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Effect of Linseed (*Linum usitatissimum*) Mucilage and Chitosan Edible Coatings on Quality and Shelf-Life of Fresh-Cut Cantaloupe (*Cucumis melo*)

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Abstract: We have evaluated the effect of edible coatings (ECs) based on linseed mucilage (LM), chitosan (CH), and their combination (LMCH) on the quality and shelf life of fresh-cut cantaloupe. Cantaloupe was washed, sanitized, and processed (peeled, seeded, and cut) and then coated by immersion, packed, and stored for 18 days at 4 °C. The ECs were effective at reducing the juice leakage and softening of the product. The EC based on CH was the most effective at preserving the color parameter and reducing the general microbiological growth. However, the LMCH combination decreased the antimicrobial effect of chitosan against microorganisms. Also, CH and LM ECs helped preserve the overall sensory characteristics, increasing the acceptance to 12–15 days. Finally, the LMCH combination helped preserve the characteristics of color and odor; however, it modified the texture and taste of fresh-cut cantaloupe and its sensory acceptance was similar to the control (up to 9 days).

Keywords: linseed mucilage; fresh-cut fruit; cantaloupe; quality; shelf life

1. Introduction

The present-day accelerated lifestyle has increased the production and consumption of minimally processed horticultural and ready-to-eat products [1–3]. However, the development of fresh-cut products from fruits such as pineapple, papaya, watermelon, mango, and cantaloupe, among others, has been limited because these foods are highly perishable compared to intact fruit. Also, processing operations, such as disinfection, washing, drying, cutting, and packaging, can cause alterations in physical integrity (e.g., mechanical damage of fruit tissue) and product safety (e.g., microbial cross-contamination), leading to a series of changes related to microbial susceptibility and physicochemical and sensory stability, which decrease overall quality and shelf life [4–6].

Cantaloupe is one of the most popular fresh-cut fruits on the market and is consumed worldwide [7–10]. Cantaloupe is characterized by its aroma, intense flavor [11], and dietary fiber content, as well as its vitamin (A, B, and C), calcium, potassium, iron, and β-carotene levels [8,12–14]. However, fresh-cut cantaloupe has a short shelf life (up to 9 days) because the processing and storage of the product trigger changes in physical integrity, loss of juice, softening of the pulp, enzymatic browning and darkening, alteration in organic acid and soluble solid content, degradation of ascorbic acid, production of ethylene, accumulation of ethanol and acetaldehyde [11], development of spoilage microorganisms, and changes in aroma and flavor, which are determinants of quality [6].

Some of the methods used to improve the quality and increase the shelf life of cantaloupe products include packaging in modified atmospheres [15], treatment with ozone [16], ultraviolet light [7,17,18], gamma radiation [19], and edible coatings (ECs). ECs are considered safe and effective for the conservation of highly perishable products [3].

The use of polysaccharide-based ECs has been successful at reducing some problems associated with the loss of quality (physicochemical, microbiological, or sensory) and shelf life of fresh-cut cantaloupe due to its mechanical and barrier properties, as well as the incorporation of some active ingredients [20,21]. Among the most important materials used for this purpose are chitosan (CH), alginate, pectin [8,9,12–14,22–24], gellan [22], carboxymethylcellulose [25], and, recently, *Aloe vera* [5].

CH is a linear cationic polymer comprised of units of *D*-glucosamine and *N*-acetyl-*D*-glucosamine and is characterized by its antimicrobial properties (against fungi, bacteria, and viruses), low toxicity, biodegradability, biocompatibility, and low cost [26]. This polysaccharide has been effective as an EC in fresh cut-fruit, such as papaya [27], kiwi [28], and cantaloupe [6,9,10]. On the other hand, linseed mucilage (LM) is a heteropolymer composed of a mixture of acidic (rhamnogalacturonan) and neutral (arabinoxylan) polysaccharides, which comprises approximately 8% of the weight of linseed (*Linum usitatissimum*) and is characterized as a highly viscous, colorless liquid with good water retention properties [29,30]. Because of these properties, LM can be used as a dietary fiber, thickening agent, foaming agent, emulsifier, stabilizer, and as a drug delivery system, among other applications [31]. Interestingly, LM has been explored little as an EC in fresh-cut fruit [3,32,33]. Thus, we hereby aimed to determine the effect of LM and CH ECs and their combination (LMCH) on quality parameters and shelf life of fresh-cut cantaloupe.

2. Materials and Methods

2.1. Materials

Linseed and cantaloupe were purchased at a local market (Mercado de Abastos Estrella, San Nicolas de los Garza, Mexico). Cantaloupe was selected based on the following characteristics: uniform size, color and characteristic odor, absence of physical damage, no evidence of fungal infection, and with a soluble solids content between 8–10 degrees Brix (°Bx) [8]. Crab shell CH (85% deacetylation) was acquired from Sigma-Aldrich (St. Louis, MO, USA) and glycerol (99.5%) from Jalmek Científica S.A. de C.V. (San Nicolas de los Garza, Mexico).

2.2. Mucilage Extraction Process

Linseeds were placed in distilled water (30% *w*/*v*) and kept under constant agitation (2 h) until a viscous solution was formed. Subsequently, the seeds were removed using a strainer and precipitation of mucilage was made by adding two volumes of ethanol (2:1, Jalmek 96°) to the solution. Precipitated mucilage was recovered using a strainer and dried in a muffle (70 °C for 24 h), pulverized mechanically to obtain a fine powder, and stored until later use [32].

2.3. Development and Application of Coating-Forming Solutions

Three different treatments were evaluated: (a) LM: 2.0% linseed mucilage and 0.5% glycerol; (b) CH: 1.0% chitosan, 1.0% acetic acid, and 0.5% glycerol; and (c) LMCH: 1.0% linseed mucilage, 0.5% chitosan, 0.5% acetic acid, and 0.5% glycerol. Cantaloupe was washed with potable water and sanitized in a solution of sodium hypochlorite (250 mg kg^{-1}) for 1 min, then peeled, seeded, cut into 2 cm-sided cubes and laid (immersed) in the different coating-forming solutions for 2 min. Coated cantaloupe pieces were allowed to drain (to remove the coating solution excess) and dried for 20 min inside a laminar airflow cabinet. Pieces of fresh-cut cantaloupe without coating were used as control. Finally, cantaloupe pieces were packaged (800 g) in polyethylene terephthalate containers with lids (capacity of 32 oz/946 mL) and stored under refrigeration (4 °C to 90% RH) for a period of 18 days [8,13,22].

