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Composite Alginate–Ginger Oil Edible Coating for Fresh-Cut Pears

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Abstract: Fresh-cut fruit is highly perishable due to damage to its external protective skin leading to the acceleration of chemical and biochemical activities, respiration rate, ethylene production, texture softening and moisture loss. Edible films and coatings can provide effective barrier properties to control respiration and transpiration of produce. Sodium alginate and ginger oil have been successfully employed as coating materials in several studies. This study focused on evaluating the effect of composite alginate and ginger-essential-oil-based edible coatings for controlling physiological and microbiological activity in fresh-cut pear during refrigerated storage. A 2% sodium alginate solution with 0.5% ginger oil as a herbal antimicrobial agent was used as coating material and a 2% calcium chloride dip was used for cross linking and firming. Coated cut fruit and control cut fruit were sealed in plastic containers and stored at 4 °C for two weeks. Respiration rate, color, texture, moisture loss and other quality parameters were evaluated during the storage. The coated fruit (both with and without ginger oil) had significantly better retention of product quality with no microbial spoilage up to 15 days as compared to the control fruit which spoiled within a week. The sodium alginate–ginger oil–calcium alginate formulation was recommended as a good composite coating for extending the refrigerated shelf-life of cut pears.

Keywords: emulsion; cut fruit; edible coating; shelf life; antimicrobial

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1. Introduction

Fruit and vegetables play a very important role in the human diet and are the sources of many nutrients in the human diet. Food security is therefore important. It is essential that we conserve the food we grow. Food losses occur at every step of postharvest supply chain management, starting in the field through harvesting, handling, storage, processing, transportation and, distribution, and finally with consumer use [1]. Nearly 40% of food is wasted overall in one way or the other at different stages of fruit and vegetable handling [2]. There is a huge global demand for fresh-cut fruit and vegetables, but their perishability rate is very high. Post-harvest spoilage factors include several physiological activities such as respiration and transpiration rates, ethylene production, microbial, physical, and chemical activities, and other environmental conditions during postharvest handling. Postharvest applications such as refrigeration, controlled and modified-atmosphere storage/packaging, irradiation, application of edible coatings, etc., have been explored for effective control of spoilage and shelf-life extension [1].

Edible coatings have been found to be promising preservative methods and they have an effect on external appearance and glossiness. Edible coatings offer a physical barrier between the fruit surface and the external surroundings which eventually leads to preservation of post-harvest quality [3]. Recent studies of edible coatings with plant extracts (ginger, cinnamon, oregano, lemongrass essential oils), organic acids (acetic, benzoic, lactic, propionic acid), nitrites, sulfites, and other components have found that these can extend the coatings' effectiveness [4,5]. Edible coatings have been found to effectively control both

respiration and transpiration activities, and therefore to control physiological activities as well as moisture loss. However, many of the active films/coatings formed by these pure biomacromolecules often do not meet the real needs for food packaging and preservation [6].

Edible coating is defined as a thin layer that is applied to the surface of the fruit to create a barrier between the fruit and the environment, but which can be eaten as part of the whole product [2,3]. In explorative studies, coating and film application are usually carried out using dipping and casting processes, and on a commercial scale, extrusion and spraying processes are used for film formation [5]. Different biopolymers such as proteins, polysaccharides, gums, and lipids [4,7] are used. The polysaccharides used include various starches such as modified starches, chitosan, alginates, gums, cellulose derivatives, and pectin [4,7]. The most used protein-based edible coatings are gelatin, corn zein, wheat gluten, soy protein and casein, and collagen. Shellac- and oil-based coatings, fatty acids, and monoglycerides are some lipid-based edible coatings [7].

