, it is important to consider that excessive blockage of oxygen flow can induce an anaerobic state in the fruit, which may negatively affect its quality. When oxygen concentrations fall below the required levels for aerobic respiration, a fermentative process can occur, leading to the development of off-flavors [15].

Guava fruits with higher gellan gum content in the coatings exhibited significantly ($p < 0.05$) lower respiration values, which can be attributed to the increased formation of links between both gellan helices, resulting in a more compact structure. The coatings applied directly to the fruit surface create a semipermeable barrier that limits the movement of gases (CO_2 and O_2) between the surrounding environment and the fruit, leading to a modified atmosphere [5]. Reduced oxygen levels and increased CO_2 concentrations decrease ethylene production, respiration rate, and other processes, such as loss of firmness, reduction of green coloration in the fruit skin, and decreased acidity [16]. The reduction in

respiration rate also affects the synthesis and utilization of metabolites, resulting in a lower content of soluble solids.

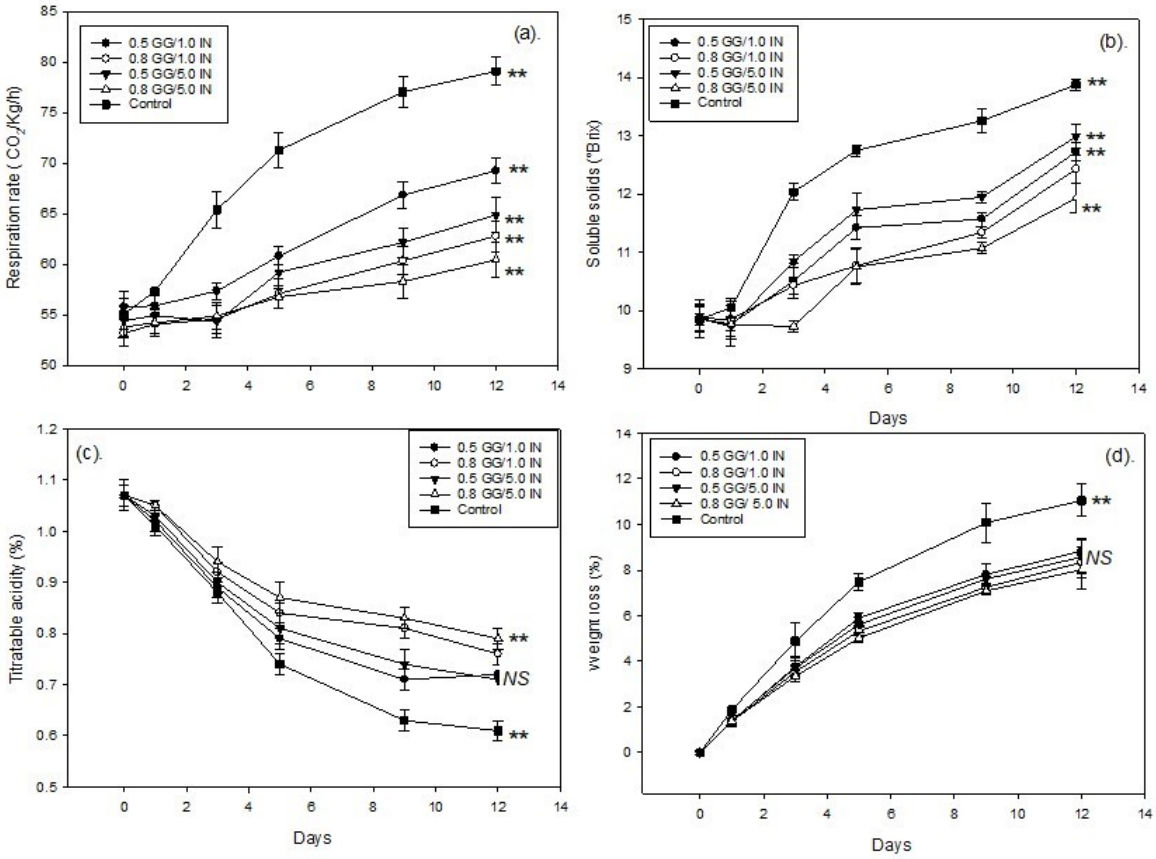

Figure 1. Physicochemical characteristics of guava fruits coated with gellan gum and inulin. (**a**) Respiration rate values; (**b**) soluble solids; (**c**) acidity; and (**d**) weight loss. (** significant difference in $p < 0.05$ according to LSD test for end of the storage time; *NS*: there was no significant difference in $p < 0.05$). Vertical bars indicate standard error of the means.

