



## Article

# Mucilage-Based and Calcium Ascorbate Edible Coatings Improve Postharvest Quality and Storability of Minimally Processed Cactus Pear Fruit Stored under Passive Atmosphere

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**Abstract:** The minimally processed fruit and vegetable industry showed rapid growth worldwide, primarily due to the increasing consumer need for ready-to-eat fresh products characterized by high nutritional, sensory and healthy value. The postharvest life of peeled cactus pear fruits is relatively short, due to the processing operations that affect fruit integrity and cause metabolic disfunctions, as well as pulp browning, microbial growth, loss of firmness, off-flavor development, and nutraceutical value loss. In this study, we investigated the effects of mucilage-based (OFI) and calcium ascorbate edible coating on minimally processed cactus pear summer-ripening fruit, cold stored under passive atmosphere. The effect of the edible coating on the postharvest life, quality attributes, and nutraceutical value of fruit was evaluated by colors, total soluble solids content, carbohydrates; titratable acidity, ascorbic acid, betalains, DPPH, visual quality, and sensorial analysis. Our data showed a significant effect of mucilage-based and calcium ascorbate-based coating on preserving quality, nutritional value, sensorial parameters, and improving postharvest life of minimally processed cactus pear fruits; OFI had the most effective barrier effect. Furthermore, both coating treatments did not negatively affect the natural taste of minimally processed cactus pear fruits, which is an important aspect regarding the use of edible coatings when taste modification is undesirable.

**Keywords:** *Opuntia ficus-indica*; fresh-cut; marketability; nutraceutical value; visual score; sensorial traits; microbial growth



**Citation:** Liguori, G.; Greco, G.; Gaglio, R.; Settanni, L.; Gentile, C.; Inglese, P. Mucilage-Based and Calcium Ascorbate Edible Coatings Improve Postharvest Quality and Storability of Minimally Processed Cactus Pear Fruit Stored under Passive Atmosphere. *Horticulturae* **2023**, *9*, 15. <https://doi.org/10.3390/horticulturae9010015>

Academic Editor: Vitalijs Radenkovs

Received: 2 November 2022

Revised: 9 December 2022

Accepted: 12 December 2022

Published: 21 December 2022



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## 1. Introduction

In the last decades there was a very fast ready-to-eat produce industry growth worldwide, mostly due to the increasing consumer need for fresh, healthy, useful fruits and vegetables (eaten anytime and anywhere). Fresh-cut fruit and vegetables are so attractive because they require no work from the consumer and generate no waste through peeling and coring [1].

Cactus pear [*Opuntia ficus-indica* L. (Mill.)] is a non-climateric fruit with a short postharvest life span, being very sensitive to browning, water loss, and decay; fresh fruits are also very susceptible to chilling injury [2]. The overall quality of the summer-ripening cactus pear fruits declines faster than that of the autumn-ripening production [1]. Under shelf-life conditions cactus pear fruits may deteriorate in a few weeks due to the rapid aging and decay. Fruit decay may result from the peel or stem-end damage occurring during harvest and storage, or after glochids removal: the main agents are *Penicillium* spp. and *Alternaria* spp.

Cactus pear is a spiny fruit and the glochids presence confines the consumption and diffusion in the local and international markets, especially in countries where people are not familiar with this fruit [3]. For that reason, peel removal is a relevant process in cactus pear fruits and could be an occasion to improve its suitability, consumption, and distribution in national and international markets.

Minimally processed fruit and vegetables are very perishable products; wounds caused by processing operations cause an increase in ethylene and respiration production rates, accelerating the loss of respirable substrates, firmness, and senescence [1]. In recent years, the relevant changes in human lifestyles caused an increase in the attractiveness of minimally processed foods that are ready-to-eat; among them, the consumption of fresh-cut fruit and vegetables has undergone a sharp growth and the industry interest in the fresh-cut cactus pears production has led to a significant increase in per capita consumption, but despite its market volume it still accounts for a small percentage of the total production [4,5]. The increasing demand for peeled cactus pear had a noticeable impact on companies involved in processing and distribution, and for that reason, more attention should be paid to hygienic requirements and new packaging solutions should be adopted to meet logistics and consumer requirements [6].

The postharvest life of peeled cactus pear fruits is quite short, due to the processing operations that affect fruit integrity and cause intracellular enzymes release, which induces a series of biological events leading to metabolic dysfunctions, tissue browning, microbial proliferation, firmness loss, off-flavor development, and nutraceutical value loss [5]. Microbial spoilage is a significant hazard, mainly when there is a contamination by pathogenic microorganisms with potentially hurtful effects on consumer health [1]. Cactus pear is characterized by high sugar content and low acidity, making this fruit, more than others, a perfect substrate for microbiological growth; for that reason, it is essential to use proper processing methods and adopt an effective postharvest treatment and packaging [1].

Amongst new postharvest environment-friendly management trends for fresh fruit handling, the use of edible coatings can be an excellent solution for extending fresh-cut products' shelf-life by reducing the harmful effects caused by minimal processing operations. Edible coatings may act as a semipermeable barrier against water vapor and gases; they may positively affect fruit tissue metabolism by reducing respiration rate, preserving the color, decreasing firmness and moisture loss, carrying antioxidant, antimicrobial, and other stabilizers, controlling microbial growth, and preserving fruit quality for a more extended period [5,7]. In addition, edible coating can be consumed along with food, can provide additional nutrients, enhance sensory characteristics, and improve product quality. Several studies reported that the applications of edible coatings based on chitosan, *Aloe vera* gel, essential oils, *Opuntia ficus-indica* mucilage, plant extracts, acids, calcium salts, and edible coatings improve postharvest shelf-life of fresh-cut fruits [5,8].

Allegra et al. [9] showed that calcium ascorbate treatment applied to pear fresh-cut slices significantly improved their shelf-life, inhibiting browning and color changes, revealing a higher antioxidant activity and a lower content of total phenols during cold storage.

Del Nobile et al. [10] reported that *Opuntia ficus-indica* fruits treated with fish protein or agar strongly reduced their shelf life, most probably due to water migration from the nearby hydrogel to the fresh-cut product. On the contrary, alginate edible coating improved fresh-cut cactus pear fruits shelf life until about 13 days, confirming the potential of the biodegradable film application instead of plastic packaging [10]. Kahramanoğlu et al. [8] reported that *A. vera* gel-based edible coating prevented weight loss and protected the visual and sensory quality of fresh-cut cactus pear fruit stored at 5°C. Liguori et al. [5] showed that *O. ficus-indica* mucilage-based edible coating was effective in maintaining cactus pear fruit fresh-cut quality, sensorial traits, visual score, and microbial growth during the entire cold storage period.

In this study, we investigated the effects of mucilage-based and calcium-ascorbate edible coatings on minimally processed cactus pear summer-ripening fruit cold stored under passive atmosphere.