2.4. Analysis of Quality and Shelf Life of the Product

Evaluations for coated and uncoated fresh-cut cantaloupe were performed on days 0, 3, 6, 9, 12, 15, and 18 of storage at 4 °C.

2.4.1. Microbiological Quality Analysis

Fresh-cut cantaloupe (10 g) was weighed (three replicates for each treatment) and placed in sterile bags (Nasco Whirl-Pak®, 18 oz/532 mL). Subsequently, 90 mL of sterile peptone water (0.85% NaCl and 0.1% peptone) were added to the bags and contents were homogenized mechanically (1 min). Then, for microbial counts, serial dilutions were made and aliquots of 1 mL of each dilution were inoculated in sterile Petri dishes [27,34]. For total aerobic counts (aerobic mesophilic microorganisms), plate count agar (Difco™, 20 mL per plate) was used, and samples were incubated at 35 ± 2 °C for 48 h. Moreover, for mold and yeast counts, potato dextrose agar (BD Bioxon® 20 mL per plate) was used, and the samples were incubated at 25 ± 2 °C for 5 days [6,9]. Finally, after incubation, the colonies were counted, and results were expressed as colony-forming units per gram (CFU g^{-1}).

2.4.2. Physicochemical Quality Analysis

- Juice Leakage, Firmness, and Color

Juice leakage of fresh-cut cantaloupe (10 replicas per treatment) was determined based on the weight of the product throughout the storage time using an analytical balance (Mettler Toledo PG4002-S, Columbus, OH, USA), according to the following equation: weight loss (%) = (initial weight of the fruit) − (final weight of the fruit)/(initial weight of the fruit) × 100 [8,12]. For firmness evaluations of the fruit (five replicas per treatment), a digital penetrometer (Extech model FHT200, Waltham, MA, USA) equipped with a 3 mm tip was used; the results were expressed in newtons (N). Finally, the color analysis was carried out with a digital colorimeter (Blue-HP200, Bluemetric, S.A. de C.V., Monterrey, Mexico), and the results were expressed based on the color coordinates L^* (luminosity), a^* (green–red), and b^* (yellow–blue) [8]. In addition, overall color difference (ΔE) was calculated according to the following formula: $\Delta E^* = [(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2]^{1/2}$ [3], where, L_0, a_0 and b_0 are the initial color measurements (day 0), and L, a and b represent the color measurements at a specific day.

- pH, Titratable Acidity, Total Soluble Solids, and Ascorbic Acid Determinations

Fresh-cut cantaloupe for the different treatments was homogenized in a food processor and used for chemical determinations. pH determination was carried out using a previously calibrated pH meter (Beckman, model 390; Method 981.12, AOAC, Brea, CA, USA) [35]. Total acidity (TA) was determined by titration with sodium hydroxide solution (0.1 N) based on the method reported by Chong et al. [9] and the results were expressed as grams of malic acid per 100 g of sample. Total soluble solids content (TSS) was determined using a hand-held refractometer (Extech model RF15) and expressed using the °Bx scale (Method 932.14, AOAC) [35]. Finally, ascorbic acid content (AA) was determined by titration with iodine (Hycel de México, S.A. de C.V., Zapopan, Mexico; 0.1 N) based on previous reports [36], and results were expressed as milligrams per 100 g of sample. Determinations were conducted in triplicate (n = 3).

2.4.3. Sensory Quality Analysis

Sensory evaluations were carried out to determine the acceptance of coated fresh-cut cantaloupe by consumers. The sensory panel was made up of students and staff of our college's Biotechnology Institute (n = 10) who frequently consume this product. Color, odor, flavor, texture, and general acceptance were evaluated according to the following scale: 1 = dislike extremely, 2 = dislike, 3 = neither like nor dislike, 4 = like, and 5 = like very much; these parameters were decisive for the determination of quality and shelf life of fresh-cut cantaloupe (scores ≥2.5 were considered acceptable) [8,13]. Finally, the presence of molds and yeasts, as well as the visual damage caused by these microorganisms on the product surface (decay rate), was determined based on the following scale: 1 = undamaged fruit (0%), 2 = slightly damaged fruit (up to 25%), 3 = moderately damaged fruit (26%–50%), 4 = severely damaged fruit (51%–75%), and 5 = extremely damaged fruit (76%–100%). Decay rate scores ≤ 1.0 were considered acceptable [37].

2.5. Statistical Analysis

Statistical differences between the treatments were determined by one-way analysis of variance (ANOVA) and Tukey test using SPSS 20.0 software. p values ≤ 0.05 were considered statistically significant.

3. Results and Discussion

3.1. Microbiological Quality Testing

The development of spoilage microorganisms during the shelf life of fresh-cut cantaloupe is shown in Figure 1. In relation to aerobic mesophilic microorganisms, initial counts (day 0) were significantly ($p < 0.05$) higher in the control fruit (3.52 ± 0.01 log CFU g^{-1}) compared to LMCH- (2.32 ± 0.05 log CFU g^{-1}), LM-, and CH-coated samples (<1.00 log CFU g^{-1}). During storage, a gradual increase ($p < 0.05$) was observed in the microbial levels of all treatments. However, by day 18, this increase was significantly higher ($p < 0.05$) in the control fruit (7.75 ± 0.10 log CFU g^{-1}), followed by the LM- and LMCH-coated samples, whose microbial growth was very similar ($p > 0.05$) between days 12 and 18 of storage (ranging from 5.81 to 7.30 log CFU g^{-1}). Finally, by the end of the storage time, fruit treated with CH presented the lowest microbial counts (5.68 ± 0.01 log CFU g^{-1}, Figure 1A).

