agronomy

MDPI

Article

Effect of Application of a Cactus Pear Mucilage-Based Edible Coating Enriched with Glycerol and L-Glutamine on Minimally Processed White-Flesh Loquats

Giuseppe Greco, Francesco Gargano, Miriam La Motta, Ignazio Maria Gugino and Giorgia Liguori *

Department of Agricultural, Food and Forest Sciences, University of Palermo, Viale delle Scienze, Bldg. 4, 90128 Palermo, Italy; giuseppe.greco03@unipa.it (G.G.); francesco.gargano07@unipa.it (F.G.); miriam.lamotta@unipa.it (M.L.M.); ignaziomaria.gugino@unipa.it (I.M.G.)
* Correspondence: giorgia.liguori@unipa.it

Abstract: Loquat (Eriobotrya japonica Lindl.), a non-climacteric fruit, is susceptible to physical and mechanical damage, as well as decay, especially after minimal processing, resulting in a short postharvest lifespan The objective of our study was to evaluate the impact of a cactus pear (OFI) mucilage-based edible coating enriched with glycerol and l-glutamine on the quality and nutraceutical value of minimally processed white-flesh *Martorana* loquat fruits during cold storage. After washing and processing the cladodes, mucilage was extracted, and two different coatings (EC1: 60% OFI mucilage, 40% glycerol; EC2: 67% OFI mucilage, 30% glycerol, 3% glutamine) were formulated and compared with an untreated sample (CTR). Our analyses covered various parameters, including color, total soluble solid content, titratable acidity, antioxidant activity, and total phenols. Additionally, sensory analysis was conducted and visual scores were obtained. The results suggest that the application of a cactus pear mucilage-based edible coating, supplemented with glycerol and L-glutamine, effectively preserves the quality attributes of minimally processed loquat fruits.

Keywords: *Opuntia ficus-indica*; antioxidant activity; postharvest; nutraceutical value; shelf life

check for updates

Citation: Greco, G.; Gargano, F.; Motta, M.L.; Gugino, I.M.; Liguori, G. Effect of Application of a Cactus Pear Mucilage-Based Edible Coating Enriched with Glycerol and L-Glutamine on Minimally Processed White-Flesh Loquats. *Agronomy* **2024**, *14*, 1246. https://doi.org/10.3390/agronomy14061246

Academic Editors: Peter J. Batt and Baskaran Stephen Inbaraj

Received: 8 April 2024
Revised: 1 June 2024
Accepted: 3 June 2024
Published: 8 June 2024

---

1. Introduction

The loquat (*Eriobotrya japonica* Lindl.), a prominent member of the Rosaceae family, is a significant commercial fruit crop indigenous to southeastern China [1]. Revered in traditional medicine, the loquat fruit is esteemed for its diverse medicinal attributes, encompassing anti-inflammatory, hypoglycemic, antioxidant, antitumor, antiviral, cytotoxic, antimutagenic, and hypolipidemic activities, with suggested benefits against chronic bronchitis and nephropathy [2].

However, despite its revered medicinal standing, the postharvest life of the loquat fruit is fraught with challenges. Ripening under the heat of the rainy season, the fruit succumbs swiftly to chilling injury, browning, and the emergence of purple spots postharvest. Further complexities arise from postharvest diseases, exacerbated by mechanical injury and fruit processing [3,4]. Despite extensive efforts involving refrigeration and diverse treatments, the fruit's shelf life at ambient temperatures remains ephemeral, primarily due to flesh browning and fungal decay [5–9]. While cold storage remains a cornerstone postharvest strategy, its efficacy often diminishes in preserving optimal fruit and vegetable quality during the rigors of transportation and marketing. This predicament has necessitated the integration of advanced postharvest technologies, with techniques such as modified atmosphere, controlled atmosphere, and edible coating emerging as stalwarts in the preservation of minimally processed products [10–12].

In the domain of postharvest innovations, edible coatings have emerged as a highly efficient solution, functioning as an effective barrier to water movement, champions in moisture retention, and conductors of a subtle transformation in the fruit's atmosphere by curbing gas exchange. A recent addition to this field is the mucilage derived from the cladodes of *Opuntia ficus-indica*, proving to be a versatile coating material, especially for highly perishable fruits, minimally processed products, and the world of fresh-cut or sliced items [13–16]. The judicious addition of glycerol injects a layer of flexibility into these coatings, although the delicate balance is tipped as it may influence water vapor and gas permeability, given its hydrophilic and hygroscopic nature [17–20]. Simultaneously, in the realm of dietary supplements and functional foods, amino acids, particularly the increasing utilization of L-glutamine (Gln), has witnessed an unprecedented surge in popularity over the past decade. This surge is particularly pronounced in sports nutrition and the vibrant landscape of "energy" products [21]. L-Glutamine assumes a pivotal role in acid–base balance in the kidney and stands as a crucial fuel source for the intestine and immune system [22]. The supplemental use of L-Glutamine has been shown to elevate intestinal villous height, kindle gut mucosal cellular proliferation, and uphold mucosal integrity [23].

Beyond these functions, L-glutamine extends its protective influence, showcasing efficacy against oxidative stress and inflammation [22]. Within this nuanced context, our study aims to unravel the effects of applying *O. ficus-indica* mucilage and glycerol-based edible coatings, enhanced with L-glutamine (Gln), on the pomological, physiochemical, sensory, and nutraceutical parameters of minimally processed white-flesh Martorana loquat cultivars during cold storage at 5 ± 0.5 °C and 90% relative humidity. The contribution of this study lies in the potential to extend the shelf life of minimally processed loquat fruits, reduce waste, and decrease the amount of food discarded.

2. Materials and Methods

2.1. Loquat Fruit Samples

Loquat fruits, *Eriobotrya japonica* Lindl, white-flesh (cv. Martorana—MRT), were harvested in Palermo (Italy) on a commercial orchard located in the "Ciaculli" district (38°03′59″ N, 13°24′46″ E, 102–110 m a.s.l.). All the samples were hand-picked at the ripe stage by gently detaching the fruit (Figure 1A). Immediately after harvesting, fruits were transported to the laboratory, where the initial analyses were conducted. Fruit quality parameters were assessed using 30 fruits. Upon arrival to the laboratory, the fruits were washed with tap water and sanitized by immersion in a solution of 200 mg kg^{-1} sodium hypochlorite for 5 min. Subsequently, the fruits were peeled using a previously sterilized scalpel. Only peeled fruits without external injuries were selected, and fruit processing operations were conducted under sanitary conditions at 15 °C (Figure 1A,B).