## 2. Materials and Methods

### 2.1. Fruit Sample

Cactus pear fruits were collected from 10-year-old *Opuntia ficus-indica* plants, cv. Gialla, spaced 6 × 5 m apart and trained to a globe shape. The commercial orchard was in Roccapalumba, Palermo, Italy (37°48' N, 13°38' E, 350 m a.s.l.) on sandy-loam Mediterranean red-soils. Cactus pear fruits were harvested at the end of August (summer-ripening production) at commercial maturity, which was based on peel color breakage (green–yellow) and were quickly moved to the nearby laboratory. After harvest, fruits were sorted for homogenous size and no defects.

### 2.2. Edible Coating Preparation and Application

#### 2.2.1. *Opuntia ficus-indica* Mucilage Based Edible Coating

One-year-old cladodes were collected from 4-year-old *O. ficus-indica* plants of the cultivar “Gialla”, located in the Department of Agricultural, Food and Forest Sciences, University of Palermo (38°7'4.0800" N 13°22'11.2800" E, 29 m a.s.l.). One-year-old cladodes were harvested and moved to the laboratory where they were processed for mucilage extraction, using a patented method developed by Du Toit and De Witt [11].

No chemicals were used during this extraction process, and as such the extracted mucilage obtained is natural and unadulterated by chemicals.

#### 2.2.2. Calcium Ascorbate Edible Coating

The edible coating was prepared according to Allegra et al. [9]:

- distilled water (500 mL) with 2% calcium ascorbate (ASC) and 50 mL of glycerol used as plasticizer.

Cactus pear selected fruits, work surface area, and cutting tools were washed in tap water, sanitized by immersion in 200 mg kg<sup>-1</sup> of sodium hypochlorite for 5 min, and left to dry at room temperature, before and during fruit processing.

Fruits were then peeled, about 0.5 cm of fruit peel was removed from each distal end by cutting with a sharp knife, and the peel was then carefully removed along the longitudinal axis. Only peeled fruits with no defects were selected and fruit processing operations were carried out in sanitary conditions at 4 °C.

After cutting, cactus pear fruits were divided into three treatment groups (uncoated fruits—control: OFI-CTR; mucilage-based coated fruits: OFI M and calcium ascorbate coated fruits: OFI-CA). Each treatment group (OFI-CTR; OFI-M, and OFI-CA) consisted of 5 replicates (3 fruits each) for each sampling date (4), plus 20 replicates (3 fruits each) for sensory analysis and visual score (5 replicates for each sampling date) and 5 replicates (3 fruits each) for weight loss checking. OFI-CTR samples were treated with distilled sterile water and used as control. Mucilage edible coating, calcium ascorbate coating and distilled water were applied by using an atomizing spray system (flow rate: 1 L h<sup>-1</sup>; air pressure: 50 kPa) [12]. Immediately after coating, all samples were air-dried at room temperature for 15 min, then, uncoated and coated fruits (OFI-CTR, OFI-M, and OFI-CA), were placed in rigid polypropylene 25 × 20 cm retail boxes (3 fruits for each box), sealed with 35 µm microperforated polypropylene film (O<sub>2</sub> permeability: ~12,000 mL m<sup>-2</sup> d<sup>-1</sup> atm<sup>-1</sup>; CO<sub>2</sub> permeability: ~13,000 mL m<sup>-2</sup> d<sup>-1</sup> atm<sup>-1</sup> at 5 °C) and stored at 5 ± 0.5 °C and 95% RH for 9 days.

### 2.3. Quality Parameters: Soluble Solid Content, Titratable Acidity, Carbohydrate, Color, and Weight Loss

Minimally processed cactus pear fruits quality was evaluated soon after coating (0 d) and at 3, 6, and 9 days of storage at 5 °C. For each experimental treatment and sampling date, five boxes (3 fruits for each) were randomly chosen and analyzed.

The fruit pulp was cut into pieces to get a uniform sample for each replicate. A part was homogenized to measure total soluble solids (TSS) content and titratable acidity (TA), and the remainder was immediately frozen at –80 °C for the nutraceutical analysis. Total soluble

solids content (TSS) was analyzed using a digital refractometer (Palette PR-32, Atago Co., Ltd., Tokyo, Japan); titratable acidity (TA) was analyzed by titration of 10 mL homogenized fruit flesh juice with 0.1 N NaOH to an endpoint of pH 8.1 and expressed as the percentage of citric acid (mod. S compact titrator, Crison Instruments, Barcelona, Spain).

Analysis of carbohydrates was performed by coupling a liquid chromatograph system with a Bio-Rad Carbo-P micro-guard cartridge thermostated at 80 °C, according to Palma et al. [4]. Stock standard solutions of each carbohydrate were arranged in ultrapure water and their quantifications, in cactus pear fruit juice, were estimated according to the linear calibration curves of standard compounds.

Cactus pear weight loss was monitored on 5 boxes for each treatment and expressed as the percentage reduction concerning the initial time according to Equation (1), using a two-decimal precision digital balance (Mod. CENT-2 10000, Gibertini, Milan, Italy).

$$\% \text{ Weight loss} = [(W_i - W_s)] / W_i \times 100 \quad (1)$$

where  $W_i$  is the initial weight, and  $W_s$  is the weight measured during storage.

Fresh-cut cactus pear samples external color was measured at two opposite points on each fruit using a colorimeter (Chroma Meter CR-400C, Minolta, Osaka, Japan). *CIE L\*a\*b\** 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).

#### 2.4. Headspace Gas Composition

In-packages,  $O_2$ , and  $CO_2$  partial pressure were measured immediately before quality evaluation, using an  $O_2$  and  $CO_2$  portable analyzer (Dansensor Checkpoint, Ametek Mocon, Minneapolis, MN, USA) after 0, 3, 6, and, 9 days at 5 °C on 5 packages for each treatment.

#### 2.5. Nutraceutical Attributes

The betalain, total phenolic compounds, ascorbic acid content, and antioxidant activity of fresh-cut cactus pear fruits were measured soon after coating (0 d) and at 3 (3 d), 6 (6 d), and 9 (9 d) days of storage at 5 °C. For each sampling date and experimental treatment (OFI-CTR; OFI-M; OFI-CA), three samples were randomly chosen and analyzed.

##### 2.5.1. Quantitation of Betalains in Fruit Extracts

Betanin and indicaxanthin in fruit extracts were evaluated spectrophotometrically after separation by gel filtration on a Sephadex G-25 column (40 cm × 2.2 cm) [13], and betanin was quantified by the absorbance at 536 nm, using a molar extinction coefficient of 65,000 [14]. Owing to the overlapping of betanin absorbance with the indicaxanthin absorbance at 482 nm, the indicaxanthin concentration was determined according to Equation (2) as reported in previous research [15]:

$$[\text{indicaxanthin}] (\mu\text{M}) = 23.8A_{482} - 7.7A_{536} \quad (2)$$

This equation was obtained considering the indicaxanthin molar at 482 nm [ $A_{482}$  (indicaxanthin) = 42,600] [16] and of betanin at either 536 or 482 nm.

