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Fresh-Cut Mangoes: How to Increase Shelf Life by Using Neem Oil Edible Coating

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Abstract: The mango is the most widely cultivated tropical fruit. Fresh-cut mango is very useful, but it is very perishable. The purpose of this study was to highlight the effects of neem oil on fresh-cut mango fruits kept for 9 days at 4 ± 1 °C and 80 ± 5% relative humidity. The neem plant (*Azadirachta indica*) has numerous antioxidant and antibacterial properties. Despite this, very few studies have been carried out on neem oil added to edible coatings (EC) to retard ripening processes. Two formulations were tested: EC1 (hydroxypropyl methylcellulose + $CaCl_2$) and EC2 (hydroxypropyl methylcellulose + $CaCl_2$ + neem oil), both compared with an untreated sample (control). Physicochemical, microbial, proximate and sensory analyses were carried out. Neem oil reduced loss of firmness and colour, while hydroxypropyl methylcellulose and $CaCl_2$ reduced normal cell degradation (weight loss and soluble solids content). Microbiological investigation showed that the EC2 inhibited the development of the main spoilage bacteria during the entire storage period, prolonging the preservation of fresh-cut fruits. The sensory analysis showed a rapid degradation after 5 d in the control sample, while the EC2 was the best.

Keywords: post-harvest; edible coating; neem oil; fresh-cut; *Mangifera indica* L.; polysaccharides

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1. Introduction

The mango fruit (*Mangifera indica* L.), known as the 'King of Fruits', is one of the world's most extensively cultivated tropical plants due to its organoleptic characteristics that are highly appreciated by consumers [1,2]. In fact, the growing demand for mangoes on the European market has led to an increase in mango exports both within Italy and abroad.

According to Sivakumar et al. [3], mango cultivation started in India, China, Thailand, Indonesia, the Philippines, Pakistan and Mexico, but soon spread to all tropical and sub-tropical areas subject to certain soil and climate conditions. Indeed, mangoes cannot be grown in areas where temperatures fall below 15 °C, but their development is favoured by temperatures ranging from 24 to 33 °C [4]. In addition, mangoes tolerate soils with an optimum pH of 5.5 to 7.5 on well-drained sandy or gravelly soils, also essential for optimal flowering [5]. For this reason, the expansion of mango plants is favoured only along the coasts of Sicily, where numerous tropical species are spreading widely such as avocado [6], loquat [7], cherimoya [8] and litchi [9]. However, fresh mango fruits are susceptible to pathogens due to increased respiration rate after harvesting [10].

The mango is a climacteric fruit characterised by rapid post-harvest ripening often processed into fresh-cut, jams, juices or dried products [11,12]. However, fresh mango fruits are susceptible to pathogens due to increased respiration rate after harvesting [13]. Indeed, due to the high perishability of this fruit, good post-harvest practices are required to prolong its shelf life [14].

Numerous studies have been performed to maintain the quality characteristics of the mango after harvesting. The use of dipping techniques in hot water is the most widely used due to its ease of application and because it has been found to be effective in reducing the development of infestations to *Colletotrichum gloeosporioides* (which causes anthracnose formation on the epicarp of the fruit) and black spots caused by the presence of the *Alternaria alternata* fungus [15,16]. The use of modified atmospheres, UV irradiation or hot vapour irradiation have also been extensively studied for maintaining the shelf life of mango fruits after harvesting [3,15,17].

Recently, the attention of researchers has focused on the study of edible coating (EC), a less invasive and greener method to maintain the organoleptic qualities of the fruit. European Directives [18] and the US Code of Federal Regulations [19] define them as "coatings formulated with food additives". The requirements that define an EC are, in fact, its transparency and barrier properties, water vapour and permeable solutes, selective gas permeation and volatile compounds [20,21]; it must also be odourless and tasteless, so as not to affect the sensory profile of the fruit in question [22,23]. Its composition must comply with Food and Drug Administration (FDA) regulations or acquire GRAS (Generally Recognized as Safe) status [19]. The edible coating is a formulation of edible materials, in fact, each component performs a specific function depending on the fruit to which the solution is applied [24]. For example, it was seen that an EC based on $CaCl_2$ and *Aloe vera* gel was useful for keeping the cell wall in papaya slices during storage [25].

Studies on whole mangoes, for example, showed that chitosan added to the inside of the edible coating inhibited the development of bacterial colonies and the formation of fungal spores, while limiting the weight loss of the fruit and keeping its texture high [9,11]. Carboxymethylcellulose (CMC), on the other hand, retained high firmness values and a higher preference by the judges performing the sensory analysis [26]. In the last decade, hydroxypropyl methylcellulose (HPMC), another little-known cellulose extract, has attracted the attention of many researchers who have researched it further. In previous studies, this was applied together with *Aloe vera* gel to fresh fruit products such as pears [27], apples [28], peaches [29] and kiwis [30]. In these studies, HPMC seems to be decisive in keeping the weight and texture characteristics of ready-to-eat fruit slices almost completely unchanged, but above all, in keeping their brightness and colour characteristics unchanged for a longer period during storage.

According to a recently published review [31], one of the plant extracts with fungal and antibacterial properties is the oil extracted from *Azadirachta indica*, also known as the neem plant, which comes from the Meliaceae family. This plant has numerous antioxidant, microbial and medicinal properties, and is known in India as 'the village pharmacy'. In addition, the importance of neem is recognised in the US National Academy of Sciences report entitled *Neem: A Tree for Solving Global Problems* in 1992 [32]. This oil, usually used as an insect and mite repellent on many crops, contains several bioactive compounds, such as azadirachtin (the best limonoid compound [33,34]), salannin, nimbidin, margolonone, gedunin and others, which is food safe and can be used for food conservation [35], but it has never been applied directly to ready-to-eat fruit products. A few experiments, such as the one carried out on tomatoes, involved the creation of an EC containing neem oil, *Aloe vera* gel and citric acid, which played an essential role in delaying the ripening of tomatoes and maintaining their texture, colour and flavour characteristics for up to 36 days [36].

Other recent studies were carried out with neem oil mixed with chitosan, HPMC and other film-making compounds on carrot [37], pitaya [38], guava [39], mango [40] and apple [41]. Neem oils can be extracted from the leaves and seeds and are residue-free and safe for human consumption, which distinguishes them from synthetic fungicides. In addition, some authors, after toxicological studies carried out in vivo in rats for 90 days, stated that azadirachtin is a non-toxic compound for mammals and that it did not indicate mortality or changes in physical or blood parameters [42].

Thus, the aim of this study was to develop and test a new EC based on neem oil, $CaCl_2$ and HPMC and investigate the influence of the neem oil component on the ready-to-eat mango fruit quality. Therefore, we studied the effects of the EC on physicochemical, proximate, microbiological and sensory properties on fresh-cut mango cubes stored at low temperatures in biodegradable packaging for 9 days.

2. Materials and Methods

2.1. Plant Material

Fifty mature mango drupes of the 'Keitt' cultivar were selected and harvested in a commercial orchard in Sicily for homogeneity in weight and absence of defects (Figure 1). The fruits were cold stored (3 ± 1 °C and 75 ± 5% RH) in the laboratories of the Department of Agricultural, Food and Forestry Sciences of the University of Palermo for three days before being processed.

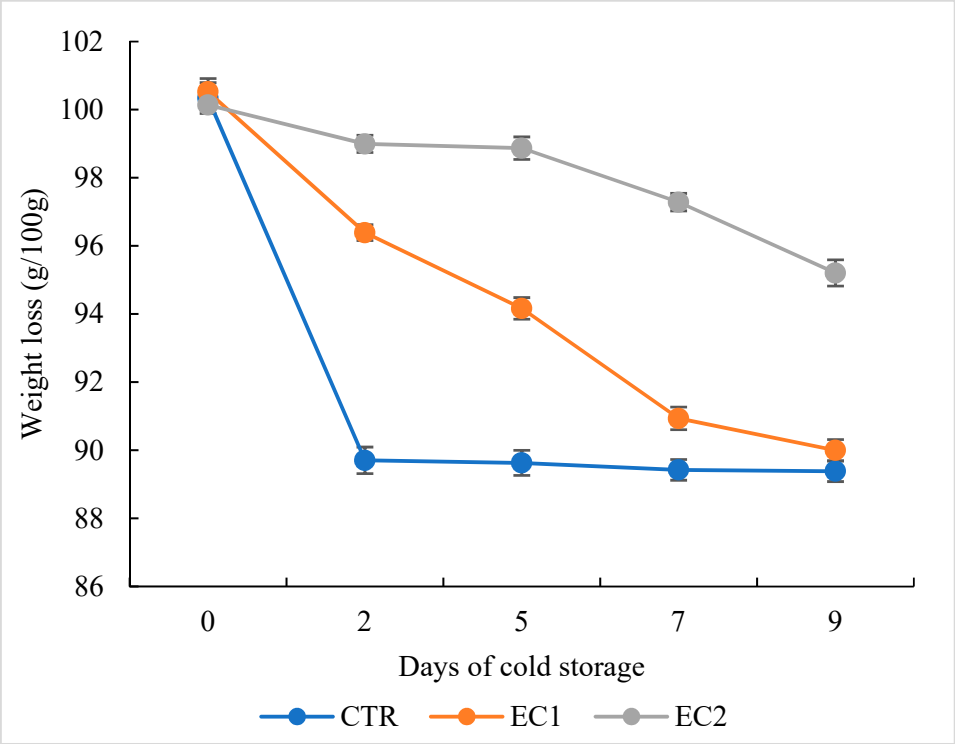


Figure 1. Variation in weight loss (WL–g/100 g) measured during 9 days of cold storage. Data correspond to the mean and bars indicate the standard deviation (SD) of three replicates (n = 3).