Sodium alginate has been widely used in coating applications. Alginate is obtained from brown seaweed and contains salts of alginic acid. Alginate has some desirable functions including reduction of shrinkage and retention of the moisture, color, and odor of food commodities. An alginate-based coating with cinnamon extract has been found to be effective on fresh-cut apple and pear against *Aspergillus carbonarius* growth and ochratoxin A production and in extending shelf-life [8]. In one of the studies, sodium alginate coating with a subsequent calcium chloride dip has been shown to extend the shelf life of cut strawberries stored at 4 ºC for up to 15 days [9]. Presently, there has been an increased interest in the development of natural edible coatings, using herb extracts such as cinnamon, clove, lemongrass, oregano, rosemary, and mint because these can contribute antimicrobial properties to edible coatings. Many herb extracts have been proven to possess antimicrobial activities, and these extracts are generally recognized as safe (GRAS) [9,10]. The incorporation of essential oils into edible coatings has been widely studied in the literature, with reports of reduced postharvest losses in plums as well as peaches [4,11]. Composite coatings have been considered as the future of these coatings, and are made by the incorporation of combinations of polysaccharides, proteins, and lipids to deliver an effective barrier [12]. Oms-Oliu used edible coatings with anti-browning agents to maintain the sensory quality and antioxidant properties of fresh-cut pears [13]. Composite edible coatings are most suitable coatings for cut fruit and vegetables for prolonging the shelf life.

Pears belong to the family *Rosaceae*, also called pome-type/false fruit. Like all other fruit, pear is consumed fresh or processed into cut pieces, puree, juice, fiber or other products and preserved in many different forms; fresh, canned, frozen, dehydrated, etc. Refrigerated and controlled-atmosphere storage/packaging are the best approaches used for fresh storage. Cut fruit is sold to a limited extent in packaged refrigerated formats. Fresh-cut pear has become an important food commodity, with demand growing quickly due to the preserved freshness, to it being part of a healthy diet and to increased demand in various food sectors. Fresh-cut pears have a very high susceptibility to enzymatic browning and tissue softening after cutting [14,15]. Many studies, noticeably those using starch [16,17]. Pectin [15], and aloe vera-based coatings [14], have been carried out on the coating of fresh fruit, and very few coating materials have been successfully employed on fresh-cut pears. A few studies have also been carried out using whey protein for cut pears [18,19]. In general, shelf-life has been extended by 10–12 days under refrigerated conditions for cut pears.

Edible coating using sodium alginate and ginger oil has not been explored with cut pear cylindrical pieces, especially when used with a calcium dip and a citric-acid-enhanced medium. Ginger essential oil has been incorporated into coating solutions mainly because it is less expensive compared to other essential oils such as cinnamon and mint, etc. Like other herbal extracts, it exhibits excellent antimicrobial and oxidative properties, and it also has additional health benefits for consumers as it can relieve several health complaints [20]. Therefore, this study was focused on evaluating the efficiency of sodium alginate–calcium chloride treatment together with Tween-80 stabilized ginger oil for

controlling the physiological, physicochemical, textural, microbiological, and appearance quality of fresh-cut pears.

2. Materials and Methods

2.1. Sample Preparation

Fresh pears were purchased from a local market in bulk and were selected based on similar appearance, color and shape/size and stored at 4 °C and used within two days. The fruit was washed in water and cut into round cylindrical slices of 1 cm thickness and 2 cm diameter and dipped in 1% ascorbic acid solution for 5 min and drained before coating to prevent discoloration. Cut-fruit pieces were again washed with water, drained, and left for 10 min at room temperature, and were then divided in to three lots and held in plastic containers at 4 °C for treatment and storage.

2.2. Preparation of Sodium Alginate and Calcium Chloride Solutions

Sodium alginate (Sigma, Oakville, ON, Canada) solution 2% (*w*/*w*) was prepared by dissolving sodium alginate into water with mixing facilitated by a magnetic stirrer at 300 rpm with no heat until complete dissolution [9] and then the solution was autoclaved. A 2% calcium chloride solution (Sigma, Oakville, ON, Canada) was used as the firming agent, and was prepared by dissolving the required amount of calcium chloride in distilled water.

2.3. Preparation of Coating Solution/Emulsion

Two edible coating solutions were prepared, one with essential oil and the other one without. The ginger essential oil (Hana, Paul Street, London, UK) (at 0.5%) was solubilized by adding Tween 80 (Croda, Inc., Mill Hall, PA, USA) as an emulsifier. Citric acid (Milliard, Lakewood, NJ 8701, USA) was added to provide an acidic sensorial property and also to enhance the synergistic functional properties of the coating solution. A high-speed homogenizer was used at 18,000 rpm for 5 min to create a stable emulsion [21]. The sodium alginate–citric acid sample was labeled SACC, and the coating incorporating ginger oil was labeled SAGEO.

