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# Effect of Mucilage-Based Edible Coating Enriched with Oregano Essential Oil on Postharvest Quality and Sensorial Attributes of Fresh-Cut Loquat

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**Abstract:** Due to pulp browning, weight loss, firmness loss, and decay, loquat fruits, and even more minimally processed fruits have a very short post-harvest life. The aim of our study was to evaluate the effect of *Opuntia ficus-indica* mucilage-based edible coating enriched with oregano oil on postharvest quality, microbial growth, and sensorial attributes of fresh-cut cv Martorana loquat fruit during cold storage. Fresh-cut loquat fruits were dipped in the mucilage-based solution enriched with oregano essential oil (MO-EC) and in distilled water used as control (CTR). According to our results, the mucilage-based edible coating enriched with oregano oil significantly improved the postharvest life of minimally processed loquat fruits by preserving quality, nutraceutical value, and sensory aspects. MO-EC had a barrier effect on fresh-cut loquat fruit, reducing weight and firmness losses, inhibiting TSS, TA, ascorbic acid content decrease, and enhancing the antioxidant activity until the end of the cold storage period (11 days at 5 °C). Microbiological analysis revealed that coated loquat fruits were characterized by a cell density of spoilage microorganisms 1 Log cycle lower than control fruits. The mucilage-based coating enriched with OEO positively affects the visual appearance of fresh-cut loquat fruits, at the end of the cold storage period, MO-EC samples did indeed report visual ratings that were five times greater than CTR samples. Our research suggests that applying mucilage-based coating enriched with OEO improves peeled loquat fruit shelf-life and allows the producers to sell products that are usually considered unmarketable (fruit with epicarp with large spot areas) to the market.

**Keywords:** *Eriobotrya japonica*; ready-to-eat; essential oil; antioxidant activity; microbial decay

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## 1. Introduction

Loquat (*Eriobotrya japonica* Lindl.) is a non-climacteric fruit that is mostly consumed fresh, is high in phytochemicals, and has a very limited shelf life, with fruit perishing rapidly after harvest and losses in flavor, titratable acidity, juiciness, and internal browning occurring swiftly throughout shelf life [1,2]. Loquat fruits are rich in vitamins, minerals, and phenolics; loquat fruit bioactive components include triterpenic acids, flavonoids, and carotenoids and show considerable high scavenging activity against chemically generated radicals, preventing human low-density lipoproteins oxidation [2,3].

During cold storage, loquat fruit is susceptible to lignification, juiciness loss, internal browning, and microbial deterioration, which causes quality degradation and reduces its marketability and consumer acceptability [4]. Various research underlined that refrigeration is one of the key methods combined with different treatments, as well as, chemical reagents, packaging, hot air treatment, and edible coating to extend the postharvest life of loquat fruit [4–6].

In the last decades, significant changes in human lifestyles increased the market for ready-to-eat fresh food, among them, there has been a noticeable rise in the intake of freshly cut fruit and vegetables [2]. The fruit peeling process (resulting in juice movement from the inner to the fruit surface) explains why microbial growth is higher on fresh-cut fruits compared with intact fruits, therefore, a variety of microbiological populations, including those that may produce significant amounts of human pathogens, may grow on the surface of freshly cut fruit [7].

The application of natural edible coating resulted in very active new sustainable postharvest strategies [2,8]. In cold storage, edible coatings act as a semipermeable barrier against gases and vapors, lowering the respiration rate, maintaining firmness and moisture, preserving the color, transmitting antioxidants and other preservatives, preventing the growth of microorganisms, and preserving fruit quality for a lengthy period of time [2]. The edible coating based on plant extracts (ECPE) is considered environment friendly and can be beneficial for extending the shelf life of fresh commodities; ECPE are usually classified as lipids (fatty acid, waxes, and acylglycerol), hydrocolloids (protein and polysaccharides), and composite extracts [9,10].

Several studies reported that *Opuntia ficus-indica* mucilage-based edible-coating positively affected fruit quality, reducing weight, water transpiration and browning, preserving visual score values, nutraceutical attributes and fruit firmness, controlling microbial growth, allowing a longer storage period [2,11–16]. Several studies reported that polysaccharide-based edible coatings application resulted very effective on stone fruits [17].

*Opuntia ficus-indica* mucilage is a complex carbohydrate mixture based on varying amounts of D-galactose, L-arabinose, D-xylose, and L-rhamnose, as well as galacturonic acid. It also contains significant amounts of polyphenols, which adds value to a natural edible coating, because of its high nutraceutical value, it is useful for the preservation of fruits and other foods [2].

In the last years, the use of essential oils (EOs) added in edible coatings, as natural antimicrobial agents, received particular attention due to their potential to control decay and extend the storage life of perishable fruits and vegetables [18]. Remarkably interest was achieved by the essential oregano oil, which is rich in the GRAS monoterpene carvacrol, has excellent antimicrobial properties, and reduces bacteria and fungi growth Pirozzi et al. [18]. The use of edible coatings enriched with EOs is also important as carriers for a wide variety of food additives, including antioxidants, antimicrobials, colorants, anti-browning agents, spices, and nutrients [18]. Ridzuan et al. [19] reported interesting data regarding the application of pectin coating enriched with oregano essential oil (0–3% $v/v$) on fresh-cut papaya, indeed the incorporation of OEO to pectin coating preserved the physicochemical and microbiological quality of fresh-cut papaya more than the uncoated ones until 12 days of storage at 4 °C.

Only a few research reported results on the postharvest performance of fresh-cut loquat fruits [2,20], and, to date, there has been no information regarding the effect of edible coatings enriched with essential oils on the shelf-life behavior of minimally processed loquat fruit.

Therefore, the aim of the present study was to evaluate the effect of mucilage-based edible coating enriched with oregano oil on postharvest quality and sensorial attributes of fresh-cut cv *Martorana* loquat fruit during cold storage at 5 ± 0.5 °C and 90% RH.

## 2. Materials and Methods

### 2.1. Fruit Samples

Loquat, *Eriobotrya japonica* Lindl., white-flesh (cv. *Martorana*) fruits were harvested from trees grown following standard commercial practices in a commercial orchard located in Palermo (38°04′ N, 13°23′ E, 99–104 m a.s.l.). Loquat fruits were collected at the ripening stage (light-orange peel color) appropriate for the fresh fruit market. Loquat fruits were hand-picked and quickly moved to the laboratory where they were analyzed in terms of fruit quality parameters (30 fruits). Loquat fruits were sanitized by immersion in 200 mg kg$^{-1}$ of sodium hypochlorite tap water solution for 5 min and then hand-peeled in a refrigerated room at 8 ± 0.5 °C. Fruit processing operations took place under sanitary conditions using only peeled fruit with no external damages or injuries. Work surface area and cutting equipment were sanitized with sodium hypochlorite water solution before and during fruit processing.

### 2.2. Edible Coating Preparation and Application

Cladodes (one-year-old) were collected from *O. ficus-indica* (OFI) plants located in the experimental station of 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). Harvested cladodes were then 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 [2].