2.2. Coating Formulation

The edible coating was made entirely with 100% natural products. HPMC (Aldrich Chemical Company, Inc., Milwaukee, WI, USA) and $CaCl_2$ (Sigma-Aldrich Chemic, Steinheim, Germany) were used to implement the gelling properties of the coating, according to previous studies [25,28], while commercial neem oil (obtained from Laszlo Aromatologia, Belo Horizonte, Brazil) was used as an antibacterial and fungicidal agent.

Two different treatments were provided:

- EC1: 3 g of HPMC + 1 g of $CaCl_2$ was added in 200 mL of distilled water;
- EC2: 3 g of HPMC + 1 g of $CaCl_2$ + 3 mL of neem oil was added in 200 mL of distilled water. The treated fruits were compared with an untreated sample (CTR).

One percent of citric acid was added to the solutions as antioxidant agent.

The coating was kept in an autoclave set at 90° for 40 min to avoid the formation of microbial colonies as much as possible. These were then homogenised with ultra-Turrax at 3000 rpm for 3 min.

2.3. Sample Preparation

All utensils were previously washed and sterilised in the work area. The temperature was set at 5 ± 1 °C to avoid bacterial spoilage. Whole mangoes were first washed under tap water to remove field residues and then immersed in an aqueous solution of sodium hypochlorite (300 µL/L) for 5 min [27]. After that, the fruits were peeled and cut with a sterilised stainless-steel knife to remove the pulp from the seed. The pulp was first cut into 2 cm slices and then into 2 × 2 cm^2 cubes [43]. The mango cubes were left to dry for 20 min and divided into three lots for subsequent treatments.

2.4. Experimental Design

A total of 45 Polyamide/Polyethylene bags (15 bags per treatment: 3 replicates for each day of analysis) composed at PA 80%–PE 20% were prepared for cold storage [44] of the mango cubes. In each bag, 100 ± 1 g of fruit was stored to make the sample homogeneous. First, untreated cubes (CTR treatment) were retained. After that, the two edible coatings (EC1 and EC2) were applied to the remaining mango cubes by spraying technique [44], using an airbrush (0.8 mm nozzle) fed with N_2, for 2 min per lot. Each cube was covered with approximately 0.3 mm of coating. The lots were then allowed to dry for 3 min and packed in biodegradable bags. Thereafter, the bags were stored in a cold room at 4 ± 1 °C and 80 ± 5% RH for 9 days and analysed for physical, chemical, microbiological and sensory traits after 2, 5, 7 and 9 days of storage (d 2, d 5, d 7 and d 9, respectively). To obtain the initial comparison parameter, a subsample of cut mango was analysed (d 0—as fresh fruit).

2.5. Physical Analyses

– Weight loss (WL) and firmness (F):

WL of the bags was measured using a digital balance (Gibertini, Milan, Italy) and the values were expressed as grams per 100 g of weight.

In order to analyse the F parameters of the mango cubes previously brought to room temperature (20 °C), a texturometer TA.XTplus (Stable Microsystems, Ltd., Surrey, UK) was used, equipped with a 50 N load cell and connected to a personal computer with the following conditions: pre-test speed 5 mm/s; test speed 1 mm/s; post-test speed 5 mm/s; penetration distance 4 mm; force 5 g. A flat stainless-steel probe with a diameter of 4 mm (P/4) was used. The force–distance curves were obtained from the penetration tests and the hardness was taken as the area underlying the curve (expressed in N).

– Brightness (L^*), browning index (BI) and total colour difference (ΔE^*):

A Minolta Chroma Meter (4Chroma Meter CR-400, Konica Minolta Sensing Inc., Tokyo, Japan) was used to determine the colour variation (CIE$L^*a^*b^*$ colour space): L^* is the parameter indicating the brightness of the sample, identifying a range of values between 0 (black) and 100 (white); a^* is the parameter indicating the range of colours from green (−100) to red (+100); finally, b^* is the parameter that includes values between −100 (blue) and +100 (yellow).

By transforming the parameters L^*, a^* and b^* into the RGB colour space (by means of an online converter, https://www.e-paint.co.uk/convert-lab.asp (accessed on 10 November 2021)), a table was prepared showing the colour variation during the storage period of the three samples analysed. In addition, with the values of L^*, a^* and b^*, the browning of the mango cubes was calculated using the formula of Ruangchakpet and Sajjaanantakul [45]:

$$(BI) = [100\ (x - 0.31)]/0.17], \quad (1)$$

Where $x = (a^* + 1.75L^*)/(5.645L^* + a^* - 0.3012b^*)$; the total colour difference (ΔE^*) was calculated using the following formula:

$$\Delta E^* = [(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2]^{1/2}. \quad (2)$$

2.6. Chemical Analyses

– Soluble solids content (SSC) and titratable acidity (TA)::

The juice extracted from the mango cubes by means of a centrifuge (Ariete, Florence, Italy) was used to determine the SSC, expressed as °Brix, using a digital refractometer (Atago Co, Ltd., Tokyo, Japan) and the TA, using a pH meter titrator (Crison Instruments, SA, Barcelona, Spain), and it was expressed as g of citric acid per L.

2.7. Microbiological Analyses

Samples of mango cubed and edible coatings were microbiologically analysed in order to evaluate on their hygiene and safety aspects. All edible coating samples (1 mL) were serially diluted directly in Ringer's solution (Sigma-Aldrich, Milan, Italy), while coated and untreated mango cubes (25 g) were first homogenized in 225 mL of Ringer's solution (Sigma-Aldrich, Saint Louis, MO, USA) by the Stomacher Bag-Mixer 400 (Interscience, Saint Nom, France) for 2 min at maximum speed and then serially diluted. Cell suspensions were plated on agar media to analyse the main spoilage (*Pseudomonas* spp., yeasts and moulds) and pathogenic (members of the Enterobacteriaceae family, coagulase-positive staphylococci (CPS), *Listeria monocytogenes*, *Escherichia coli* and *Salmonella* spp.) microbial populations following the approach of Passafiume et al. [27].

Briefly, the microbial groups were inoculated as follows.

Pseudomonads on *Pseudomonas* agar base (PAB); members of the Enterobacteriaceae family on violet-red bile glucose agar (VRBGA); yeasts on dichloran rose bengal chloramphenicol (DRBC) agar; moulds on potato dextrose agar (PDA) supplemented with chloramphenicol (0.1 g/L) to prevent bacterial growth; CPS on Baird Parker (BP) supplemented with rabbit plasma fibrinogen (RPF); *L. monocytogenes* on Listeria selective agar base with SR0140E supplement; *Salmonella* spp.; *E. coli* on Hektoen Enteric Agar (HEA). All edible coatings and fruit samples were also subjected to the enumeration of total mesophilic microorganisms (TMM) and total psychrotrophic microorganisms (TPM) on plate count agar (PCA). All media and chemicals were purchased from Microbiol Diagnostici (Uta, Italy). Plate counts were executed in triplicate at each collection time.

2.8. Proximate Composition

Proximal compounds were determined through the AOAC (Association of Official Analytical Chemists) methods [46], while the Kjeldahl method was used for protein determination [47].

The carbohydrate content (TSG), either free or present in polysaccharides, was obtained with the anthrone method reported in Loewus [48].

The contents of K, Na, Ca and Fe were determined using atomic absorption spectroscopy following wet mineralisation, while P was determined using a colorimetric method [49,50].

The total content of polyphenols was determined according to the Folin–Ciocalteu method, while total, soluble and insoluble fibres were measured by the chemical–enzymatic method [46].

The riboflavin (vitamin B2) and vitamin C content was determined following the method of Palazzolo et al. (2011) [46,49].

2.9. Sensory Analysis

Ten semi-trained judges with extensive experience in food sensory evaluation performed a hedonic liking test on the mango cubes (both treated and untreated) previously prepared for sensory analysis. The method uses a 9-point hedonic scale (1 = "extremely dislike," 5 = "neither like nor dislike," 9 = "extremely like") [29]. First of all, the tasters were submitted to a study of the visual aspect of the mango cubes. After that, they were trained using different mango samples to recognise aroma, flavour and texture attributes during the training session. The panel test consisted of a total of 19 descriptors, as follows: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour

(EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA).

At the end of each tasting, a glass of water, for rinsing the mouth, was provided to the consumers. In addition, all descriptors were assessed from day 0 (as fresh product) to the last day of storage (d 9).

2.10. Statistical Analysis

Using XLSTAT software version 9.0 (Addinsoft, Paris, France), repeated measures ANOVAs and Tukey's Honestly Significant Difference (HSD) tests ($p \leq 0.05$) were performed for all parameters studied in order to assess significant differences between the mean of the treatments, except for the microbiological analysis, where $p \leq 0.001$ was considered significant. Data correspond to the mean and bars indicates the standard deviation (SD) of the replicates ($n = 3$).