Regarding soluble solids (SS), an increase can be observed in Figure 1b for both the coated fruits and the control. At the beginning of storage (day 0), the °Brix values ranged between 9.85 and 9.87. These values increased over time, and differences ($p < 0.05$) were observed at the end of storage (day 12), influenced by the type of coating. Gull et al. [14] found that the concentrations of Albizia gum and storage time influenced the soluble solid (SS) content in Gola guava fruits. These authors reported initial values of 8.21, with final values increasing to 13.13 in uncoated fruits and ranging between 11.97 and 12.32 in coated guavas. In the present study, the fruits coated with 0.8 GG/5.0 IN had the lowest °Brix values (11.93), followed by fruits coated with 0.8 GG/1.0 IN (12.43). On the other hand, guavas coated with lower concentrations of GG (0.5% *p*/*v*) had higher °Brix values, with values of 12.99 and 12.73 for samples coated with 0.5 GG/5.0 IN and 0.5 GG/1.0 IN, respectively. In contrast, the control guavas showed the highest SS concentrations at the end of storage (13.88°Brix). Control guavas exhibited significantly ($p < 0.05$) higher SS values than guavas coated with gellan gum and inulin. This aligns with the findings of Nascimento et al. [17], who reported higher SS values in control guava pieces stored at 4 °C compared to fruits coated with chitosan and citric acid. Anjum et al. [18] also found higher SS content in control guavas compared to guavas coated with gum arabic and various plant extracts such as aloe vera, garlic, and ginger. Similar results were reported by Formiga et al. [16], who found higher SS content in uncoated guavas than in guavas coated with different proportions of hydroxypropylmethylcellulose and beeswax. Climacteric fruits tend to increase in SS content during post-harvest storage [19], primarily due to

a higher conversion of sucrose (non-reducing) into monomeric sugars such as glucose (reducing), resulting in increased accumulation of free sugars and concentration of solids due to fruit mass loss [16,20]. The increase in free sugar content leads to a rise in SS concentration during storage [19]. The reduction in SS loss observed in coated fruits has been associated with a decrease in the respiration rate and metabolic activity of the fruit [21].

The behavior of titratable acidity (TA) values in control guava fruits and those covered with different proportions of gellan gum and inulin is presented in Figure 1c. It is evident that the TA significantly ($p < 0.05$) decreased throughout the storage period, indicating the ongoing maturation process. By the end of the storage time, the guava fruits coated with 0.8 GG/5.0 IN (0.79%) and 0.8 GG/1.0 IN (0.76%) exhibited the highest acidity values. These results can be attributed to a reduction in the degradation of organic acids, facilitated by the low oxygen environment created by the application of the coatings [22]. This trend is further supported by the lower TA values (0.61%) observed in the control fruits at the end of storage. Gull et al. [14] reported initial acidity values of approximately 1% in Gola guavas. After 15 days of storage, a reduction in acidity was observed, with values decreasing to 0.29% in uncoated fruits and ranging between 0.40% and 0.37% in guavas coated with Albizia gum.

Anjum et al. [18] also reported higher TA values (1.12%) in guavas coated with gum arabic and garlic extract compared to uncoated fruits (0.95%). These findings demonstrate that the application of coatings based on gellan gum and inulin, particularly the 0.8 GG/5.0 IN ratio, delays the fruit ripening process by reducing the respiration rate, TA, and soluble solids, thereby delaying maturation [17].

3.2. Guava Fruit Weight Loss

The determination of weight loss is one of the most crucial parameters in assessing packaging options and holds great importance in determining the quality of guava, as it influences firmness, texture, and nutritional value [20]. Figure 1d shows that the coated fruits had a significantly lower weight loss ($p < 0.05$) than the control fruits. Similar behavior was reported by Anjum et al. [18] in control guavas, which exhibited weight losses close to 28%, while guavas covered with gum arabic, ginger extract, garlic extract, and aloe vera extract showed losses of 22.36%, 20.65%, and 21.76%, respectively. Similarly, Gull et al. [14] found that the application of edible coatings based on Albizia gum at 4.5% reduces weight loss by 27% in Gola guava stored for 15 days at 20 °C with a relative humidity between 85–90%. The application of coatings reduces transpiration as it covers the stomata, lenticels, and micropores of the fruit, creating a semi-permeable barrier to gas exchange [7].