(**A**) (**B**)

Figure 1. (**A**) Loquat fruits after harvest. (**B**) Peeled loquat fruits.

2.2. Fresh Mucilage Extraction and Edible Coating Processing

After harvest the cladodes were moved to the laboratory for mucilage extraction, using a modified patented method by Du Toit and De Witt developed in South Africa and used in previous research [24]. This process commenced with the careful washing of cladodes using chlorinated water, effectively eliminating impurities and spines. A pivotal step involved the removal of chlorenchyma using a peeler, ensuring the attainment of high-quality, pure mucilage. Sliced into squares, the cladodes underwent a brief microwave cooking episode (900 W for 2 min) before being subjected to homogenization with a homogenizer (Omni-Mixer. 17,107, Dupont Instruments Sorvall, Miami, FL, USA), a crucial step facilitating mucilage extraction.

After homogenization, the plant material underwent centrifugation using a Sigma centrifuge (Sigma Laborzentrifugen GmbH, Osterode am Harz, Germany) at 12,500 rpm for 15 min at 4 °C. This process effectively separated the liquid mucilage from residual vegetable fiber, with the solid material remaining in the falcon tubes being duly discarded.

The extracted mucilage, identified as OFI mucilage, was decanted and weighed. This valuable mucilage, rich in properties advantageous for coating applications, was then carefully transferred into 2 × 1 L beakers.

In one of the two beakers, 40% glycerol (Lubrisolve, Long Sutton, UK) was added, while in the other, 30% glycerol and 3% glutamine (My Muscle) were added. These formulations were, respectively, designated as EC1 and EC2 (Figure 2).

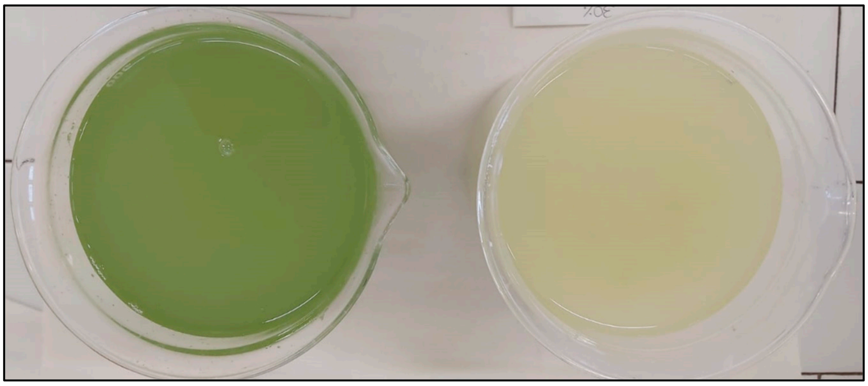

Figure 2. Edible coating solutions (EC1 and EC2).

After sterilizing the work surfaces and cutting tools with a sodium hypochlorite solution (200 mg kg^{-1}), the fruits were peeled, segmented according to their respective treatments, and then immersed in the solutions for approximately 10 min, allowing for optimal adhesion of the coating to the fruit surfaces (Figure 3). The treated fruits were compared with untreated samples, designated as CTR, for analysis.

Figure 3. Loquat samples dipped in coating solution.

Subsequently, all treated fruits underwent air-drying at room temperature for 15 min (approximately 25 °C). Following this, both coated (EC1 and EC2) and uncoated samples (CTR) were carefully arranged in rigid polypropylene retail boxes measuring 25 × 20 cm. Each box accommodated three peeled loquat fruits. The boxes were hermetically sealed using a 35 µm microperforated polypropylene film, characterized by an O_2 permeability of ∼12,000 mL m^{-2} d^{-1} atm^{-1} and a CO_2 permeability of ∼13,000 mL m^{-2} d^{-1} atm^{-1} at 5 °C. The arranged samples, representing each treatment (EC1, EC2, and CTR), were then stored in a controlled environment at 5 ± 0.5 °C and 95% relative humidity for a duration of 11 days. During the refrigerated storage period, physicochemical, nutraceutical, and sensory analyses were conducted for each of the designated sampling dates (4–6–8–11 days at 5 °C).

2.3. Determination of Fruit Quality: Total Soluble Solid Content, Titratable Acidity, Extractable Juice, Weight Loss, and Color

The quality assessment of minimally processed white-flesh loquat fruits occurred immediately after harvest (T0) and after 4, 6, 8, and 11 days of storage. For each sampling date and experimental treatment, five samples (consisting of 3 fruits each) were randomly selected and subjected to analysis. The fruit pulp was homogenized to measure the total soluble solid (TSS) content and titratable acidity (TA). The TSS content was determined using a digital refractometer (Palette PR-32, Atago Co., Tokyo, Japan); pH was measured with a digital pH meter (model HI8453, Hanna Instruments, Villafranca Padovana, Italy); titratable acidity (TA) was determined by titrating 10 mL of homogenized fruit flesh juice with 0.1 N NaOH to an endpoint of pH 8.1 and expressed as the percentage of malic acid (S compact titrator, Crison Instruments, Alella, Spain).

Extractable juice was established by measuring the weight loss from tissue disks (6 mm in diameter and 10 mm in thickness) after centrifuging for 10 min at 1500× g at ambient temperature [14]. The result was expressed as a percentage of tissue plug fresh weight loss after centrifugation.

Weight loss for each treatment was calculated using five packages for each treatment (5 boxes of 3 fruits) and expressed as the percentage reduction with respect to the initial time, utilizing a two-decimal precision digital balance (CENT-2 10000, Gibertini, Novate Milanese, Italy).

$$\%\ \text{Weight loss} = [(\text{Wi} - \text{Ws})]/\text{Wi} \times 100 \tag{1}$$

where Wi is the initial weight and Ws is the weight measured during storage.

The external color of minimally processed loquat fruits for each treatment was measured at two opposite points on each fruit using a colorimeter (Chroma Meter CR-400 C, Minolta, Osaka, Japan). CIE Lab* coordinates were recorded as L* (lightness), a* (positive values for reddish colors and negative values for greenish colors), and b* (positive values for yellowish colors and negative values for bluish colors). Subsequently, the values of c* (chroma, the distance from the lightness axis (L*), which starts at 0 in the center), hue angle (angle that starts at the +a* axis and is expressed in degrees), and Δe (the overall distance or difference between two colors) were calculated.

