



Article

Use of Aloe Vera Gel-Based Edible Coating with Natural Anti-Browning and Anti-Oxidant Additives to Improve Post-Harvest Quality of Fresh-Cut ‘Fuji’ Apple

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Abstract: Recently, there is increasing use of edible and biodegradable films and packaging that are both environmentally friendly and functional for storage and market distribution. Fresh-cut ‘Fuji’ apples, harvested in an organic farm, were treated, using a spraying technique, with three new edible coatings based on Aloe vera gel (AVG—40% *v/w*) and in combination with natural additives: lemon essential oil (LEO—1% *v/w*) and hydroxypropyl methylcellulose (HPMC—0.1% *v/w*) and compared with untreated sample (CTR), the physicochemical and sensory characteristics and the proximate compounds were evaluated. During cold storage, weight loss, soluble solids content, and color of uncoated slices were reduced, while softening, ripening, browning, and acidity were accelerated. In contrast, the AVG/HPMC treatment significantly delayed the above parameters related to post-harvest quality loss, while the AVG/LEO treatment delayed the browning processes, maintaining an excellent color during cold storage. Concerning proximate compounds, the treatments did not alter their concentration in the fruit tissues. Sensory analyses revealed no detrimental effect on taste, aroma, or flavor. Our data evidenced the positive effect of Aloe vera gel in combination with LEO and HPMC on fresh-cut apple quality as an innovative and sustainable technique to maintain fresh-cut apple quality.

Keywords: agri-food system; post-harvest; bio-based films; hydroxypropyl methylcellulose; lemon essential oil; human health benefits; sustainability; consumer acceptability

1. Introduction

In recent years, there has been a growing focus on sustainability, starting with the study of the orchard, cultivation techniques, and their impact on the environment [1] until the fruit production supply chain in future climate change scenarios [2].

To date, synthetic antioxidants and artificial additives are still widely used in the food industry to inhibit oxidation and decay of products. To reduce waste and limit losses, researchers study the exclusive use of natural and biodegradable materials to create edible films and packaging that are both environmentally friendly, healthy, and functional for storage and market distribution [3]. In fact, postharvest softening of fresh-cut fruit is a serious commercial problem resulting in quality losses both for growers and distributors. For these reasons, researchers’ attention is more focused on fresh, fresh-cut, peeled, sliced, and packaged fruit and vegetables which, if they have physicochemical characteristics suitable for sale on the market, can be sold and appreciated more by consumers, thanks to their freshness, convenience (as a ready-to-eat product), and human health benefits. For example, water loss, browning, and texture are among the most important quality parameters that influence the acceptability of many fruits by consumers [4].

Particularly with regard to apple (*Malus domestica* Borkh) fruits, the 'Fuji' is a popular apple variety largely cultivated, especially in organic orchards and commercialized in Sicily [5]. Apple fruit is characterized by a delicious taste, good hardness and color, and long shelf-life [6]. However, one of the most frequent physiological disorders in whole apple fruit is the bitter pit (BP), commonly associated with the low Ca and high Mg concentration in fruit tissues. When prepared as fresh-cut, it is subject to enzymatic browning due to the action of polyphenol oxidase on phenolic compounds causing undesirable changes in appearance, taste, and nutrient composition and leading to a decrease in product quality [7]. These phenomena limit the fruit shelf life with a consequential increase in waste production at the end of the storage chain [8].

In this regard, edible coatings consist of natural hydrocolloids, polysaccharides, proteins, lipids, and waxes and form an invisible, odorless, and tasteless barrier on the fruit surface that separates it from the surrounding atmosphere [9]. The edible coatings are frequently used to improve the aesthetic value and to increase the storage period [10]. In addition, by incorporating totally natural ingredients, such as antimicrobials, anti-browning, antioxidants, and colorants, the microbial contamination risk can be reduced [11] and proximate compounds and nutraceutical, thanks to the addition of vitamins, antioxidants, and polyphenols, can be increased. In this regard, many minerals play a vital role in biological processes and are considered important allies in the prevention of chronic diseases [12].

More recently, the biopolymers as an edible film matrix composed of a combination of different components (antimicrobials and antioxidants) extracted from plants [13], e.g., the cellulose-based coating, which has been reviewed by many authors [14–16], were introduced and studied. The hydroxypropyl methylcellulose (HPMC) is one of largely used cellulose derivatives [17]. It is a readily available non-ionic edible plant derivative forming transparent, odorless, tasteless, oil-resistant, and water-soluble edible films. HPMC is approved for food uses by the United States Food and Drug Administration (FDA) (21 CFR 172.874) and the European Union (EU) [18]; its safety in food use has been confirmed by the Joint FAO/WHO Expert Committee on Food Additives and Contaminants (JECFA) [19]. It is easy to use, available, water-soluble, non-toxic, and chemically stable [20] and anti-browning agents can be added.

In most cases, natural additives are considered healthier than chemical additives because they can perform various functions in nutrition, and give additional value (bioactivity, nutraceutical) by reducing waste production to zero [3]. Essential oils and Aloe vera gel are also widely studied as natural components of edible coatings on both whole and fresh-cut fruit [21,22]. Essential oils are natural substances extracted from fruit and vegetables based on terpenes, terpenoids, and other aromatic and aliphatic constituents [23]. On the one hand, the essential oils incorporation in edible coatings has been described as a good natural alternative to maintain bioactive compounds during storage [24,25] and to preserve minimally processed products, such as fresh-cut melon [26], apple [27], or pear [28]. Rojas-Graü, M.A. et al. [27] applied lemongrass, oregano oil, and vanillin into an apple puree coating on the 'Fuji' apple slices. They obtain a significant reduction in O₂, while CO₂ production was observed in samples containing high concentrations of essential oils. Lemon essential oil, which is extracted from Citrus, has limonene, valencene, and ocimene as major components. Limonene, which has the Generally Recognized As Safe (GRAS) status of the United States FDA [29], is used as a food additive or flavoring agent and has fungicidal properties [30]. Its intense aroma and potential toxicity were reduced, incorporating this compound in very low doses into the formulation of edible coatings [31]. On the other hand, in regard to Aloe vera gel-based edible coatings, several studies have been carried out on the quality parameters of covered fresh-cut apple fruits. Song, H.Y. et al. [32] reduced populations of bacteria, molds and yeasts, browning processes, and delayed senescence. Chauhan, O.P. et al. [33] applied shellac and Aloe vera gel coatings, reducing respiration and ethylene synthesis rates, polyphenol oxidase and peroxidase activity. Supapvanich, S. et al. [34] maintained the values of lightness (L*) and delayed the increase in browning index (BI) and CIELAB color differences (ΔE^*) in 'Taaptimjaan' apple. The increasing interest in the use of gelatinous parenchyma of Aloe vera (*Aloe barbadensis* Miller) in the food industry, mainly depends on its characteristic of functional foods [34,35].