Some research mentions that the morphology of the fruit's epidermis (number of stomata, lenticels, type, and thickness of the cuticle), as well as the physical properties of the coatings, influence the mass transfer of coated fruits [23,24]. Weight loss is attributed to water loss in the fruit during storage due to fruit transpiration, which is caused by the difference in vapor pressure between the fruit's surface and the surrounding environment. Therefore, creating a modified atmosphere between the fruit and the coating can reduce respiration and transpiration, thus extending the shelf life of guava. This is a crucial factor for the marketing and storage of fresh fruit [25].

In the results presented here, weight loss is directly proportional to the storage time within the analyzed period (12 days). The highest losses were observed on day 12, specifically in the control group ($p < 0.05$), with a weight loss of 11.05%. Among the coated fruits, the lowest weight losses were found in fruits covered with 0.8 GG/5.0 IN (8.02%) and 0.8 GG/1.0 IN (8.34%). Formulations with higher gellan gum content exhibited lower weight loss, which can be explained by the increased number of linkages established between the gellan gum helices, thereby reducing the permeability of the coating. Similar results were reported by Nascimento et al. [17], who found mass loss values of approximately 8.37% in guava slices coated with chitosan and citric acid stored at 4 °C. Weight loss increases due to desiccation or water loss from the fruit, but the coatings act as barriers and help maintain the fruit's weight. One of the primary causes of post-harvest quality

deterioration in guava fruits is weight loss [14]. In summary, this work is significant as it reports for the first time the use of gellan gum, inulin, and a probiotic bacterium in the preservation of whole guava fruits. This approach successfully reduced weight loss, respiration rate, soluble solids, and titratable acidity—all factors traditionally associated with an extended shelf life of plant-based products. Therefore, among the coating formulations used, 0.8 GG/5.0 IN exhibited the most effective reduction in water loss.

3.3. Total Phenol Content

Figure 2 shows an increase in the total phenol content for all samples during the analysis time, and this result can be attributed to the concentration of phenolic compounds in the fruit pulp due to water loss during storage. The average value at the beginning of storage was 124.23 mg/100× g for all the samples. This value notably increased until the fifth day of storage, after which significant differences ($p < 0.05$) were observed between the control and coated fruits. The final values of total phenols in control fruits were 246.36 mg/100 g, while the coated fruits had the following values: 326.44 mg/100× g for the 0.8 GG/5.0 IN coating, 317.94 mg/100× g for fruits coated with 0.8 GG/1.0 IN, 303.44 mg/100× g for fruits coated with 0.5 GG/5.0 IN, and 285.73 mg/100× g for fruits coated with 0.5 GG/1.0 IN. Similar behavior regarding the increase in total phenol content was reported by Formiga et al. [16] in guavas covered with HPMC, and 20% and 40% beeswax. The increase in phenolic content over storage time may be a consequence of the stress caused to the fruit by reduced oxygen availability resulting from the coating application. The total phenol content has been linked to antioxidant activity. This behavior also can be attributed to the nature of the guava fruits and the crop [18].

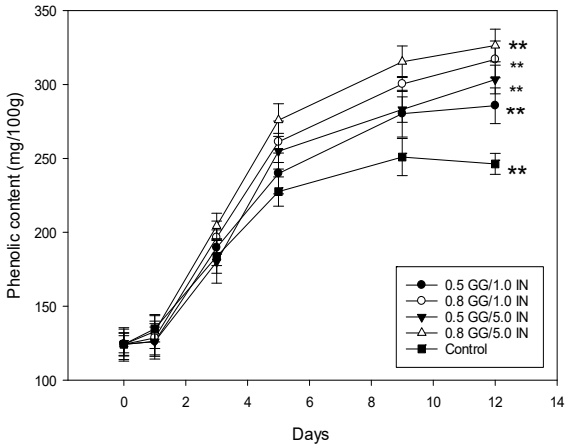

Figure 2. Phenolic content of guava fruits coated with gellan gum and inulin. (** significant difference in $p < 0.05$ according to LSD test for end of the storage time. Vertical bars indicate standard error of the means. Vertical bars indicate standard error of the means.