##### 2.5.2. Total Phenolic Content

According to Folin and Denis, the total phenolic content (TPC) of ethanolic extracts was quantified using the reduction in phosphotungstic-phosphomolybdic acid (Folin-Ciocalteu's reagent) to blue pigments in alkaline solution [17]. Quantification was achieved by gallic acid (GA) calibration curve, and the results were expressed as mg GA equivalents (GAE) per 100 g fresh weight (FW).

### 2.5.3. DPPH Assay

Fruit extracts radical-scavenging activity was evaluated by DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. The assay is based on the monitoring of the radical DPPH at 735 nm solution decolorization [18]. The radical scavenging activity of each sample was expressed as Trolox equivalent (TE) per 100 g of FW. Samples were tested at five different dilutions, and for each sample the assay was repeated three times.

### 2.5.4. Ascorbic Acid Content

Ascorbic acid in uncoated and coated OFI samples was determined by extracting 10 g of blended fruit sample in 100 mL metaphosphoric acid ( $\text{HPO}_3$ ), then filtered through Whatman no 1 filter paper. A volume of 10 mL from the filtered solution was determined volumetrically with the 2–6 dichlorophenol-indophenol reagent until a slightly pink coloration was detected and persisted for 15 s [19]. The reading of ascorbic acid content was expressed in mg/100 g FW.

## 2.6. Sensory Analysis and Visual Score

At each sampling date, 5 boxes (3 fruits in each) for each treatment (OFI-CTR; OFI-M, and OFI-CA) were subjected to sensory evaluation. The sensory profile was constructed by a panel made of 10 judges (5 females and 5 males, cactus pears fruit consumers, aged between 25 and 55 years) trained during several preliminary meetings: by using commercial fruit, the judges created a descriptors list. Sensory analysis was focused on firmness, taste, acidity, sweetness, aroma, off-flavor development, and overall acceptance. The different descriptors were quantified using a nine-point intensity scale where digit 1 indicates the descriptor absence while digit 9 is the full intensity [5]. The samples presentation order was randomized among judges. Water was provided for mouth rinsing between samples.

At each sampling date, 5 boxes (3 fruits in each) for each treatment (OFI-CTR; OFI-M, and OFI-CA) were also assessed by each judge for the visual score. The visual appearance score resulted from the medium value of visible structural integrity, color, and visual appearance [20]. The different descriptors were quantified using a subjective rating scale (1–5) with 1 = very poor (inedible), 2 = poor (limit of edibility), 3 = sufficient (limit of marketability), 4 = good and 5 = very good [5]. The samples presentation order was randomized among judges.

## 2.7. Microbiological Analyses

Edible coatings and minimally processed cactus pear fruit samples were microbiologically investigated to evaluate the levels of the main spoilage and pathogenic microorganisms associated to food matrices. All samples collected during experimentation were subjected to the decimal serial dilution (1:10). In particular, 1 mL edible coatings were directly serially diluted in Ringer's solution (Oxoid, Milan, Italy), while 10 g of OFI-CTR, OFI-M and OFI-CA were homogenized by the stomacher Bag-Mixer 400 (Interscience, Puycapel, France) for 2 min and then serially diluted.

The homogenized samples and the appropriate dilutions were plated on agar media to allow the development of: Total Mesophilic Microorganisms (TMM); Total Psychrotrophic Microorganisms (TPM); pseudomonads; members of the Enterobacteriaceae family; *Listeria monocytogenes* and yeasts. All media and supplements were purchased from Microbiol Diagnostici (Uta, Italy). Microbiological analyses were performed in triplicate and minimally processed cactus pear fruit samples were analyzed soon after production and after 3, 6, and 9 days of refrigerated storage at 5 °C.

## 2.8. Statistical Analyses

All data were submitted to one-way analysis of variance (ANOVA) and means were separated with Tukey's test at  $p \leq 0.05$ . The statistical analysis was carried out using Systat 10 (Systat, Chicago, IL, USA).

### 3. Results and Discussion

#### 3.1. Quality Parameters: Soluble Solid Content, Titratable Acidity and Carbohydrate

Concerning chemical parameters, there was evidence of slight changes (Table 1). TA values remained stable in all samples during cold storage, and coating treatment did not affect TA as reported by previous studies [4,5].

TSS showed similar values in OFI-M and OFI-CA samples in all sampling dates, with no significant differences from the beginning to the end of the cold storage period, while OFI-CTR samples showed a significant decrease with a loss of 15% from the beginning to the end of the cold storage period. OFI-M and OFI-CTR samples showed significantly higher TSS values than OFI-CTR at the end of the cold storage with a loss of TSS of 3% and 5%, respectively, from the beginning to the end of the cold storage period, showing the effectiveness of OFI mucilage and CA coating in terms of maintaining fruit cell structure (Table 1).

Glucose and fructose were the main detected soluble sugars (Table 1), while sucrose was not identified, as reported by previous studies [4]. In all the samples, glucose was always higher than fructose, with an average ratio of 1.56, 1.54, and 1.54, in OFI-CTR, OFI-M and OFI-CA, respectively. Glucose and fructose content was affected by the coating treatments, and OFI-M and OFI-CA samples showed significantly higher values than OFI-CTR samples from the sixth day of cold storage (Table 1). OFI-M and OFI-CA showed a glucose content decrease of 11% and 14%, respectively, while OFI-CTR showed a glucose content decrease of 17% from the beginning to the end of the cold storage period (Table 1). Fructose content showed higher differences between coated and uncoated samples, OFI-M and OFI-CA samples showed a fructose content decrease of 6% and 7%, respectively, while OFI-CTR samples showed a glucose content decrease of 15% from the beginning to the end of the cold storage period (Table 1). As reported by previous studies [4,21], the individual sugars concentration, as well as their absolute and relative changes, are crucial factors affecting taste because sweetness perception changes with sugars.

In our study, OFI mucilage and calcium ascorbate coating preserved the sugar content in minimally processing cactus pear fruits during cold storage, positively affecting fruit taste and acceptability.

#### 3.2. Total Phenolic Content, Ascorbic Acid, Betalains, and Antioxidant Activity

Previous studies reported that phenolic compounds acted as non-enzymatic antioxidant and their accumulation might play a strong role in free radical scavenging and keeping cells from the oxidative damage caused by free radicals in fruits and vegetables [5]. After the processing operations, the antioxidant activity could be increased by some factors (i.e., phenols, ascorbic acid, betalains) and decreased by others, and its behavior would reflect the contribution given by each factor [4].