2.4. Nutraceutical Attributes

The total polyphenolic content and antioxidant activity of minimally processed loquat fruits were assessed soon after harvest (T0) and after 4,6, 8, and 11 days of storage. For each sampling date and experimental treatment (EC1, EC2 and CTR), three samples were randomly chosen and analyzed.

2.4.1. Total Phenolic Content and Antioxidant Activity

The total polyphenolic content (TP) was evaluated by colorimetric methods according to Singleton and Rossi (1965) [25].

The Folin–Ciocalteu reagent method was employed to determine the total phenolic content [26]. Fresh loquat juice was squeezed in duplicates for each treatment during the fruit storage process. The different samples were diluted 1:10 (1 g of fruit in 10 mL of methanol); the mixture was centrifuged at 7000 rpm for 10 min (4 °C). Subsequently, 0.25 mL of this extract was combined with 0.25 mL of distilled water. Then, 2.5 mL of Folin–Ciocalteu reagent was added to this mixture, followed by the addition of 2 mL of sodium carbonate to each tube. After cooling, the absorbance was measured at 650 nm using a spectrophotometer, with Gallic acid serving as the standard. The total polyphenol content was determined in terms of µg of Gallic acid equivalent (GAE)/mL.

2.4.2. Antioxidant Activity

The antioxidant activity of loquat fruit juice was evaluated by the DPPH [2,2-diphenyl-1-picrylhydrazy] free radical scavenging assay [26]. Fresh loquat juice was squeezed in duplicates for each treatment during the fruit storage process.

For the DPPH assay, an aliquot of 0.1 mL of the diluted samples was mixed with 3.9 mL of DPPH methanolic solution (60 µM) and allowed to react for 30 min in the dark. Measurements were performed in duplicates at 515 nm with a Beckmann DU650 spectrophotometer (Pasadena, CA, USA).

All solutions were freshly prepared before analysis and the results are reported as %RSA (radical scavenging activity).

2.5. Sensory Analysis and Visual Score

On each sampling date, 5 boxes (3 fruits in each) for each treatment (CTR, EC1, EC2) underwent sensory evaluation. The sensory profile was developed by a panel of 10 judges who had undergone training in a few preliminary meetings, using commercial fruit to generate a list of descriptors [14]. The sensory analysis focused on the following descriptors: sweetness, juiciness, chewiness, off-flavor development, typical loquat taste, bitterness, tartness, and herbaceous scent. The order of presentation was randomized between judges, and water was provided for rinsing between samples. The fruits were assessed on a 1–10 scale, where a value of 10 indicated maximum intensity, and a value of 1 indicated the absence of the descriptor [13]. Additionally, on each sampling date, 5 boxes (3 fruits in each) for each treatment (CTR, EC1, EC2) were visually scored by each judge. The visual appearance score resulted from the mean value of color, visible structural integrity, and overall visual appearance [7]. Different descriptors were quantified using a subjective 5–1 rating scale with 5 = very good, 4 = good, 3 = sufficient, 2 = poor (limit of edibility), and 1 = very poor (inedible) [7]. A score of 3 was considered the limit of marketability. The order of presentation was randomized between judges [14].

2.6. Statistical Analysis

The data were analyzed using a one-way analysis of variance (ANOVA), and pairwise comparisons between the samples of control and treated fruits were evaluated using Tukey's test. The differences were considered significant for $p < 0.05$. The statistical analysis was carried out using Systat 10 (Chicago, IL, USA) with 3 replications per treatment for each sampling date that occurred.

3. Results and Discussions

3.1. Determination of Fruit Quality: Soluble Solid Content, Titratable Acidity, Extractable Juice, Color, and Weight Loss

In terms of chemical properties, TSSs and TA showed evidence of slight changes during storage in the CTR, EC1, and EC2 samples. TSSs remained constant throughout the entire storage period. The first significant difference between the treatments (CTR, EC1, and EC2) was observed at the end of the storage period (T11 days at 5 °C). Indeed, the CTR samples showed a TSS loss of 21% from the beginning to the end of the cold storage period; instead, EC1 and EC2 showed TSS losses of 11% and 10%, respectively (Table 1). The EC1 and EC2 treatments slightly inhibited the decrease in TSS, acting as a barrier, as reported by previous research [8,14].

Table 1. Changes in total soluble solid (TSS), TA, and extractable juice in minimally processed white-flesh loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) at harvest and during cold storage (11 days at 5 ± 0.5 °C). Data are the mean ± S.E.

Storage Time (Days)	Treatments	TSS (Brix)	TA (% Malic Acid)	Extractable Juice (%)
0	CTR	11.67 ± 0.43^{a}	0.58 ± 0.04^{a}	59.41 ± 1.08^{a}
4	CTR	10.36 ± 0.24^{c}	0.49 ± 0.03^{a}	
6	CTR	10.25 ± 0.38^{b}	0.42 ± 0.01^{b}	52.12 ± 0.43^{b}
8	CTR	10.04 ± 0.22^{b}	0.40 ± 0.01^{b}	
11	CTR	9.26 ± 0.18^{b}	0.36 ± 0.02^{b}	46.06 ± 0.35^{b}
0	EC1	11.67 ± 0.43^{a}	0.58 ± 0.04^{a}	59.41 ± 1.08^{a}
4	EC1	11.21 ± 0.30^{a}	0.54 ± 0.02^{a}	
6	EC1	10.93 ± 0.19^{a}	0.52 ± 0.01^{a}	55.06 ± 0.51^{a}
8	EC1	10.53 ± 0.31^{a}	0.50 ± 0.03^{a}	
11	EC1	10.42 ± 0.15^{a}	0.49 ± 0.02^{a}	53.32 ± 0.49^{a}
0	EC2	11.67 ± 0.43^{a}	0.58 ± 0.04^{a}	59.41 ± 1.08^{a}
4	EC2	10.98 ± 0.24^{b}	0.55 ± 0.03^{a}	
6	EC2	10.79 ± 0.35^{a}	0.54 ± 0.01^{a}	54.98 ± 0.47^{a}
8	EC2	10.56 ± 0.27^{a}	0.53 ± 0.02^{a}	
11	EC2	10.45 ± 0.20^{a}	0.50 ± 0.04^{a}	53.09 ± 0.53^{a}

Different superscript letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date.

The CTR, EC1, and EC2 samples' TA values decreased slightly during cold storage, with the EC1 and EC2 samples' values remaining higher than the CTR samples from the sixth day at 5 °C until the end of the cold storage period. The EC1 and EC2 samples showed TA values around 1.4 times higher than the CTR ones at the end of the cold storage period.