Cladodes were dipped in a solution of chlorinated water to remove impurities and spines and to extend the mucilage shelf-life. Cladodes were then sliced and cooked in a microwave oven (900 W) for 3–5 min, until soft. Cooked cladodes portions were ground using an Omni Mixer Homogenizer to improve the mucilage yield during the extraction processing (mod. Omni General Laboratory Homogenizer—GLH 850, Omni International, Kennesaw, GA, USA) until a homogeneous pulp was obtained. The resulting pulp was subjected to centrifugation (Sigma centrifuge mod. 6K15, Sigma Laborzentrifugen GmbH, Osterode am Harz, Germany) at 8117× *g* for 15 min at 4 °C, to separate the liquid mucilage from the fibers.

After centrifugation, the mucilage was transferred into a laboratory beaker using a sterile spatula and the cladode fibrous portion was removed and thrown out. No chemicals were used during the mucilage extraction.

The extracted OFI mucilage was cooled and 1.5% ($v/v$) of oregano essential oil (OEO) was added to incorporate into the mucilage solution. The complete solution was subjected to magnetic stirring for a few minutes until the mucilage-based edible coating (EC) with OEO was formed.

After peeling, loquat fruits were made up of two treatment groups (control: CTR and coated: MO-EC). Each sampling group consisted of 5 replicates (3 fruits each) for every sampling date (0, 4, 6, 9, and 11 days of cold storage) plus 25 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. MO-EC loquat fruits were dipped in the mucilage-based solution enriched with OEO for 2 min to allow the coating solution to cover the entire fruit surface, forming a uniform coating; similar treatment was conducted for CTR loquat fruits that were dipped in distilled water.

Loquat samples were then dried at 25 °C for 1 h, placed in rigid polypropylene retail boxes 25 × 20 cm (3 peeled loquat fruits in each box), and stored at 5 ± 0.5 °C and 95% RH for 11 days. Loquat fruits were analyzed after 0, 4, 6, 9, and 11 days of cold storage.

### 2.3. Physicochemical Analysis: Firmness, Soluble Solid Content, Titratable Acidity, Extractable Juice, Color, and Weight Loss

The quality of fresh-cut loquat fruits was analyzed immediately after coating (0 day) and at 4, 6, 9, and 11 days of storage at 5 ± 0.5 °C. For each sampling date and experimental treatment, five samples (3 fruits for each) of loquat fruits were randomly chosen and analyzed.

Firmness was measured on 15 fruits for treatments (2 measurements for fruit) using a digital fruit firmness tester with an 8-mm-diameter probe (mod. 53205, TR Turoni, Forlì, Italy), after removal of a small piece of peel.

The total soluble solids content (TSS) of fruit homogenized pulp was determined by a digital refractometer (Palette PR-32a, Atago Co., Ltd., Tokyo, Japan) [3]. For the determination of titratable acidity (TA) 10 mL of fruit pulp juice was titrated with NaOH 0.1 N to an endpoint of pH 8.1 [3] and the results were expressed as malic acid (mod. S compact titrator, Crison Instruments, Barcelona, 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 [2,4]. The result was expressed as a percentage of tissue plugs fresh weight loss after centrifugation [4].

Loquat fruits weight loss was monitored on 5 packages (3 fruits for each) for all treatments and expressed in terms of percentage reduction with respect to the initial time, using a two-decimal precision digital balance (Mod. PCB 2000-1, Kern, Zanè, Italy).

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

where $W_i$ is the initial weight, and $W_{st}$ is the weight measured during storage.

Fresh-cut loquat fruit brightness (L*) was measured twice per fruit, trying to cover the largest portion of the fruit surface area, using a colorimeter (Chroma Meter CR-400C, Minolta, Osaka, Japan).

### 2.4. Nutraceutical Attributes

Total carotenoids, ascorbic acid content, superoxide dismutase, and catalase activity of fresh-cut loquat fruit samples were quantified immediately after coating (0 day) and at 4, 6, 9, and 11 days of storage at 5 ± 0.5 °C. For each sampling date and experimental treatment (CTR and MO-EC), three samples were randomly chosen and analyzed.

#### 2.4.1. Ascorbic Acid Content

By extracting 10 g of mixed fruit in 100 mL of metaphosphoric acid ($HPO_3$) and filtering the solution through Whatman no. 1 filter paper, the ascorbic acid concentration was ascertained. Using the 2–6 dichlorophenol-indophenol reagent, a volume of 10 mL of the filtered solution was evaluated volumetrically until a faint pink coloring was noticed and remained for 15 s [21]. The results of ascorbic acid content were expressed as milligrams per 100 g fresh weight (FW). All measurements were conducted in triplicate.

#### 2.4.2. Total Phenolics Content

According to Folin Ciocalteau's method [22], the total phenolic content (TPC) of the extract was determined by reducing phosphotungstic-phosphomolybdic acid (Folin Ciocalteu's reagent) to blue pigments in alkaline solution. One gram of loquat flesh tissue was mixed in 80% (*v*/*v*) methanol containing 2% formic acid and centrifuged at 14,344× *g* (20 min at 4 °C). The supernatant was collected for measuring the TPC. The assay medium was kept in a water bath at 30 °C for 1 h and then measured the absorbance at 765 nm with a spectrophotometer [4]. The results were expressed as mg gallic acid (GA) equivalents (GAE) per 100 g of fresh weight [2]. All measurements were conducted in triplicate.

#### 2.4.3. Total Carotenoids Content

The total carotenoids were extracted in flesh loquat fruits as described by Petriccione et al. [3] and assessed spectrophotometrically in accordance with Kichtenthaler and Wellburn [23]. Results were expressed as milligrams per 100 g fresh weight (FW). All measurements were conducted in triplicate.

#### 2.4.4. Superoxide Dismutase (SOD) and Catalase (CAT) Activities Measurements

Enzymes extractions were conducted at 4 °C as reported by Cao et al. [6]. For Superoxide dismutase (SOD) extraction, 2 g of frozen flesh tissue was shredded using 5 mL of 50 mM sodium phosphate buffer (pH 7.8) [6]. The extract was homogenized and centrifuged at 20,000× *g* for 20 min at 4 °C and the supernatant was used for the enzyme assay. SOD activity was determined following the method of Rao et al. [24]; one unit of SOD activity was defined as the amount of enzyme which caused 50% of nitro blue tetrazolium reduction per second at 560 nm and expressed as U mg $^{-1}$ based on protein content [4].

For catalase (CAT) extraction, 2 g of frozen flesh tissue was ground with mL of 50 mM sodium phosphate buffer (pH 7.0) following the method of Cao et al. [6]. The extract was homogenized and centrifuged at 20,000× *g* for 20 min at 4 °C and the supernatant was used for the enzyme assay. CAT activity was determined as reported by Cao et al. [6]. One unit of CAT activity was defined as the amount of enzyme that decomposed 1 μmol of $H_2O_2$ per second at 240 nm and expressed as U $mg^{-1}$ based on protein content [4].