3.4. Measurement of Color in Guava Fruits

The visual color of fruits is an important aspect for consumers in determining the product's quality, as it indicates maturity and harvest time [2]. The results of color retention are presented in Table 1. The L^* values increased in all samples, which could be related to the ripening process [12]. The coated fruits exhibited lower L^* values than the control fruits, suggesting that gellan gum acts as a barrier and delays color changes, thus slowing the fruit-ripening process [1]. The highest L^* values were obtained in the control fruits on day 12, with a value of 63.57. Among the treated fruits, the 0.8 GG/5.0 IN coating showed the lowest L^* values during storage compared to the other coatings. An increase in guava luminosity was reported by Formiga et al. [16] in "Pedro Sato" guavas, which was attributed to the natural ripening process that lightens the fruit and results in higher L^* values. In contrast, the 0.8 GG/5.0 IN coating demonstrated greater efficiency in delaying the ripening process of the guavas used, thus preserving their color.

Table 1. Color parameters *a**, *b**, *L**, *C** and color changes of guava fruits coated with gellan gum and inulin.

Color Parameters	Days	Control	0.5 GG/1.0 IN	0.8 GG/1.0 IN	0.5 GG/5.0 IN	0.8 GG/5.0 IN
*L**	0	44.97 ± 0.02 ^{a}	44.72 ± 0.04 ^{a}	45.80 ± 0.02 ^{a}	46.30 ± 0.02 ^{b}	44.37 ± 0.04 ^{a}
	1	48.80 ± 0.00 ^{a}	47.15 ± 0.04 ^{a}	44.82 ± 0.04 ^{b}	46.77 ± 0.02 ^{a}	44.62 ± 0.02 ^{b}
	3	54.10 ± 0.05 ^{a}	51.75 ± 0.00 ^{b}	49.20 ± 0.02 ^{cd}	50.17 ± 0.02 ^{c}	48.17 ± 0.00 ^{d}
	5	56.72 ± 0.00 ^{a}	53.30 ± 0.02 ^{b}	51.95 ± 0.02 ^{b}	51.45 ± 0.04 ^{b}	49.33 ± 0.00 ^{c}
	9	60.95 ± 0.00 ^{a}	54.32 ± 0.03 ^{b}	51.32 ± 0.04 ^{c}	52.65 ± 0.04 ^{c}	51.02 ± 0.02 ^{c}
	12	63.57 ± 0.04 ^{a}	54.47 ± 0.02 ^{b}	53.10 ± 0.02 ^{b}	53.05 ± 0.02 ^{b}	52.3 ± 0.05 ^{b}
*a**	0	−5.90 ± 0.04 ^{a}	−5.90 ± 0.02 ^{b}	−5.87 ± 0.00 ^{b}	−6.00 ± 0.02 ^{b}	−5.90 ± 0.00 ^{b}
	1	−6.00 ± 0.02 ^{a}	−4.77 ± 0.00 ^{b}	−5.55 ± 0.02 ^{b}	−5.20 ± 0.00 ^{b}	−5.65 ± 0.02 ^{b}
	3	−2.65 ± 0.02 ^{a}	0.87 ± 0.00 ^{b}	−3.25 ± 0.00 ^{a}	−3.14 ± 0.00 ^{a}	−3.85 ± 0.00 ^{c}
	5	0.20 ± 0.00 ^{a}	0.70 ± 0.02 ^{b}	−1.45 ± 0.00 ^{c}	−0.90 ± 0.00 ^{d}	−1.55 ± 0.02 ^{e}
	9	7.40 ± 0.02 ^{a}	2.90 ± 0.02 ^{b}	0.85 ± 0.00 ^{c}	1.22 ± 0.00 ^{d}	−0.47 ± 0.00 ^{e}
	12	10.35 ± 0.00 ^{a}	3.73 ± 0.01 ^{b}	2.85 ± 0.02 ^{c}	3.52 ± 0.02 ^{d}	1.05 ± 0.01 ^{e}
*b**	0	31.05 ± 0.02 ^{a}	36.72 ± 0.12 ^{b}	36.47 ± 0.05 ^{b}	36.85 ± 0.10 ^{b}	36.87 ± 0.05 ^{b}
	1	41.85 ± 0.08 ^{a}	40.82 ± 0.10 ^{a}	39.82 ± 0.10 ^{a}	39.77 ± 0.10 ^{a}	37.3 ± 0.05 ^{b}
	3	45.97 ± 0.04 ^{a}	42.72 ± 0.04 ^{b}	40.5 ± 0.12 ^{c}	41.3 ± 0.04 ^{c}	39.77 ± 0.02 ^{d}
	5	49.85 ± 0.04 ^{a}	44.15 ± 0.08 ^{b}	42.22 ± 0.12 ^{c}	44.25 ± 0.04 ^{b}	41.08 ± 0.02 ^{c}
	9	47.25 ± 0.12 ^{a}	44.52 ± 0.08 ^{b}	43.00 ± 0.02 ^{b}	44.27 ± 0.04 ^{b}	41.95 ± 0.00 ^{c}
	12	38.27 ± 0.10 ^{a}	47.7 ± 0.04 ^{b}	43.75 ± 0.08 ^{c}	45.07 ± 0.05 ^{d}	41.47 ± 0.05 ^{e}
*C**	0	31.60	37.19	36.93	37.33	37.33
	1	42.27	41.09	40.20	40.10	37.72
	3	46.04	42.72	40.63	41.41	39.95
	5	49.80	44.15	42.24	44.25	41.02
	9	47.82	44.61	43.00	44.28	41.95
	12	39.64	45.60	43.84	45.20	41.48
Δ*E*	1	11.45	4.89	3.50	3.06	0.55
	3	17.79	11.45	5.88	6.55	5.20
	5	22.95	13.12	9.50	10.35	7.78
	9	26.35	15.18	10.87	12.14	9.97
	12	25.73	17.56	13.50	14.26	11.50