Compared to control fruits, the edible coatings EC1 and EC2 preserved a greater percentage of extractable juice. The CTR samples showed an extractable juice loss of 22% from the beginning to the end of the cold storage period, while the EC1 and EC2 samples showed a loss of 10%. The EC1 and EC2 samples showed extractable juice values that were significantly higher from the sixth day at 5 °C until the end of the cold storage period, while the CTR samples showed the lowest values in terms of extractable juice until the end of the cold storage period.

The uncoated loquat fruit exhibited a higher weight loss compared to the coated counterparts. At the end of the cold storage period, the untreated samples showed a weight loss that was 2.4 and 2.7 times higher than the EC1- and EC2-treated ones, respectively (Figure 4). The impact of *Opuntia ficus-indica* mucilage coating on weight loss aligns with findings from previous studies [14,27]. This reduction in weight loss can be attributed to the enhanced water retention facilitated by the hydrophilic nature of the mucilage coating. The mucilage coating mitigates transpiration and respiration by sealing the openings of stomata and lenticels [1].

In the case of the treated samples (EC1 and EC2), the weight loss rates were 0.63% and 0.54%, respectively, at the end of the cold storage period (Figure 4). This trend was consistently observed throughout the entire storage duration. The synergy between cactus pear mucilage and glycerol had a positive effect on weight loss. Furthermore, other studies demonstrate that these two components alone are capable of reducing the weight loss of minimally processed fruits [14,28,29]. Notably, sample EC2, enriched with 3% L-Glutamine, exhibited the lowest weight loss. The data hint at the potential role of glutamine in minimizing percentage weight loss, warranting further dedicated research to unravel its specific contributions in this context.

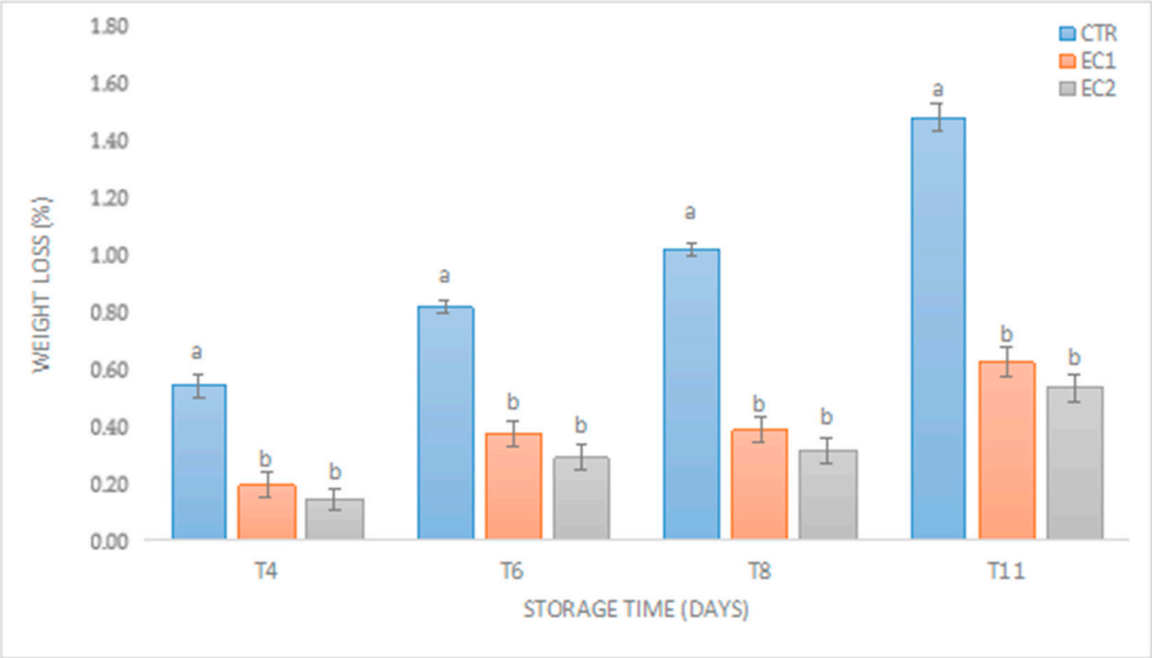

Figure 4. Weight loss of fresh loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) during cold storage (11 days at 5 ± 0.5 °C). Data are the mean ± S.E. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date.

Overall, in CTR, there was a general decrease in L* values (lightness) and an increase in a* values (red–green axis) during the storage period (Table 2). The increase in b* values (yellow–blue axis) also suggests a tendency toward yellow hues, while the rise in c* values indicates an intensification of color (Table 2). These observations collectively indicate a shift towards reduced brightness, a change in color towards red tones, and an increased prevalence of yellow hues during the refrigerated storage period. The fruits treated with EC1 exhibited a more pronounced decrease in L* values, indicating a reduction in brightness. There is a significant increase in both a* and b* values, contributing to a change in color. Chroma (c*) and hue values fluctuate, suggesting variations in color intensity. The fruits treated with EC2 exhibited similar trends to EC1, but the variations in L*, a*, and b* values were less pronounced. Chroma (c*) and hue values remained relatively stable (Table 2). EC1 and EC2 experienced a percentage decrease in brightness of 17.3% and 11.74%, respectively (Table 2). Our findings indicate that glutamine contributed to a reduction in light loss, highlighting the need for further research in this domain.

The color of the fruit is a crucial factor influencing consumer preferences, acceptance, and marketability. Loquat fruit pulp boasts a rich composition of carotenoids, including β-carotene, β-cryptoxanthin, lutein, violaxanthin, α-carotene, and γ-carotene. Additionally, it contains essential vitamins such as B1 and B2, along with nicotinamide [30].

Table 2. Changes in CIE Lab parameters in minimally processed white-flesh loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) at harvest and during cold storage (11 days at 5 ± 0.5 °C). Data are the mean ± S.E.