### 2.5. Decay Index Measurements

The decay index was visually evaluated according to Wang et al. [4] by rating a five-grade scale, where 0 represented no decay area in the fruit surface; 1 represented decay area <10% in the fruit surface; 2 represented decay area between 10% and 30% in the fruit surface; 3 represented decay area between 30% and 50% in the fruit surface; and 4 represented decay area >50% of the fruit surface. The decay index was calculated using the following formula:

$$\text{decay index} = \sum [(\text{decay scale}) \times (\text{number of fruit at that scale})]/(4 \times \text{total number of fruits in each treatment}) \times 100\%. \tag{2}$$

### 2.6. Sensory Analysis and Visual Score

Fruit sensory analysis was carried out at the Department of Agricultural, Food and Forest Sciences, University of Palermo, (SAAF) and was carried out on 15 fruits per treatment (CTR and MO-EC) during cold storage (0, 4, 6, 9, 11 days). The panel consisted of 10 judges trained in some preliminary meetings: Using commercial fruit, the judges generated a list of descriptors. Sensory analysis was focused on appearance, sweetness, acidity, aroma, off-flavor incidence, taste, texture, juiciness, fruity odor, fruity flavor, oregano odor, oregano flavor, and overall acceptance. The different descriptors were assessed using a ten-point intensity scale, with 1 denoting the lack of the descriptor and 10 denoting its maximum intensity [2]. The order of presentation was randomized between judges. In order to rinse between samples, water was available.

The visual score was evaluated at each sampling date on 15 fruits for treatment (CTR and MO-EC) by each judge. Visual appearance score resulted from the medium value of color, visual appearance, and visible structural integrity [2]. The different visual parameters were quantified using a subjective 5–1 rating scale with 5 = very good, 4 = good, 3 = sufficient (limit of marketability), 2 = poor (limit of edibility), and 1 = very poor (inedible) [8]. The samples were presented to the judges in randomized order and water was provided between tastings.

### 2.7. Microbiological Analysis

Hygiene and safety aspects of the edible coating, CTR, and MO-EC-treated loquat fruits were evaluated by a culture-dependent approach. The edible coating sample (1 mL) was directly serially diluted to a ratio of 1:10 [25], while loquat fruit samples were firstly homogenized by a stomacher [26] and then serially diluted. Appropriate dilutions were placed on selective agar media to enumerate the main spoilage and pathogenic populations as reported in Table 1.

**Table 1.** Microorganisms and growth conditions.

| Microorganisms | Media | Incubation Conditions | Company |
|---|---|---|---|
| TMM | Plate Count Agar | 30 °C for 72 h | Biotec, Grosseto, Italy |
| TPM | Plate Count Agar | 7 °C for 7 days | Biotec, Grosseto, Italy |
| *Pseudomonas* spp. | *Pseudomonas* Agar Base | 25 °C for 48 h | Condalab, Madrid, Spain |
| Yeasts | Yeast Peptone Dextrose Agar | 30 °C for 48 h | Sigma-Aldrich, Milan, Italy |
| Molds | Potato Dextrose Agar | 25 °C for 7 days | Microbiol Diagnostici, Uta, Italy |
| Enterobacteriaceae | Violet Red Bile Glucose Agar | 37 °C for 24 h | Condalab, Madrid, Spain |
| *L. monocytogenes* | *Listeria* Selective Agar Base | 37 °C for 24 h | Oxoid, Hampshire, UK |
| *E. coli* | Chromogenic Medium | 37 °C for 24 h | Condalab, Madrid, Spain |
| *Salmonella* spp. | Hektoen Enteric Agar | 37 °C for 24 h | Microbiol Diagnostici, Uta, Italy |

Abbreviations: TMM, Total Mesophilic Microorganisms; TPM, Total Psychrotrophic Microorganisms; *L.*, *Listeria*; *E.*, *Escherichia*.

Except for the members of the Enterobacteriaceae family, which were plated by pour plate technique, all other microbial groups were counted using the spread plate method inoculating 100 µL from appropriate cell suspensions of edible coating, untreated and coated loquat fruit samples [27].

*2.8. Statistical Analyses*

All experiments were carried out using a completely randomized design. All analyses were performed in triplicate and all data were analyzed using one-way analysis of variance (ANOVA) and means comparisons between control samples and coated loquat fruits were evaluated using the 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. Physicochemical Analysis: Firmness, Soluble Solid Content, Titratable Acidity, Extractable Juice, Color, and Weight Loss*

Fruit firmness significantly decreased during cold storage in uncoated (CTR) and coated (MO-EC) fresh-cut loquat fruit (Table 2). MO-EC fresh-cut loquat fruits showed significantly higher values than CTR ones during the entire cold storage period (11 days at 5 °C) (Table 2). CTR fresh-cut loquat fruit showed the highest firmness decrease with a loss of firmness of 42% from the beginning to the end of the cold storage period (Table 2). Whilst MO-EC fresh-cut loquat fruit reported better behavior in retaining firmness with a significantly lower loss of 23% from the beginning to the end of the cold storage period (Table 2). MO-EC samples showed firmness values 1.3 higher than CTR ones, our data reported that the mucilage-based coating with the addition of OEO was effective in reducing firmness losses in fresh-cut loquat fruits.

**Table 2.** Evolution of firmness, total soluble solids (TSS) titratable acidity (TA), and extractable juice in fresh-cut cv *Martorana* loquat fruits, uncoated (CTR) and coated with OFI mucilage and OEO (MO-EC) during cold storage (11 days at 5 °C). Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments in each sampling date. Data are the mean ± SE ($n$ = 5).

| Storage Time | Treatments | Firmness | | TSS | | TA | | Extractable Juice | |
|---|---|---|---|---|---|---|---|---|---|
| | | (N) | | (°Brix) | | (% malic acid) | | (%) | |
| 0 days | CTR | 9.38 ± 0.15 | - | 11.65 ± 0.29 | - | 0.75 ± 0.03 | - | 58.62 ± 1.11 | - |
| | MO-EC | 9.38 ± 0.15 | - | 11.65 ± 0.29 | - | 0.75 ± 0.03 | - | 58.62 ± 1.11 | - |
| 4 days | CTR | 8.64 ± 0.08 | b | 11.26 ± 0.27 | - | 0.63 ± 0.01 | - | | |
| | MO-EC | 8.98 ± 0.09 | a | 11.52 ± 0.23 | - | 0.66 ± 0.02 | - | | |
| 6 days | CTR | 7.74 ± 0.08 | b | 10.42 ± 0.38 | b | 0.51 ± 0.03 | b | 50.62 ± 0.45 | b |
| | MO-EC | 8.10 ± 0.07 | a | 11.51 ± 0.32 | a | 0.62 ± 0.02 | a | 53.79 ± 0.43 | a |
| 9 days | CTR | 6.44 ± 0.16 | b | 10.21 ± 0.20 | b | 0.45 ± 0.04 | b | | |
| | MO-EC | 7.68 ± 0.11 | a | 11.37 ± 0.21 | a | 0.57 ± 0.03 | a | | |
| 11 days | CTR | 5.41 ± 0.04 | b | 9.57 ± 0.25 | b | 0.41 ± 0.01 | b | 46.24 ± 0.63 | b |
| | MO-EC | 7.19 ± 0.05 | a | 11.04 ± 0.16 | a | 0.53 ± 0.01 | a | 51.37 ± 0.59 | a |