In contrast, the presence of mold and yeasts was not detected between days 0 and 6 of storage in fruit coated with CH and LMCH (<1.00 log CFU g^{-1}), while the fruit coated with LM and the control presented microbial levels that fluctuated between 1.01 and 1.21 log CFU g^{-1}. During days 9 to 18 of storage, a significant increase ($p < 0.05$) was detected in the mold and yeast counts of all treatments. CH EC was the most effective at reducing the growth of these microorganisms (1.05–1.39 log CFU g^{-1}), followed by LMCH and LM ECs, whose microbial levels fluctuated between 1.04–1.88 CFU g^{-1} and 1.37–2.04 CFU g^{-1} between days 9 and 18 of storage, respectively. Finally, the highest counts were recorded on uncoated fresh-cut cantaloupe, with microbial counts of 1.68–3.26 log CFU g^{-1} (days 9 to 18, Figure 1B).

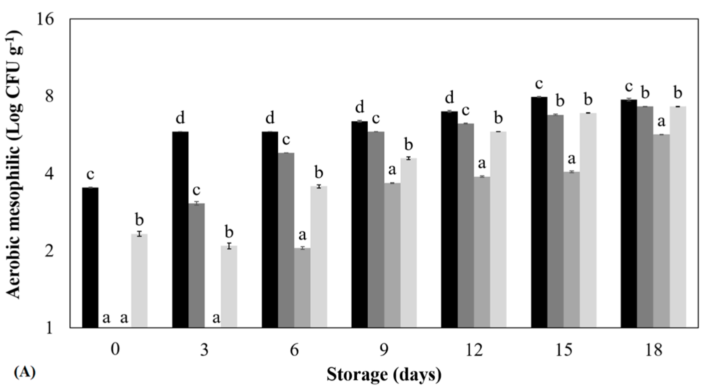

Figure 1. *Cont.*

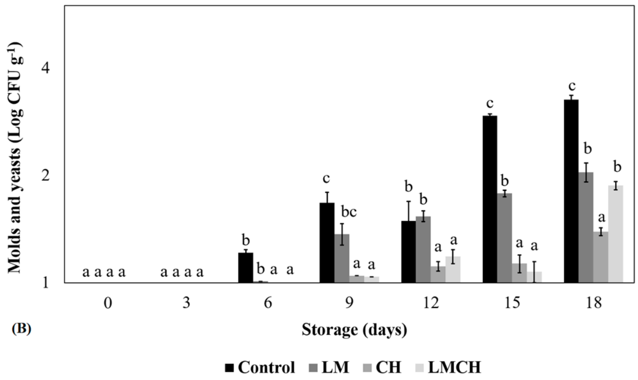

Figure 1. Growth of (**A**) aerobic mesophilic microorganisms (total aerobic counts) and (**B**) molds and yeasts in fresh-cut cantaloupe with and without an edible coating (control) during 18 days of storage at 4 °C. Means which do not have a common letter (a, b, c) are significantly different ($p \leq 0.05$). Vertical bars represent ± SD. LM: linseed mucilage; CH: chitosan; LMCH: linseed mucilage + chitosan.

In general, the ECs based on LM were able to reduce the growth of molds and yeasts, which is similar to the finding of Yousuf et al. [3] in pomegranate arils. Moreover, it has been proposed that the effectiveness of ECs based on CH [8,9,13,14,25] can be attributed to the positive charge of the protonated amino group (NH_3^+) present in the C-2 of the polysaccharide; this group has the ability to interact with phosphoryl groups present in the cell membrane, altering the cellular permeability and causing leakage of proteinaceous and other intracellular components [9,26]. The EC based on LMCH was not as effective at reducing the microbial levels when compared to the CH EC; this effect can be attributed to an electrostatic interaction between these polymers (polyelectrolytes with opposite charges), which can reduce the antimicrobial activity of CH. Similar results have been reported by Poverenov et al. [14] with ECs based on CH/alginate in fresh-cut cantaloupe and Treviño et al. [32] with ECs based on CH and mucilages of cactus, linseed, and *Aloe vera* in fresh-cut pineapple.

3.2. Juice Leakage, Firmness, and Color Tests

Table 1 shows the juice leakage of fresh-cut cantaloupe. Juice leakage values on day 3 of storage fluctuated between 0.28% and 0.56%, with no significant differences ($p > 0.05$) among treatments. Between days 6 and 18 of storage, a significant increase was found in all treatments; however, this increase was most evident in the control fruit (2.64%–5.12%); on the other hand, we detected no significant differences ($p > 0.05$) among fresh-cut cantaloupe coated with LM, CH, and LMCH, with leakage values of between 3.32% and 3.78% by day 18 of storage. Our results are consistent with those of Chong et al. [9], who worked with ECs based on CH/$CaCl_2$ in fresh-cut honeydew melon. In contrast, Yousuf et al. [3] reported higher values for this parameter with EC based on linseed mucilage/lemongrass essential oil in ready-to-eat pomegranate arils.

Additionally, the application of ECs significantly increased ($p < 0.05$) the firmness of LM-coated cantaloupe from 19.20 to 28.32 N (day 0; Table 1). During storage time, a decrease in firmness "tissue softening" was observed in LM-, LMCH-coated, and control samples, without significant differences ($p > 0.05$) between days 3 and 18. Nonetheless, coated cantaloupe pieces showed slightly higher firmness values compared to control samples (Table 1). In addition, the fluctuations found in firmness values between the different days of evaluation could be related to the inherent variability of the fruit. On the other hand, CH-coated fruit presented the highest and stable firmness values during the total storage time ($p < 0.05$; Table 1). A similar effect has been reported in previous studies [24,25,37]. Compared to previous studies, lower firmness values have been reported on fresh-cut cantaloupe coated with pectin [23], cellulose [38], carboxymethylcellulose [25], and alginate [24]. Conversely, higher values have been reported using multilayered ECs with the formula CH/pectin/trans-cinnamaldehyde [8].

Table 1. Physical properties of fresh-cut cantaloupe with and without EC (control) during 18 days of storage at 4 °C.