The same lowercase letters in the same row indicate that the means do not differ significantly ($p < 0.05$).

Color preservation can also be explained by the values obtained for the co-ordinates *a*, *b*, and *C**, which indicate the tendency of the fruit to be less green or more yellow due to chlorophyll degradation and carotenoid formation. Negative values of *a** indicate a green coloration in the sample. The lowest values of *a** were observed in the sample coated with 0.8 GG/5.0 IN, with an average of −2.72, followed by 0.8 GG/1.0 IN with −2.07. The loss of green coloration (−*a**) is associated with the degradation of chlorophyll molecules involving the enzyme chlorophyllase, whose increased activity is linked to ethylene production and action during fruit ripening. Chlorophyll degradation allows the characteristic pigments of the fruit, located in both the skin and pulp, to become more prominent. Consequently, as guavas mature, the chlorophyll content decreases, causing the skin to turn yellowish and the flesh to become reddish.

Regarding the *b** co-ordinates, which are related to the yellow coloration of the fruit when positive values are registered, the highest value for *b** (49.80) was reached in the control fruits on day 5 of storage. After that, a decrease in the value was observed, which is a consequence of the typical enzymatic ripening processes that ultimately lead to fruit softening. The *a** and *b** values indicate that the fruits coated with 0.8 GG/5.0 IN retain their green color for a longer period. This behavior suggests that this coating has a beneficial effect on the epicarp's permeability, modifying gas exchange and reducing oxidative processes and chlorophyll degradation [20]. The formation of a modified atmosphere between the fruit surface and the coating surface reduces pigment degradation by minimizing the presence of oxygen, resulting in a reduced occurrence of undesired color changes [26].

The color changes (ΔE) in the fruits can be considered a summary of the results obtained for the a^*, b^*, and L^* co-ordinates using Equation (3). The control fruits exhibited the highest ΔE value (20.85), while the coated fruits showed smaller changes, particularly in the fruits coated with 0.8 GG/5.0 IN (7.0), followed by 0.8 GG/1.0 IN (8.65). These results support the notion that the 0.8 GG/5.0 IN coating is highly effective in delaying the ripening process of guavas. In terms of chromaticity, this parameter gradually increased with longer storage time. The increase in C^* values indicates the degradation of chlorophyll and the synthesis of carotenoids, which are typical processes during the ripening of climacteric fruits [27]. The smallest increases in C^* values were observed in the coated fruits, as low oxygen environments delay fruit ripening by inhibiting the expression of genes associated with senescence. As a result, the oxidation and degradation of chlorophylls and carotenoids are minimized [28].

3.5. Primary Modeling of *Lactobacillus casei*

In the present study, the Baranyi and Roberts model was used to fit the growth data of *L. casei* in the prepared coatings to calculate the kinetic parameters of growth: initial concentration of bacterial cells (Y_0), specific growth rate (μ_{max}), and final cell concentration. Table 2 presents the effect of different coating formulations on the microbial growth phases.