Fruit texture is one of the more important marketability attributes in fresh-cut fruits, as the enzymatic reactions caused by fruit processing operations (peeling, slicing, etc.) lead to rapid losses in firmness [28]. In our research MO-EC fresh-cut loquat fruits reported the highest fruit firmness values during the cold storage period, highlighting the ability of mucilage to keep fruit structure (Table 2). According to previous research, calcium in *O. ficus-indica* mucilage maintains fruit cell wall integrity by reacting with the pectic acid in the cell walls to generate calcium pectate, which is what is responsible for the MO-EC's beneficial effect on fruit texture [29]. In our study the application of edible coating reduced firmness losses during cold storage on loquat fruits as reported by Riva et al. [17] in nectarines, cherries, peaches, apricots, and plums, this effect was probably caused by the reduction of respiration rate [2] that affect cell wall degradation enzymes activity. The respiration rate was not measured in this trial, but we monitored it in a previous study related to the application of *O. ficus-indica* mucilage-based edible coating on minimally processed loquat fruits and we reported that the application of edible coating acting as a barrier reduced the respiration rate of coated fruits during the shelf-life [2].

TSS content showed a slight decrease in MO-EC fresh-cut loquat fruit samples with significantly higher values than CTR ones, during the entire cold storage period (Table 2).

CTR and MO-EC fresh-cut loquat fruit samples reported a loss in terms of TSS content of 18% and 5%, respectively, from the onset and the end of the cold storage interval (Table 2). Furthermore, in this case, the mucilage-based coating with the addition of OEO was effective in terms of TSS content retaining in fresh-cut loquat fruits during cold storage, with losses more than 3 times lower in coated samples than in uncoated ones (Table 2). TA showed a slight decrease in CTR and MO-EC fresh-cut loquat fruit samples, during cold storage, with no significant differences between the treatments until the fourth day of cold storage, from that point on, MO-EC displayed considerably higher TA values than CTR ones during the remaining time of the cold storage period (Table 2). CTR and MO-EC fresh-cut loquat fruit samples reported a loss in terms of TA of 45% and 29%, respectively, from the beginning to the end of the cold storage period (Table 2). The mucilage-based coating with the addition of OEO reduced the losses in terms of TA in fresh-cut loquat fruits during cold storage, showing TA values 1.3 times higher in coated samples than in uncoated ones (Table 2). Our results as also reported by other research confirmed that the TA loss rate was reduced by the application of the edible coating, this was probably due to slowing metabolic activities as noted in raspberry, strawberry, and sweet cherry [30]. The mucilage-based coating enriched with OEO kept a significantly high level of extractable juice in comparison to the control during storage time (Table 2). CTR and MO-EC fresh-cut loquat fruit samples reported a loss in terms of extractable juice of 21% and 12%, respectively, from the beginning to the end of the cold storage period (Table 2). The positive effect of MO-EC is due to the low rates of respiration, transpiration, and metabolic activity, which delay the senescence process of loquat fruit. The mucilage-based coating with OEO polysaccharidic content allows it to act as a barrier reducing fresh-cut fruit respiration and transpiration, a similar effect was reported by Wang et al. [4] with nano-$SiO_2$ packing treatment and Liguori et al. [2] with mucilage-based edible coating.

The weight loss gradually increased during cold storage in both uncoated and coated fresh-cut loquat fruits (Figure 1). MO-EC fresh-cut loquat fruits showed significantly higher values than CTR ones starting from 4 days until the end of the cold storage period (Figure 1). In terms of loss of weight, MO-EC fresh-cut loquat fruit samples reported values 2 times lower than CTR ones at the end of the cold storage period (Figure 1). Edible coating maintains high relative humidity inside the fruit, mucilage-based coating enriched with OEO acts as a barrier to water transfer, reducing the weight loss, as reported in several treated fruits [30]. Our data confirm that mucilage-based coating enriched with OEO was significantly effective in preventing weight loss, as reported by previous studies that used mucilage coating in loquat [2], cactus pear [8], strawberry [15,31] and kiwifruit [32].

Fruit flesh brightness (L*) was similar in fresh-cut loquat fruits of both uncoated and coated fruits at the time of treatment. Fruit flesh color slightly decreased during storage in both treatments with values of 15% and 10%, respectively lower in CTR and MO-EC samples from the beginning to the end of the cold storage period (Figure 2).

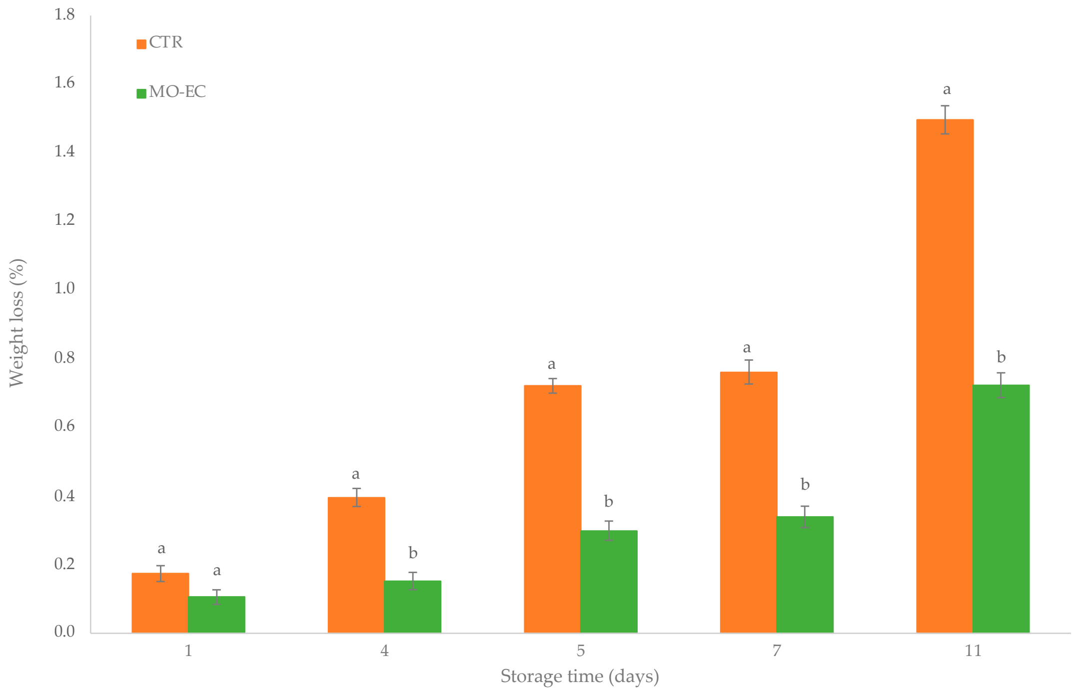


**Figure 1.** Changes in weight loss in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments in each sampling date. Data are the mean ± SE (Vertical bars represent standard error; $n$ = 5).