Our study showed a slight decrease in total phenolic content in all the treatments; OFI-M and OFI-CA coated samples showed significantly higher values than OFI-CTR from the sixth day to the end of the cold storage period (Table 2). Both coating treatments prevented the decline of total phenolics content, showing a decrease of 2% in OFI-M and of 3% in OFI-CA samples at the end of the cold storage period, while OFI-CTR samples showed a decrease of 10% at the end of the cold storage period (Table 2). A similar behavior was reported by Palma et al. [22] and Piga et al. [23], which showed a slight decline in total phenolics content in minimally processed *O. ficus-indica* fruits treated with different edible coatings. Total phenolics content decrease was slight in all treatments, due to three factors: (1) the cold storage temperature; (2) the effect of modified atmosphere packaging on reducing the phenylalanine ammonio-lyase activity and enhancing the phenol-synthesizing mechanism; and (3) the minimal processing, limited on fruit peeling that causes only slight tissues injuries [4,24].

**Table 1.** Changes in titratable acidity (TA), total soluble solid (TSS), fructose and glucose in minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean  $\pm$  SE ( $n = 5$ ).

Storage Time (Days)	TA (g Citric Acid 100 g <sup>-1</sup> FW)			TSS (°Brix)			Glucose (g 100 g <sup>-1</sup> )			Fructose (g 100 g <sup>-1</sup> )		
	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA
T0	0.091 $\pm$ 0.03 ns	0.091 $\pm$ 0.03 ns	0.091 $\pm$ 0.03 ns	14.75 $\pm$ 0.18 ns	14.75 $\pm$ 0.18 ns	14.75 $\pm$ 0.18 ns	8.75 $\pm$ 0.11 ns	8.75 $\pm$ 0.11 ns	8.75 $\pm$ 0.11 ns	5.69 $\pm$ 0.18 ns	5.69 $\pm$ 0.18 ns	5.69 $\pm$ 0.18 ns
T3	0.083 $\pm$ 0.02 ns	0.085 $\pm$ 0.02 ns	0.084 $\pm$ 0.01 ns	14.21 $\pm$ 0.23 ns	14.52 $\pm$ 0.21 ns	14.24 $\pm$ 0.18 ns	8.51 $\pm$ 0.13 ns	8.67 $\pm$ 0.13 ns	8.63 $\pm$ 0.12 ns	5.32 $\pm$ 0.11 ns	5.43 $\pm$ 0.12 ns	5.41 $\pm$ 0.15 ns
T6	0.082 $\pm$ 0.04 ns	0.084 $\pm$ 0.03 ns	0.084 $\pm$ 0.03 ns	13.51 $\pm$ 0.29 b	14.39 $\pm$ 0.19 a	14.14 $\pm$ 0.18 a	8.04 $\pm$ 0.11 b	8.47 $\pm$ 0.12 a	8.45 $\pm$ 0.10 a	5.01 $\pm$ 0.11 b	5.38 $\pm$ 0.09 a	5.32 $\pm$ 0.08 a
T9	0.078 $\pm$ 0.05 ns	0.083 $\pm$ 0.02 ns	0.082 $\pm$ 0.01 ns	12.46 $\pm$ 0.27 b	14.25 $\pm$ 0.22 a	14.02 $\pm$ 0.18a	7.25 $\pm$ 0.11 b	7.79 $\pm$ 0.12 a	7.51 $\pm$ 0.13 a	4.83 $\pm$ 0.12 b	5.34 $\pm$ 0.11 a	5.29 $\pm$ 0.12 a
Significance Storage	ns	ns	ns	*	ns	ns	*	ns	ns	*	ns	ns

Significance: ns = not significant; \* = significant at  $p < 0.05$ .

**Table 2.** Changes in Total phenolics, Indicaxantin, Ascorbic Acid and DPPH in minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean  $\pm$  SE ( $n = 5$ ).

Storage Time (Days)	Total Phenolics (mg Gallic Acid Equiv. 100 g <sup>-1</sup> )			Indicaxantin (mg 100 g <sup>-1</sup> FW)			Ascorbic Acid (mg 100 g <sup>-1</sup> FW)			DPPH (mmol TE 100 g <sup>-1</sup> FW)		
	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA	OFI-CTR	OFI-M	OFI-CA
T0	92.65 $\pm$ 1.51 ns	92.65 $\pm$ 1.51 ns	92.65 $\pm$ 1.51 ns	8.51 $\pm$ 0.19 ns	8.89 $\pm$ 0.20 ns	8.63 $\pm$ 0.22 ns	26.7 $\pm$ 0.15 a	26.7 $\pm$ 0.15 a	26.7 $\pm$ 0.15 a	5.31 $\pm$ 0.32 a	5.31 $\pm$ 0.32 a	5.31 $\pm$ 0.32 a
T3	90.29 $\pm$ 1.36 ns	91.51 $\pm$ 1.17 ns	91.20 $\pm$ 1.14 ns	6.81 $\pm$ 0.28 b	8.62 $\pm$ 0.22 a	8.22 $\pm$ 0.27 a	22.2 $\pm$ 0.13 b	26.3 $\pm$ 0.14 a	26.1 $\pm$ 0.12 a	4.67 $\pm$ 0.18 a	5.01 $\pm$ 0.28 a	4.98 $\pm$ 0.28 a
T6	87.53 $\pm$ 1.53 b	90.82 $\pm$ 1.21 a	90.55 $\pm$ 1.19°	6.84 $\pm$ 0.17 b	8.56 $\pm$ 0.23 a	8.10 $\pm$ 0.31 a	20.6 $\pm$ 0.15 b	25.1 $\pm$ 0.10 a	24.9 $\pm$ 0.11 a	3.52 $\pm$ 0.20 b	4.95 $\pm$ 0.27 a	4.76 $\pm$ 0.27 a
T9	83.62 $\pm$ 1.11 b	90.45 $\pm$ 1.01 a	90.18 $\pm$ 1.23°	6.83 $\pm$ 0.21 b	8.41 $\pm$ 0.18 a	7.98 $\pm$ 0.39 a	19.7 $\pm$ 0.11 b	24.3 $\pm$ 0.14 a	23.6 $\pm$ 0.15 a	2.41 $\pm$ 0.23 b	4.90 $\pm$ 0.23 a	4.65 $\pm$ 0.21 a
Significance <sup>x</sup> Storage	*	ns	ns	*	ns	ns	*	*	*	*	ns	ns

<sup>x</sup> Significance: ns = not significant; \* = significant at  $p < 0.05$ .