Table 2. Kinetic parameters of *L. casei* calculated by applying the Baranyi model.

Parameter	0.5 GG/ 1.0 IN	0.8 GG/ 1.0 IN	0.5 GG/ 5.0 IN	0.8 GG/ 5.0 IN
Y_0	4.29	4.35	4.23	4.32
Ymax	9.99	10.01	9.88	9.45
μ_{max}	0.03	0.03	0.05	0.06

Y_0 did not show significant variation ($p > 0.05$) among the coatings tested, as values ranging from 4.23 to 4.35 log CFU/g were observed. This indicates that Y_0 primarily depends on the initial bacterial concentration inoculated into the edible coating. Y_0 values are important for the design of fermented products, as they help optimize the initial bacterial concentrations of probiotics used for raw material inoculation. However, it is worth noting that Y_0 has not traditionally been a parameter used in predictive models since it can be controlled by the number of bacteria inoculated into the substrate [8].

The specific growth rate (μ_{max}) provides information about the rate at which a micro-organism grows in a food system. In coatings with higher concentrations of inulin (0.8 GG/5.0 IN and 0.5 GG/5.0 IN), μ_{max} values of 0.069 and 0.056 h^{-1} were obtained, respectively. Coatings with lower inulin concentrations showed μ_{max} values of 0.039 and 0.033 h^{-1}. These results suggest that *L. casei* utilizes inulin as a substrate, leading to higher growth rates and reaching higher cell concentrations. This finding is consistent with previous publications by Santos at al. [29], where inulin exhibited a protective effect on *Lactobacillus acidophilus* during microencapsulation.

Regarding Ymax, which represents the maximum bacterial concentration achieved at the end of the logarithmic phase, it is noteworthy to observe values higher than 9 log CFU/g. This can be attributed to the presence of inulin in the coatings, as well as the inoculation of the micro-organism during the logarithmic phase, resulting in the absence of a latency phase.

4. Conclusions

The coatings made from gellan gum, inulin, and incorporating *Lactobacillus casei* have proved to be a good alternative for the preservation of whole guava fruits, particularly the 8.0 GG/5.0 IN formulation. This formulation effectively delays the ripening process by reducing the respiration rate, soluble solids, weight loss, and color change, ultimately extending the shelf life of the fruit. Additionally, coatings with higher inulin content showed enhanced growth of *L. casei*, which may contribute to the antimicrobial effect of

the coating. Therefore, the combined application of *L. casei* and inulin in gellan gum-based coatings can be considered a suitable treatment to prolong the shelf life and preserve the quality of guava fruits. Future research should include sensory analysis as well as microbiological studies of the food matrix.

Author Contributions: Conceptualization, R.E.G.-C., L.M.-N., V.C.R.-R., and R.O.-T.; data curation, L.M.-N. and V.C.R.-R.; formal analysis, L.M.-N.; funding acquisition, L.M.-N. and V.C.R.-R.; investigation, R.E.G.-C., L.M.-N., and V.C.R.-R.; methodology, R.E.G.-C., L.M.-N., V.C.R.-R., and J.H.-F.; project administration, L.M.-N. and V.C.R.-R.; resources, L.M.-N. and V.C.R.-R.; software, L.M.-N. and V.C.R.-R.; supervision, R.E.G.-C. and L.M.-N.; validation, R.E.G.-C., L.M.-N., V.C.R.-R., J.H.-F., and R.O.-T.; visualization, R.E.G.-C., J.H.-F., and R.O.-T.; writing—original draft, R.E.G.-C., L.M.-N., and V.C.R.-R.; writing—review and editing, J.H.-F. and R.O.-T. All authors have read and agreed to the published version of the manuscript.

Funding: This research had no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author/s.