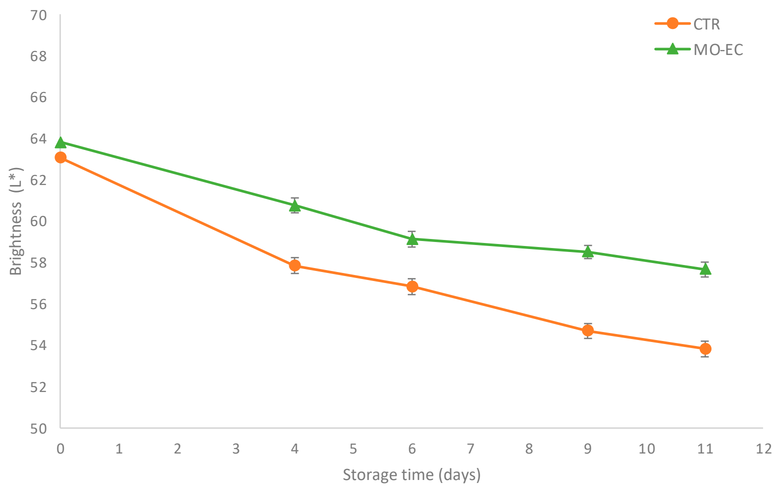


**Figure 2.** Changes in brightness (L*) in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Data are the mean ± SE (Vertical bars represent standard error; $n$ = 5).

One of the key elements influencing fruit consumers' preferences, acceptance, and marketability is fruit color, loquat fruit pulp contains carotenoids (β-carotene, β-cryptoxanthin, lutein, violaxanthin, α- carotene and γ-carotene), vitamins B1 and B2 and nicotinamide [2,33]. Fruit flesh brightness (L*) decrease is an indicator of fruit browning that is a result of natural polyphenols being oxidized by enzymes into quinones, which are subsequently polymerized with other quinones and amines resulting in brown pigments [2], our data showed that mucilage-based coating enriched with OEO prevent the loss of brightness in fresh-cut loquat fruits, reducing browning incidence.

### *3.2. Nutraceutical Attributes*

#### 3.2.1. Ascorbic Acid, Total Phenolics, and Total Carotenoids Content

Ascorbic acid content, total phenolic, and total carotenoids were significantly affected by storage time and treatment (Table 3). The ascorbic acid content decreased in both uncoated and coated fresh-cut fruit during the cold storage period (Table 3). The coated fresh-cut samples showed significantly higher values than uncoated ones during storage, indeed, at the end of the cold storage, MO-EC samples revealed values that were 1.6 times greater than CTR samples (Table 3). Ascorbic acid content is one of the indicators to measure loquat fruit quality, acting not only as nutraceutical compounds but also as one of the most abundant antioxidants to eliminate reactive oxygen species (ROS) in loquat fruit [4,34]. Mucilage-based coating enriched with OEO reduced the loss in terms of ascorbic acid in MO-EC fresh-cut loquat fruit might be due to the low edible coating oxygen permeability which inhibited enzyme activities and prevented the ascorbic acid oxidation, as reported in previous studies [4,35].

**Table 3.** Ascorbic Acid, total carotenoids, and total phenolic content in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments in each sampling date. Data are the mean ± SE ($n$ = 5).

| Storage Time | Treatments | Ascorbic Acid | | Total Carotenoids | | Total Phenolic Content | |
|---|---|---|---|---|---|---|---|
| | | (mg 100 g$^{-1}$ FW) | | (mg 100 g$^{-1}$ FW) | | (mg GAE/100 g FW) | |
| 0 days | CTR | 6.32 ± 0.02 | - | 1.45 ± 0.04 | - | 46.08 ± 0.65 | - |
| | MO-EC | 6.32 ± 0.02 | - | 1.45 ± 0.04 | - | 46.08 ± 0.65 | - |
| 6 days | CTR | 5.03 ± 0.04 | b | 1.55 ± 0.07 | - | 52.21 ± 1.04 | b |
| | MO-EC | 5.56 ± 0.03 | a | 1.61 ± 0.03 | - | 63.25 ± 1.21 | a |
| 11 days | CTR | 3.01± 0.03 | b | 1.75 ± 0.07 | - | 49.96 ± 0.63 | b |
| | MO-EC | 4.93 ± 0.02 | a | 1.81 ± 0.02 | - | 60.39 ± 0.89 | a |

Both coated and uncoated fresh-cut loquat fruit exhibited a small increase in total carotenoids after cold storage (Table 3). The treatment with mucilage-based coating enriched with OEO did not affect the total carotenoid content in fresh-cut loquat fruits, as reported by previous research [2]. As reported in Table 3, total phenolics content increased at day 4, instead both coated and untreated fresh-cut loquat fruit samples dropped till the conclusion of the cold storage period. The MO-EC improved the level of the amount of total phenolics during the storage, the content of total phenolics was significantly higher in coated fresh-cut samples than in the control during the whole storage time (Table 3). According to several studies, phenolic compounds play a significant role as non-enzymatic antioxidants and their accumulation may significantly contribute to the scavenging of free radicals, hence lowering the oxidative damage caused to cells in fruits and vegetables by free radicals [4,32,36,37]. Mucilage-based coating enriched with OEO was effective in terms of total phenolics content, MO-EC samples reported values 1.2 times higher than CTR ones at the end of the cold storage period (Table 3). Our study confirmed that edible coating applications reduce polyphenol losses and maintain higher antioxidant capacity throughout postharvest storage, as reported in other fruits, as well as plums, cherries, and apricots Riva et al., 2020 [17].

#### 3.2.2. Superoxide Dismutase (SOD) and Catalase (CAT) Activities Measurements

Superoxide dismutase (SOD) activity showed a slight decrease trend in CTR fresh-cut loquat fruit during the whole cold storage period (Figure 3). Mucilage-based coating enriched with OEO treatment induced higher SOD activity on day 3, avoiding the decline afterward, MO-EC fresh-cut loquat fruit maintained significantly higher levels of SOD activity than CTR during the entire cold storage period (Figure 3). At the end of the cold storage period, MO-EC samples had SOD activity levels that were 1.2 times greater than CTR samples (Figure 3).