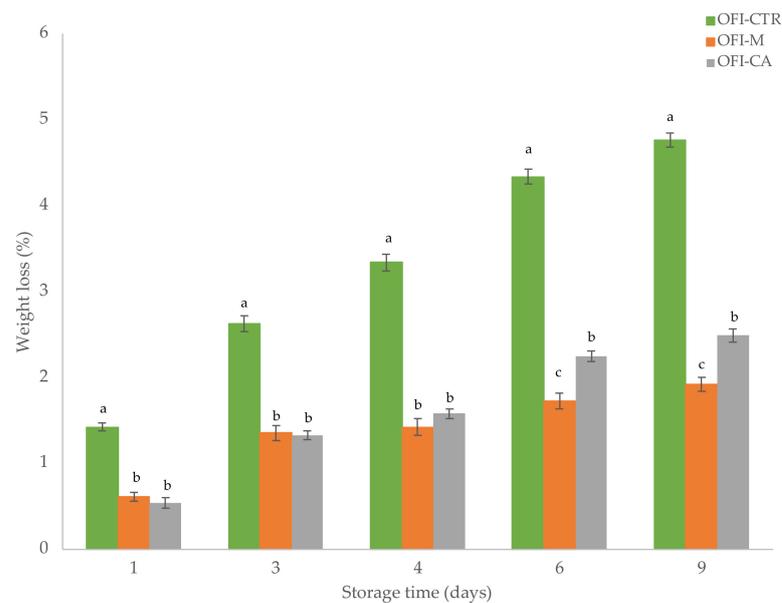
Betain content showed a slight decrease in OFI-CTR samples, otherwise was stable in OFI-M and OFI-CA samples during the cold storage period, but no significant differences were measured between the treatments. Indicaxantin content was significantly higher in OFI-M and OFI-CA samples than in OFI-CTR ones on each sampling date, showing values 1.2 times higher in both coated samples at end of the cold storage period (Table 2). OFI-CTR samples showed an indicaxantin content decrease of 20% at the end of the cold storage period, while OFI-M and OFI-CTR indicaxantin content remained almost stable, with losses of about 5% and 7%, respectively, from the beginning to the end of the cold storage period (Table 2). Betalains and ascorbic acid are important nutraceutical components of cactus pears that give the fruit a peculiar antioxidant capacity [4,25]. Fruit maturity stage, antioxidant compounds content, in-package atmosphere composition, and storage temperature could all stimulate synthesis and affect losses of betacyanins and betaxanthins content during storage [4]. Low temperatures combined with reduced O<sub>2</sub> levels stimulated the synthesis of the pigments; in our study betain and indicaxanthin did not increase during storage, which was probably due to the O<sub>2</sub> in-package partial pressure that was not low enough to stimulate new pigment synthesis, as reported by Palma et al. [4].

Ascorbic acid content showed a moderate decrease during cold storage, with losses of about 26%, 9%, and 12% in OFI-CTR, OFI-M, and OFI-CA, respectively, showing a positive effect of the coating treatments on minimally processed fruit ascorbic content losses (Table 2). In most horticultural products, ascorbic acid content decreases during storage with degradation rates depending on genotype, maturity stage, and storage conditions. In fresh-cut, due to wounding causing fruit physical injuries, the degradation rate can be particularly high. In cactus pears, the processing operations are normally being limited to peeling, and the impact of wounding is expected to be moderate [4]. Our study showed that the mucilage coating was the most effective coating treatment, significantly reducing the ascorbic acid content losses during storage; indeed, OFI-M samples showed losses 3 times lower than in OFI-CTR ones, from the beginning to the end of the cold storage period (9% vs. 26%) (Table 2).

The antioxidant activity in OFI-CTR samples decreased remarkably during storage, showing a loss of 55% from the beginning to the end of the cold storage period, as reported by a previous study [5] (Table 2). The loss in terms of DPPH in OFI-CTR samples appeared after 6 days of storage decreasing until the end of the cold storage period (Table 2). DPPH in OFI-M and OFI-CA samples were almost stable during storage, showing values 2 times higher than in OFI-CTR ones at end of the cold storage period (Table 2). In our study all coating treatments showed a positive effect on minimally processed cactus pear fruits radical scavenging activity (DPPH), while OFI-CTR samples showed a sharp decrease during the cold storage, DPPH was almost stable in OFI-M and OFI-CA during the storage period (Table 2).

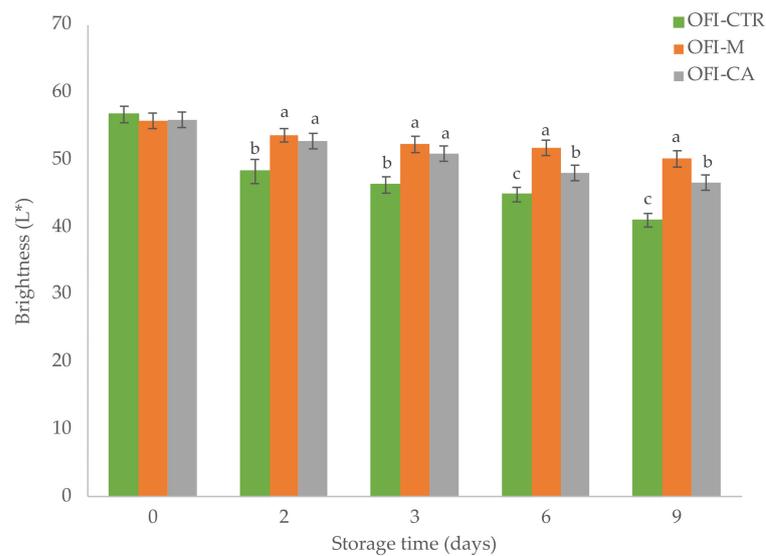
### 3.3. Quality Parameters: Weight Loss and Color

The coating treatments significantly retained weight loss during the cold storage period (Figure 1). OFI-CTR samples showed a weight loss of 2 and 2.5 times higher than OFI-CA and OFI-M samples, respectively, during cold storage (Figure 1). Differences between coated and uncoated fruit were significant starting from the first day to the end of the cold storage period (Figure 1). One of the most beneficial effects of fruit coating is the maintenance of high RH inside the packaging; in our study, cactus pear mucilage was the most effective treatment, acting as a barrier to water transfer and reducing weight loss, as reported by previous studies [2,5,26].



**Figure 1.** Changes in weight loss (%) in minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean  $\pm$  SE (Vertical bars represent standard error;  $n = 5$ ).

Color and appearance are the main factors that affect fruit consumer acceptability and choice, and in fresh-cut fruit changes in color can be caused by the synthesis of new pigments, discoloration, or browning of bruised or wounded surfaces or both [4,5]. OFI-CTR fruit showed a continuous drop in flesh brightness, with lower values than OFI-M and OFI-CA fruit during the entire cold storage period (from 0 to 9 days of storage at 5 °C) (Figure 2). OFI-M and OFI-CA samples showed similar flesh brightness values until the third day of storage, with losses of 6% and 9%, respectively, while from the sixth to the end of the cold storage period, OFI-M showed the highest values with a loss of 10% compared to the loss of 17% of OFI-CA samples (Figure 2). OFI-CTR showed a sharp drop with a loss of 28% of flesh brightness from the beginning to the end of the cold storage period (Figure 2). Previous studies reported a slight decrease in fruit brightness and an increase in darkening in white and red peeled cactus pears, respectively [5,27], while Allegra et al. [28] did not find important changes in yellow minimally processed cactus pear fruits flesh color during storage. In our study, OFI-CTR samples brightness decreased significantly during cold storage, as reported by previous studies [5], while OFI-M and OFI-CA showed brightness values 1.1 and 1.2 times, respectively, higher than OFI-CTR at the end of the cold storage period (Figure 2). Fruit flesh brightness ( $L^*$ ) was similar in OFI-CTR, OFI-M and OFI-CA samples at the time of treatment. Fruit color loss is probably related to betalains content changes, and in our study the betalains degradation was strictly correlated to the loss in brightness in uncoated cactus pear samples during storage.