3. Results and Discussions

3.1. Physicochemical Analyses

– Weight loss (WL) and firmness (F):

Concerning WL starting from the initial weight of 100.00 ± 1.00 g, CTR samples already underwent a high WL from the second day of storage, losing 10.71% of their initial value with a peak at d 2 and a progressive reduction. As shown in Figure 1, statistically significant differences ($p < 0.05$) were already shown between CTR and the two treatments (EC1 and EC2) from the second day of storage.

This behaviour could be associated with the presence of the treatments positively influencing the storage by keeping the mango cubes longer and limiting their weight loss.

On the other hand, samples EC1 and EC2 showed a limited weight reduction, but the EC1 reached the same CTR value at 9 d of storage and was not statistically significant, while EC2 was different ($p < 0.05$) from the other two treatments (CTR and EC1) throughout the storage period. However, EC2 limited the weight loss until d 5, showing no significance ($p < 0.05$) between the various analysis times, while a day from which it showed significant differences between both times and treatments. In fact, the edible coatings appeared to have had a positive influence on the containment of liquids within the cell structure during the first 5 d of storage, but the coating formulated with neem oil (EC2) lost only 4.93% of its weight compared to CTR and EC1, which lost approximately 10.96% ($p < 0.05$) at d 9 compared to the initial value.

Therefore, this behaviour could be associated with the presence of neem oil in the coating solution, which may have reduced the phenomena of oxidative stress and loss of compactness of the cell structure. Indeed, azadirachtin, the active compound in neem oil, helps to reduce the degradation of pectin molecules during storage, as it appears to strengthen them while reducing the possibility of removing the methyl group from the α galacturonic acid residue [51]. Similar results in WL were observed in mango treated with neem oil (10% v/v) [52]. In addition, the presence of HPMC and calcium chloride ($CaCl_2$) in the edible coating appears to enhance the maintenance of cell wall peptide bonds [30]. Indeed, $CaCl_2$ appears to reduce metabolic activities and the rate of respiration, in agreement with other studies on mangoes, papayas and strawberries. [25,53,54].

Regarding the maintenance of firmness (F), as shown in Figure 2, the CTR samples differed significantly ($p < 0.05$) from the two treatments (EC1 and EC2) starting from d 2, while there were no significant differences between EC1 and EC2 throughout the storage period, but only between one day of analysis and the next. In particular, at d 9 F was reduced by approximately 2% compared to the initial value for CTR, 1.9% for EC1 and 1.8% for EC2.

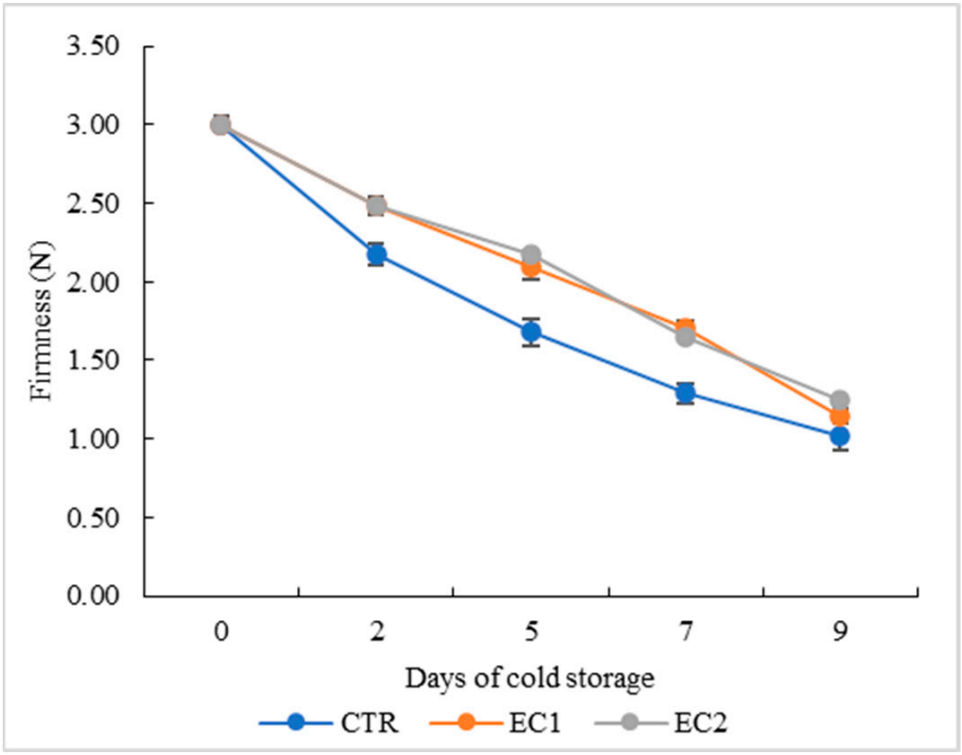


Figure 2. Variation in firmness (F—N) measured during 9 days of cold storage. Data correspond to the mean and bars indicate the standard deviation (SD) of three replicates (n = 3).

Considering that, in this case, neem oil did not show any improvement in the treatment of mango cubes, firmness retention seems to be associated with the presence of polysaccharide agents (HPMC and $CaCl_2$) that retard pectin degradation. During fruit ripening, depolymerisation or shortening of the pectin chain occurs in correspondence with an increase in the activities of the enzymes pectinesterase and polygalacturonase. Low oxygen concentrations and high levels of carbon dioxide (especially, in general, in the case of climacteric fruits) reduce the activity of these enzymes and thus affect the firmness of fruit and vegetables during storage [55].

Furthermore, the presence of neem oil, $CaCl_2$ and HPMC in the edible coating seems to have a positive influence on the delayed breaking of the peptide's bonds in the cell wall. Probably, the increased concentration of organic acids tends to decrease the ripening phenomena, a result of the respiratory process.

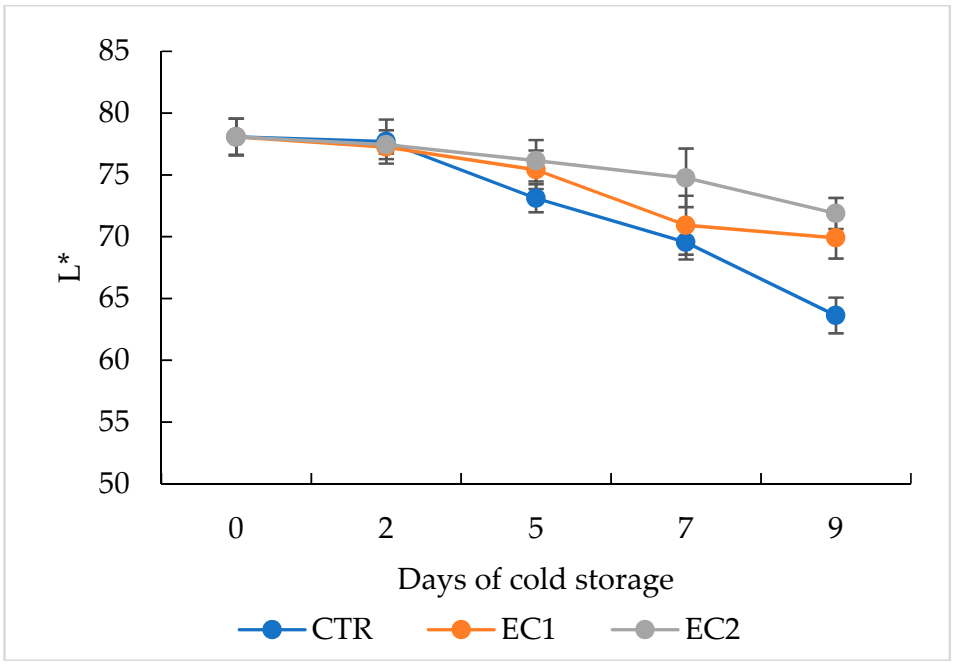
– Brightness (L^*), browning index (BI) and total colour difference (ΔE^*):

With regard to the variation in the colour of the mango cubes, the analyses showed that the parameter L^* (Figure 3a), up to d 5, showed no significant difference between the three treatments. In fact, starting from d 7, the CTR samples suffered a decrease in brightness values, showing, together with EC1, a significant difference ($p < 0.05$) compared to the EC2 treatment, which seems to have had a better performance, as the L^* values remained similar to d 0 for a longer time. This positive influence could be associated with the presence of neem oil. Indeed, according to other studies, the antioxidant effect of agents, such as essential oils or natural plant extracts, seems to improve the appearance of the pulp of treated fruits [25,56,57].