Nonetheless, today no studies have been carried out on the effects of applying an Aloe vera gel-based edible coating in combination with lemon essential oil and hydroxypropyl methylcellulose on the surface of fresh-cut 'Fuji' apple as a sustainable alternative to synthetic by-products.

For this reason, the purpose of this work was to determine how much the proximate compounds, vitamins, physicochemical, and sensory characteristics of fresh-cut 'Fuji' apple slices are influenced by the treatments with an Aloe vera gel-based edible coating and in combination with hydroxypropyl methylcellulose and lemon essential oil, using a spraying technique and simulating commercial storage.

2. Materials and Methods

2.1. Vegetal Material

Fifteen 'Fuji' apples have been selected and harvested with uniform size (250 ± 10 g) at commercial maturity in an organic farm located near Caltavuturo ($37^{\circ}49'$ N and 850 m a.s.l.). This area is characterized by a typically Mediterranean climate. The soil is of medium texture tending to clayey, with good fertility. Another important aspect is the quantity of water accumulated in the areas of the fields thanks to the presence of several water rivulets. The plants are placed along single rows spaced 4×1.5 m, grafted onto M9 rootstocks, and subjected to the ordinary cultivation regime of organic farming.

Fruits were transported to the laboratories of the Department of Agricultural, Food and Forestry Sciences of the University of Palermo, where they were treated with edible coatings.

2.2. Coating Formulations

Coating formulations were made on site. Matured leaves of Aloe vera plant were harvested at the experimental field of the University of Palermo. The epidermis was separated from the gel, which was manually cut into portions of 10 ± 1 mm in thickness, and the sample was maintained at $4^{\circ} \pm 1$ °C in a refrigerator. The gelatinous parenchyma was separated from the leaves by means of a stainless-steel knife removing the external epidermis. It was triturated using an ultra-Turrax T25 (Janke and Kunkle, IKA Labortechnik, Breisgau, Germany) for 5 min at 24,500 rpm to form a homogeneous substance, and filtered to remove the fibrous portion [36]. Based on our previous studies, the threshold for sensory acceptance was established at 40% of its volume in 300 mL of water (*v/w*) due to a bitter taste that occurred at higher concentrations (data not shown). Therefore, the treatments are as follows:

Untreated (CTR): only chlorinated water 0.5% (*v/w*);

AVG: 40% (*v/w*) of Aloe vera gel (AVG);

AVG/HPMC: 40% (*v/w*) of AVG and 0.1% (*v/w*) of hydroxypropyl methylcellulose (HPMC);

AVG/LEO: 40% (*v/w*) of AVG and 1% (*v/w*) of lemon essential oil (LEO).

To prevent browning and to maintain the pH value below 3.5, 1% (*v/w*) of ascorbic acid and 1% (*v/w*) of citric acid were added to the solutions, except in the CTR.

2.3. Experimental Design

'Fuji' apples were cored and sliced into 8 pieces with a 2 cm of thickness, using a stainless-steel knife. The total sample of apple slices (144) was divided into four different lots, which were treated with the spraying technique. Thirty-six slices were coated with AVG treatment, 36 with AVG/HPMC treatment, and 36 with AVG/LEO treatment. The last 36 apple slices were stored as CTR. In all treatments and in the CTR, the apple slices were sprayed for 2 min through an airbrush (0.8 mm nozzle) powered by N₂. After treatments, three apple slices \times PET (polietilentereftalato) tray ($12 \times$ treatment) were stored in a passive atmosphere at low temperature ($4^{\circ} \pm 1$ °C and $90\% \pm 5\%$ Relative Humidity (RH) for 9 days. Each tray (125 mm \times 115 mm and 150 cc) were thermally sealed on the top with a bi-oriented polypropylene (BOPP) film of 50 mm of thickness. The permeability of the BOPP was 2.004 mL O₂ m⁻²d⁻¹atm⁻¹ and 3.824 mL CO₂ m⁻²d⁻¹atm⁻¹. All of the analysis was carried out in three replicate and on an interval of three days for nine total days (T0, T3, T6, and T9). All the analyses were

carried out in all the trays starting from day 0 of storage. Therefore, the values at T0 are influenced by the weight of the apple slices and the addition of the coating.

2.4. Physical Analysis

The weight loss was measured every three days with a two-decimal precision digital scale (Gibertini, Italy). The value was expressed as a relative percentage and calculated as weight loss (%) = $(w_i - w_t)/w_i \times 100$ (where w_i is the initial weight, and w_t is the weight measured during storage).

The surface color of fresh-cut apples was analyzed using a pre-calibrated Minolta colorimeter (Chroma Meter CR-400, Konica Minolta Sensing Inc., Tokyo, Japan). Color samples were measured regarding Hunter values: lightness (L^*), redness (a^*), and yellowness (b^*).

Three measurements of an apple slice were taken at different locations of each sample to acquire a uniform color measurement.

The firmness of the flesh ($\text{kg}\cdot\text{cm}^{-2}$) was determined by means of a digital penetrometer TR5325 (Turoni, Forlì Italia) with an 8 mm diameter plunger and a 'Shore A' durometer.

2.5. Chemical Analysis

After apple juice extraction by a squeezing–centrifugal machine (Ariete, Italy), we measured the soluble solids content (SSC) as °Brix, by means of an optical digital refractometer ATAGO (Atago Co, Ltd., Tokyo, Japan); the titratable acidity (TA), expressed as malic acid (g/l^{-1}), and the pH value, with a Crison Compact titrator pH-meter (Crison Instruments, SA, Barcelona, Spain).

2.6. Proximate Composition

Ash content was determined through the procedure described in Association of Official Analytical Chemists (AOAC) [37–41], while the Kjeldahl method was used for protein determination. In particular, a sample rate was subjected to acid-catalyzed mineralization to turn the organic nitrogen into ammoniacal nitrogen and, subsequently, was distilled in an alkaline pH. The ammonia formed during this distillation was collected in a boric acid solution and determined through titrimetric dosage. The value of ammoniacal nitrogen was multiplied by 6.25 [42].

The fat content (FAT) was obtained through acid hydrolysis with a 1:4 HCl solution on the sample followed by filtration and dehydration in a heater (70 °C). After solvent evaporation, the extraction in Soxhlet with petroleum ether was determined through a gravimetric method of residual fat.

Complex carbohydrates have a significantly more elaborate biochemical structure than other carbohydrates (simple sugars with a simpler structure, determined with the Fehling reagent). The carbohydrate content (TSG), either free or present in polysaccharides, was obtained with the anthrone method reported in Loewus [43]. Carbohydrates were first hydrolyzed into simple sugars using dilute hydrochloric acid. In hot acidic medium, glucose is dehydrated to hydroxymethyl furfural that with anthrone forms a green-colored product with an absorption maximum at 630 nm.