Storage Time (Days)	**Treatments**	**CieLab**			
		L*	**c***	**Hue**	**Δe**
HARVEST		66.49 ± 2.25 ^{aA}	36.14 ± 2.36 ^{aA}	90.81 ± 0.45 ^{aA}	-
4	CTR	55.87 ± 4.56 ^{aB}	31.89 ± 2.23 ^{aA}	86.40 ± 1.24 ^{Ba}	11.89 ± 5.57 ^{aA}
6	CTR	55.65 ± 4.52 ^{aB}	33.18 ± 3.34 ^{aA}	85.46 ±1.24 ^{Ba}	6.13 ± 4.29 ^{aB}
8	CTR	56.09 ± 3.68 ^{aB}	34.47 ± 2.61 ^{aA}	84.42 ± 0.51 ^{Ba}	6.89 ± 4.27 ^{aB}
11	CTR	60.50 ± 4.21 ^{aC}	34.86 ± 3.73 ^{aA}	87.87 ± 1.42 ^{BCa}	7.25 ± 2.80 ^{aB}

Table 2. *Cont.*

Storage Time (Days)	Treatments	CieLab			
		L*	c*	Hue	Δe
4	EC1	53.93 ± 4.54 ^{aB}	31.40 ± 3.00 ^{aA}	84.18 ± 1.00 ^{Ba}	13.96 ± 5.49 ^{aA}
6	EC1	50.39 ± 7.53 ^{bB}	33.24 ± 5.20 ^{aA}	82.10 ± 0.95 ^{Bb}	9.78 ± 6.50 ^{aA}
8	EC1	54.04 ± 5.10 ^{aB}	32.36 ± 2.85 ^{aA}	83.24 ± 0.70 ^{Ba}	9.74 ± 7.54 ^{aA}
11	EC1	54.98 ± 3.97 ^{bB}	35.26 ± 3.88 ^{aB}	83.24 ± 0.93 ^{Bb}	7.75 ±3.63 ^{aB}
4	EC2	58.03 ± 5.39 ^{aB}	33.63 ± 5.46 ^{aA}	87.83 ± 0.70 ^{Bb}	10.08 ± 5.76 ^{aA}
6	EC2	56.24 ± 4.47 ^{aB}	33.97 ± 3.58 ^{aA}	86.67 ± 0.93 ^{Ba}	7.81 ± 4.12 ^{aA}
8	EC2	55.47 ± 5.98 ^{aB}	33.41 ± 3.27 ^{aA}	85.35 ± 0.70 ^{Ba}	7.16 ± 4.52 ^{aA}
11	EC2	58.68 ± 5.31 ^{abB}	35.84 ± 3.77 ^{aB}	85.61 ± 0.76 ^{Bb}	7.20 ± 5.24 ^{aA}

Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage periods in each sampling treatment.

3.2. Total Phenolic Content and Antioxidant Activity

The polyphenol content (Table 3) exhibited differences among the treatments and showed a slight decrease during the entire cold storage period. The CTR samples showed higher activity until 6 days of cold storage compared to EC1 and EC2; instead, EC1 and EC2 showed a higher total polyphenol content from 8 days to the end of the cold storage period. The lowest activity was observed in the CTR sample at the end of the storage period. Comparable results were also found by Cenobio-Galindo et al. [31]. It is noteworthy that, at the end of the cold storage period, the total phenolic content reached higher values for EC2 samples compared to the values observed in EC1 and CTR. These results affirm that the application of cactus mucilage coating with the addition of glycerol and glutamine in the appropriate proportions enables the maintenance of elevated antioxidant activity, even after eleven days of storage.

Table 3. Changes in total phenolic content and antioxidant activity in minimally processed white-flesh loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) at harvest and during cold storage (11 days at 5 ± 0.5 °C). Data are the mean ± E.S.

Treatments	Storage Time (Days)	Total Phenolic Content (µg GAE/mL)	Antioxidant Activity (%RSA)
CTR	0	271.0 ± 0.04 ^{a}	44.50 ± 1.05 ^{b}
	4	270.2 ± 0.02 ^{a}	35.91 ± 1.03 ^{c}
	6	269.0 ± 0.03 ^{a}	30.08 ± 1.02 ^{b}
	8	195.9 ± 0.02 ^{c}	28.11 ± 1.01 ^{b}
	11	178.9 ± 0.05 ^{c}	15.40 ± 1.04 ^{b}
EC1	0	266.8 ± 0.05 ^{a}	47.80 ± 1.03 ^{a}
	4	263.5 ± 0.04 ^{a}	43.19 ± 1.00 ^{b}
	6	262.6 ± 0.02 ^{b}	39.56 ± 1.01 ^{a}
	8	216.3 ± 0.03 ^{b}	32.29 ± 1.02 ^{a}
	11	208.1 ± 0.05 ^{b}	22.41 ± 1.03 ^{a}
EC2	0	259.2 ± 0.04 ^{a}	49.85 ± 1.03 ^{a}
	4	257.0 ± 0.03 ^{c}	48.79 ± 1.01 ^{a}
	6	257.2 ± 0.02 ^{c}	41.40 ± 1.00 ^{a}
	8	233.0 ± 0.04 ^{a}	34.16 ± 1.02 ^{a}
	11	221.5 ± 0.05 ^{a}	24.83 ± 1.01 ^{a}

Different superscript letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date.

CTR, EC1, and EC2 showed a reduction in antioxidant activity over time (Table 3). Notably, the EC2 treatment consistently demonstrated superior antioxidant activity values during the entire cold storage period, while the control treatment consistently exhibited the lowest values.

Furthermore, the EC1 and EC2 treatments highlighted their highest antioxidant activity at the end of the cold storage period with values 1.5 and 1.6 times higher than the CTR ones (Table 3).

The CTR and EC1 samples showed a decrease as early as the fourth day of cold storage, with losses of 19% and 9%, respectively, from T0 to day T4, while the EC2 samples remained almost the same in terms of antioxidant activity over the same period (Table 3). The CTR, EC1, and EC2 samples showed a decrease of 65%, 53%, and 49%, respectively, from T0 to day T11 in terms of antioxidant activity (Table 3). From these results, it seems that glutamine enhances the antioxidant activity of the edible coating based on *O. ficus-indica* mucilage supplemented with glycerol (EC1). According to our research, an edible coating based on OFI mucilage that has been enhanced with glutamine and glycerol may be beneficial in scavenging reactive oxygen species, protecting against cell membrane damage and peroxidation, and preventing the senescence of loquat fruits.