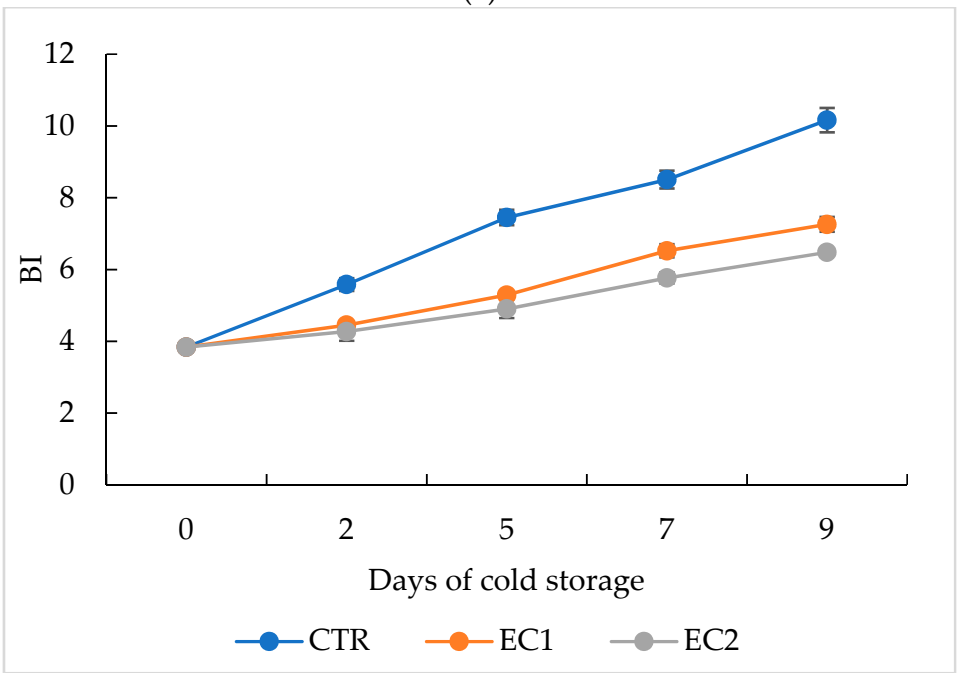
When compared with the BI analysis (Figure 3b), it shows that the CTR samples underwent rapid browning from the first days of storage while both EC treatments maintained lower values until the end of the observations. Therefore, there seems to be a correlation between the presence of antioxidant agents and mango flesh browning. According to some studies, the presence of antioxidant agents reduces the pH of the fruit and inhibits the

action of polyphenol oxidase (PPO), which acts as a reducing agent (from o-quinones to diphenols) [58].

On the other hand, EC2 seems to limit flesh oxidation by keeping *BI* values low until the last day of storage. Even if EC1 treatment, containing only polysaccharides, seems to limit the progress of browning, it does not seem to limit the degree of flesh oxidation. In fact, this seems to be the difference between the two treatments, also confirmed by the statistical analysis, according to which the only significances ($p < 0.05$) were shown by the CTR samples not only during the whole period of analysis, but also compared to the other two treatments.

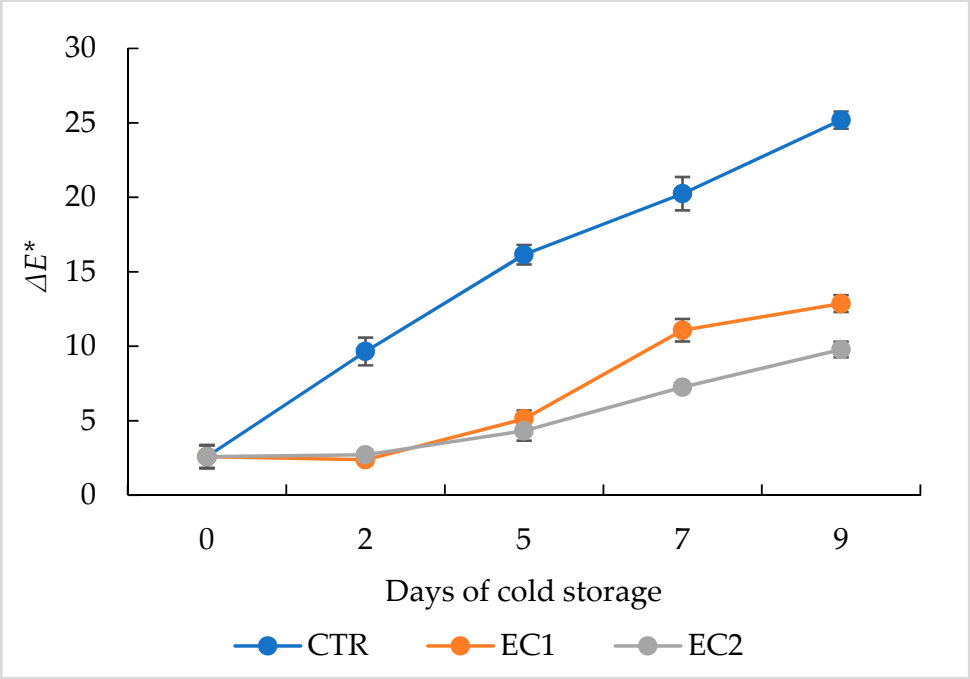


(**a**)



(**b**)

Figure 3. *Cont.*



(**c**)

Figure 3. (**a**–**c**) Variation in brightness (**a**–*L**), browning index (**b**–*BI*) and total colour differences (**c**–Δ*E**) measured during 9 days of cold storage. Data correspond to the mean and bars indicate the standard deviation (SD) of three replicates (n = 3).

*L** and *BI* refer to the quality of the fruit because in ready-to-eat fruit, colour is a decisive parameter that has great potential on consumer preference and allows people to have an idea about the final food product [59].

The influence of EC on fruit colour is most evident in its variation during 9 d of storage (Δ*E**—Figure 3c). Both treated samples had the same colour during the first 5 d of cold storage, while CTR samples already underwent a very rapid colour change ($p < 0.05$) from the second day of storage (d 2).

Indeed, the combination of the polysaccharide agents used (HPMC and $CaCl_2$) with the antioxidant agent (neem oil) seems to decelerate the browning and colour degradation processes. Our results agree with other results obtained by combining polysaccharides with other essential oils [27,28,30]. Membrane lesions allow the normally separated polyphenol oxidase (PPO) enzyme and oxidisable substrates to mix, reducing oxidation and browning phenomena [60]. Significantly, by comparing the initial colour with each day of analysis, we understood the essential role of EC1 and EC2 treatment for fresh-cut mango cubes, as CTR samples were much browner and degraded at the last day of the period compared to treated samples.

The same results are more evident in the RGB colour table (Figure 4) that show the time course of the real mango cubes' colour. Even in this case, it is possible to see the effective improvement of the mango cubes, due to the effect of the edible coating containing both antioxidant agents and natural polysaccharides. The differences with the control were already evident from d 5 onwards, while EC1 and EC2 maintained the colour of the fresh fruit almost unchanged. From d 7 the difference between treated and untreated fruit increased. There was also a difference between EC1 and EC2 with less colour change for this latter treatment.

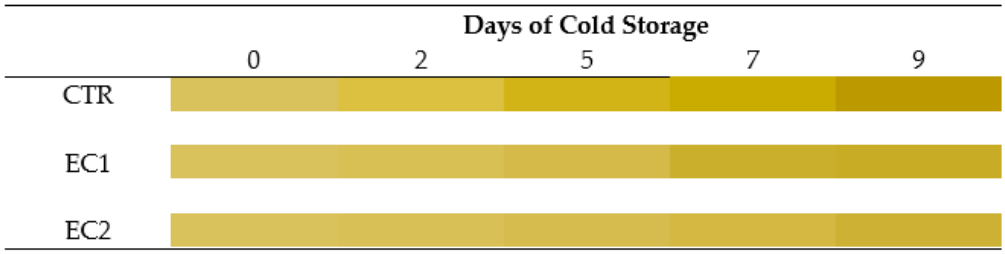


Figure 4. Colour table obtained from the results of the total colour difference (ΔE^*) recorded in the CIEL*a^*b^* colour space and converted to the red/green/blue (RGB) scale through the www.e-paint.co website (accessed on 10 November 2021). This figure shows the differences between the coated (EC1 and EC2) and uncoated (CTR) mango cubes at day 0 and after 2, 5, 7 and 9 days of cold storage at 4 ± 1 °C and 80 ± 5% RH.

– Soluble solids content (SSC) and titratable acidity (TA)

SSC is a determinant biological index of fruit and vegetable products [40]. The results highlighted in Figure 5 show that SSC increased as the storage period progressed in both treated and untreated mango cubes. Generally, the increase in SSC could be attributed to the conversion of sugar molecules during the storage [41]. Throughout the cold storage period the variation in SSC was higher and did not show significance between the days of analysis, as well as between the CTR (15.23 g malic a. × L^{-1}) and EC1 (15.00 g a. malic acid × L^{-1}) treatments, while the EC2 fruits had the lowest values (13.93 g malic a. × L^{-1}) and were statistically different from the first two ($p < 0.05$). In fact, up to the end of the storage period, EC2 remained the best treated fruit, recording a lower and appreciable SSC value even after 9 d of storage, while EC1 was almost completely equal to the untreated samples (CTR). These results confirmed the active role of the edible coating composed of $CaCl_2$, HPMC and neem oil in maintaining the SSC value of the ready-to-eat mango during cold storage. Similarly, Treviño-Garza et al. [61] explained that polysaccharide-based edible coatings appear to improve the physical, chemical and sensory properties of strawberry fruits, leading to an increase in their shelf life from 6 to 15 days. Other researchers studied the effect of edible coatings on the SSC of mango fruits [62–65] and obtained a similar trend during different storage periods and at different temperatures.