The contents of K, Na, Ca, Fe, Cu, Mn, and Zn were determined using atomic absorption spectroscopy following wet mineralization, while P was determined using a colorimetric method [44–46]. The total content of polyphenols was determined according to the Folin–Ciocalteu method. The extraction of the phenolic compounds was carried out by weighing 0.25 g of sample and adding 5 mL of an 80% (*v/v*) methanol solution. The mixture was stirred by means of a Vortex shaker for 1 min and then stirred on a magnetic stirrer in a cold room for 30 min. The mixture was, therefore, centrifuged for 10 min at 6000 rpm at room temperature. The solid part has separated from the liquid extract. The latter was recovered in a test tube. A counter-extraction was carried out for each sample, resuspending the pellet obtained after centrifugation, according to the above procedure. At the end, it was the supernatant that was recovered and added to the first. The extract thus obtained was further centrifuged to sediment any solid particles left, thus obtaining a clear extract. This extract was transferred in flasks by Rotavapor and was concentrated until the achievement of a final volume of 3 mL. The concentrated extract was resuspended in 80% (*v/v*) methanol up to a final volume total of 4.5 mL and was placed in Eppendorf

and stored at $-20\text{ }^{\circ}\text{C}$ until the moment of the analysis, while total, soluble, and insoluble fibers were measured by the chemical–enzymatic method 1995 (AOAC 994.13 [37]).

The riboflavin (vitamin B2) was extracted in an autoclave with a solution of diluted H_2SO_4 , and later, after enzymatic treatment, was determined through HPLC (for the fluorescent spectra) [38].

For the ascorbic acid (vitamin C) determination, the dried methanolic extract (100 mg) was extracted with 10 mL of 1% metaphosphoric acid for 45 min at room temperature and filtered through Whatman No. 4 filter paper. The filtrate (1 mL) was mixed with 9 mL of 2,6-dichlorophenolindophenol, and the absorbance was measured within 30 min at 515 nm against a blank. Ascorbic acid was calculated based on the calibration curve of authentic L-ascorbic acid ($0.02\text{--}0.12\text{ mg mL}^{-1}$) [47].

2.7. Sensory Analysis

The sensory analysis was carried out by a group of judges. All panelists were trained and had broad expertise in sensory evaluation of foods and, in particular, of apples [48]. Panel members were trained using different apple samples to recognize aroma, flavor, and texture attributes during the training session, using references to products and ingredients. Twenty qualitative and quantitative descriptors were considered: appearance (A), flesh color (FC), firmness (F), apple odor (AO), herbaceous odor (EO), honey odor (HO), almond odor (AIO), off-odor (OO), sweetness (S), acidity (AC), bitter (B), astringent (AS), crunchiness (C), flouriness (FI), juiciness (J), apple flavor (AF), herbaceous flavor (EF), honey flavor (HF), almonds flavor (AIF), off-flavor (OF), overall assessment (OA). The judges assessed the intensity of each attribute on a discontinuous scale from 1 (absence of the descriptor) to 9 (maximum intensity of the descriptor).

2.8. Statistical Analysis

All data were tested for differences between treatments and sampling times using the one-way analysis of variance (ANOVA; general linear model) followed by Tukey's multiple range test for $p \leq 0.05$. All statistical analysis was conducted using XLSTAT software version 9.0 (Addinsoft, Paris, France).

3. Results and Discussions

3.1. Weight Loss

During storage, there was a difference in weight loss between the uncoated and coated fresh-cut apples. At the beginning of the experiment, CTR apple slices weighed 44.14 g, AVG apple slices weighed 48.9 g, AVG/HPMC apple slices weighed 45.4 g, and AVG/LEO apple slices weighed 44.8 g. After three days of storage, the apple slices uncoated (CTR) and AVG treatment lost 3.44% and 0.52%, respectively, by weight, giving a result (expressed in grams) of 42.62 g and 48.64 g. The fruits treated with AVG/HPMC, instead, weighed 45.13 g (showing a weight loss percentage of 0.54%), while the AVG/LEO treatment showed a weight loss of 0.96% (the tray weighs 44.35 g). After 6 days of storage, the tray with the untreated slices (CTR) weighed 42.10 g (it lost 4.62% in weight), the slices treated only with AVG weighed 47.85 g, showing a weight loss of 2.13%. One percent weight loss was detected for AVG/HPMC treatment (which had a weight of 44.92 g), while AVG/LEO had a weight loss of 1.50%, reaching 44.10 g. Finally, after 9 days of storage, the weight of the CTR and the AVG-treated apple slices decreased to 41.94 g and 47.47 g, respectively, whereas the apple slices coated with AVG/HPMC and AVG/LEO weighed 44.70 g and 44.08 g, respectively. The results at the end of the storage period indicated that the CTR and the AVG-treatment lost 4.98% and 2.92%, respectively, while the AVG/HPMC and AVG/LEO treatments minimized weight loss (1.50% and 1.56%, respectively) by maintaining the water content in fresh-cut apple. In fact, this weight loss is probably caused by the water evaporation on the fruit surface and is a leading cause of quality loss, such as shriveling of the surface and decreased juiciness [6,42]. Nonetheless, there are not many studies available in the literature concerning the mixing of HPMC with Aloe vera gel and lemon essential oil to form edible or biodegradable films or packages, to compare with our data. Bai, J. et al. [49] also reported that the coatings were effective

in preventing weight loss in apples. In particular, the Aloe vera gel-based edible coating acts as a very efficient barrier for oxygen, carbon dioxide, and lipids, but with poor resistance to water vapor transport [50]. Moreover, Klangmuang and Sothornvit [51] have been combined Aloe vera gel with other lipids to reduce water vapor permeability and to reduce weight loss, as Velickova et al. [52] they did before on strawberries. Edible films and coatings based on HPMC have been extensively studied to improve the shelf life and quality of whole citrus fruit. Navarro-Tarazaga et al. [53] and Perez-Gago et al. [54] have contributed to maintaining the quality of the fruits by reducing its weight loss and improving its mechanical integrity. HPMC has also been studied in combination with different components, such as fatty acids [12] or cellulose nano-particles [55] but never with Aloe vera. In fact, on fresh-cut apples, the effect of edible coating based on HPMC, whey proteins, and beeswax was only studied [56].

Regarding the use of lemon essential oil, Perdones A. et al. [31] applied an edible coating based on chitosan and lemon essential oil to strawberries cv. Camarosa, and found significant differences, compared to untreated fruits, as the coated products slowed the respiration rate of the samples when lemon essential oil was added.

3.2. Color Analysis

As regards color parameters (Table 1 and Figure 1), initial Lightness (L^*), redness (a^*) and yellowness (b^*) values of the apple slices were 78.28 ± 1.40 , -4.01 ± 0.86 , and 34.44 ± 0.55 , respectively. For all treatments and uncoated apple slices, there was no difference in the b^* value. Conversely, the L^* value and a^* value, respectively, decrease and increase during storage, according to Iglesias, Echeverría, and Lopez [57] and Marquina et al. [58].

Table 1. Color characteristics of fresh-cut apples at 0, 3, 6, and 9 days of storage at $4^\circ \pm 1^\circ \text{C}$ and $90\% \pm 5\%$ RH (relative humidity) after all treatments.