Storage (Days)	Control	LM	CH	LMCH
		Juice Leakage (%)		
3	^{A}0.56 (0.07) ^{f}	^{A}0.45 (0.13) ^{f}	^{A}0.28 (0.04) ^{d,e}	^{A}0.34 (0.16) ^{d,e}
6	^{C}2.64 (0.07) ^{e}	^{B}1.44 (0.27) ^{e}	^{A}0.83 (0.13) ^{d}	^{AB}1.05 (0.33) ^{c,d}
9	^{C}3.98 (0.12) ^{d}	^{B}2.83 (0.24) ^{d}	^{A}2.14 (0.38) ^{c}	^{A}1.97 (0.13) ^{b,c}
12	^{B}4.33 (0.22) ^{c}	^{A}3.13 (0.22) ^{c}	^{A}2.59 (0.23) ^{b,c}	^{A}2.72 (0.25) ^{a,b}
15	^{B}4.74 (0.11) ^{b}	^{A}3.43 (0.34) ^{b}	^{A}3.05 (0.22) ^{a,b}	^{A}3.33 (0.33) ^{a}
18	^{B}5.12 (0.15) ^{a}	^{A}3.78 (0.29) ^{a}	^{A}3.32 (0.25) ^{a}	^{A}3.53 (0.69) ^{a}
		Firmness (N)		
0	^{A}19.20 (0.13) ^{b,c}	^{B}28.32 (1.70) ^{c}	^{A,B}21.97 (2.00) ^{a}	^{A}20.67 (1.42) ^{a,b}
3	^{A}23.57 (2.24) ^{c}	^{A}25.80 (0.72) ^{b,c}	^{A}27.85 (3.51) ^{a}	^{A}22.42 (2.35) ^{b}
6	^{A}15.15 (1.02) ^{a,b}	^{A}16.63 (1.77) ^{a}	^{A}19.73 (1.21) ^{a}	^{A}18.42 (1.44) ^{a,b}
9	^{A}10.90 (0.96) ^{a}	^{AB}13.92 (1.58) ^{a}	^{B}21.23 (2.69) ^{a}	^{A,B}14.20 (1.25) ^{a,b}
12	^{A}14.23 (1.13) ^{a,b}	^{A}18.91 (2.71) ^{a,b}	^{A}21.13 (1.08) ^{a}	^{A}12.72 (2.11) ^{a}
15	^{A}10.40 (0.19) ^{a}	^{B}17.32 (0.59) ^{a,b}	^{A,B}16.20 (2.02) ^{a}	^{A,B}14.48 (1.04) ^{a,b}
18	^{A}14.05 (0.79) ^{a,b}	^{A}15.12 (0.65) ^{a}	^{B}23.09 (1.31) ^{a}	^{A}13.78 (1.67) ^{a,b}

Note: Values within a column (lowercase) or row (uppercase) which do not have a common letter are significantly different ($p \leq 0.05$). The values in parentheses indicate ± standard deviation. EC = edible coating, LM = linseed mucilage, and CH = chitosan.

In general, the changes found during the shelf life of fresh-cut cantaloupe regarding parameters of juice leakage and firmness are associated with the superficial evaporation of water due to respiration and transpiration processes [9,23]. Also, microbial growth and enzymatic degradation of cellular polysaccharides (e.g., pectin) can produce pulp softening [14,25]. Application of semipermeable polymeric ECs on the surface of the pieces of cantaloupe provides improved structural integrity and helps control gas diffusion, moisture loss (Table 1), and microbial growth [38] (Figure 1).

Application of ECs did not change ($p > 0.05$) initial parameters (day 0) of color in fresh-cut cantaloupe; luminosity (L^*) fluctuated between 50.57 and 55.38, the a^* coordinate (redness) presented values of 14.15–15.24, and the b^* coordinate (yellowness) fluctuated between 38.40 and 41.87 (Figure 2A–C). Regarding the L^* parameter (Figure 2A), the values remained constant during storage and although no significant effect was found ($p > 0.05$), by day 18, the coated cantaloupe pieces presented slightly higher luminosity values (50.79–55.61) compared to the control group (47.78 ± 4.11). Conversely, between days 9 and 18 of storage, there was a significant decrease ($p < 0.05$) in the values of a^* in all treatments, but without significant difference ($p > 0.05$) among the cantaloupe pieces coated with LMCH and LM and the control (days 0–18; 13.42–6.61, 14.40–4.90, and 13.13–5.78, respectively; Figure 2B). In addition, the fresh-cut cantaloupe pieces coated with CH showed the highest a^* values (days 0–18; 14.40–9.32). On the other hand, after day 9, a significant decrease ($p < 0.05$) was also found in the values of the b^* coordinate in all treatments. Nevertheless, by the end of storage, the CH EC was more effective at maintaining the b^* values (24.75 ± 1.95) relative to LMCH, LM, and the control, whose values fluctuated between 19.47 and 21.23 (Figure 2C).