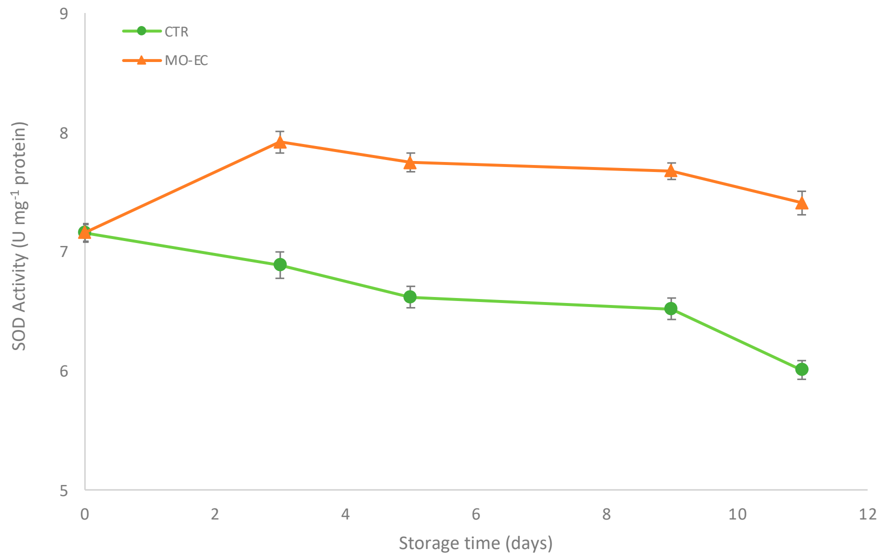


**Figure 3.** Changes in SOD activity in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Data are the mean ± SE (Vertical bars represent standard error; *n* = 5).

Catalase activity (CAT) of MO-EC fresh-cut loquat fruit showed a sharp increase, reaching the peak value on day 9, and then decreased after the end of the cold storage period (Figure 4). CTR fresh-cut loquat fruit CAT activity showed a similar trend with significantly lower values than MO-EC until the end of the cold storage period (Figure 4). Mucilage-based coating enriched with OEO treatment significantly enhanced catalase activity until day 9 in MO-EC fresh-cut loquat fruit, mitigating oxidative damage. MO-EC samples showed CAT activity values 1.3 times higher than CTR ones at the end of the cold storage period (Figure 4).

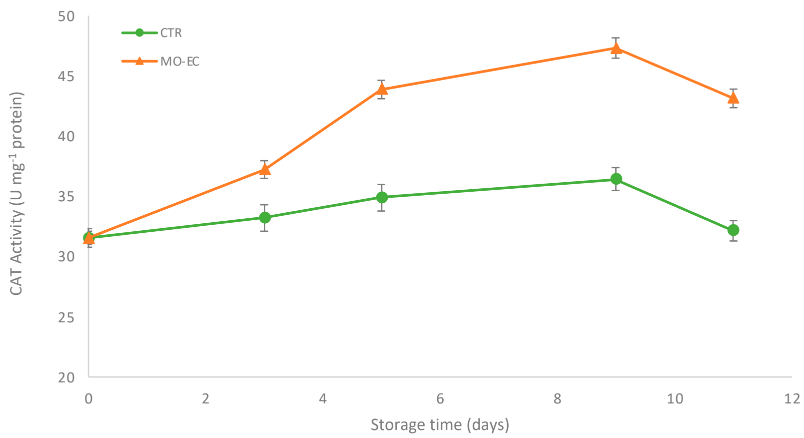


**Figure 4.** Changes in CAT activity in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Data are the mean ± SE (Vertical bars represent standard error; *n* = 5).

Enzymatic antioxidants SOD and CAT play a significant role as defensive antioxidants; $O_2$ is dismutated to $H_2O_2$ by SOD, while $H_2O_2$ is dismutated to oxygen and water by CAT [1]. The steady-state level of $O_2$ and $H_2O_2$ is dependent on the balance between the SOD and CAT activities in cells [1]. In our study, SOD and CAT activities were 1.2 and 1.3 times greater than CTR ones at the conclusion of the cold storage period as a result of MO-EC treatment as compared to control (Figures 3 and 4), similar results, in loquat fruits, were reported by Wang et al. [4] with nano-$SiO_2$ packaging. One of the primary reasons that promote oxidation resistance, delays senescence, and preserves the quality of loquat fruit during postharvest may be the combined activity of SOD and CAT [4].

### 3.3. Decay Index Measurements

Decay was affected by mucilage-based coating enriched with OEO; indeed, throughout the whole cold storage period, MO-EC samples reported noticeably reduced levels (Figure 5). CTR fresh-cut loquat fruits showed a decay index more than two times higher than MO-EC ones at the end of the cold storage period (Figure 5). Mucilage-based coating enriched with OEO significantly inhibited the increase of decay-coated samples (Figure 5). Decay and browning are the main limiting factors on postharvest quality, marketability, and acceptability of loquat fruit [4]. Our study showed that mucilage-based coating enriched with OEO reduced flesh browning and fungi decay, leading to better postharvest quality in MO-EC than CTR ones after 11 days of cold storage [Figure 5], thus mucilage and OEO can be considered natural antimicrobial agents [2,18]. Mucilage-based edible coating forming a protective covering, limited the pathogens proliferation and decay of coated loquat fruits that remain significantly lower than uncoated ones, as reported in other treated fruits [30].

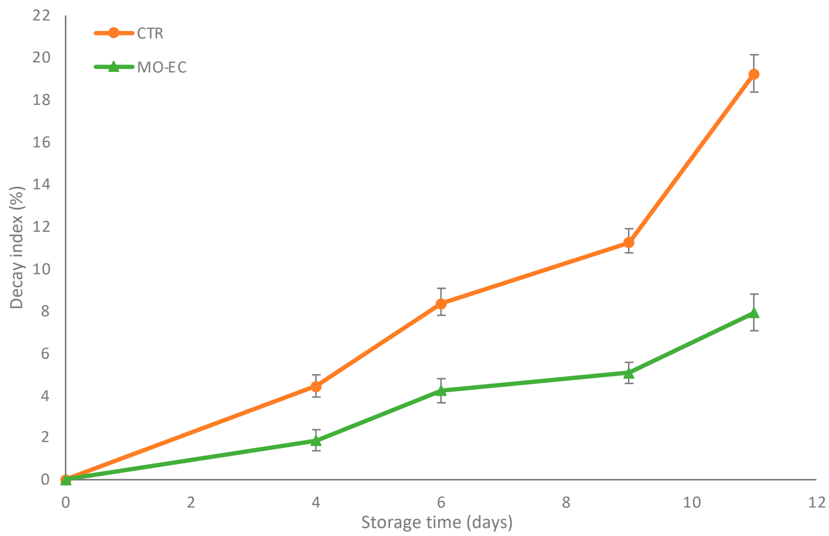


**Figure 5.** Decay index in fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) and coated fruits (MO-EC) during cold storage (11 days at 5 °C). Data are the mean ± SE (Vertical bars represent standard error; $n$ = 5).

### 3.4. Sensory Analysis and Visual Score

Fresh-cut loquat fruit sensory profiles were positively affected by mucilage-based coating enriched with OEO; indeed, judges gave higher scores in terms of overall acceptance to MO-EC samples compared to CTR ones from the fourth day to the end of the cold storage period (Figures 6 and 7). At the end of the cold storage period (11 days at 5 °C), MO-EC fresh-cut fruits were preferred by panelists showing the highest scores in all sensorial parameters: appearance, sweetness, aroma, taste, texture, juiciness, fruity odor, fruity flavor, and overall acceptance (Figures 6 and 7). Panelists perceived the oregano odor and flavor only at harvest, immediately after the MO-EC treatment, after that the oregano odor and flavor were not perceived (Figure 7).