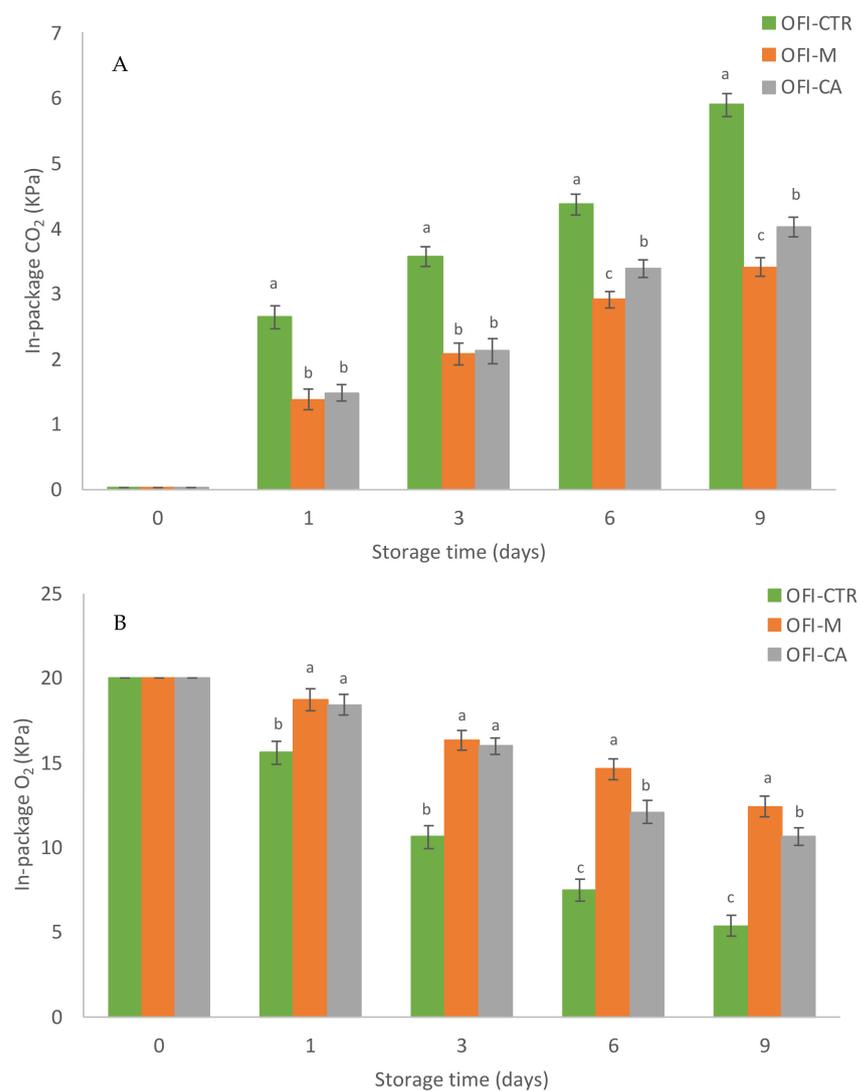


**Figure 2.** Changes in brightness ( $L^*$ ) in minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean  $\pm$  SE ( $n = 5$ ).

### 3.4. Headspace Gas Composition

According to previous studies [4,5], in-package atmosphere was significantly affected by storage time in all the treatments,  $CO_2$  and  $O_2$  increased and decreased, respectively, during the cold storage period (Figure 3A,B).

OFI-CTR samples showed a significantly higher level of  $CO_2$  than OFI-M and OFI-CA ones during the entire cold storage period, showing an in-package  $CO_2$  concentration 1.7 and 1.5 times higher than in OFI-M and OFI-CA, respectively, after 9 days of cold storage (Figure 3A). OFI-M and OFI-CA samples showed significantly higher levels of  $O_2$  than OFI-CTR during storage with values 2.3 and 2.0 times, respectively, higher than in OFI-CTR samples at the end of the cold storage period (Figure 3B). OFI-M and OFI-CA samples showed a similar trend in terms of in-package gas composition until the third day of cold storage (Figure 3A,B), while after six days of storage the mucilage coating treatment resulted in the most effective in terms of fruit gas exchange (Figure 3A,B). After 9 days of cold storage, the  $O_2/CO_2$  in-packages concentration (kPa) in OFI-CTR, OFI-M, and OFI-CA, was about 5/6, 12/3, and 10/4, respectively (Figure 3A,B). OFI-CTR samples showed the higher respiration rate during cold storage than OFI-M and OFI-CA fruits; indeed, OFI-CTR samples showed a loss in terms of in-package  $O_2$  concentration of 66% from the beginning to the end of the cold storage; otherwise, OFI-M and OFI-CA showed a loss in terms of in-package  $O_2$  concentration, respectively, of 38% and 47%, from the beginning to the end of the cold storage period (Figure 3A,B). In our study, the mucilage-based coating was the most effective barrier against gaseous exchange among the environment and coated samples by reducing  $O_2$  permeability and promoting  $CO_2$  accumulation in the in-package atmosphere, as reported by previous studies [5,26].