Acknowledgments: The authors would like to acknowledge the Universidad de Córdoba and Universidad de Cartagena for their support in this work.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Forato, L.A.; Britto, D.; De Rizzo, J.; Gastaldi, T.; Assis, O. Effect of cashew gum carboxymethylcellulose edible coatings in extending the shelf-life of fresh and cut guavas. *Food Packag. Shelf Life* **2015**, *5*, 68–74. [CrossRef]
2. Nair, M.S.; Saxena, A.; Kaur, C. Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). *Food Chem.* **2018**, *240*, 245–252. [CrossRef]
3. Etemadipoor, R.; Ramezanian, A.; Dastjerdi, A.M.; Shamili, M. The potential of gum arabic enriched with cinnamon essential oil for improving the qualitative characteristics and storability of guava (*Psidium guajava* L.) fruit. *Sci. Hortic.* **2019**, *251*, 101–107. [CrossRef]
4. Germano, T.A.; Aguiar, R.P.; Rocha, B.M.; Azevedo, M.R.; Ayala-Zavala, J.F.; Alcântara de Miranda, M.R. Galactomannan-carnauba wax coating improves the antioxidant status and reduces chilling injury of 'Paluma' guava. *Postharvest Biol. Technol.* **2019**, *149*, 9–17. [CrossRef]
5. Santos, T.M.; de Souza, F.M.; Silva, D.O.; da Silveira, M.R.; de Mirand, M.R.; Lopes, M.A.; Azeredo, M.C. Enhancing storage stability of guava with tannic acid-crosslinked zein coatings. *Food Chem.* **2018**, *257*, 252–258. [CrossRef]
6. Aquino, A.B.; Blank, A.F.; Santana, L.C. Impact of edible chitosan-cassava starch coatings enriched with *Lippia gracilis* Schauer genotype mixtures on the shelf life of guavas (*Psidium guajava* L.) during storage at room temperature. *Food Chem.* **2015**, *15*, 108–116. [CrossRef]
7. Oliveira, V.R.; Santos, F.K.; Leite, R.H.; Aroucha, E.M.; Silva, K.N. Use of biopolymeric coating hydrophobized with beeswax in postharvest conservation of guavas. *Food Chem.* **2018**, *259*, 55–64. [CrossRef] [PubMed]
8. González-Cuello, R.E.; Moron-Alcazar, L.B.; Pérez-Mendoza, J.A. Recubrimientos a base de goma gelana de bajo acilo conteniendo α-pineno y extracto de arándano para la conservación de la calidad post-cosecha de fresas. *Inf. Tecnol.* **2022**, *33*, 93–102. [CrossRef]
9. González-Cuello, R.E.; Ramos-Ramírez, E.G.; Cruz-Orea, A.; Salazar-Montoya, J.A. Rheological characterization and activation energy values of binary mixtures of gellan. *Eur. Food Res. Technol.* **2012**, *234*, 305–313. [CrossRef]
10. Agriopoulou, S.; Stamatelopoulou, E.; Sachadyn-Krol, M.; Varzakas, T. Lactic acid bacteria as antibacterial agents to extend the shelf life of fresh and minimally processed fruits and vegetables: Quality and safety aspects. *Microorganisms* **2020**, *8*, 952. [CrossRef]
11. Marín, A.; Plotto, A.; Atarés, L.; Chiralt, A. Lactic acid bacteria incorporated into edible coatings to control fungal growth and maintain postharvest quality of grapes. *HortScience* **2019**, *54*, 337–343. [CrossRef]
12. Silva, W.B.; Cosme, G.M.; Bortolini, S.D.; Rodrigues, S.A.; Barbosa, M.D.; Belghith, I.; Martins, N.; Menezes, M.H.; Polete, G.M. Chitosan delays ripening and ROS production in guava (*Casei guajava* L.) fruit. *Food Chem.* **2018**, *242*, 232–238. [CrossRef] [PubMed]
13. Bustamante, M.; Villarroel, M.; Rubilar, M.; Shene, C. *Lactobacillus acidophilus* La-05 encapsulated by spray drying: Effect of mucilage and protein from flaxseed (*Linum usitatissimum* L.). *LWT-Food Sci. Technol.* **2015**, *62*, 1162–1168. [CrossRef]
14. Gull, S.; Ejaz, S.; Ali, S.; Ali, M.; Hussain, S.; Sardar, H.; Azam, M.; Nawaz, A.; Naz, S.; Maqbool, M. A novel edible coating based on Albizia [*Albizia lebbeck* (L.) Benth.] gum delays softening and maintains quality of harvested guava fruits during storage. *Int. J. Biol. Macromol.* **2024**, *277*, 134096. [CrossRef]