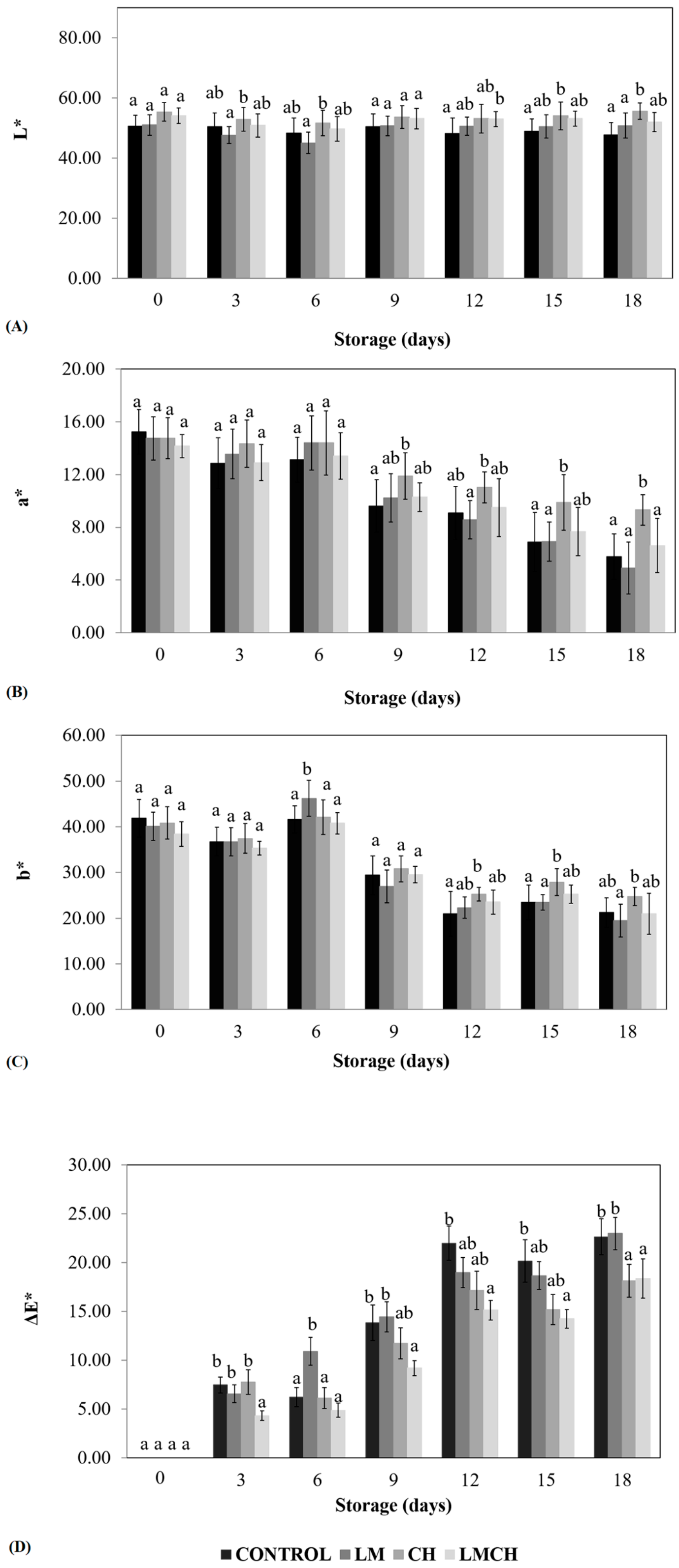

Figure 2. Color attributes—(**A**) *L**, (**B**) *a**, (**C**) *b**, and (**D**) Δ*E**—of fresh-cut cantaloupe with and without an edible coating (control) during 18 days of storage at 4 °C. Means which do not have a common letter (a, b, c) are significantly different ($p \leq 0.05$). Vertical bars represent ± SD.

In general, after 18 days of storage (Figure 2D), ECs elaborated with CH and LMCH were the most effective at reducing ($p < 0.05$) the changes in the color (ΔE = 18.13 and 18.34, respectively) and in preserving the yellow-orange color compared to LM and control (ΔE = 22.97 and ΔE = 22.63, respectively); these parameters are indicators of a reduction of oxidative (e.g., oxidizable phenol compounds) and enzymatic browning (e.g., polyphenol oxidase activity) [8,9,13,24] and also are associated with symptoms of translucency (dark and glassy pulp) in the fresh-cut cantaloupe [39,40]. These results are consistent with those found in our sensory color evaluations (Figure 3a).

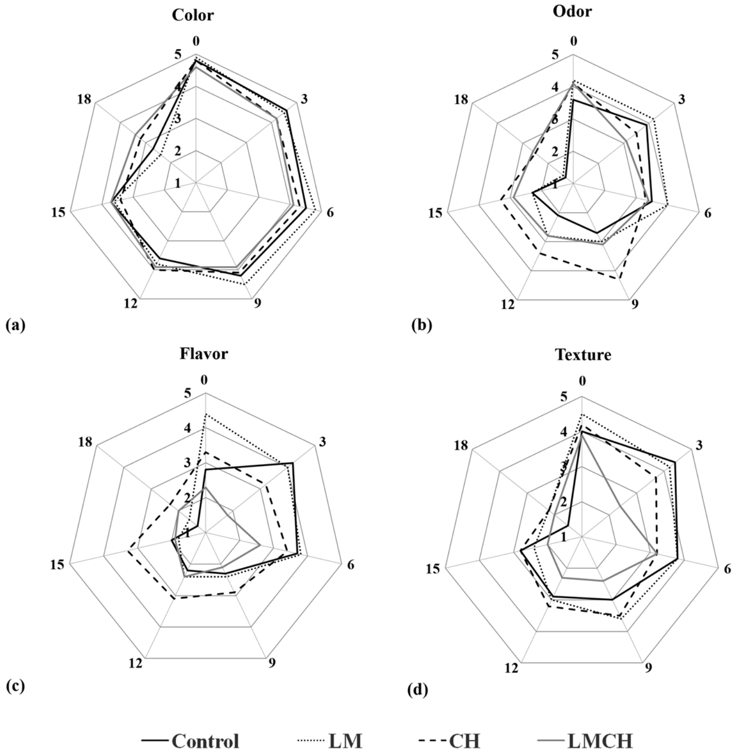

Figure 3. Sensory quality parameters—(**a**) color, (**b**) odor, (**c**) flavor, and (**d**) texture—of fresh-cut cantaloupe with and without an edible coating (control) during 18 days of storage at 4 °C.

pH, TA, TSS, and AA Content

Regarding physicochemical analysis, the application of ECs decreased ($p < 0.05$) the pH of fresh-cut cantaloupe (day 0, Table 2). The low pH values in the fruit coated with CH (5.99 ± 0.01) and LMCH (5.72 ± 0.01) can be attributed to the pH of the solutions forming the coating (CH, 3.62 ± 0.01; LMCH, 3.93 ± 0.01, data not shown), which contained acetic acid for the dissolution of CH. According to the reports of Martiñon et al. [8] and Chong et al. [9], the reduction in pH values can have a beneficial effect in reducing the early development of spoilage microorganisms, which is in agreement with the results found in our microbiological analysis (Figure 1). Moreover, the LM EC presented pH values similar to the control fruit, which is consistent with the findings of Yousuf et al. [3] in pomegranate arils. Between days 6 and 18, there was a decrease ($p < 0.05$) in the pH values of all treatments; the lowest values were presented by the fruit treated with LMCH (4.33 ± 0.02), followed by the control, LM, and CH (5.38–5.57, Table 2), which is in line with previous studies [3,5,8,41]. Changes in this parameter during storage can be attributed to the accumulation of organic acids characteristic of the metabolism of fresh-cut cantaloupe [9,41,42].

Table 2. Chemical properties of fresh-cut cantaloupe with and without EC (control), during 18 days of storage at 4 °C.