Treatment	Days of Storage	L^*	a^*	b^*
CTR	0	78.3 ± 1.4 Aa	-4.0 ± 0.9 Aa	34.4 ± 0.5 Aa
	3	75.4 ± 1.2 Bab	-1.4 ± 0.5 Bb	34.3 ± 1.2 Aa
	6	73.3 ± 0.8 Bb	-0.9 ± 1.0 Bbc	33.8 ± 1.3 Aa
	9	73.2 ± 0.8 Bb	0.0 ± 0.7 Cc	33.5 ± 0.5 Aa
AVG	0	78.4 ± 0.8 Aa	-3.7 ± 0.6 Aa	30.8 ± 2.5 Ba
	3	76.4 ± 1.5 ABb	-3.4 ± 0.3 Aa	30.5 ± 0.9 Ba
	6	75.7 ± 0.3 ABb	-2.2 ± 1.0 ABb	30.3 ± 2.3 Ba
	9	75.3 ± 1.7 ABb	-0.7 ± 0.7 Bc	30.0 ± 1.1 Ba
AVG/HPMC	0	78.6 ± 0.3 Aa	-3.6 ± 0.8 ABa	31.1 ± 0.8 Ba
	3	78.3 ± 0.5 Aa	-3.5 ± 0.5 Aa	30.3 ± 0.4 Ba
	6	76.9 ± 0.2 Ab	-2.4 ± 0.3 Ab	29.6 ± 1.5 Ba
	9	76.8 ± 0.4 Ab	-2.1 ± 0.1 Ab	27.2 ± 1.7 Cb
AVG/LEO	0	77.8 ± 0.3 Aa	-3.3 ± 0.5 Ba	29.2 ± 0.7 Ba
	3	77.6 ± 0.2 ABa	-2.9 ± 0.4 ABab	28.7 ± 0.7 Ba
	6	76.4 ± 0.8 ABb	-2.0 ± 0.4 ABb	28.6 ± 2.1 Ba
	9	76.3 ± 0.6 ABb	-0.8 ± 0.3 Bc	28.4 ± 2.4 BCa

Lightness (L^*), redness (a^*), and yellowness (b^*). Data correspond to the means \pm standard deviation of three replicates. Means with different letters are significantly different at $p \leq 0.05$ using Tukey's test. Different capital letter denotes significant differences ($p < 0.05$) among different treatments for the same sampling time. Different lowercase letter denotes significant differences ($p < 0.05$) among different sampling times for the same treatment.



Figure 1. Visual aspect of treated and untreated fresh-cut 'Fuji' apple after 9 days of cold storage at $4^{\circ} \pm 1^{\circ} \text{C}$ and $90\% \pm 5\% \text{RH}$.

From the sixth day of storage, the a^* (redness) coordinate decreased for both coated and uncoated samples, but only the AVG/HPMC treatment maintained a constant value until the 9th day. This increase in redness is probably due to an increase in the respiration rate and enzymatic processes that lead to a loss of quality of the fruit [59].

Concerning yellowness (b^*), no significant differences ($p \leq 0.05$) were found between treated and untreated fruits.

Treatments with an edible coating effectively delay color loss of fresh-cut apples during storage. Only two coating formulations (AVG/HPMC and AVG/LEO) led to a significant reduction in color loss, in terms of brightness (L^*) and redness (a^*), compared to uncoated apple slices and AVG treatment, which undergo rapid color deterioration.

Aloe vera gel slows down the ripening process and the respiration rate of apple slices [50]. Aloe vera gel applied to table grapes [60], cherries [50], and plums [61], has shown excellent results in terms of improving product presentation and reducing browning of treated fruits. Similar results were also found by Marpudi SK., Ramchandaran P. and Srividya N. [62] for figs coated with Aloe vera gel, which maintained the color of the fruit, its texture, and ripeness during storage.

On the other hand, the gloss and transparency of the films are relevant properties since they have a direct impact on the appearance of the coated product. In general, significant differences were associated with the nature and amount of the essential oil (EO). Sánchez-González, L. et al. [63] observed that the addition of EO to the HPMC matrix led to a reduction in gloss (L^*), despite concentration. The reduction in gloss in lipid-containing composite films has also been observed by several authors [63,64]. The gloss of the films is related to the surface morphology achieved during the drying of the film. In general, the smoother the surface, the glossier it is.

Additionally, the amorphous state of the HPMC has allowed limiting the crystallization of the coating on the surface of the apple slice, maintaining almost unchanged the properties of brightness and transparency of the coating. The amorphous state of the HPMC was reported by Kou et al. [65] through X-ray diffraction analysis.

Rojas-Graü et al. [27] covered apple slices with alginate-based edible coating and essential oils of oregano, lemongrass, and vanillin, showing significantly smaller differences in color data than in the control. In our case, the edible coating enriched with lemon essential oil showed better color retention values than the control.

3.3. Firmness

AVG/LEO treatment limits, especially during the first six days, the loss of firmness (N) compared to CTR, while AVG and AVG/HPMC do not seem to have an improving effect on this parameter

(Table 2). These data are in agreement with Hye-Yeon Song [32], according to whom the treatment of edible coating with aloe vera gel allowed the maintenance of a constant firmness of the fresh-cut apple flesh compared to the untreated fruits. The differences between the results observed in this work rely on the high initial level of firmness values of apple slices, as this cv has intrinsic compactness characteristics Rojas-Graü, M. A. et al., [27].

Table 2. Physico-chemical traits of fresh-cut apples at 0, 3, 6, and 9 days of storage at $4^{\circ} \pm 1^{\circ} \text{C}$ and $90\% \pm 5\% \text{RH}$ after all treatments..