2.4. Sample Treatment

Prepared coating solutions (with or without ginger essential oil) were poured into marked treatment containers and fresh-cut pear samples that were pre-dipped in ascorbic acid (Sigma, Oakville, ON, Canada) were added and held immersed in the coating solutions for 5 min, drained, dipped into 2% calcium chloride solution for 5 min in order to fix the coating material better, and were finally drained again for 3 min. They were then spread on aluminum foil at room temperature for surface drying for 10–15 min. The coated cut fruit was placed in plastic containers with 3–5 small holes (to prevent anaerobic conditions) on the top cover and stored in a refrigerator at 4 °C for 15 days. Samples were taken out at 3-day intervals for testing for different quality parameters.

3. Physiological Properties

3.1. Respiration Rate

Control samples and coated samples weighing 50 g (expressed in kg) were kept in an airtight Plexi-glass chamber (18 cm × 12 cm × 27 cm) at room temperature (22 °C) for 2 h [9,22]. The chamber was fitted with a CO_2 sensor (ACR Systems Inc., St-Laurent, QC, Canada), data from which were transferred to a computer through a data acquisition system (Smart Reader plus 7). CO_2 evolution data were gathered every 1 min up to 2 h and the rate of change in concentration was used to compute the respiration rate using Equation (1) based on the CO_2 evolution rate (mL CO_2 evolved per h). Tests were carried out in triplicate. Respiration is a physiological activity and is vital for the living produce. The natural respiration rate can be expected to increase once the pear fruit is cut, thereby exposing the internal surface to the environment. An edible coating is applied in

order to reduce the respiration rate in cut fruit by covering the open fruit tissues with a protective layer.

$$\text{Respiration rate} = CO_2 \text{ evolution rate (mL/h)/Mass (kg); } mLCO_2/kg{\cdot}h; mLCO_2\ kg^{-1}\ h^{-1} \quad (1)$$

3.2. Transpiration Rate

The weight loss in cut pears over time was taken as a measure of the transpiration loss under the conditions of storage. The control samples and the coated samples were weighed on day 0 and again every 3 days during storage using a balance, (Denver instrument, APX-323, Bohemia, NY, USA). Weight loss or moisture loss was recorded and presented as percentage of the initial weight of the sample [9,15]; tests were carried out in triplicate.

$$\text{Weight loss (\%)} = [(W1 - W2)/W1] \times 100 \quad (2)$$

where W1 was the initial weight and W2 the weight measured after storage.

3.3. Color and Appearance

Color parameters were measured using a colorimeter, a tristimulus Minolta Chroma Meter (Minolta crop, Ramsey, N). The colorimeter was calibrated with white standard and calibration was carried out each time while taking readings. A total of 15 cut-pear samples from each treatment were used to evaluate the L value (lightness, loss of whiteness or brightness), a* value (green to red shades), and b* value (yellow to blue shades) which were used to evaluate hue angle and chroma at room temperature. A total of 15 samples from each treatment, SACC, SAGEO, and control, were kept in storage containers for up to 15 days at (4 °C). The external surface was evaluated, and browning of samples and mold growth were observed.

4. Physio-Chemical and Textural Properties

4.1. pH

The 50 g control samples and coated samples were separately homogenized with 150 mL distilled water using a blender, followed by filtration, and the filtrate was divided into three replicates in 30 mL small beakers. pH was measured with a calibrated pH meter (Brinkman Co., Mississauga, ON, Canada).

4.2. TSS (Total Soluble Solids) (° Brix)

A digital refractometer (ATAGO N1, Kirkland, DC, USA) was used to measure the total soluble solids (TSS) of the control samples and the coated samples. The test was conducted in triplicate, and TSS was expressed in degrees Brix. The 50 g control samples and coated treatment samples were blended and filtered using a sieve; filtrate was used to measure TSS.

4.3. Titratable Acidity (%)

The 50 g control samples and coated samples were separately blended with 150 mL distilled water and filtered using a sieve. A total of 10 mL of filtered juice (control and coated) was titrated with 0.1 Normal NaOH using two drops of phenolphthalein added as color-change indicator. The AOAC procedure of titratable acidity measurement for fruit was followed [23]. Titratable acidity (%) was calculated using volume of NaOH used, applying a multiplication factor (0.064) for citric acid, and the results were expressed as citric acid (%).