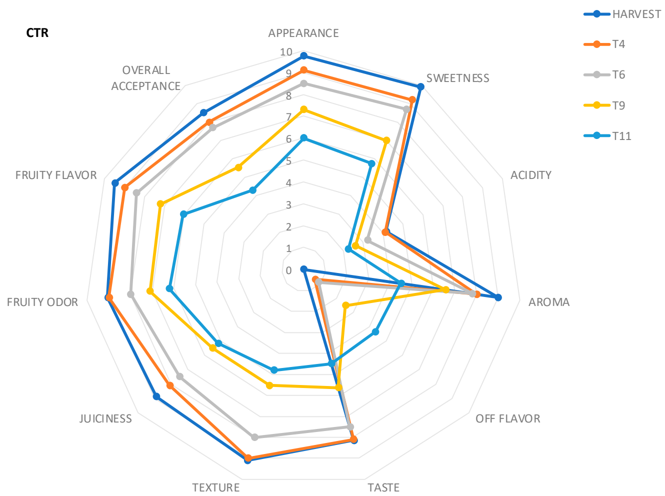


**Figure 6.** Sensorial analysis of fresh-cut cv *Martorana* loquat fruits uncoated fruit (CTR) after harvest, 4 (T4), 6 (T6), 9 (T9), and 11 (T11) of cold storage at 5 °C. Data are the mean ± SE ($n$ = 5).

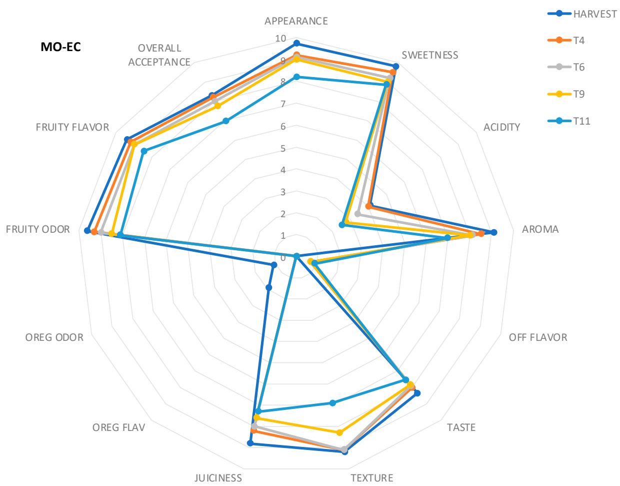


**Figure 7.** Sensorial analysis of fresh-cut cv *Martorana* loquat fruits coated fruit (MO-EC) after harvest, 4 (T4), 6 (T6), 9 (T9), and 11 (T11) of cold storage at 5 °C. Data are the mean ± SE ($n$ = 5).

Panelists reported off-flavor mean scores 2.7 higher in CTR fresh-cut loquat fruits than in MO-EC ones during the cold storage period; CTR samples obtain scores almost 5 times higher than MO-EC ones after 11 days of cold storage (Figures 6 and 7).

Judges reported the largest difference in fruity odor, fruity flavor, taste, aroma, and sweetness descriptors in MO-EC samples with scores 1.9, 1.7, 1.7, 1.5, and 1.5 times, respectively, higher than in CTR at the end of the cold storage period (Figures 6 and 7).

Judges preferred coated samples at the end of the cold storage period, according to the sensory analysis. The natural flavor of loquat fruits was not adversely impacted by the mucilage-based coating enhanced with OEO (oregano flavor and odor were only detectable at $T_0$), which is an important consideration when using edible coatings enriched with essential oils. However, MO edible coating boosted some significant parameters, including fruity odor, fruity flavor, aroma, sweetness, and taste which consumers particularly prefer. Mucilage-based edible coating created a barrier and reduced the biochemical attributes degradation such as TSS and prevented the losses in volatile taste compounds during cold storage, our results are in line with previous findings [30].

The visual score showed a sharp decrease during the cold storage period in both uncoated and coated samples (Figure 8). The mucilage-based coating enriched with OEO positively affects the visual appearance of fresh-cut loquat fruits, keeping the visual scores above the marketability threshold until 9 days and edibility until 11 days of cold storage (Figures 8 and 9). Otherwise, CTR fresh-cut loquat fruits showed a severe decrease in terms of visual score, dropping below the limit of marketability after 6 days and edibility after 9 days of cold storage (Figures 8 and 9). At the end of the cold storage period, MO-EC fresh-cut samples reported visual scores that were five times higher than CTR ones (Figure 8), confirming the effectiveness of the mucilage-based coating enriched with OEO in terms of acceptability and marketability of fresh-cut loquat fruits. As reported by previous studies [2,8,30], mucilage coating positively affects fruit overall acceptance and visual appearance during cold storage, uncoated fresh-cut loquat fruits showed a severe descending trend. The present study reported that MO-EC maintained better overall acceptability of loquat fresh-cut fruits by preventing postharvest senescence during storage.

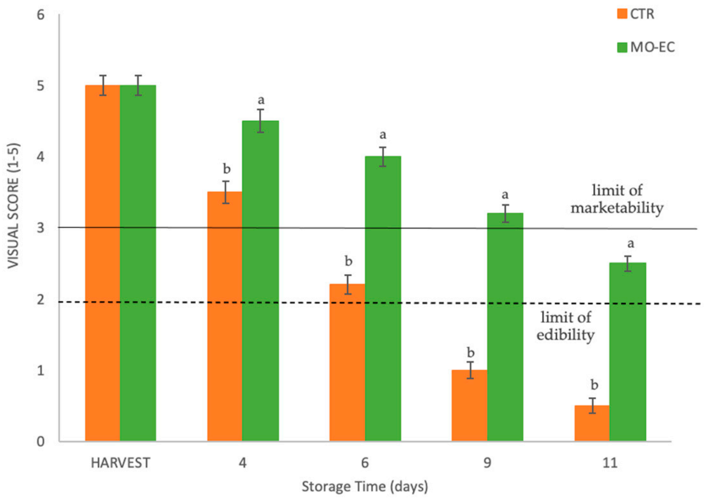


**Figure 8.** The visual score of fresh-cut cv *Martorana* loquat fruits uncoated (CTR) and coated fruit (MO-EC) during cold storage (11 days at 5 °C). Different lowercase letters indicate significant differences between the treatments in each sampling date. Data are the mean ± SE (Vertical bars represent standard error; $n$ = 5). Data are the mean ± 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)].