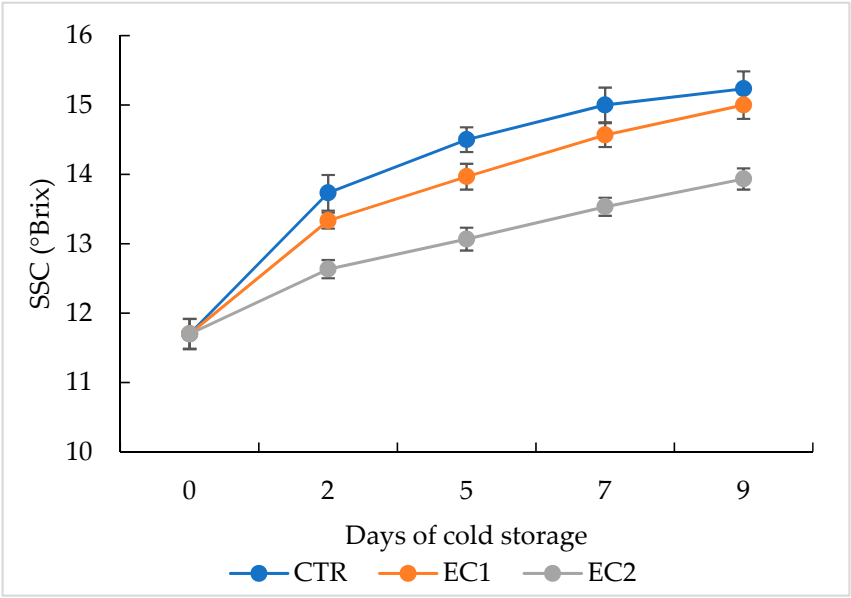


Figure 5. Evolution of soluble solids content (SSC) measured during 9 days of cold storage. Data correspond to the mean and bars indicate the standard deviation (SD) of three replicates ($n = 3$).

The titratable acidity (TA) decreased with storage period in all three treatments but to a greater extent in the CTR samples (Figure 6). Indeed, the acidity decreases due to the accumulation of organic/malic acids and their conversion into respiratory substrates [66–68]. On the fifth day of analysis, it was found that CTR samples and EC1-treated samples showed no significant difference, whereas EC2-treated samples had a significantly higher TA ($p < 0.05$). At d 5, in the CTR samples and EC1 samples, TA decreased more than in EC2 treated fruit, showing a significant difference ($p < 0.05$) between treatments. This improvement could be due to the edible coating applied, which significantly delayed the use of organic acids as respiratory substrates.

These results agree with previous studies that reported that the TA of fruit decreases both with increasing storage period and in fruits that do not undergo any post-harvest treatment [69]. In fact, as also reported by Tefera et al. [70], the lower use of organic acids is caused by post-harvest treatments that delay respiration. Furthermore, according to the sensory analysis, CTR samples were unacceptable after 9 d of storage.

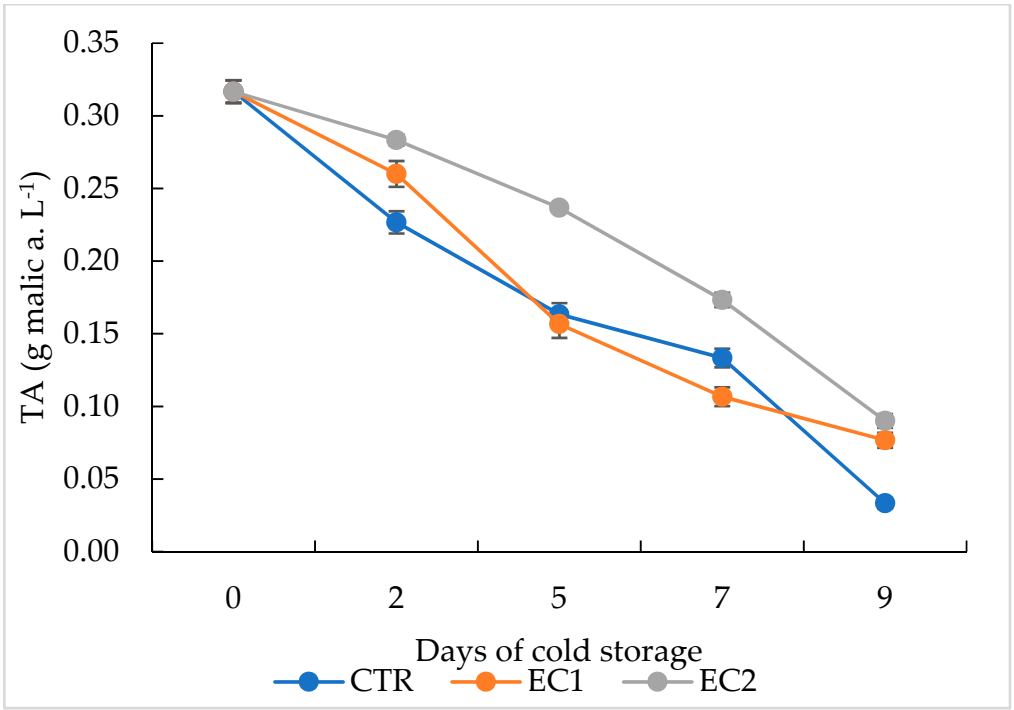


Figure 6. Evolution of titratable acidity (TA) measured during 9 days of cold storage. Data correspond to the mean and bars indicate the standard deviation (SD) of three replicates ($n = 3$).

3.2. Microbiological Analyses

Neither spoilage nor pathogenic populations developed from serial dilutions of the edible coatings analysed. Thus, the hygienic characteristics of the natural coatings of this study were suitable with food application. The microbial loads of the untreated (CTR) and coated (EC1 and EC2) mango cubes collected during refrigerated storage are reported in Table 1.

The presence of microscopic fungi (yeasts and moulds), responsible for the microbial decay of a wide range of fruit commodities [71,72] as well as that of the main bacterial foodborne pathogens such as CPS, *E. coli*, *L. monocytogenes* and *Salmonella* spp., which are the leading cause of outbreaks related to fresh produce of non-animal origin [73,74], was never found (for this reason, these results are not reported in Table 1). According to Tukey's test, at the seventh day, statistically significant differences were found for the levels of TMM, TPM and pseudomonads among trials. In particular, all three groups

appeared in CTR and EC1 samples and were 10^3 and 10^2 CFU/g, respectively. Thus, the dominating populations of CTR and EC1 samples were mainly psychrotrophic bacteria able to grow and survive at refrigeration temperatures [75]. Pseudomonads are commonly associated with the spoilage of fruits and vegetables [76,77] due to their ability to cause maceration of plant tissues and generation of off-flavours and off-odours [78,79]. However, after 9 d, the levels of TMM, TPM and pseudomonads of the trials CTR and EC1 were around 10^4 and 10^3 CFU/g, respectively, while they were undetectable in EC2 samples. The absence of microorganisms in EC2 samples confirmed the antibacterial activity of neem oil against both Gram-negative and Gram-positive bacteria of the neem oil [80] even after edible coating inclusion.

Table 1. Microbial loads of mango cube samples.

Days of Cold Storage	Treatments	Microbial Loads		
		TMM	TPM	Pseudomonads
d 0	CTR	<2 [a]	<2 [a]	<2 [a]
	EC1	<2 [a]	<2 [a]	<2 [a]
	EC2	<2 [a]	<2 [a]	<2 [a]
	p value	N.S.	N.S.	N.S.
d 2	CTR	<2 [a]	<2 [a]	<2 [a]
	EC1	<2 [a]	<2 [a]	<2 [a]
	EC2	<2 [a]	<2 [a]	<2 [a]
	p value	N.S.	N.S.	N.S.
d 5	CTR	<2 [a]	<2 [a]	<2 [a]
	EC1	<2 [a]	<2 [a]	<2 [a]
	EC2	<2 [a]	<2 [a]	<2 [a]
	p value	N.S.	N.S.	N.S.
d 7	CTR	2.98 ± 0.19 [a]	3.01 ± 0.23 [a]	2.94 ± 0.14 [a]
	EC1	2.39 ± 0.13 [b]	2.24 ± 0.17 [b]	2.45 ± 0.21 [b]
	EC2	<2 [c]	<2 [c]	<2 [c]
	p value	<0.0001	<0.0001	<0.0001
d 9	CTR	3.85 ± 0.14 [a]	3.96 ± 0.13 [a]	3.92 ± 0.25 [a]
	EC1	3.15 ± 0.12 [b]	3.16 ± 0.22 [b]	3.09 ± 0.14 [b]
	EC2	<2 [c]	<2 [c]	<2 [c]
	p value	<0.0001	<0.0001	<0.0001

Units are log CFU/g. Results indicate mean values ± S.D. of three plate counts. Data within a column followed by the same letter are not significantly different according to Tukey's test. Abbreviations: CTR, untreated mango cube samples; EC1, mango cube samples coated with HPMC + $CaCl_2$; EC2, mango cube samples coated HPMC + $CaCl_2$ + neem oil; TMM, total mesophilic microorganisms; TPM, total psychrotrophic microorganisms. For each sampling dates different letters indicate significant differences between treatments. N.S., not significant (*p* value ≥ 0.01).

3.3. Proximate Compounds and Vitamin Content

According to Lebaka et al. [81], mangoes have different protein contents depending on the region of cultivation. Analysis of Sicilian mangoes revealed an average protein content of 0.38 ± 0.01 m/100 g pulp. As we can see from Table 2, this content decreased more for EC1 fruits than for the other treatments, though not significantly.