3.3. Sensory Analysis and Visual Score

Uncoated CTR and coated EC1 and EC2 loquat fruit samples underwent sensory evaluation and visual scores on each sampling date. The CTR, EC1, and EC2 samples showed similar scores immediately after treatment with no significant differences between the samples (Figure 5A). Afterward, sensory evaluation indicated that the EC1 and EC2 samples maintained higher scores in terms of quality parameters than the CTR samples during the entire cold storage period (Figure 5B–D). The EC1 and EC2 samples showed quality mean descriptors scores 1.2 and 1.4 times higher, respectively, than CTR after 4 days of cold storage (Figure 5B); 1.4 and 1.5 times higher, respectively, than CTR ones after 8 days of cold storage (Figure 5C); and, 1.3 and 1.7 times higher, respectively, than CTR at the end of the cold storage period (Figure 5D). Untreated loquat fruit had the lowest visual quality scores during the first 6 days, with no significant differences detected between coated and uncoated treatments. After 11 days at 5 °C, the EC1 and EC2 samples obtained the highest scores in terms of sweetness, with values 2.0 and 2.3 times higher, respectively, than CTR fruits (Figure 5D). Another important aspect concerns the typical loquat taste, and in this case, both EC1 and EC2 samples maintained higher scores than CTR during the entire cold storage period; in particular, EC1 and EC2 achieved mean scores of 1.3 and 1.4 times higher than CTR from day 4 to the end of the cold storage period, respectively (Figure 5B–D). Our data showed that the treated samples (EC1 and EC2) received positive evaluations from the panelists, and EC2 was particularly appreciated in terms of sweetness, juiciness, and overall acceptance (Figure 5A–D). It has already been demonstrated in other studies that prickly pear mucilage maintains and enhances the sensory profile of both loquat fruits [14] and other fruits such as cactus pear [13], strawberry [16], yam [32], and pineapple [33]. In all these instances, including the present study, panelists consistently preferred fruits treated with prickly pear mucilage.

Visual scores for the CTR, EC1, and EC2 samples drastically declined during storage; in fact, after six days at 5 °C, the CTR samples showed a sharp downward trend that brought them below the marketability threshold (Figure 6). On the other hand, until the end of the cold storage period, the EC1 and EC2 samples showed visual scores that were higher than the marketability limit (Figure 6). From day 6 until the end of the cold storage period, the mean scores of the EC1 and EC2 samples were 1.5 times higher than those of the CTR samples, confirming the effectiveness of the edible coating treatments. It has been previously demonstrated that edible coatings made from prickly pear mucilage and glycerol effectively preserve the visual quality of minimally processed fruits, such as sliced kiwifruit [27]. The glutamine contained in the edible coating positively contributed to the visual score and sensory profile of minimally processed loquat fruits.

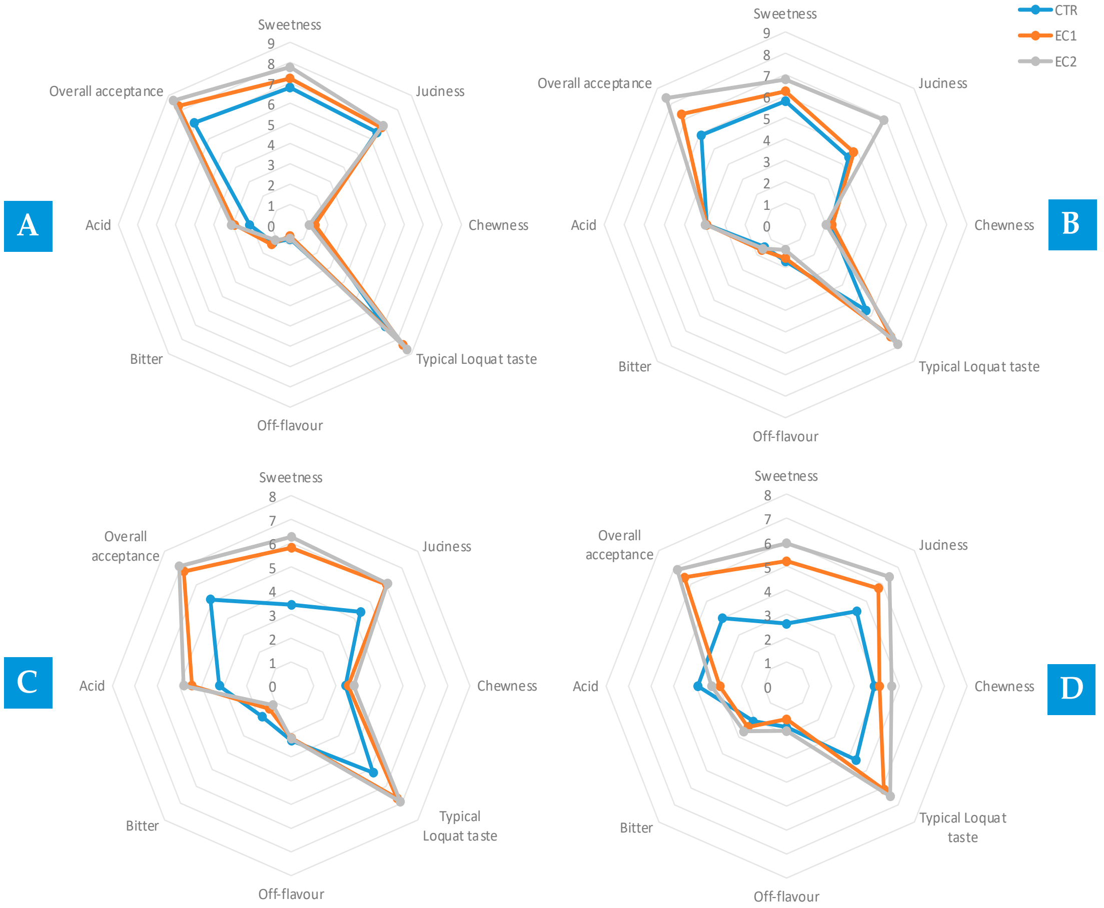

Figure 5. Sensorial analysis of loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) immediately after treatment (**A**), after 4 days of cold storage (**B**), after 8 days of cold storage (**C**), and after 11 days of cold storage (**D**) at 5 ± 0.5 °C. Data are the mean ± S.E. (n = 5).