15. Beaudry, R.M. Responses of horticultural commodities to low oxygen: Modified atmosphere packaging. *HortTechnology* **2000**, *10*, 491–500. [CrossRef]
16. Formiga, A.S.; Pinsetta, J.S.; Pereira, E.; Cordeiro, I.; Mattiuz, B. Use of edible coatings based on hydroxypropyl methylcellulose and beeswax in the conservation of red guava 'Pedro Sato'. *Food Chem.* **2019**, *290*, 144–151. [CrossRef] [PubMed]
17. Nascimento, J.G.; Montenegro, S.T.; Castelo, N.F.; dos Santos, N.I.; Barbosa, M.A.; Estevez, M.M.; Stamford-Arnaud, T.M.; Pereira, S.N.; Montenegro, T.L. Chitosan–citric acid edible coating to control *Colletotrichum gloeosporioides* and maintain quality parameters of fresh-cut guava. *Int. J. Biol. Macromol.* **2020**, *63*, 1127–1135. [CrossRef] [PubMed]
18. Anjum, M.; Akram, H.; Zaidi, M.; Ali, S. Effect of gum arabic and Aloe vera gel based edible coatings in combination with plant extracts on postharvest quality and storability of 'Gola' guava fruits. *Sci. Hortic.* **2020**, *271*, 109506. [CrossRef]
19. Parven, A.; Sarker, M.R.; Megharaj, M.; Meftaul, I.M. Prolonging the shelf life of Papaya (*Carica papaya* L.) using Aloe vera gel at ambient temperature. *Sci. Hortic.* **2020**, *265*, 109228. [CrossRef]
20. Arroyo, B.J.; Campos, B.A.; Lins, O.L.; Jarma, A.S.; Almeida de Melo, E.; Pinheiro, A.M. Antimicrobial active edible coating of alginate and chitosan add ZnO nanoparticles applied in guavas (*Psidium guajava* L.). *Food Chem.* **2020**, *309*, 125566. [CrossRef]
21. Gol, N.B.; Patel, P.R.; Rao, T.V. Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharvest Biol. Technol.* **2013**, *85*, 185–195. [CrossRef]
22. Khaliq, G.; Abbas, H.T.; Ali, I.; Waseem, M. Aloe vera gel enriched with garlic essential oil effectively controls anthracnose disease and maintains postharvest quality of banana fruit during storage. *Hortic. Environ. Biotechnol.* **2019**, *60*, 659–669. [CrossRef]
23. Hagenmaier, R.D.; Baker, R.A. Reduction in gas exchange of citrus fruit by wax coatings. *J. Agric. Food Chem.* **1993**, *41*, 283–287. [CrossRef]
24. Navarro-Tarazag, M.L.; Massa, A.; Pérez-Gago, M.B. Effect of beeswax content on hydroxypropyl methylcellulose-based edible film properties and postharvest quality of coated plums (Cv. Angeleno). *LWT-Food Sci. Technol.* **2011**, *44*, 2328–2334. [CrossRef]
25. Chen, H.; Sun, Z.; Yang, H. Effect of carnauba wax-based coating containing glycerol monolaurate on the quality maintenance and shelf-life of Indian jujube (*Zizyphus mauritiana* Lamk.) fruit during storage. *Sci. Hortic.* **2019**, *244*, 157–164. [CrossRef]
26. Pérez-Guzmán, A.E.; Saucedo-Veloz, C.; Arana-Errasquin, R. Effect of individual seal packaging in plastic films on the quality of Dancy mandarins stored under refrigeration. *Food Sci. Technol. Int.* **1999**, *5*, 215–222. [CrossRef]
27. Abreu, J.R.; Santos, C.D.; Abreu, M.C.; Castro, E.M. Histochemistry and morphoanatomy study on guava fruit during ripening. *Ciênc Tecnol. Aliment.* **2012**, *32*, 179–186. [CrossRef]
28. Tran, D.T.; Verlinden, B.E.; Hertog, M.; Nicolaï, B. Monitoring of extremely low oxygen control atmosphere storage of "Greenstar" apples using chlorophyll fluorescence. *Sci. Hortic.* **2015**, *184*, 18–22. [CrossRef]
29. Santos, D.X.; Casazza, A.A.; Aliakbarian, B.; Bedani, R.; Isay, S.M.; Perego, P. Improved probiotic survival to in vitro gastrointestinal stress in a mousse containing *Lactobacillus acidophilus* La-5 microencapsulated with inulin by spray drying. *LWT-Food Sci. Technol.* **2019**, *99*, 404–410. [CrossRef]