In addition, the dry residue was determined (Table 2), as the increase in this value is taken into account as an index of ripeness [82]. The dry matter concentration remained at a high level in CTR and EC1 fruits, with values of about 80.00 g/100 g pulp for the first 7 days of storage, and then decreased. In EC2 it increased after 2 days and then remained at low values up to the ninth day. This could be due to the protective effect of the edible coating that forms an invisible barrier on the fruit surface separating it from the surrounding atmosphere [25], reducing respiration rates and thus slowing down the ripening rate [83].

Furthermore, according to many research studies conducted on fresh fruit, edible coatings based on $CaCl_2$, as in EC2, maintain the quality and firmness of fruit [84,85].

The loss of total sugars shown after 5 d of storage was observed in all treatments (Table 2). Since sugar is metabolised and replaced by the hydrolysis of starch, this is probably the result of respiration. Starch depletion during ripening could at some point result in more sugar being metabolised than is produced by starch hydrolysis, causing a net loss of sugar content [86]. However, fruit treated with EC had a lower decrease in total sugar concentration than CTR due to the protective barrier created by the edible film, which limits respiration rates. EC2 fruits maintained a high total sugar content until the end of storage.

Mango pulp is a good source of essential minerals for biochemical reactions. From the mineral composition analysis (Table 3), the treatments are statistically similar ($p > 0.05$). The content of K, Na, Ca, Mg, P and Zn remained similar to the values at d 0 (fresh fruit), demonstrating that mango cubes treated with ECs retain their nutritional value and can continue to provide the adequate amount of fibre, vitamins and minerals in the human diet [87].

Table 2. Grams of proximate compounds in mango cube samples.

Treatments	Time	Dry Matter (g)				Protein Content (g)				Fat Materials (g)				Fibres (g)				Total Sugars (g)			
CTR	d 0	84.68	±	0.47	a	0.38	±	0.01	a	0.32	±	0.01	b	0.75	±	0.01	b	13.37	±	0.01	a
	d 2	83.93	±	0.08	a	0.35	±	0.01	a	0.33	±	0.01	b	0.99	±	0.01	a	13.20	±	0.02	a
	d 5	82.26	±	0.99	ab	0.36	±	0.03	a	0.43	±	0.01	a	0.70	±	0.02	c	10.46	±	0.51	b
	d 7	80.26	±	0.99	b	0.26	±	0.03	b	0.37	±	0.04	ab	0.69	±	0.05	cb	9.46	±	0.51	bc
	d 9	74.70	±	0.59	c	0.31	±	0.03	ab	0.43	±	0.01	a	0.74	±	0.04	c	8.81	±	0.10	c
EC1	d 0	84.68	±	0.47	a	0.38	±	0.01	a	0.32	±	0.01	b	0.75	±	0.01	b	13.37	±	0.01	b
	d 2	83.93	±	0.62	a	0.36	±	0.03	a	0.37	±	0.02	ab	0.85	±	0.15	b	14.17	±	0.13	a
	d 5	82.48	±	0.54	a	0.33	±	0.01	a	0.40	±	0.01	a	1.13	±	0.03	a	12.35	±	0.12	b
	d 7	78.37	±	0.06	b	0.29	±	0.03	b	0.32	±	0.02	b	0.70	±	0.02	c	10.46	±	0.51	c
	d 9	77.71	±	0.56	b	0.29	±	0.03	b	0.32	±	0.02	b	0.70	±	0.02	c	10.46	±	0.51	cb
EC2	d 0	84.68	±	0.47	a	0.38	±	0.01	a	0.32	±	0.01	b	0.75	±	0.01	b	13.37	±	0.01	a
	d 2	83.19	±	0.14	a	0.32	±	0.01	a	0.42	±	0.01	a	0.99	±	0.01	a	11.69	±	0.30	a
	d 5	77.17	±	0.92	b	0.31	±	0.02	a	0.38	±	0.12	ab	0.99	±	0.01	a	10.62	±	0.54	b
	d 7	76.30	±	0.82	b	0.31	±	0.01	a	0.45	±	0.01	a	0.98	±	0.01	a	11.33	±	0.94	a
	d 9	76.63	±	0.44	b	0.31	±	0.01	a	0.45	±	0.01	a	0.98	±	0.01	a	11.33	±	0.94	ab

Abbreviations: CTR, untreated mango cube samples; EC1, mango cube samples coated with HPMC + $CaCl_2$; EC2, mango cube samples coated HPMC + $CaCl_2$ + neem oil. Time of storage: 9 days at 4 ± 1 °C and 80 ± 5% RH (d 0 = fresh; d 2 = after 2 days of storage; d 5 = after 5 days of storage; d 7 = after 7 days of storage; d 9 = after 9 days of storage). Means with different letters are significantly different at $p < 0.05$ using Tukey's test. For each treatment, different letters indicate significant differences between sampling dates.

Table 3. Milligrams of mineral compounds in mango cube samples.

Treatments	Time	K (mg)		Na (mg)		Ca (mg)		Mg (mg)		P (mg)		Zn (mg)	
CTR	d 0	24.16 ±	0.09 ^{b}	7.50 ±	0.06 ^{c}	9.70 ±	0.22 ^{b}	0.63 ±	0.04 ^{b}	10.10 ±	0.02 ^{c}	0.29 ±	0.01 ^{b}
	d 2	33.13 ±	0.21 ^{a}	8.39 ±	1.74 ^{a}	10.40 ±	0.02 ^{b}	0.81 ±	0.01 ^{a}	23.93 ±	0.06 ^{a}	0.30 ±	0.01 ^{b}
	d 5	30.97 ±	0.25 ^{a}	7.94 ±	0.14 ^{b}	12.34 ±	0.10 ^{a}	0.88 ±	0.05 ^{a}	15.55 ±	0.13 ^{b}	0.43 ±	0.02 ^{a}
	d 7	27.96 ±	0.19 ^{b}	8.50 ±	0.07 ^{a}	10.81 ±	0.06 ^{b}	0.79 ±	0.02 ^{ab}	17.19 ±	0.46 ^{b}	0.32 ±	0.01 ^{b}
	d 9	24.16 ±	0.09 ^{b}	7.50 ±	0.06 ^{c}	9.70 ±	0.22 ^{b}	0.63 ±	0.04 ^{b}	10.10 ±	0.02 ^{c}	0.29 ±	0.01 ^{b}
EC1	d 0	24.16 ±	0.09 ^{b}	7.50 ±	0.06 ^{b}	9.70 ±	0.22 ^{b}	0.63 ±	0.04 ^{b}	10.10 ±	0.02 ^{b}	0.29 ±	0.01 ^{b}
	d 2	30.97 ±	0.25 ^{a}	7.94 ±	0.14 ^{ab}	12.34 ±	0.10 ^{a}	0.88 ±	0.05 ^{a}	15.55 ±	0.13 ^{ab}	0.43 ±	0.02 ^{a}
	d 5	31.51 ±	0.31 ^{a}	8.20 ±	0.31 ^{a}	10.78 ±	0.41 ^{b}	0.78 ±	0.04 ^{ab}	17.97 ±	0.16 ^{a}	0.29 ±	0.01 ^{b}
	d 7	31.51 ±	0.31 ^{a}	8.34 ±	0.30 ^{a}	10.78 ±	0.41 ^{b}	0.78 ±	0.04 ^{ab}	17.67 ±	0.28 ^{a}	0.29 ±	0.01 ^{b}
	d 9	27.96 ±	0.19 ^{ab}	8.38 ±	0.11 ^{a}	10.81 ±	0.06 ^{b}	0.79 ±	0.02 ^{ab}	17.19 ±	0.46 ^{a}	0.32 ±	0.01 ^{b}
EC2	d 0	24.16 ±	0.09 ^{b}	7.50 ±	0.06 ^{b}	9.70 ±	0.22 ^{b}	0.63 ±	0.04 ^{b}	10.10 ±	0.02 ^{b}	0.29 ±	0.01 ^{a}
	d 2	31.16 ±	0.81 ^{a}	7.83 ±	0.41 ^{a}	10.31 ±	1.08 ^{b}	0.72 ±	0.10 ^{a}	13.97 ±	5.50 ^{a}	0.29 ±	0.01 ^{a}
	d 5	31.16 ±	0.81 ^{a}	7.83 ±	0.41 ^{a}	12.34 ±	0.88 ^{a}	0.72 ±	0.10 ^{a}	13.97 ±	5.50 ^{a}	0.29 ±	0.01 ^{a}
	d 7	31.16 ±	0.81 ^{a}	7.83 ±	0.41 ^{a}	10.31 ±	1.08 ^{b}	0.72 ±	0.10 ^{a}	13.97 ±	5.50 ^{a}	0.29 ±	0.01 ^{a}
	d 9	26.16 ±	2.74 ^{b}	7.88 ±	0.59 ^{a}	10.90 ±	0.18 ^{b}	0.73 ±	0.10 ^{a}	13.49 ±	4.77 ^{a}	0.30 ±	0.03 ^{a}

Abbreviations: CTR, untreated mango cube samples; EC1, mango cube samples coated with HPMC + $CaCl_2$; EC2, mango cube samples coated HPMC + $CaCl_2$ + neem oil. Time of storage: 9 days at 4 ± 1°C and 80 ± 5% RH (d 0 = fresh; d 2 = after 2 days of storage; d 5 = after 5 days of storage; d 7 = after 7 days of storage; d 9 = after 9 days of storage). Results indicate mean values ±S.D. Means with different letters are significantly different at $p < 0.05$ using Tukey's test. For each treatment, different letters indicate significant differences between sampling dates.