4.4. Texture & Elasticity

Texture measurements were made using a Texture Analyzer (Model TA XT Plus, Texture Technologies corporation, Scarsdale, NY, USA/Stable microsystems, Godaminig, Surrey, UK). In total, 15 cut pieces of pear samples from both control and coated samples were tested using a round-tipped puncture TA52 probe (2 mm diameter) with a crosshead

speed of 10 mm/s. Firmness (N) and elasticity (mm) values were obtained from the TA software.

4.5. Mold Count

The 10 g of samples from each treatment were blended with 0.1% peptone water and filtered. The serial dilution method was followed. PCA (Plate count agar) media was used and the pour plate method was followed. Every 3 days, mold colonies were counted; tests were carried out in triplicate and counts were represented as log CFU/mL.

5. Statistical Analysis

Minitab Statistical Software was used to conduct a one-way analysis of variance (ANOVA) at a 95% level of confidence and 5% level of significance. Tukey's method of comparison was used to indicate the significant difference between the control samples and the coated samples during storage as well as between the different storage times for all three treatments, i.e., the control samples and the two coated samples ($p < 0.05$).

6. Results and Discussion

6.1. Physiological Activity

6.1.1. Respiration Rate

One-way ANOVA results showed no significant difference ($p \geq 0.05$) between the control samples and the coated samples (Figure 1a). The control samples and the SACC samples showed similar CO_2 evolution rates of 64.3 and 64.4 $mLCO_2\ kg^{-1}\ h^{-1}$, respectively, on day 0 and a somewhat higher respiration rate was found in the SAGEO samples, with 79 $mLCO_2\ kg^{-1}\ h^{-1}$. A significant increase in the CO_2 level ($p < 0.05$) was observed with the control samples on day 3, while no increase in CO_2 was observed in samples coated with SACC, and a decrease in the respiration rate was noted in the SAGEO samples which had a lower respiration rate of 63.5 $mLCO_2\ kg^{-1}\ h^{-1}$. By day 6, the respiration rate increased to over 103 $mLCO_2\ kg^{-1}\ h^{-1}$ in the control samples, 85 $mLCO_2\ kg^{-1}\ h^{-1}$ in the samples coated with SACC, and 69 $mLCO_2\ kg^{-1}\ h^{-1}$ in the SAGEO samples. The samples coated with SACC and SAGEO continued to show lower CO_2 levels until day 9, while levels increased to 149 $mLCO_2\ kg^{-1}\ h^{-1}$ for the control samples. On day 12, an increase was seen in all three treatments, with control samples reaching the climacteric peak at 242 $mLCO_2\ kg^{-1}\ h^{-1}$ while SACC and SAGEO samples increased to only 152 $mLCO_2\ kg^{-1}\ h^{-1}$ and 122 $mLCO_2\ kg^{-1}\ h^{-1}$, respectively.

A decrease in CO_2 was observed on day 15 in control samples but there was no change in samples coated with SACC. A slight increase in CO_2 was recorded in SAGEO-treated samples but it was still lower than in the control samples. One-way ANOVA showed significant ($p < 0.05$) difference among the treatments during the 15 days of storage time. Physiological factors such as transpiration and gas exchange show higher metabolic activity upon harvesting and cutting of samples due to the exposure of cut internal surfaces. The use of modified atmospheric packaging along with postharvest techniques is generally employed to combat the high respiration rate [24].

Some studies have shown that the presence of Ca^{2+} ions in a film-forming solution reduces the initial respiration rate and ethylene production of coated cut apples and cut strawberries [9,13]. In agreement with these studies, dipping cut pears into $CaCl_2$ lowered the respiration rate. The obtained data are in agreement with some published studies demonstrating how the incorporation of essential oils and other additives improves the effectiveness of edible coating. Rojas-Graü et al. [25] reported that the concentration of essential oil can affect the headspace gas composition on fresh-cut apple coated with sodium alginate edible coating containing essential oil. The gas barrier properties of the edible coating were improved due to the interactions between the essential oils and the coating material [26]. Edible coatings help in reducing the respiration and diffusion of gases, but special care has to be taken to maintain the internal gas composition. Very low O_2 concentration may lead to anaerobic respiration which will result in ethanol and off

flavor production [26]. In one of the studies [27], the authors reported that 0.5% nano chitosan coatings could slow down ripening and climacteric respiration peak. This study also confirmed that sodium alginate coating lowered the respiration rate of coated samples compared to the control samples. Significant differences were also noted in the CO_2 level among the cut apples coated with alginate coating with and without essential oils [28].