Storage (Days)	Control	LM	CH	LMCH
		pH		
0	^{D}6.79 (0.02) ^{d}	^{C}6.68 (0.03) ^{d}	^{B}5.99 (0.01) ^{d,e}	^{A}5.72 (0.01) ^{f}
3	^{A}6.12 (0.02) ^{c}	^{B}6.34 (0.09) ^{c}	^{A}6.10 (0.01) ^{e}	^{A}6.00 (0.01) ^{e}
6	^{B}5.68 (0.03) ^{b}	^{A}5.53 (0.01) ^{b}	^{C}5.78 (0.00) ^{c,d}	^{A}5.56 (0.00) ^{d}
9	^{D}5.52 (0.03) ^{a,b}	^{C}5.47 (0.01) ^{a,b}	^{B}5.65 (0.01) ^{b,c}	^{A}4.98 (0.00) ^{c}
12	^{B}5.53 (0.04) ^{a,b}	^{B}5.53 (0.03) ^{b}	^{B}5.40 (0.19) ^{a}	^{A}4.53 (0.02) ^{b}
15	^{C}5.58 (0.03) ^{b}	^{B}5.40 (0.04) ^{a}	^{B}5.42 (0.01) ^{a,b}	^{A}4.35 (0.04) ^{a}
18	^{C}5.38 (0.14) ^{a}	^{B}5.53 (0.05) ^{b}	^{B}5.57 (0.10) ^{a,b,c}	^{A}4.33 (0.02) ^{a}
		TA (Malic Acid, g 100 g^{-1})		
0	^{A}0.026 (0.00) ^{a}	^{A}0.034 (0.01) ^{a}	^{C}0.103 (0.00) ^{b,c}	^{B}0.073 (0.00) ^{a}
3	^{A}0.064 (0.01) ^{a}	^{A}0.073 (0.00) ^{a}	^{B}0.107(0.00) ^{b,c}	^{B}0.115 (0.01) ^{b}
6	^{B}0.265 (0.00) ^{d}	^{B}0.282 (0.12) ^{d}	^{A}0.188 (0.00) ^{d}	^{A}0.158 (0.01) ^{c}
9	^{B}0.213 (0.00) ^{c}	^{B}0.218 (0.01) ^{c}	^{A}0.179 (0.01) ^{d}	^{C}0.269 (0.01) ^{e}
12	^{B}0.162 (0.01) ^{b}	^{B}0.171 (0.00) ^{b}	^{A}0.128 (0.01) ^{c}	^{C}0.265 (0.00) ^{e}
15	^{A}0.068 (0.00) ^{a}	^{B}0.145 (0.00) ^{b}	^{A}0.077(0.01) ^{a,b}	^{C}0.205 (0.01) ^{d}
18	^{A}0.055 (0.00) ^{a}	^{A}0.043(0.01) ^{a}	^{A}0.059 (0.01) ^{a}	^{B}0.205 (0.01) ^{d}
		TSS (°Bx)		
0	^{C}9.00 (0.00) ^{b}	^{A}8.00 (0.00) ^{c}	^{D}10.0 (0.00) ^{d}	^{B}8.30 (0.17) ^{b}
3	^{B}9.00 (0.00) ^{b}	^{A}8.10 (0.05) ^{c}	^{B}9.33 (0.06) ^{c}	^{B}9.00 (0.00) ^{c}
6	^{B}8.90 (0.10) ^{b}	^{A}8.00 (0.00) ^{c}	^{A}8.10 (0.10) ^{b}	^{A}8.07 (0.06) ^{b}
9	^{A}8.10 (0.06) ^{a}	^{A}8.03 (0.05) ^{c}	^{A}8.17 (0.06) ^{b}	^{B}9.13 (0.06) ^{c}
12	^{C}8.90 (0.11) ^{b}	^{A}8.03 (0.06) ^{c}	^{B}8.27 (0.10) ^{b}	^{D}9.17 (0.06) ^{c}
15	^{B}8.00 (0.00) ^{a}	^{A}7.03 (0.06) ^{b}	^{B}8.03 (0.06) ^{b}	^{A}7.20 (0.17) ^{a}
18	^{C}8.00 (0.00) ^{a}	^{A}6.47 (0.25) ^{a}	^{B}7.10 (0.06) ^{a}	^{B}7.27 (0.06) ^{a}
		AA (mg 100 g^{-1})		
0	^{A}10.09 (1.03) ^{c}	^{A}10.68 (1.78) ^{b}	^{A,B}13.05 (1.03) ^{c}	^{B}14.83 (1.03) ^{b}
3	^{A,B}9.49 (1.03) ^{c}	^{B}10.68 (0.10) ^{b}	^{B}11.27 (1.03) ^{b,c}	^{A}7.71 (1.03) ^{a}
6	^{A}8.31 (1.03) ^{b,c}	^{A}6.53 (1.03) ^{a}	^{A}7.12 (1.03) ^{a}	^{A}8.31 (1.03) ^{a}
9	^{A}6.53 (1.03) ^{a,b}	^{A}7.12 (1.09) ^{a}	^{A}8.31 (1.03) ^{b}	^{A}6.53 (1.03) ^{a}
12	^{A,B}6.53 (1.03) ^{a,b}	^{B}5.34 (0.10) ^{a}	^{B}7.71 (1.03) ^{a}	^{A,B}7.12 (1.03) ^{a}
15	^{A}6.53 (1.03) ^{a,b}	^{A}6.53 (1.03) ^{a}	^{A}6.53 (1.03) ^{a}	^{A}5.93 (1.03) ^{a}
18	^{A}4.75 (1.03) ^{a}	^{A}5.93 (1.03) ^{a}	^{A}5.93 (1.03) ^{a}	^{A}5.93 (1.03) ^{a}

Note: Values within a column (lowercase) or row (uppercase) which do not have a common letter are significantly different ($p \leq 0.05$). The values in parentheses indicate standard deviation. EC = edible coating, LM = linseed mucilage, CH = chitosan, TA = titratable acidity, TSS = total soluble solids, and AA = ascorbic acid.