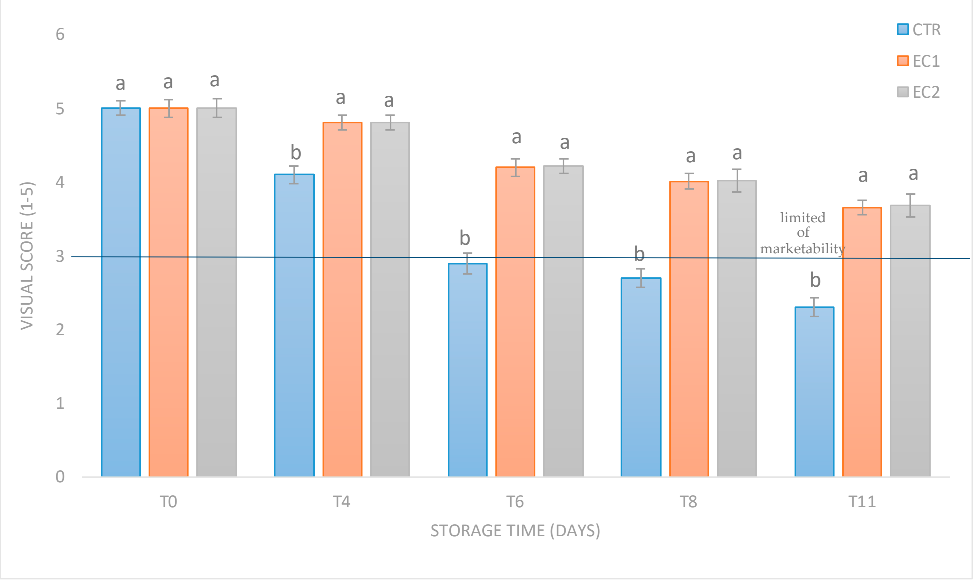

Figure 6. Visual score of loquat fruit control samples (CTR) and treated loquat fruit samples (EC1; EC2) at harvest and during cold storage (4, 6, 8, and 11 days at 5 ± 0.5 °C). Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Data are the mean ± S.E. (n = 5).

4. Conclusions

This study confirms the effectiveness of *Opuntia ficus-indica* (OFI) edible coating, enriched with 30% glycerol and 10% L-glutamine, in preserving the quality of loquat fruits. The results demonstrate that this edible coating formulation provided better postharvest protection than mucilage edible coating alone, maintaining TSS, TA, and extractable juice, reducing weight loss, and slightly increasing antioxidant activity in treated samples, even after 11 days of storage at 5 ± 0.5 °C. This approach can help minimize economic losses due to mechanical damage during the handling and transportation of loquat fruits.

The addition of glycerol and L-glutamine to the cactus mucilage coating has proven beneficial in enhancing the nutritional profile of fruits throughout the entire cold storage period. Changes in soluble solid content and color were primarily influenced by storage conditions and only marginally by the coating treatment. Sensory and visual quality analysis revealed a preference for the treated samples at the end of the storage period. Furthermore, it was found that the mucilage coating did not compromise the natural taste of loquat fruits. Specifically, EC2 exhibited an enhancement in sensory parameters such as typical loquat taste, sweetness, and juiciness, which are crucial aspects for consumer acceptance. These findings suggest the potential benefits of glutamine in enhancing the overall performance of edible coatings, making it a promising avenue for future investigations.

Author Contributions: Conceptualization, G.G. and G.L.; methodology, G.G., G.L., F.G. and I.M.G.; software, G.G., F.G., I.M.G. and G.L.; validation, G.L.; formal analysis, G.G., F.G., I.M.G. and M.L.M.; investigation, G.G., F.G., I.M.G. and M.L.M.; resources, G.L.; data curation, G.G., G.L., F.G., I.M.G. and M.L.M.; writing—original draft preparation, G.G., G.L., F.G. and I.M.G.; writing, G.G. and G.L.; visualization, G.G. and G.L.; supervision, G.L.; project administration, G.L.; funding acquisition, G.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The authors will provide the raw data used to support the findings of this article upon request.

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

References

1. Lin, S.; Sharpe, R.H.; Janick, J. Loquat: Botany and horticulture. *Horticlutral Rev.* **1999**, *23*, 233–276.
2. Baljinder, S.; Seena, G.; Dharmendra, K.; Vikas, G.; Bansal, P. Pharmacological potential of Eriobotrya japonica—An overview. *Int. Res. J. Pharm.* **2010**, *1*, 95–99.
3. Cai, C.; Chen, K.; Xu, W.; Zhang, W.; Li, X.; Ferguson, I. Effect of 1-MCP on postharvest quality of loquat fruit. *Postharvest Biol. Technol.* **2006**, *40*, 155–162. [CrossRef]
4. Pareek, S.; Benkeblia, N.; Janick, J.; Cao, S.; Yahia, E.M. Postharvest physiology and technology of loquat (*Eriobotrya japonica* Lindl.) fruit. *J. Sci. Food Agric.* **2014**, *94*, 1495–1504. [CrossRef]
5. Cao, S.; Zheng, Y.; Yang, Z.; Tang, S.; Jin, P. Control of anthracnose rot and quality deterioration in loquat fruit with methyl jasmonate. *J. Sci. Food Agric.* **2008**, *88*, 1598–1602. [CrossRef]
6. Liguori, G.; Farina, V.; Sortino, G.; Mazzaglia, A.; Inglese, P. Effects of 1-methylcyclopropene on postharvest quality of white- and yellow-flesh loquat (*Eriobotrya japonica* Lindl.) fruit. *Fruits* **2014**, *69*, 363–370. [CrossRef]
7. Petriccione, M.; Pasquariello, M.S.; Mastrobuoni, F.; Zampella, L.; Di Patre, D.; Scortichini, M. Influence of a chitosan coating on the quality and nutraceutical traits of loquat fruit during postharvest life. *Sci. Hortic.* **2015**, *197*, 287–296. [CrossRef]
8. Wang, L.; Shao, S.; Madebo, M.P.; Hou, Y.; Zheng, Y.; Jin, P. Effect of nano-SiO_2 packing on postharvest quality and antioxidant capacity of loquat fruit under ambient temperature storage. *Food Chem.* **2020**, *315*, 126295. [CrossRef] [PubMed]
9. Cao, S.; Yang, Z.; Cai, Y.; Zheng, Y. Fatty acid composition and antioxidant system in relation to susceptibility of loquat fruit to chilling injury. *Food Chem.* **2011**, *127*, 1777–1783. [CrossRef]
10. Salehi, F. Edible coating of fruits and vegetables using natural gums: A review. *Int. J. Fruit Sci.* **2020**, *20*, 570–589. [CrossRef]
11. Guimaraes, A.; Abrunhosa, L.; Pastrana, L.M.; Cerqueira, M.A. Edible films and coatings as carriers of living microorganisms: A new strategy towards biopreservation and healthier foods. *Compr. Rev. Food Sci. Food Saf.* **2018**, *17*, 594–614. [CrossRef] [PubMed]
12. Jongsri, P.; Wangsomboondee, T.; Rojsitthisak, P.; Seraypheap, K. Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit. *LWT* **2016**, *73*, 28–36. [CrossRef]
13. Liguori, G.; Gaglio, R.; Greco, G.; Gentile, C.; Settanni, L.; Inglese, P. Effect of *Opuntia ficus-indica* mucilage edible coating on quality, nutraceutical, and sensorial parameters of minimally processed cactus pear fruits. *Agronomy* **2021**, *11*, 1963. [CrossRef]