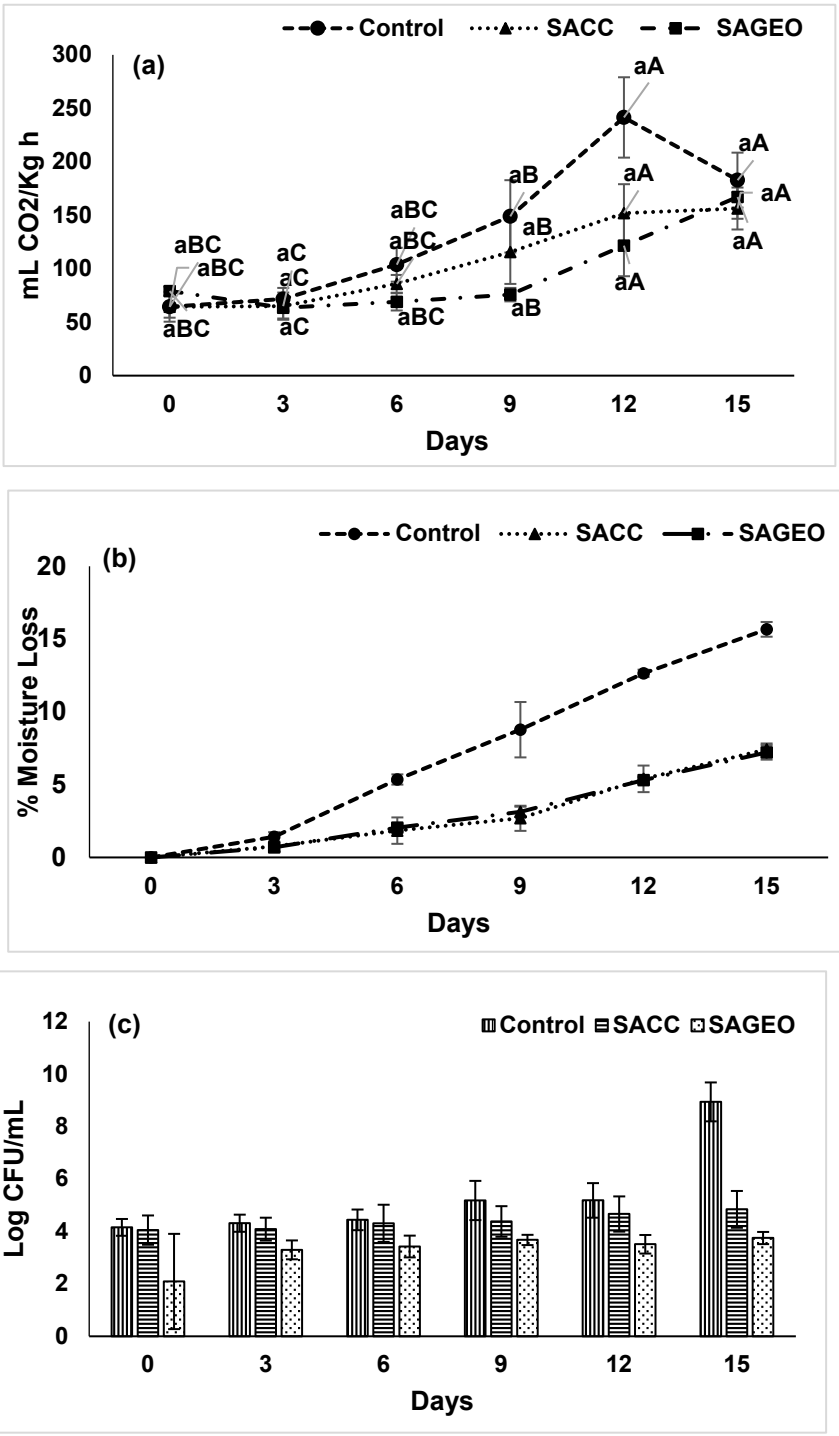

Figure 1. (**a**) Changes in respiration rate, (**b**) moisture loss and (**c**) mold growth during 15-day storage period. Vertical bars indicate standard deviation (±). SACC: samples coated with sodium alginate only; SAGEO: samples coated with sodium alginate incorporating ginger essential oil. Different letters in lower case indicate a significant difference between the treatments. Different letters in upper case indicate values within the same storage day are significantly different ($p \leq 0.05$).