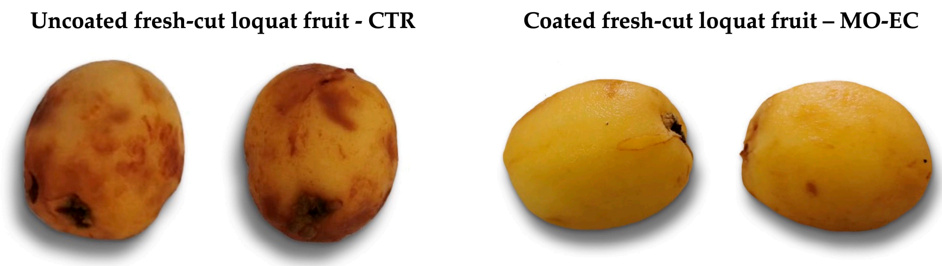


**Figure 9.** Fresh-cut cv *Martorana* loquat fruits uncoated (CTR) and coated fruit (MO-EC) after 9 days at 5 °C.

### *3.5. Microbiological Evolution during Refrigerated Storage*

Loquat is a perishable fruit, due to its susceptibility to microbial spoilage determined by bacteria and fungi (yeasts and molds) [38]. To this purpose, as per all vegetable and fruit products, the monitoring of microbial composition during refrigerated storage of loquat fruits is necessary to predict their marketability [2].

Before edible coating application, *O. ficus-indica* mucilage containing 1.5% ($v/v$) of oregano essential oil was characterized for the microbial load. As reported by previous investigations [8,15,30], *O. ficus-indica* mucilage did not host any microbial agent showing its suitability for food applications. During the 11 days of monitoring, CTR and MO-EC-treated loquat fruits showed undetectable levels (<2 Log CFU/g) of all undesired groups, represented by members of Enterobacteriaceae family, *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella* spp., responsible for food-borne diseases outbreaks [39]. The initial amount of aerobic bacteria (TMM, TPM, and Pseudomonas) and yeasts in loquat fruits are typically between $10^2$ and $10^3$ CFU/g [40], but in this study, none of the samples examined right after production and up until 4 days of refrigerated storage were found to contain these microorganisms. These outcomes clearly showed that the sanitization and handling of loquat fruits adhered to the standards of food safety and cleanliness. As reported in Table 4, significant differences ($p < 0.05$) were found from the 3rd sampling time (6 days) for the levels of TMM, TPM, Pseudomonads, yeasts, and molds among the CTR and MO-EC-treated loquat fruits. These microorganisms, responsible for the physicochemical and sensorial alterations of horticultural products [41,42], appeared in CTR samples at about $10^3$ CFU/g, while they were below the detection limits in MO-EC-treated loquat fruits.

**Table 4.** Microbial loads of control and MAP-treated loquat samples.

| Storage Time | Samples | Microbial Loads | | | | |
|---|---|---|---|---|---|---|
| | | TMM | TPM | Pseudomonads | Yeasts | Molds |
| 0 days | CTR | <2 a | <2 a | <2 a | <2 a | <2 a |
| | MO-EC | <2 a | <2 a | <2 a | <2 a | <2 a |
| 4 days | CTR | <2 a | <2 a | <2 a | <2 a | <2 a |
| | MO-EC | <2 a | <2 a | <2 a | <2 a | <2 a |
| 6 days | CTR | 2.89 ± 0.29 a | 2.94 ± 0.24 a | 2.82 ± 0.27 a | 2.80 ± 0.19 a | 2.74 ± 0.21 a |
| | MO-EC | <2 b | <2 b | <2 b | <2 b | <2 b |
| 9 days | CTR | 4.09 ± 0.24 a | 3.74 ± 0.29 a | 3.55 ± 0.19 a | 4.25 ± 0.27 a | 4.01 ± 0.30 a |
| | MO-EC | 3.19 ± 0.31 b | 2.85 ± 0.25 b | 2.76 ± 0.23 b | 3.20 ± 0.11 b | 3.11 ±0.23 b |
| 11 days | CTR | 5.21 ± 0.33 a | 4.87 ± 0.23 a | 4.98 ± 0.21 a | 5.33 ± 0.19 a | 5.16 ± 0.33 a |
| | MO-EC | 4.17 ± 0.30 b | 4.02 ± 0.27 b | 3.91 ± 0.25 b | 4.12 ± 0.20 b | 4.24 ± 0.25 b |

Units are Log CFU/g. Results indicate the mean values ± standard deviation (S.D.) of three plate counts. Data within a column followed by the same letter are not significantly different according to Tukey's test. Abbreviations: TMM, total mesophilic microorganisms; TPM, total psychrotrophic microorganisms; CTR, uncoated fruit; MO-EC, fruits coated with *O. ficus-indica* mucilage containing 1.5% (*v*/*v*) of oregano essential oil.

After 9 days of refrigerated storage, aerobic bacteria and fungi (yeasts and molds) were detected even in MO-EC-treated loquat fruits at levels of about 1 Log cycle lower than CTR fruits. However, at the end of refrigerated storage (11 days), these microorganisms reached values in CTR and MO-EC-treated loquat fruits of about $10^5$ and $10^4$ CFU/g, respectively. The lower concentrations of bacteria, yeasts, and molds in MO-EC-treated loquat fruits confirmed the antimicrobial activity of *O. ficus-indica* mucilage [43] and oregano essential oils [43] also when applied as edible coatings.

## 4. Conclusions

The aim of our study was to determine the impact of *O. ficus-indica* mucilage-based edible coating enriched with oregano oil on postharvest quality, microbial growth, and sensorial attributes of fresh-cut loquat fruit.

Our results reported a significant effect of mucilage-based edible coating enriched with oregano oil (MO-EC) on preserving quality, nutraceutical value, sensorial parameters, and improving postharvest life of minimally processed loquat fruits. MO-EC had a barrier effect on fresh-cut loquat fruit during cold storage, reducing weight and firmness losses, inhibiting TSS, TA, ascorbic acid content decrease, and enhancing the antioxidant activity after 11 days of cold storage at 5 °C. This factor could be interesting in terms of reducing economic losses, indeed, loquat fruit is easily bruised and scratched, and the damaged areas usually turn brown or black in the air later.

At the end of the cold storage, panelists' preferences for coated loquat fruits over control ones were most evident, as indicated by their visual score and sensory rating. Although the coated fresh-cut loquat fruits were preferred by panelists, future research is needed on the removal of unacceptable oregano flavor and odor perceived immediately after treatment on coated fruits ($T_0$). The mucilage-based coating enriched with OEO positively affects the visual appearance of fresh-cut loquat fruits, keeping the visual scores above the marketability threshold until 9 days of the cold storage period, compared to uncoated ones that reported scores below the limit of marketability after 6 days of cold storage period.

Regarding the microbiological investigations, the obtained results revealed that the use of *O. ficus-indica* mucilage edible coating containing 1.5% (*v*/*v*) of oregano essential oil limited the growth of aerobic bacteria, yeasts, and molds during storage.

According to our research, loquat fruits with huge spots on the epicarp, which are typically regarded as unmarketable, can still be sold on the market after being peeled and coated with a mucilage-based coating enriched with OEO.

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