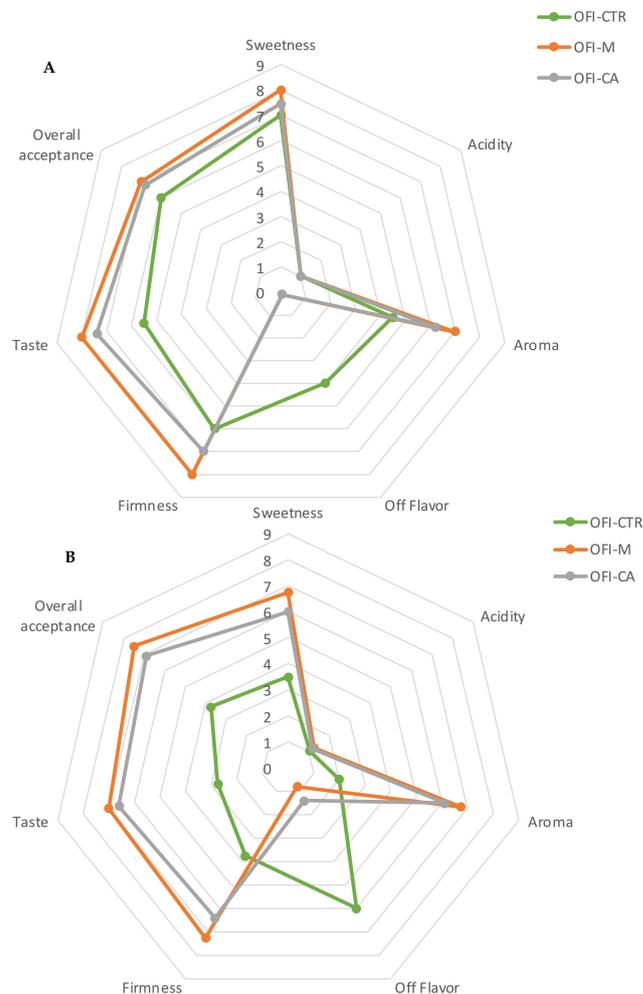
**Figure 3.** Concentrations of CO<sub>2</sub> (A) and O<sub>2</sub> (B) in minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean  $\pm$  SE ( $n = 5$ ).

### 3.5. Sensory Analysis and Visual Score

Fresh fruit sensory quality is the result of a combination of taste (sweet, acid, salty, bitter), aroma, and textural properties. In the case of cactus pear, if fruit has significant sugar levels, firmness (crunchiness, more precisely) is considered one of the most important sensorial attributes affecting overall acceptability [4].

Uncoated (OFI-CTR) and coated (OFI-M, OFI-CA) cactus pear fruit samples were subjected to sensory evaluation at each sampling date. Fresh-cut cactus pear fruits' sensory profiles were positively affected by mucilage and calcium ascorbate coating; indeed, panelists preferred OFI-M and OFI-CA samples in each sampling date with mean scores 1.8 and 1.6 times, respectively, higher than OFI-CTR during the cold storage period (data not shown). OFI-M and OFI-CA coated samples showed mean scores 1.2 and 1.3 times, respectively, higher in terms of sensory evaluation than OFI-CTR samples after 3 days of storage at 5 °C (Figure 4A). Panelists perceived the largest difference in the aroma, firmness, and taste descriptors in OFI-M and OFI-CA samples with scores 1.4 times, almost higher than OFI-CTR ones and in the off-flavor descriptor with scores 4 times lower than OFI-CTR ones (Figure 4A). Sensory analysis descriptors showed the same trend until the end of the storage (9 days), OFI-M and OFI-CA samples were preferred by judges showing the highest

scores in almost all sensorial parameters, obtaining sensory evaluation mean scores 2 times higher than OFI-CTR ones (Figure 4B). Panelists perceived off-flavor in OFI-CTR samples from 3 days to 9 days at 5 °C (Figure 4A,B), while the perception of this descriptor was almost absent in OFI-M and OFI-CA samples in each sampling date (Figure 4A,B).

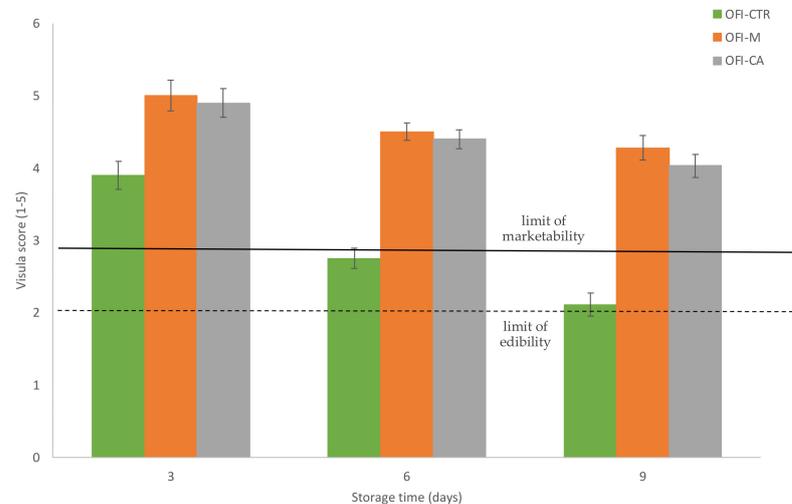


**Figure 4.** Sensory analysis of minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) after 3 days (A), and 9 days (B) of cold storage at 5 °C. Data are the mean  $\pm$  SE ( $n = 5$ ).

The sensory analysis showed that judges had a higher preference for both coated samples at the end of the cold storage period. The sensory analysis highlighted that the judges appreciated mucilage-based coated samples at the end of the cold storage period, as reported by previous studies in cactus pear [4], strawberry [29], kiwifruit [20] and fig [30]. Coated samples were preferred by the panelists in all the descriptors and received scores of 7.5 and 7 for OFI-M and OFI-CA samples, respectively, in terms of overall acceptance, while OFI-CTR samples had scores of 4 in overall acceptance after 9 days of cold storage (5 °C) (Figure 4B). The mucilage coating was the most effective treatment and did not negatively affect the natural fruit taste, which is an important aspect regarding the use of edible coatings when taste modification is undesirable; indeed, mucilage coating has exalted some important parameters, as well as aroma, sweetness, and taste that are particularly appreciated by consumers.

The visual appearance of uncoated samples significantly decreased during storage, and indeed OFI-CTR samples had a severe descending trend that dropped below the limit of marketability and edibility after six days and nine days of storage, respectively, as reported by previous studies [5], whereas all the coated samples recorded visual scores above the

limit of marketability and edibility during the entire cold storage period (Figures 5 and 6). OFI-M and OFI-CA samples showed a visual score almost 2 times higher than OFI-CTR ones at the end of the cold storage period (Figure 5), confirming that coating positively affects the overall fruit appearance.



**Figure 5.** Visual score of minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C). Different lowercase letters indicate significant differences (Tukey's test at  $p \leq 0.05$ ) between the treatments in each sampling date. Data are the mean  $\pm$  SE (Vertical bars represent standard error;  $n = 5$ ). [(5 = very good, 4 = good, 3 = fair (limit of marketability), 2 = poor (limit of edibility) and 1 = very poor (inedible)].



**Figure 6.** Minimally *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) at the end of the cold storage (9 days at 5 °C).

### 3.6. Evolution of Microbiological Parameters

Cactus pear fruit is considered very susceptible to microbial spoilage determined by bacteria and microscopic fungi (yeasts, and molds) [31]. For this purpose, it is important to evaluate the microbial composition of these fruits to predict their storability. The results of microbiological characteristics of minimally processed cactus pear fruit coated samples (OFI-M and OFI-CA) and uncoated samples (OFI-CTR) are reported in Table 3.

**Table 3.** Microbial loads of minimally processed *O. ficus-indica* fruits non-treated (OFI-CTR) and treated with mucilage (OFI-M) and calcium ascorbate coating (OFI-CA) during cold storage (9 days at 5 °C).