14. Liguori, G.; Greco, G.; Gaglio, R.; Settanni, L.; Inglese, P.; Allegra, A. Influence of cactus pear mucilage-based edible coating on marketability and edibility parameters of minimally processed loquat fruits. *Agronomy* **2022**, *12*, 2120. [CrossRef]
15. Gheribi, R.; Khwaldia, K. Cactus mucilage for food packaging applications. *Coatings* **2019**, *9*, 655. [CrossRef]
16. Del-Valle, V.; Hernández-Muñoz, P.; Guarda, A.; Galotto, M.J. Development of a cactus-mucilage edible coating (*Opuntia ficus indica)* and its application to extend strawberry (*Fragaria ananassa*) shelf-life. *Food Chem.* **2005**, *91*, 751–756. [CrossRef]
17. Farahnaky, A.; Saberi, B.; Majzoobi, M. Effect of glycerol on physical and mechanical properties of wheat starch edible films. *J. Texture Stud.* **2013**, *44*, 176–186. [CrossRef]
18. McHugh, T.H.; Krochta, J.M. Sorbitol- vs. Glycerol-Plasticized Whey Protein Edible Films: Integrated Oxygen Permeability Tensile Property Evaluation. *J. Agric. Food Chem.* **1994**, *42*, 841–845. [CrossRef]
19. Sanyang, M.L.; Sapuan, S.M.; Jawaid, M.; Ishak, M.R.; Sahari, J. Effect of plasticizer type and concentration on physical properties of biodegradable films based on sugar palm (*Arenga pinnata*) starch for food packaging. *J. Food Sci. Technol.* **2016**, *53*, 326–336. [CrossRef]
20. Sothornvit, R.; Krochta, J.M. Plasticizer effect on mechanical properties of β-lactoglobulin films. *J. Food Eng.* **2001**, *50*, 149–155. [CrossRef]
21. Shao, A.; Hathcock, J.N. Risk assessment for the amino acids taurine, L-glutamine and L-arginine. *Regul. Toxicol. Pharmacol.* **2008**, *50*, 376–399. [CrossRef]
22. Melis, G.C.; ter Wengel, N.; Boelens, P.G.; van Leeuwen, P.A. Glutamine: Recent developments in research on the clinical significance of glutamine. *Curr. Opin. Clin. Nutr. Metab. Care* **2004**, *7*, 59–70. [CrossRef]
23. Miller, A.L. Therapeutic considerations of L-glutamine: A review of the literature. *Altern. Med. Rev.* **1999**, *4*, 239–248.24.
24. Du Toit, A.; De Wit, M. A Process for Extracting Mucilage from Opuntia ficus-indica and Aloe barbadensis. South Africa Patent No. PA153178/P, 12 May 2011. Volume 12.
25. Singleton, V.L.; Rossi, J.A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158. [CrossRef]
26. Rekha, C.; Poornima, G.; Manasa, M.; Abhipsa, V.; Devi, J.P.; Kumar, H.T.V.; Kekuda, T.P. Ascorbic acid, total phenol content and antioxidant activity of fresh juices of four ripe and unripe citrus fruits. *Chem. Sci. Trans.* **2012**, *1*, 303–310. [CrossRef]
27. Allegra, A.; Inglese, P.; Sortino, G.; Settanni, L.; Todaro, A.; Liguori, G. The influence of *Opuntia ficus-indica* mucilage edible coating on the quality of 'Hayward 'kiwifruit slices. *Postharvest Biol. Technol.* **2016**, *120*, 45–51. [CrossRef]
28. Ali, S.; Anjum, M.A.; Nawaz, A.; Naz, S.; Ejaz, S.; Sardar, H.; Saddiq, B. Tragacanth gum coating modulates oxidative stress and maintains quality of harvested apricot fruits. *Int. J. Biol. Macromol.* **2020**, *163*, 2439–2447. [CrossRef]
29. Zhu, Z.; Mei, W.; Li, R.; Liu, H.; Chen, S.; Yang, H.; Xu, R.; Huang, T.; Xiang, J.; Zhu, F.; et al. Preharvest glycerol treatment enhances postharvest storability of orange fruit by affecting cuticle metabolism. *Postharvest Biol. Technol.* **2023**, *204*, 112448. [CrossRef]
30. Ding, C.K.; Chachin, K.; Hamauzu, Y.; Ueda, Y.; Imahori, Y. Effects of storage temperatures on physiology and quality of loquat fruit. *Postharvest Biol. Technol.* **1998**, *14*, 309–315. [CrossRef]
31. Cenobio-Galindo, A.d.J.; Ocampo-López, J.; Reyes-Munguía, A.; Carrillo-Inungaray, M.L.; Cawood, M.; Medina-Pérez, G.; Fernández-Luqueño, F.; Campos-Montiel, R.G. Influence of bioactive compounds incorporated in a nanoemulsion as coating on avocado fruits (*Persea americana*) during postharvest storage: Antioxidant activity, physicochemical changes, and structural evaluation. *Antioxidants* **2019**, *8*, 500. [CrossRef]
32. Morais, M.A.D.S.; Fonseca, K.S.; Viégas, E.K.D.; de Almeida, S.L.; Maia, R.K.M.; Silva, V.N.S.; Simões, A.D.N. Mucilage of spineless cactus in the composition of an edible coating for minimally processed yam (*Dioscorea* spp.). *J. Food Meas. Charact.* **2019**, *13*, 2000–2008. [CrossRef]
33. Treviño-Garza, M.Z.; García, S.; Heredia, N.; Alanís-Guzmán, M.G.; Arévalo-Niño, K. Layer-by-layer edible coatings based on mucilages, pullulan and chitosan and its effect on quality and preservation of fresh-cut pineapple (*Ananas comosus*). *Postharvest Biol. Technol.* **2017**, *128*, 63–75. [CrossRef]