Treatment	Days of Storage	Firmness (N)	SSC ($^{\circ}$ Brix)	TA (g malic acid/L)	pH
CTR	0	44.7 \pm 2.5 Aa	14.3 \pm 0.6 Aa	0.2 \pm 0.0 ns	4.0 \pm 0.1 ns
	3	42.3 \pm 2.5 Aab	12.3 \pm 2.1 Aa	0.1 \pm 0.0 ns	3.9 \pm 0.1 ns
	6	39.3 \pm 1.2 Abc	11.6 \pm 2.3 Aa	0.1 \pm 0.0 ns	4.0 \pm 0.1 ns
	9	34.7 \pm 0.6 Bc	10.3 \pm 3.3 Aa	0.1 \pm 0.0 ns	4.0 \pm 0.1 ns
AVG	0	43.0 \pm 0.0 Aa	13.3 \pm 1.2 ABa	0.2 \pm 0.0 ns	4.2 \pm 0.3 ns
	3	41.0 \pm 1.0 Ab	12.2 \pm 0.8 Aab	0.1 \pm 0.0 ns	4.0 \pm 0.1 ns
	6	39.0 \pm 1.0 Ac	10.7 \pm 0.6 Ab	0.1 \pm 0.0 ns	3.9 \pm 0.1 ns
	9	37.3 \pm 0.6 ABc	10.2 \pm 0.7 Ab	0.1 \pm 0.0 ns	3.8 \pm 0.1 ns
AVG/HPMC	0	45.3 \pm 2.5 Aa	12.3 \pm 0.6 Ba	0.2 \pm 0.0 ns	4.0 \pm 0.1 ns
	3	43.7 \pm 2.9 Aa	11.8 \pm 0.3 Aa	0.1 \pm 0.0 ns	3.9 \pm 0.1 ns
	6	42.7 \pm 3.1 Aa	10.4 \pm 0.5 Ab	0.1 \pm 0.0 ns	3.9 \pm 0.1 ns
	9	41.0 \pm 3.0 Aa	9.3 \pm 0.6 Ab	0.1 \pm 0.0 ns	3.8 \pm 0.1 ns
AVG/LEO	0	43.0 \pm 1.7 Aa	13.4 \pm 0.5 ABa	0.2 \pm 0.0 ns	3.9 \pm 0.1 ns
	3	41.7 \pm 1.5 Aab	12.7 \pm 0.3 Aab	0.1 \pm 0.0 ns	3.8 \pm 0.0 ns
	6	41.3 \pm 0.6 Aab	12.1 \pm 0.3 Ab	0.1 \pm 0.0 ns	3.8 \pm 0.0 ns
	9	38.7 \pm 1.5 ABb	11.8 \pm 0.3 Ab	0.1 \pm 0.0 ns	3.7 \pm 0.1 ns

Firmness (N), soluble solid content (SSC), titratable acidity (TA), and pH. Data correspond to the means \pm standard deviation of three replicates. Means with different letters are significantly different at $p \leq 0.05$ using Tukey's test. ns = not significant. Different capital letters denote significant differences ($p < 0.05$) among different treatments for the same sampling time. Different lowercase letters denote significant differences ($p < 0.05$) among different sampling times for the same treatment

3.4. Soluble Solids Content

With respect to soluble solids content (SSC), also shown in Table 2, both the three treatments and the control follow the same evolution. The AVG/LEO treatment was able to limit the loss of soluble solids content from the first three days of the storage period by maintaining this behavior until the last day of observation. The other treatments did not differ from the control. Studies concerning a decrease in the sugar content during apple storage confirm that this behavior could be attributed to the conversion of sugar into starch [66], and malic acid is consumed by the fruit as respiratory substrates and for the synthesis of new compounds during storage [67]. Moreover, the coating seemed to decrease the permeability to CO_2 and O_2 , with the result of a decrease in the respiration rate of apples [49]. The SSC allows the evaluation of the degree of sugar and, correlated with the titratable acidity (TA), gives useful feedback on the satisfaction of the fruit by the consumer. Together with these results, our findings indicate that coating apple slices with the AVH/HPMC and AVG/LEO treatments was effective with respect to the soluble solids content found in untreated fruits (CTR) during the 9 days of storage.

3.5. Titratable Acidity and pH

With respect to TA and pH, these two parameters are important for assessing the freshness of fruit and are strongly correlated because the pH value depends on the presence of acid compounds. As can be seen from Table 2, the presence of edible coating slowed down the increase in pH and, consequently, stabilized the titratable acidity (TA). Moreover, the evidence that the fruits coated with edible coating had a stabilized pH around 3.7 is an interesting aspect because, at this pH value, both polyphenol oxidase and microbial activities are slowed down [68]. The acid content in the fruit tends to decrease over time, probably due to the oxidation of organic acids that occurs with the ripening of the fruit [69].

Therefore, a pH increase is expected during the storage period. Compared to other studies, the results on pH and TA obtained with the application of HPMC, AVG, and LEO edible coatings were positive, especially compared with the untreated fruits or treated with AVG edible coating. As Soares and Fonseca report [70], intrinsic and extrinsic factors, such as treatment, variety, and storage conditions, are essential to determine the degree of acidity variation. The latter had the opposite trend to the evolution of pH observed by other authors [28,71,72].

3.6. Proximate Compounds

The proximate compounds into the treated and untreated apple slices were analyzed (Table 3). All the samples have values similar to the USDA Nutrient Database during the storage period.

The results show that the samples evaluated contained high variability of proximate compounds in all treatments and CTR during the 9 days of storage, according to other researchers [12,73], which explained this behavior related to different cultivars studied, growing conditions, and methodology used to determine these compounds. The increase in values during storage time is probably due to the reduction in water content and closely related to weight loss. Ca, K, and P, together with a low Na intake, are associated with protection against bone demineralization, arterial hypertension, insulin resistance, and overall cardiovascular risk [74]. As regards the essential elements (Mn, Zn, Cu, Fe) involved in many biochemical processes, there were no significant differences between treatments and CTR.

During storage, there were very low significant differences between treated and untreated apple slices. In particular, the CTR showed the highest loss of moisture during cold storage, unlike the other treatments. Concerning protein content, there were very low significant differences between treated and untreated apple slices.

In FAT content, the AVG treatment had a major increase. In carbohydrate content, AVG/HPMC treatment had a major increase. AVG/LEO treatment had a major content increase in sugars. Concerning fibers, AVG/LEO treatment had the highest content at the end of the storage period. Finally, as regards total phenolic content, AVG treatment had a greater range of variability from day 0 to day 9 of storage.

From the results obtained, it is possible to see that the treatments did not alter the nutrients content inside the treated apple slices but kept it throughout the storage time.

Table 3. Ca, K, Na, P, Mn, Zn, Cu, and Fe in fresh-cut apples at 0, 3, 6, and 9 days of storage at 4° ± 1°C and 90% ± 5% RH after all treatments.