Secondly, initial TA was higher in fresh-cut cantaloupe coated with LMCH and CH (0.073–0.103 mg 100 g^{-1}) compared to the control and LM-coated samples (0.026–0.034 mg 100 g^{-1}, Table 2), in accordance with pH values. Between days 6 and 12 of storage, an increase was observed ($p < 0.05$) in the TA of all treatments, followed by a decrease ($p < 0.05$) between days 15 and 18. As reported by Lamikanra et al. [42], this effect can be related with the loss of malic acid and the production of lactic acid due to the microbial growth (malolactic fermentation). In addition, the highest TA values observed in the fresh-cut cantaloupe coated with LMCH during the whole trial period also can be accounted for by the low pH values attributed to the addition of acetic acid in the CH-based coating-forming solutions [13,28].

The initial TSS content fluctuated between 9.00 and 10.00 °Bx, which is similar to the values reported in previous studies [8,13,41]. During the storage period, there was a decrease ($p < 0.05$) in TSS content in all treatments; this can be associated with the use of sugars as a nutrient (fermentation) during the growth of spoilage microorganisms [42]. However, by day 18, the control samples had higher TSS values (8.00 ± 0.00 °Bx) than the coated fruit, whose values fluctuated between 6.47 and 7.27 °Bx (Table 2) [9,40]. This effect might be associated with a higher rate of water loss [5,41] in accordance with our juice leakage evaluations (Table 1). Furthermore, the high content of TSS can also be an indicator of increased maturity in the control fruit [13,38].

Finally, initial AA content was higher ($p < 0.05$) for CH- and LMCH-coated samples (13.05–14.83 mg 100 g^{-1}), followed by those coated with LM and the control ($p > 0.05$), whose values fluctuated between 10.68 and 10.09 mg 100 g^{-1} (Table 2). According to Ortiz-Duarte et al. [10], this effect may be related to the oxidation of AA after rind removal and during fruit processing; the application of CH-based coatings on the surface of the cantaloupe slices helped reduce the exposure to the external environment, thus also reducing the initial loss of ascorbic acid (day 0). However, throughout storage, a gradual decrease of AA was observed in all treatments, without significant difference ($p > 0.05$) between the coated and control fruit by day 18 of storage (4.75–5.93 mg 100 g^{-1}). Similar results were reported with multilayer ECs (CH/pectin/$CaCl_2$/trans-cinnamaldehyde) in fresh-cut cantaloupe [8].

3.3. Sensory Quality Testing

The application of ECs did not change the initial parameters (day 0) of color, odor, texture, and decay rate, and there was no significant difference ($p > 0.05$) between the control and coated fruit for the different parameters evaluated (Figures 3 and 4), which is in agreement with previous reports [3,8]. On the contrary, the application of the ECs significantly influenced ($p < 0.05$) the initial parameters of flavor and overall acceptance. In the flavor parameter, the LM- and CH-coated samples presented higher evaluations (4.40 and 3.30, respectively) than the control fruit (2.80 ± 1.03), while the LMCH-coated samples presented the lowest evaluations because the panelists did not detect the characteristic flavor of the melon, and they referred to a "different" and unpleasant flavor in the product (2.30 ± 0.50). Therefore, the initial overall acceptance was lower for the LMCH-treated fruit (3.18 ± 0.32), followed by the control (3.24 ± 0.24) and fruit treated with LM and CH, which were the most frequently accepted by the panelists (scores of 3.48 and 3.86, respectively).

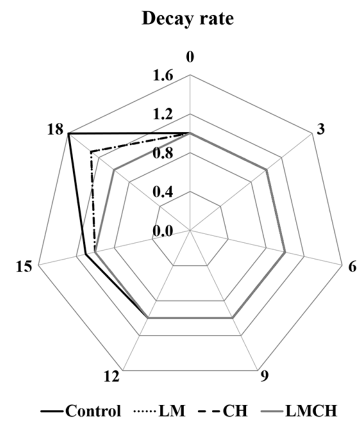

Figure 4. Decay rate of fresh-cut cantaloupe with and without an edible coating (control) during 18 days of storage at 4 °C.

Regarding evaluations performed during storage time, a decrease of color scores was observed in all treatments, with significant differences ($p < 0.05$) between days 15 and 18 (Figure 3a). CH- and LMCH-coated fruit presented the highest scores ($p < 0.05$, 3.40–3.20 and 3.40–3.70), while LM-coated samples and controls presented similar values without significant differences on days 15 and 18 ($p > 0.05$, 3.60–2.40 and 3.70–2.70, respectively). As mentioned above, the appearance of fresh-cut cantaloupe might be affected by the translucency phenomenon [22,39,43], which is characterized by a "glassy" appearance and darkening of color, changes in texture, and early maturity (associated with an increase in sugar content). These results are consistent with those obtained in our color, firmness, and TSS analyses (Figure 2, and Tables 1 and 2, respectively), and are characteristic of a senescence process [22]. The protection barrier provided by the ECs (CH and LMCH) on the surface of the product was able to reduce the perceptible changes in color, attributed mainly to the phenomenon of translucency.

Secondly, a decrease ($p < 0.05$) was found in the odor values during storage time in all treatments. However, a significant preference was found ($p < 0.05$) with respect to the fruit coated with CH (4.30–2.50) and LMCH (3.10–2.60) between days 9 and 18 relative to the fruit treated with LM (3.00–1.40) and the control (2.70–1.30, Figure 3b). Undesirable changes in the aroma of fresh-cut cantaloupe might be associated with variations in the concentration of volatile compounds specific to fruit metabolism (e.g., acetate and nonacetate esters, aldehydes, and sulfur-containing compounds) [11,38], coupled with unpleasant "fermented" odors associated with microbial spoilage. These results are consistent with the findings of our microbial analysis (Figure 1) and agree with the findings of Martiñón et al. [8].

On the other hand, during storage, a significant decrease ($p < 0.05$) was found in the flavor evaluations for control and LM-coated fresh-cut cantaloupe, which presented acceptable scores (≥2.5) until day 6 and 9, respectively (Figure 3c). Also, CH-coated fruit presented acceptable flavor scores until day 15 (3.30 ± 0.45). On the contrary, LMCH-coated samples had unacceptable scores (<2.5), since this coating modified the typical and characteristic flavor of the cantaloupe. Changes in taste are related to the generation of volatile compounds (e.g., acetaldehyde, ethanol, and ethyl acetate, among others) [13,35], as well as the decrease in sugar content and organic acids (which contribute to sweetness and pleasant taste; Table 2) [39,40,42], and with microbial spoilage [20]. In general, the ECs were effective at reducing the microbial levels (Figure 1), thereby helping to prevent the development of unpleasant flavors during the shelf life of the product.