– Vitamin content

Mangoes can be considered a good source of dietary antioxidants, such as ascorbic acid, carotenoids and phenolic compounds [88]. Vitamin C is a fundamental component of the human diet, necessary for the prevention of scurvy, and has biological functions in collagen formation, absorption of inorganic iron, inhibition of nitrosamine formation and strengthening of the immune system. Ascorbic acid acts as an antioxidant and thus offers some protection against diseases related to oxidative stress [89].

According to the United States Department of Agriculture (USDA) database, mango pulp includes four different types of water- and fat-soluble vitamins [90].

In this study, vitamins B3, C and A (Table 4) were considered because they are present in higher concentrations, as reported by Vallarino et al. [91].

The initial amount of vitamin C was 110.20 ± 0.02 mg/100 g of pulp. The vitamin C content decreased more in CTR fruits than in EC fruit. Fruit treated with EC2 maintained a high content until the end of storage, probably due to the combined effect of $CaCl_2$ and neem oil that created a very good barrier on the fruit surface. This barrier, by reducing gas exchange, slows down the natural physiological processes of fruit ripening. In addition, this can be attributed to the presence of the active compound azadirachtin in neem oil, which helps to maintain cell stability and integrity and therefore delay changes associated with maturation and senescence [92]. The ascorbic acid oxidation can be caused by several factors, including exposure to oxygen and alkaline pH [93]. Edible coatings therefore served as a protective layer and controlled the permeability of O_2 and CO_2 [94].

Vitamin A and its metabolites have high antioxidant activity, providing beneficial effects against cancer and cardiovascular disorders. The concentration of vitamin A in the analysed fruit varies between 0.88 and 0.73 mg/100 g of pulp, and thus consumption of a fresh fruit (250–300 g) provides 10–12% of the recommended daily allowance (RDA) of retinol [95]. Mango consumption is therefore one of the best ways to prevent vitamin A deficiency [96].

Regarding the evolution of vitamin A content, it decreased slightly after 9 days of storage in CTR fruit, while it remained almost unchanged in EC fruit.

Compared to vitamin A, the concentrations of vitamin B3 are lower in mango pulp [97]. Again, there were no significant differences in the concentration of vitamin B3 between the different treatments. Its concentration decreased after 5 days of storage in all treatments. The CTR fruit showed a greater decrease, with concentration values decreasing from 0.54 ± 0.04 mg (fresh fruit) to 0.13 ± 0.01 mg (9 d). In EC fruit, the concentration remained more stable. In EC2 fruit it decreased from 0.54 ± 0.04 mg (fresh fruit) to 0.39 ± 0.01 mg on the last day of storage, confirming the hypothesis that an edible protective coating based on neem oil and $CaCl_2$ decreases the permeability to O_2 and thus maintains the fruit quality for a longer shelf life.

Table 4. Milligrams of vitamins in mango cube samples.

Treatments	Time	Niacin (Vitamin B3)				Ascorbic Acid (Vitamin C)				Retinol (Vitamin A)			
CTR	d 0	0.54	±	0.04	a	110.20	±	0.02	b	0.88	±	0.01	b
	d 2	0.54	±	0.01	a	99.93	±	0.11	b	0.78	±	0.01	b
	d 5	0.36	±	0.01	b	114.47	±	1.17	a	0.87	±	0.01	a
	d 7	0.33	±	0.01	c	77.08	±	0.05	c	0.76	±	0.01	c
	d 9	0.13	±	0.01	c	75.02	±	0.71	c	0.73	±	0.01	c
EC1	d 0	0.54	±	0.04	a	110.20	±	0.02	b	0.88	±	0.01	b
	d 2	0.53	±	0.01	a	110.20	±	0.02	b	0.88	±	0.01	b
	d 5	0.46	±	0.02	b	110.20	±	0.02	b	0.93	±	0.06	b
	d 7	0.39	±	0.01	bc	103.59	±	0.04	b	0.88	±	0.01	b
	d 9	0.26	±	0.01	c	114.47	±	1.17	a	0.87	±	0.01	a
EC2	d 0	0.54	±	0.04	a	110.20	±	0.02	a	0.88	±	0.01	a
	d 2	0.53	±	0.03	a	106.90	±	4.65	a	0.98	±	0.14	a
	d 5	0.45	±	0.01	b	103.59	±	0.04	a	0.87	±	0.03	a
	d 7	0.46	±	0.02	b	110.20	±	0.02	a	0.93	±	0.06	a
	d 9	0.39	±	0.01	b	103.59	±	0.04	a	0.88	±	0.01	a

Abbreviations: CTR, untreated mango cube samples; EC1, mango cube samples coated with HPMC + $CaCl_2$; EC2, mango cube samples coated HPMC + $CaCl_2$ + neem oil. Time of storage: 9 days at 4 ± 1 °C and 80 ± 5% RH (d 0 = fresh; d 2 = after 2 days of storage; d 5 = after 5 days of storage; d 7 = after 7 days of storage; d 9 = after 9 days of storage). Results indicate mean values ± S.D. Means with different letters are significantly different at $p < 0.05$ using Tukey's test. For each treatment, different letters indicate significant differences between sampling dates.

3.4. Sensory Analyses

Throughout the days of analysis, consumers look at the product they are presented with based on its appearance, while taste and texture lead them to buy it [98].

Figures 7–11 show that the behaviour of the mango cubes of all three treatments varies according to the period of cold storage. Starting from the fresh-cut fruit (Figure 7), the judges associated high values (between 6.5 and 7.5) to all the descriptors, analysing the positive characteristics of the fruit (visual appearance, texture, flavour and odour of exotic fruit and juiciness). Likewise, they associated values below 4 to the negative descriptors (bitterness, acidity, flavour and odour of the sea, etc.). Evidently, our data show a high degree of appreciation for mango cubes immediately after cutting.

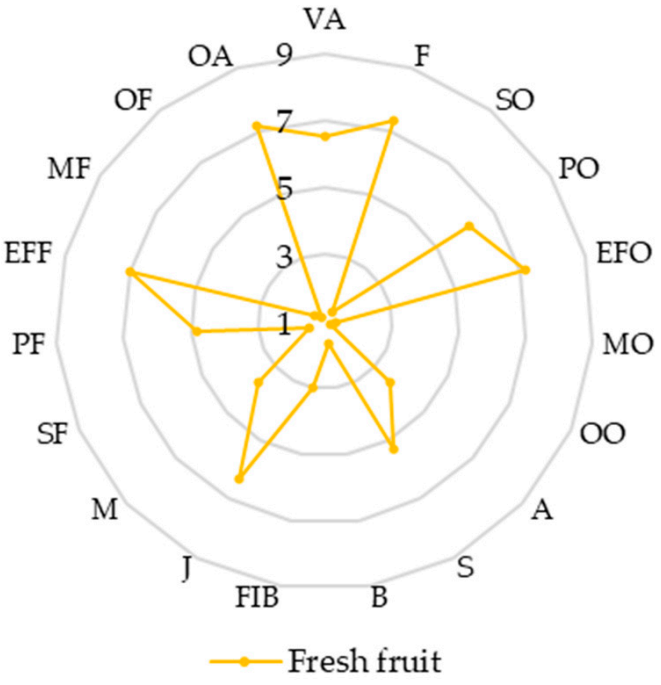


Figure 7. Sensory analyses of fresh-cut mango cubes after cutting. Descriptors: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour (EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA).

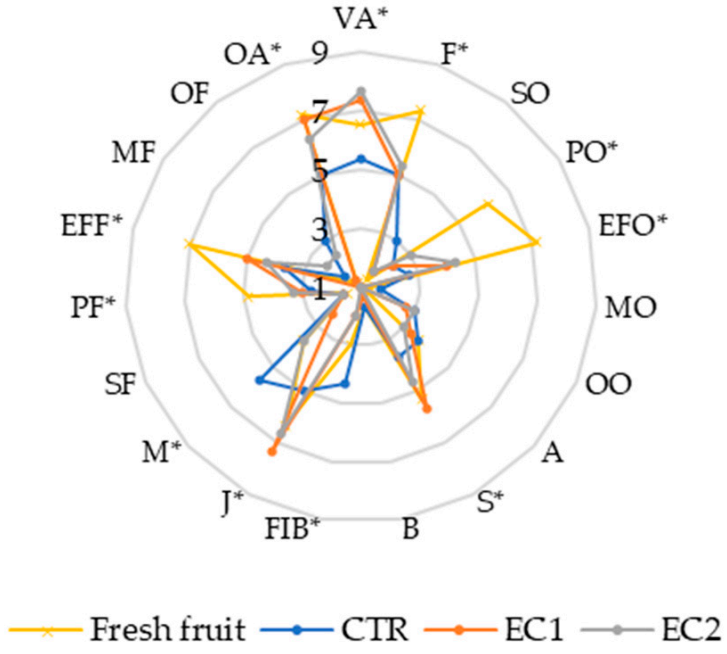


Figure 8. Sensory analyses of fresh-cut mango cubes after two days of cold storage. Descriptors: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour (EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA). Statistical differences ($p < 0.05$) were highlighted by * on the descriptors.