Storage Time	Samples	Microbial Loads				
		TMM	TPM	Pseudomonads	Enterobacteriaceae	Yeasts
0 days	OFI-CTR	<2 a	<2 a	<2 a	<1 a	<2 a
	OFI-M	<2 a	<2 a	<2 a	<1 a	<2 a
	OFI-CA	<2 a	<2 a	<2 a	<1 a	<2 a
3 days	OFI-CTR	3.54 ± 0.24 a	2.89 ± 0.22 a	3.32 ± 0.10 a	<1 a	3.41 ± 0.23 a
	OFI-M	2.57 ± 0.19 b	2.15 ± 0.11 b	2.27 ± 0.13 b	<1 a	2.44 ± 0.14 b
	OFI-CA	2.39 ± 0.15 b	2.21 ± 0.13 b	2.10 ± 0.05 b	<1 a	2.54 ± 0.17 b
6 days	OFI-CTR	5.01 ± 0.25 a	3.52 ± 0.21 a	4.60 ± 0.21 a	2.55 ± 0.24 a	4.39 ± 0.27 a
	OFI-M	3.24 ± 0.27 b	2.55 ± 0.29 b	3.05 ± 0.13 b	<1 b	3.02 ± 0.23 b
	OFI-CA	3.31 ± 0.24 b	2.73 ± 0.24 b	3.00 ± 0.23 b	<1 b	3.17 ± 0.31 b
9 days	OFI-CTR	6.11 ± 0.14 a	4.62 ± 0.23 a	5.11 ± 0.33 a	3.21 ± 0.21 a	5.72 ± 0.31 a
	OFI-M	4.68 ± 0.30 b	3.77 ± 0.25 b	4.01 ± 0.27 b	2.12 ± 0.10 b	4.17 ± 0.20 b
	OFI-CA	5.01 ± 0.23 b	3.97 ± 0.15 b	4.13 ± 0.20 b	2.33 ± 0.17 b	4.61 ± 0.24 b

Units are log CFU/g. Results indicate mean values ± S.D. of three plate counts. Data within a column followed by the same letter are not significantly different, different letters indicate significant differences according to Tukey's test, between the treatments in each sampling date. Abbreviations: TMM, total mesophilic microorganisms; TPM, total psychrotrophic microorganisms.

At the beginning of the experiment, a sample of *O. ficus-indica* mucilage and calcium ascorbate coatings were analyzed and did not reveal the presence of bacteria and yeasts. None of the analyzed minimally processed cactus pear fruit samples showed the presence of *L. monocytogenes*, which is one of the main human pathogens associated with the consumption of fresh and fresh-cut fruits and vegetables [32]. The same trend was reported by Liguori et al. [5] for untreated and coated cactus pear fruits with *O. ficus-indica* mucilage.

As reported in Table 3, significant statistical differences ( $p < 0.001$ ) were already shown between OFI-CTR and the two treatments (OFI-M and OFI-CA) from the third day of refrigerated storage onward. Aerobic bacteria (TMM, TPM, and *Pseudomonas*) and yeasts appeared in untreated and coated cactus pear fruit samples and were  $10^3$  and  $10^2$  CFU/g, respectively. Cell densities of these microorganisms, commonly associated with the microbial spoilage of ready-to-eat fruits and vegetables during refrigerated storage [33], increased over time for all trials and the final counts were 1 Log cycle higher in untreated fruit samples. These results are well correlated with the higher respiration rate detected in control fruit samples. In fact, the respiratory process is generally associated with the microbial decay [34]. Regarding members of the Enterobacteriaceae family, consisting of potential human and animal pathogens [35], they appeared after 6 days of storage in control production and reached values of 3.21 Log CFU/g at the end of the trial. These microorganisms were detected even in coated fruit samples also, but only after 9 days of refrigerated storage, and at levels of about 1 Log cycle lower than control fruits.

The lower levels of microorganisms in OFI-M and OFI-CA samples confirmed the protective effect of *O. ficus-indica* mucilage [36] and calcium ascorbate [37] applied as edible coatings.

#### 4. Conclusions

The aim of this study was to evaluate the effect of two different coatings (mucilage-based and calcium ascorbate-based) on postharvest quality, sensorial parameters, and microbial load of minimally processed cactus pear fruits stored under passive atmosphere.

Our data highlighted a relevant effect of mucilage-based and calcium ascorbate-based coating on maintaining quality parameters, nutritional value, sensorial profiles, and enhancing the postharvest life of cactus pear fresh-cut fruits. *O. ficus-indica* mucilage-base coating had the most efficient barrier effect on cactus pear fresh-cut during cold storage, resulting in a lower respiration rate and the lower weight loss of coated samples than uncoated ones, after 9 days of storage at 5 °C. This postharvest technology could help to reduce economic losses due to spoilage caused by mechanical damage during the processing, handling, and shipping of cactus pear fresh-cut fruits. Total soluble solid, carbohydrates, betalains, ascorbic acid, and total phenolics content were higher in minimally processed coated cactus pear fruits than in uncoated ones during storage, showing the positive effect

of mucilage-based and calcium-ascorbate coating on the nutritional and nutraceutical fruit value during cold storage.

Sensorial analysis and visual quality highlighted that the panelists reported a higher preference for both coated samples at the end of the cold storage period. Moreover, coating treatments did not cause any off-odor or/and off-flavor which could negatively affect the natural taste of cactus pear fresh-cut fruits; this aspect is an important factor regarding the use of edible coatings when taste alteration is undesirable. Indeed, mucilage-based coating has exalted some important parameters, as well as firmness, brightness, aroma, sweetness, and taste that are particularly appreciated by consumers. Concerning the microbiological results, the application of both edible coatings limited consistently the development of bacteria and yeasts during refrigerated storage. In conclusion, our data suggest that *O. ficus-indica* mucilage-based was the most effective coating and could be a useful environment-friendly way of maintaining cactus pear fresh-cut fruits quality parameters, nutraceutical value, visual quality, sensorial traits and extending its postharvest life.

**Author Contributions:** Conceptualization, G.L.; methodology, G.L., R.G. and C.G.; validation, G.L., P.I. and L.S.; formal analysis, G.L., G.G., R.G. and C.G. investigation, G.L., G.G., R.G. and C.G.; resources, G.L.; data curation, G.L., G.G., R.G. and C.G.; writing—original draft preparation, G.L., G.G., R.G. and C.G.; writing—review and editing, G.L. and R.G.; visualization, G.L., G.G., R.G., C.G., L.S. and P.I.; supervision, 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:** Not applicable.

**Acknowledgments:** We thank the “Garufa” cactus pear farm for granting access to the farm facilities and to give us the fruits without undue reservations.

**Conflicts of Interest:** The authors declare no conflict of interest.

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