Regarding the texture parameter (Figure 3d), the scores decreased significantly ($p < 0.05$) during storage in all treatments, as was evidenced in the firmness analysis (Table 1). Changes in texture were most evident at days 12–15 for LM- and CH-coated fruit and the control group, whose values were within the acceptable range (scores ≥ 2.5). On the contrary, from day 3, LMCH-coated cantaloupe presented lower evaluations relative to the other treatments (3.20 ± 0.45, Figure 3d), with acceptable scores only until day 9 (2.50 ± 0.25). This was because the panelists detected the presence of the coating, similarly to previous reports [8,13]. However, in the firmness evaluations (Table 1), we found that LMCH-coated fruit was significantly firmer ($p < 0.05$) than the control group. This effect might be related to the adhesion of the coating to the melon surface [14]. According to previous reports, the electrostatic deposition technique (layer by layer) can be used as an alternative approach to improve the adhesion of the polysaccharides with opposite charges on the fruit surface [14,32].

The decay rate remained stable during storage for all treatments (1.00–1.10; Figure 4). By day 18, the coated fruit had low decay rate scores (1.00–1.30), without apparent damage to the surface of the fresh-cut cantaloupe. On the contrary, the control fruit showed signs of damage (1.60 ± 0.22, <25%) and the presence of mold and yeasts on the surface. These results are consistent with the findings of our microbial analysis (Figure 1b).

For the overall sensory acceptance, due to its organoleptic characteristics, CH- and LM-coated fresh-cut cantaloupe was accepted for 12–15 days (Figures 5 and 6). Also, although LMCH-coated samples helped to preserve the properties of color, odor, texture, and decay rate, the overall sensory acceptance was similar to the control fruit (up to 9 days) due to the change in flavor detected by the panelists (Figures 3, 5 and 6).

Our findings regarding the shelf life of fresh-cut cantaloupe are similar to those reported by Moreira et al. [13] (15 days with multilayer ECs based on CH/pectin/$CaCl_2$/trans-cinnamaldehyde), Ferrari et al. [23] (14 days with ECs based on pectin/calcium lactate), and Chong et al. [9] (13 days with ECs based on CH/calcium chloride), but were higher than those reported by Haffez et al. [25] (8 days with ECs based on CH/carboxymethylcellulose/calcium chloride) and Martiñón et al. [8] (9 days with ECs based on CH/pectin/$CaCl_2$/trans-cinnamaldehyde).

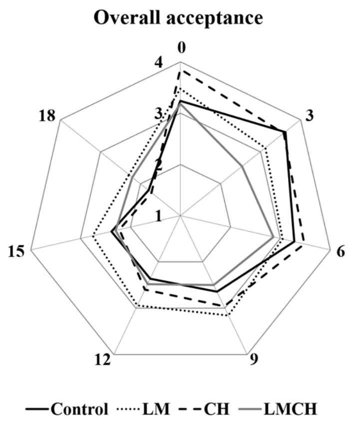

Figure 5. Overall sensory acceptance of fresh-cut cantaloupe with and without an edible coating (control) during 18 days of storage at 4 °C.

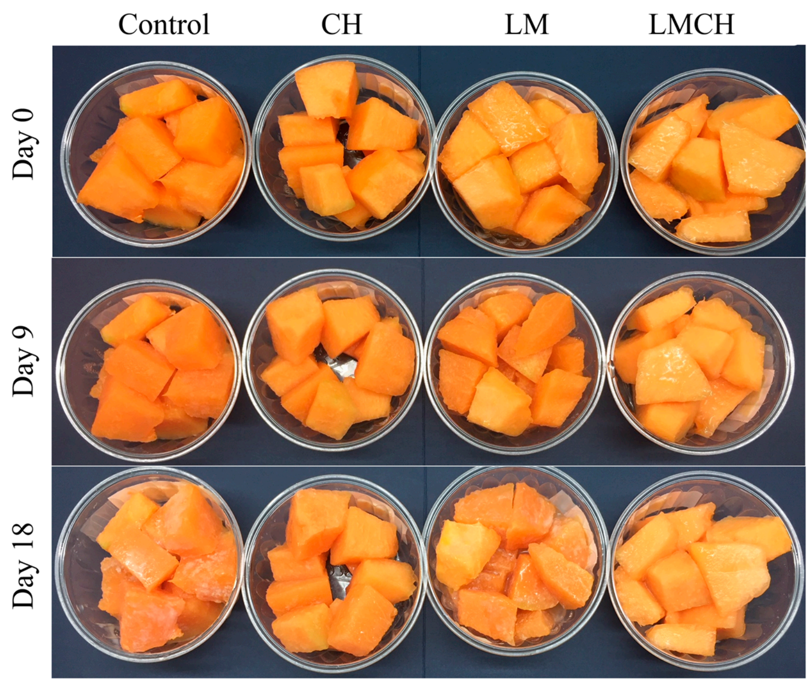

Figure 6. Appearance of fresh-cut cantaloupe with and without an edible coating (control) after 0, 9, and 18 days of storage at 4 °C.

4. Conclusions

ECs based on LM, CH, and their combination (LMCH) were effective at reducing juice leakage and fruit softening. The CH EC was the most effective at preserving the color parameters (a^* and b^*), while LM and LMCH had only a slight effect on preserving the luminosity (L^*). ECs based on CH (CH and LMCH) decreased the pH and increased TA. However, LM did not help to preserve the AA content. Moreover, the ECs helped to reduce the growth of aerobic mesophilic microorganism, molds, and yeasts. The EC based on LMCH was less effective at reducing the overall microbial levels relative to CH; this finding might be associated with an electrostatic interaction between these polymers. The antimicrobial effect of the ECs was reflected in a reduction of the sensory decay rate. The CH and LM ECs helped to preserve the overall sensory characteristics (color, odor, flavor, and texture), thereby increasing the acceptance of the fresh-cut cantaloupe to 12–15 days. Finally, the combination approach (LMCH) helped to preserve the color and odor properties. However, the overall sensory acceptance of the LMCH-coated cantaloupe was similar to the control (up to 9 days) because this EC modified the texture and flavor of the fresh-cut fruit.

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