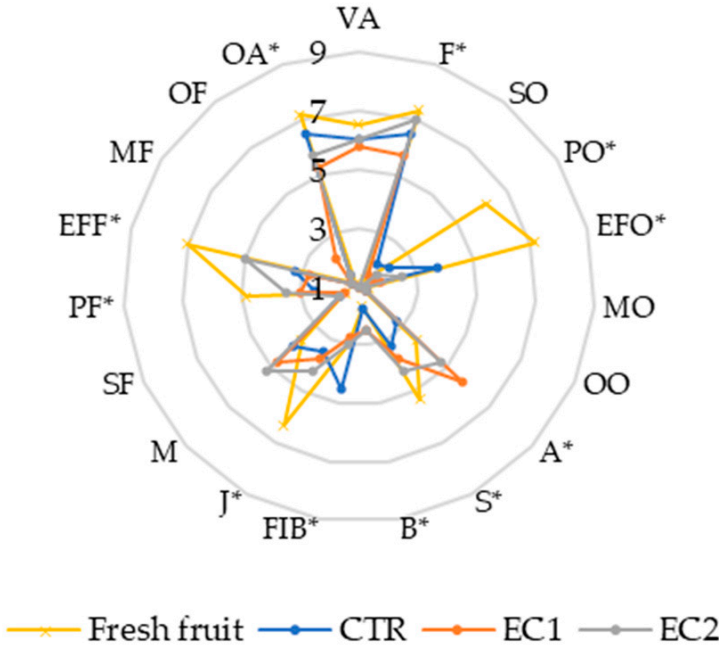


Figure 9. Sensory analyses of fresh-cut mango cubes after five days of cold storage. Descriptors: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour (EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA). Statistical differences ($p < 0.05$) were highlighted by * on the descriptors.

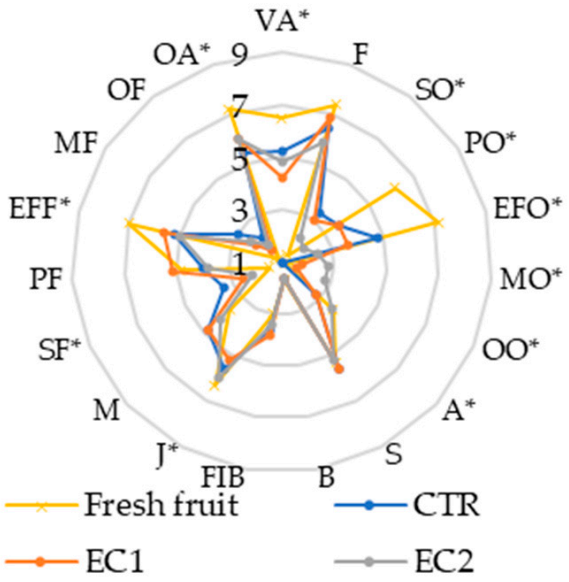


Figure 10. Sensory analyses of fresh-cut mango cubes after seven and nine days of cold storage. Descriptors: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour (EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA). Statistical differences ($p < 0.05$) were highlighted by * on the descriptors.

After 2 d (Figure 8—d 2) of cold storage, the CTR fruits were already about 2 points different ($p < 0.05$) from the initial visual appearance (VA—6.50), while the treated fruits (both EC1 and EC2) were even better than the data of the fruit immediately after cutting (d 0—7.30). This is probably due to the presence of the edible coating, which makes the flesh brighter (according to the brightness parameters—*L**) and more pleasing to the eye, without giving it an artificial appearance. The other parameters statistically different ($p < 0.05$) from the fresh fruit (d 0) were peach odour (PO), which was not as intense as at d 0 (6.17), but had decreased to 2.33 for CTR, 2.43 for EC1 and 3. 00 for EC2; exotic fruit odour (EFO) decreased from 7.17 (at d 0) to about 2 for CTR and EC1 and 4 for EC2; the sweetness parameter (S) was maintained in the treated samples with both ECs, while it decreased from 5.33 (at d 0) to 3.67 in the CTR samples. The same was true for the juiciness parameter (J), where the edible coatings slowed down the loss of juices, in agreement with the previously analysed parameters, keeping the flesh more palatable for the panel judges. The parameter that deviated most from the initial values was flesh mellowness (M), which was only very intense and different to the others ($p < 0.05$) in the CTR samples from the second day of storage (5.67).

After 5 days of cold storage (Figure 9—d 5), all descriptors were below average in intensity compared to d 0, showing a significant difference in most descriptors ($p < 0.05$). Only the EC2 samples were still appreciable in terms of firmness (F—7.00), sweetness (S—4.25), juiciness (J—4.25) and exotic fruit flavour (EFF—5.00). On the other hand, the mango cubes of the CTR samples were much more fibrous (F, 4.50) than both the treated samples (F—2.75, F—3.00, respectively, to EC1 and EC2) and the initial data (F—3.00).

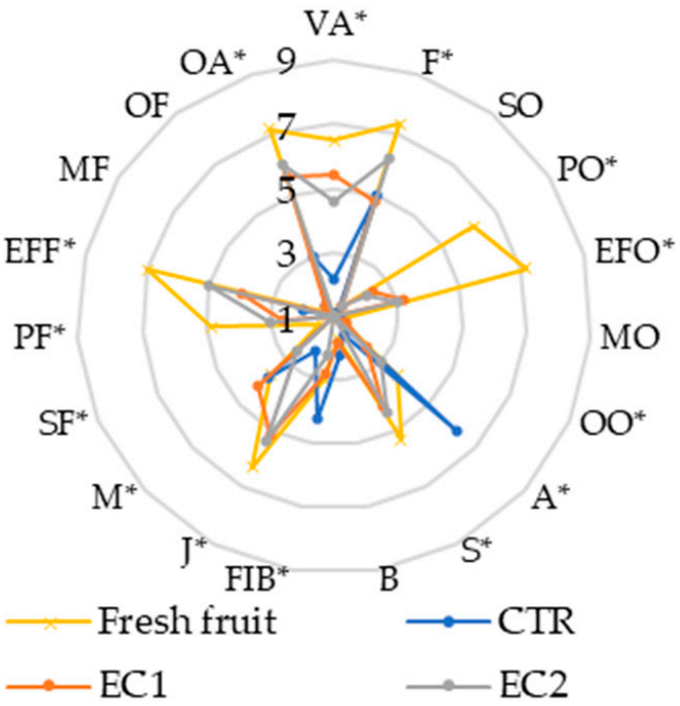


Figure 11. Sensory analyses of fresh-cut mango cubes after seven and nine days of cold storage. Descriptors: visual appearance (VA), firmness (F), sea odour (SO), peach odour (PO), exotic fruit odour (EFO), medicinal odour (MO), off-odour (OO), acidity (A), sweetness (J), bitterness (B), fibrousness (FIB), juiciness (J), mellowness (M), sea flavour (SF), peach flavour (PF), exotic fruit flavour (EFF), medicinal flavour (MF), off-flavour (OF), overall assessment (OA). Statistical differences ($p < 0.05$) were highlighted by * on the descriptors.

As regards the sensory analyses carried out on the last two days of storage (d 7 and d 9, respectively), it is possible to see in Figures 10 and 11 that almost all the descriptors fell below the average value of fruit appreciation. However, combining these data with statistical analysis, it was possible to highlight the most significant differences ($p < 0.05$), such as: the firmness (F) at d 7 was about 6.80 for all treatments analysed; the sea odour (SO) was only detected in the CTR samples at both d 7 and d 9 (3.00); the acidity parameter (A) was highest at d 9 for the CTR samples (6.20), while the EC1 and EC2 samples were below the average value (3.00); the same was true for the juiciness parameter (J), where CTR had a value of 2.20, while EC2 was still close to the value of fresh-cut fruit (5.40). The final overall assessment (OA) found that EC2 samples were much closer to the fresh fruit samples at d 0 (6.00—as revealed in Figure 11), followed by EC1 (5.76) and CTR (3.15).

These results are in agreement with other studies on the application of polysaccharides such as $CaCl_2$ and HPMC [25,28,30], which indicate that these had positive effects on maintaining flesh texture and juiciness. In addition, neem oil appears to have reduced browning and loss of the fruit's original taste and odour for up to 9 d of cold storage, but it was not possible to compare these data with the literature as no work has been carried out with neem oil in an edible coating applied to ready-to-eat mango fruit.

4. Conclusions

Edible coatings can provide shelf life improvement for fresh products. They are also very environmentally friendly and can be considered an eco-friendly alternative to chemical post-harvest treatments. Although the use of ECs is already well established in research, much remains to be investigated in relation to the functions of these films and their interaction with different plant matrices.

Our results demonstrated the ability of a new edible coating formulation to maintain the quality characteristics of ready-to-eat mango fruits. In particular, samples stored with the EC2 formulation, containing neem extract, showed the greatest control over cell maturation. In addition, the polysaccharides constituting both ECs appear to act as a natural barrier to external gas exchange. Concerning the microbiological results, the application of the edible coating containing neem oil exhibited antimicrobial activity against spoilage bacteria. The $CaCl_2$ and HPMC based edible coating, together with neem oil, may therefore play a significant role in maintaining the shelf life of fresh-cut mango fruits, as less retention of quality and organoleptic characteristics is observed compared to both CTR and the formulation without neem oil (EC1).

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