Treatment	Days of Storage	Ca g/100g DW	%	K g/100g DW	%	Na g/100g DW	%	P g/100g DW	%	Mn g/100g DW	%	Zn g/100g DW	%	Cu g/100g DW	%	Fe g/100g DW	%
CTR	0	7.028 ± 0.001 Aba		136.667 ± 29.023 Ab		1.014 ± 0.576 Aa		11.009 ± 1.943 Cb		0.031 ± 0.001 Bb		0.030 ± 0.006 Aa		0.291 ± 0.001 Aa		0.150 ± 0.026 Ac	
	3	7.310 ± 0.001 Ba	3.9	138.012 ± 23.680 Ab	1.0	1.345 ± 0.579 Aa	24.6	12.667 ± 2.887 Cb	13.1	0.029 ± 0.001 Bb	6.5	0.033 ± 0.006 Ba	10.0	0.031 ± 0.001 Aa	89.3	0.177 ± 0.026 Ab	15.1
	6	7.027 ± 0.001 Ba	0.0	149.667 ± 18.339 Ca	8.7	1.347 ± 0.579 Aa	24.7	15.078 ± 1.000 Ba	27.0	0.042 ± 0.024 Aa	26.2	0.033 ± 0.006 Ba	10.0	0.036 ± 0.002 Aa	87.6	0.177 ± 0.025 Bb	15.1
	9	7.030 ± 0.001 Ba	0.0	149.667 ± 18.339 Ca	8.7	1.330 ± 0.577 Ba	23.8	15.099 ± 1.000 Ba	27.1	0.047 ± 0.030 Aa	34.0	0.033 ± 0.006 Ba	10.0	0.037 ± 0.002 ABa	87.4	0.180 ± 0.025 Ba	16.7
AVG	0	6.000 ± 0.764 Bb		133.667 ± 4.509 ABb		1.002 ± 0.500 Aa		12.089 ± 1.052 Bb		0.037 ± 0.006 Aa		0.033 ± 0.040 Aa		0.031 ± 0.001 Ab		0.137 ± 0.026 Bc	
	3	6.833 ± 0.634 Bab	12.2	134.011 ± 7.550 Bb	0.3	1.045 ± 0.500 Aa	4.1	13.667 ± 1.528 Bb	11.5	0.040 ± 0.010 Aa	8.3	0.037 ± 0.040 Ab	9.1	0.033 ± 0.001 Ab	6.1	0.140 ± 0.015 Cc	2.1
	6	7.020 ± 0.001 Ba	14.5	154.333 ± 10.599 Ba	13.4	1.330 ± 0.560 Aa	24.7	15.333 ± 0.577 Ba	21.2	0.042 ± 0.010 Aa	12.7	0.041 ± 0.006 Aa	18.7	0.042 ± 0.002 Aa	26.2	0.193 ± 0.012 Ab	29.1
	9	7.019 ± 0.001 Ba	14.5	157.333 ± 8.021 Ba	15.0	1.348 ± 0.579 Ba	25.7	15.337 ± 0.577 Ba	21.2	0.047 ± 0.010 Aa	22.0	0.044 ± 0.006 Aa	24.2	0.043 ± 0.006 Bb	28.5	0.200 ± 0.000 Aa	31.5
AVG/HPMC	0	8.000 ± 0.488 Ac		123.333 ± 15.567 Cb		1.032 ± 0.577 Aa		12.023 ± 1.289 Bb		0.030 ± 0.006 Bb		0.293 ± 0.006 Aa		0.030 ± 0.001 Ab		0.150 ± 0.026 Bb	
	3	8.333 ± 0.577 Ac	4.0	125.002 ± 13.550 Cb	1.3	1.023 ± 0.574 Aa	0.9	12.333 ± 0.577 Cb	2.5	0.033 ± 0.006 Bb	10.0	0.031 ± 0.006 Ba	89.4	0.033 ± 0.002 Ab	10.0	0.153 ± 0.035 Bb	2.2
	6	9.667 ± 0.577 Ab	17.2	186.010 ± 11.533 Aa	33.7	1.330 ± 0.454 Aa	22.4	18.095 ± 2.000 Aa	33.6	0.033 ± 0.006 Bb	10.0	0.034 ± 0.006 Ba	88.4	0.035 ± 0.002 Bb	14.3	0.200 ± 0.035 Aa	25.0
	9	13.001 ± 1.732 Aa	38.5	192.000 ± 7.000 Aa	35.8	2.000 ± 0.967 Ab	48.4	19.333 ± 1.155 Aa	37.8	0.041 ± 0.021 Aa	26.8	0.035 ± 0.006 Ba	88.1	0.040 ± 0.006 Aa	25.0	0.200 ± 0.042 Aa	25.0
AVG/LEO	0	6.009 ± 0.576 Bb		129.667 ± 4.509 Bc		1.000 ± 0.544 Aa		13.667 ± 1.052 Ac		0.033 ± 0.006 Bb		0.030 ± 0.004 Ab		0.030 ± 0.001 Aa		0.140 ± 0.026 ABb	
	3	6.333 ± 0.577 Cb	5.1	134.010 ± 3.020 Bb	3.2	1.346 ± 0.579 Aa	25.7	15.015 ± 1.528 Ab	9.0	0.037 ± 0.006 ABab	9.1	0.037 ± 0.005 Aab	18.9	0.031 ± 0.001 Aa	3.2	0.143 ± 0.006 Cb	2.3
	6	6.667 ± 0.577 Cab	9.9	138.333 ± 1.528 Db	6.3	1.333 ± 0.577 Aa	25.0	15.333 ± 0.577 Bb	10.9	0.041 ± 0.021 Aa	18.7	0.039 ± 0.006 Aa	23.1	0.033 ± 0.003 Ba	10.0	0.190 ± 0.009 Aa	26.3
	9	7.002 ± 0.563 Ba	14.2	157.333 ± 8.021 Ba	17.6	1.667 ± 0.576 Ab	40.0	16.667 ± 1.155 ABa	18.0	0.043 ± 0.021 Aa	22.5	0.040 ± 0.006 Aa	25.0	0.033 ± 0.006 Ba	10.0	0.200 ± 0.010 Aa	30.0

Data correspond to the means ± standard deviation of three replicates. Means with different letters are significantly different at $p \leq 0.05$ using Tukey's test. ns = not significant. Different capital letters denote significant differences ($p < 0.05$) among different treatments for the same sampling time. Different lowercase letters denote significant differences ($p < 0.05$) among different sampling times for the same treatment. “%” is the percentage variation from t0.

3.7. Vitamin Content

Epidemiological studies show that diets high in vitamin C-rich fruits and vegetables are associated with a lower risk of cardiovascular disease, stroke, and cancer, and increased longevity [75].

From the results obtained concerning Vitamin C, CTR and AVG/HPMC treatments had a different trend than the others. In fact, as can be seen in Table 4, AVG and AVG/LEO treatments had the same trend up to day 3; the AVG/HPMC treatment had a constant value up to day 3, from day 6 to day 9, it decreased. According to Leahu, A. et al. [76], this behavior could be associated with the presence of Cu, sugars, and a pH of around 4.

The Riboflavin (Vitamin B2) is important for the prevention of cardiovascular disease, cancer, incipient diabetic nephropathy, and retinopathy. With regard to vitamin B2, Table 5 shows a lower loss of concentration of this vitamin in all treatments. Only CTR treatments underwent a marked decrease in B2 values from day 3. In addition, Thornalley, P. J. [77] showed in their studies, an unstable downward trend during the entire shelf life.

Table 4. Water, Protein, FAT, carbohydrate, sugars, fibers, and total polyphenol content of fresh-cut apples at 0, 3, 6, and 9 days of storage at $4^{\circ} \pm 1^{\circ}\text{C}$ and $90\% \pm 5\%$ RH after all treatments.

Treatment	Days of Storage	Water g/100g DW	%	Protein g/100g DW	%	FAT g/100g DW	%	Carbohydrate g/100g DW	%	Sugars g/100g DW	%	Fibers g/100g DW	%	Total Polyphenols g/100g DW	%
CTR	0	83.650 ± 0.260 Ab		0.220 ± 0.012 Aa		0.200 ± 0.012 Aa		13.110 ± 0.577 Aa		9.970 ± 0.406 Aa		2.120 ± 0.082 Aa		0.210 ± 0.015 ABa	
	3	83.867 ± 0.189 Aa	0.3	0.207 ± 0.012 Aa	6.1	0.193 ± 0.012 Ab	3.3	12.563 ± 0.480 Cb	4.2	9.657 ± 0.276 Aba	3.1	2.073 ± 0.064 ABab	2.2	0.203 ± 0.006 Ba	3.2
	6	82.640 ± 0.332 Ac	1.2	0.193 ± 0.012 Bb	12.1	0.210 ± 0.017 Aa	4.8	12.337 ± 0.673 Cb	5.9	9.243 ± 0.537 Cab	7.3	1.863 ± 0.101 Bb	12.1	0.167 ± 0.024 Db	20.6
	9	81.850 ± 0.510 Dd	2.2	0.190 ± 0.010 Bb	12.1	0.187 ± 0.012 Bb	0.0	10.337 ± 0.180 Dc	21.2	8.370 ± 0.202 Bb	##	1.737 ± 0.116 Cb	18.1	0.174 ± 0.008 Db	17.1
AVG	0	84.000 ± 0.353 Aa		0.200 ± 0.006 Ba		0.200 ± 0.017 Ab		12.370 ± 0.198 Cb		9.550 ± 0.064 Bb		2.000 ± 0.057 Ab		0.200 ± 0.015 Bb	
	3	83.323 ± 0.586 Cb	0.8	0.203 ± 0.006 Aa	1.6	0.190 ± 0.017 Ab	5.0	12.703 ± 0.289 Ba	2.6	9.490 ± 0.053 Cb	0.6	2.033 ± 0.058 Bab	1.6	0.197 ± 0.006 Cc	1.7
	6	83.303 ± 0.119 Bb	0.8	0.207 ± 0.006 Aa	3.2	0.190 ± 0.017 Bb	5.0	12.723 ± 0.237 Ba	2.8	9.903 ± 0.076 Aa	3.6	2.173 ± 0.047 Aa	8.0	0.277 ± 0.025 Bb	27.7
	9	82.527 ± 0.150 Cc	1.8	0.203 ± 0.006 Aa	1.6	0.217 ± 0.006 Aa	7.7	12.693 ± 0.159 Ca	2.5	9.950 ± 0.078 Aa	4.0	1.953 ± 0.057 Bb	2.3	0.340 ± 0.010 Aa	41.2
AVG/HPMC	0	83.550 ± 0.336 Bb		0.180 ± 0.012 Cb		0.200 ± 0.012 Aa		12.970 ± 0.067 Ab		9.670 ± 0.153 ABab		2.000 ± 0.065 Ab		0.200 ± 0.006 Bb	
	3	83.473 ± 0.440 Bc	0.1	0.190 ± 0.017 Bb	5.3	0.193 ± 0.012 Aab	3.3	12.910 ± 0.060 Ab	0.5	9.553 ± 0.111 Bb	1.2	2.023 ± 0.068 Bb	1.2	0.200 ± 0.006 Bb	0.0
	6	83.737 ± 0.232 Aa	0.2	0.217 ± 0.006 Aa	16.9	0.187 ± 0.015 Bab	6.7	13.027 ± 0.074 Aab	0.4	9.763 ± 0.196 Bab	1.0	2.053 ± 0.061 Bb	2.6	0.203 ± 0.006 Cb	1.6
	9	83.470 ± 0.467 Ac	0.1	0.203 ± 0.006 Aab	11.5	0.180 ± 0.026 ABb	10.0	13.273 ± 0.174 Ba	2.3	9.937 ± 0.099 Aa	2.7	2.240 ± 0.010 ABa	10.7	0.313 ± 0.006 Ba	36.2
AVG/LEO	0	83.580 ± 0.388 Abab		0.210 ± 0.006 ABa		0.180 ± 0.010 Ba		12.700 ± 0.165 Bb		9.850 ± 0.084 Ab		2.000 ± 0.198 Ac		0.220 ± 0.017 Ab	
	3	83.410 ± 0.357 Bb	0.2	0.213 ± 0.006 Aa	1.6	0.190 ± 0.010 Aa	5.3	12.777 ± 0.075 ABb	0.6	10.717 ± 1.858 Aa	8.1	2.183 ± 0.236 Aab	8.4	0.210 ± 0.017 Ab	4.5
	6	83.650 ± 0.419 Aa	0.1	0.187 ± 0.006 Bb	11.1	0.177 ± 0.006 Cab	1.9	13.393 ± 0.162 Aa	5.2	9.950 ± 0.104 Aab	1.0	2.163 ± 0.160 Ab	7.6	0.290 ± 0.017 Aa	24.1
	9	83.057 ± 0.476 Bc	0.6	0.200 ± 0.000 Aab	4.8	0.173 ± 0.006 Cb	3.7	13.577 ± 0.254 Aa	6.5	10.027 ± 0.064 Aab	1.8	2.313 ± 0.059 Aa	13.5	0.297 ± 0.006 Ca	25.8

Data correspond to the means ± standard deviation of three replicates. Means with different letters are significantly different at $p \leq 0.05$ using Tukey's test. ns = not significant. Different capital letters denote significant differences ($p < 0.05$) among different treatments for the same sampling time. Different lowercase letters denote significant differences ($p < 0.05$) among different sampling times for the same treatment. "%" is the percentage variation from t0.

Table 5. Vitamin content of fresh-cut apples at 0, 3, 6, and 9 days of storage at $4^{\circ} \pm 1^{\circ} \text{C}$ and $90\% \pm 5\%$ RH after all treatments.

Treatment	Days of Storage	Vitamin B2 Riboflavin mg/100g DW		Vitamin C Ascorbic Acid mg/100g DW	
			%		%
CTR	0	0.040 ± 0.004 Aa		5.100 ± 0.410 Aa	
	3	0.039 ± 0.002 Aa	3.3	4.723 ± 0.468 Bb	7.4
	6	0.033 ± 0.003 Ab	16.7	4.533 ± 0.416 Cc	11.1
	9	0.035 ± 0.005 Ab	11.7	4.810 ± 0.541 Ab	5.7
AVG	0	0.030 ± 0.010 Ba		4.360 ± 0.400 Bc	
	3	0.029 ± 0.010 Ba	3.3	4.520 ± 0.420 Cb	3.5
	6	0.029 ± 0.010 Ba	3.3	4.907 ± 0.272 Ba	11.1
	9	0.031 ± 0.010 Ba	3.2	4.400 ± 0.200 Bbc	0.9
AVG/HPMC	0	0.031 ± 0.030 Bb		5.000 ± 0.200 Aab	
	3	0.030 ± 0.001 Bb	2.2	5.157 ± 0.191 Aa	3.0
	6	0.029 ± 0.001 Bb	6.5	4.990 ± 0.385 Ab	0.2
	9	0.034 ± 0.001 Aa	8.8	4.467 ± 0.462 Bc	10.7
AVG/LEO	0	0.036 ± 0.010 ABa		4.200 ± 0.200 Bc	
	3	0.031 ± 0.010 Bb	14.8	4.527 ± 0.297 BCb	7.2
	6	0.030 ± 0.010 Bb	15.7	4.927 ± 0.127 Ba	14.7
	9	0.029 ± 0.010 Bc	18.5	4.737 ± 0.456 Aab	11.3

Ascorbic acid (Vitamin C) and Riboflavin (Vitamin B2). Data correspond to the means ± standard deviation of three replicates. Means with different letters are significantly different at $p \leq 0.05$ using Tukey's test. ns = not significant. Different capital letters denote significant differences ($p < 0.05$) among different treatments for the same sampling time. Different lowercase letters denote significant differences ($p < 0.05$) among different sampling times for the same treatment. “%” is the percentage variation from t0.

3.8. Sensory Analysis

Figure 2 shows moderate to severe symptoms of dehydration and browning of the control apple slices after 9 days of storage at $4^{\circ} \pm 1^{\circ} \text{C}$ and $90\% \pm 5\%$ RH and mild for treated slices even at the last sampling date. Browning and dehydration are phenomena that typically develop during storage. This behavior is associated with fruit ripening [78,79]. Therefore, the AVG/HPMC and AVG/LEO coatings delayed the loss of sensory quality of fresh-cut apples during the 9 days of storage. This behavior could be attributed to their power of water diffusion inhibition and anti-browning agents. In fact, Lanciotti, R. et al. [80] reported that the addition of 0.02% (*v/w*) citrus, mandarin, cider, lemon, and lime EOs to a minimally processed fruit mix (apple, pear, grape, peach, and kiwifruit) inhibited the microbiota proliferation and extended the shelf life of the fruit salad without affecting its sensory properties. AVG/HPMC was the most effective treatment in terms of color, firmness, and crunchiness, while AVG/LEO treatment showed superior results in terms of sweetness, color, odor, and flavor. The opposite happens in CTR and AVG, which showed “off flavors” since day 3 of cold storage. In addition, the judges did not perceive the development of “off flavor” in fresh-cut apples as a result of treatments.

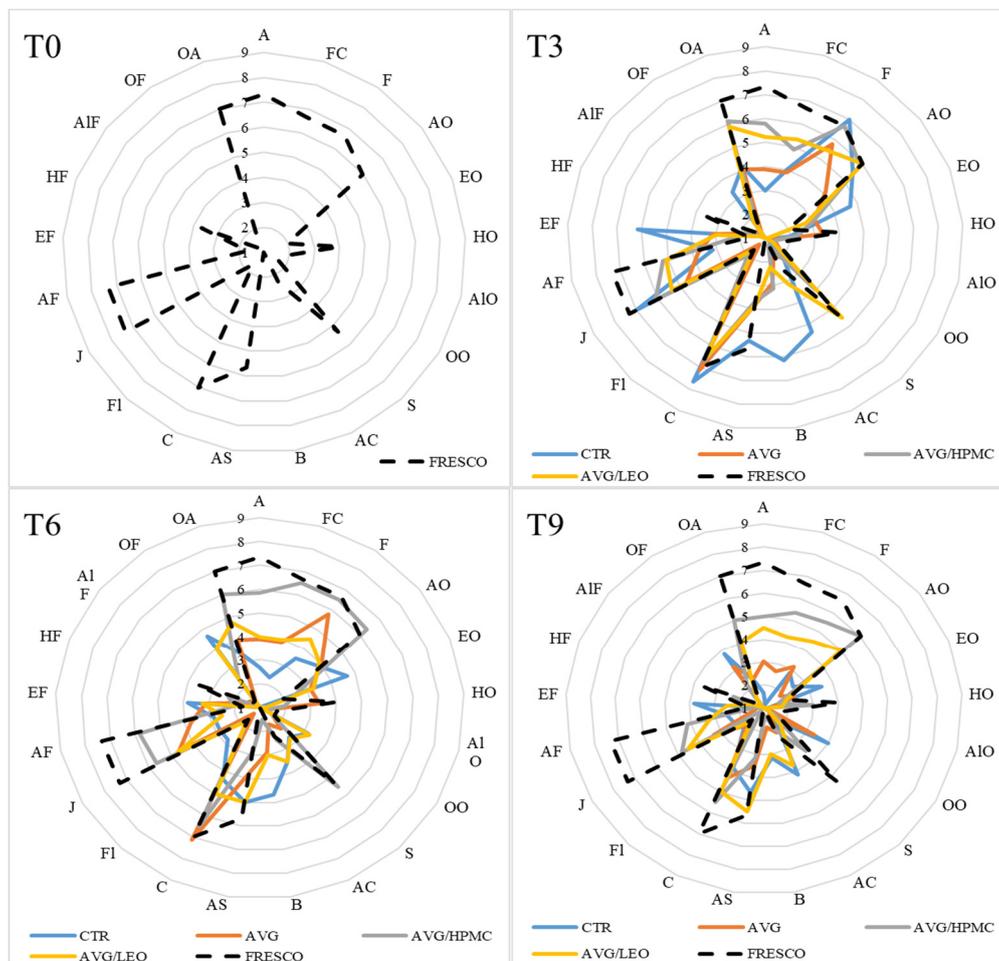


Figure 2. Sensory analyses of treated and untreated fresh-cut apples at 0, 3, 6, and 9 days of storage at $4^{\circ} \pm 1^{\circ} \text{C}$ and $90\% \pm 5\% \text{RH}$. Descriptors legend: appearance (A), flesh color (FC), firmness (F), apple odor (AO), herbaceous odor (EO), honey odor (HO), almond odor (AIO), off-odor (OO), sweetness (S), acidity (AC), bitter (B), astringent (AS), crunchiness (C), flouriness (FI), juiciness (J), apple flavor (AF), herbaceous flavor (EF), honey flavor (HF), almonds flavor (AIF), off-flavor (OF), overall assessment (OA).

4. Conclusions

The obtained results showed the best performances on treated apple slices than in the untreated (CTR). In particular, the aloe vera gel associated with HPMC gave at the apple slices an attractive natural shine, quite similar to that of freshly harvested fruit. While the AVG/LEO treatment showed the best characteristics in terms of soluble solids content, titratable acidity, and pH, in relation to a reduction in senescence processes. The analysis of proximate compounds, such as minerals, essential elements, nutrients, and vitamins content, showed that the treatments did not alter the intrinsic characteristics of the treated samples while maintaining constant values during the storage period. The results obtained were confirmed by sensory analysis, which revealed higher values of appreciation for fresh-cut ‘Fuji’ apple treated with AVG/HPMC and AVG/LEO, compared to CTR and AVG. In a system that comes ever closer to sustainability, a balance between ecological and socio-economic conditions is expected. In fact, the exclusion of chemical-based food coatings eliminates the need to remove toxic waste, reducing environmental pollution as the plant material is covered by an entirely edible coating.

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