6.1.2. Moisture Loss (Transpiration Rate)

A small change in moisture loss was observed on day 3 (1.4% with control, 0.76% with SACC and 0.69% with SAGEO). A significantly higher moisture loss of 5.4% was observed in control samples on day 6 while losses of only 1.84% for SACC and 2.4% for SAGEO were observed with the coated fruit. By day 9, moisture loss in the control samples increased to 8.78% and reached 12.6% on day 12. The cut-fruit samples coated with SACC and SAGEO showed no significant difference in moisture loss ($p \geq 0.05$), with a loss of less than 5% until day 9 and moisture losses of 5.4% and 5.31%, respectively, recorded on day 12. After 15 days, a 15.7% moisture loss was observed in the control samples, a 7.4% loss was found in samples coated with SACC, and a 7.2% loss was seen in samples coated with SAGEO. Studies have reported lower moisture loss when an essential oil is incorporated into the coating material. While high moisture loss occurs in control samples due to the increased transpiration rate, coating with essential oil lowers the weight loss due to the hydrophobic part in emulsion coating which acts as a barrier against the transpiration rate [7,26,29]. One of the studies with strawberries coated with carboxyl methyl cellulose and garlic essential oil reported that weight loss was prevented and shelf life was extended [30]. Some studies suggest that lower weight loss in coated cut-fruit samples can also be attributed to the slower ripening rate of the coated samples [31,32].

One-way ANOVA showed a significant difference in moisture loss among the control and coated treatments ($p < 0.05$) (Figure 1b). Loss in weight results from moisture loss and is also due to other components which are considered negligible [26]. Moisture plays a very important role in the shelf life of fresh fruit and vegetables. Moisture is directly related to texture (turgidity), to other metabolic activities, and to the freshness of produce.

Figure 1b shows the percentage moisture loss in all the three treatments during the 15 days of storage. Based on the data collected, moisture loss was prevented in the SACC and SAGEO samples when compared to the control samples. One-way ANOVA showed a significant difference in weight loss under control and coated treatments and during the 15-day storage period ($p < 0.05$), but no significant differences were observed in weight loss between the two coated treatments ($p \geq 0.05$) during the entire experiment.

6.1.3. Mold Growth

The coated samples showed lower mold counts than the control samples (Figure 1c). The ginger essential oil was incorporated into the coating matrix in SAGEO to provide a natural antimicrobial property. SAGEO samples showed an excellent antimicrobial property, with less than 3 log [CFU/mL] mold growth during the study. On day 0, the control and SACC samples showed 4 log [CFU/mL], whereas the SAGEO samples showed a reduced 2 log [CFU/mL] which was half as much as the other two treatments. The CFU values of the SACC treatment samples remained same on day 3, while an increase in the count to 4.4 log [CFU/mL] was observed in the control samples. With the samples coated with SAGEO emulsion, the counts were 3.3 log [CFU/mL]. As shown in Figure 1c, more than 5 log [CFU/mL] was observed in the control samples on day 9, while no increase in the count was associated with either of the coated treatments. One-way ANOVA showed no significant difference in the microbial count of the two coated treatments until day 12 ($p \geq 0.05$). On day 12, a slight increase in the count was observed in samples coated with SACC; however this was still less than the count for the control samples which crossed the threshold level [3–5 log(CFU/mL)] There was no increase in the count in the SAGEO samples which was below the threshold level. One-way ANOVA showed no significant difference in microbial growth between the control samples and the samples treated with SACC ($p > 0.05$), but there was a significant difference between the control and SAGEO treatments during storage ($p < 0.05$). Edible coatings which incorporate different combinations of essential oils have been proved to have lower gas transfer which leads to a decline in the availability of oxygen to the fruit's tissue, which could lower microbial growth on surface [24].

The control samples showed a count of 8.9 log [CFU/mL], much higher than threshold level, on day 15. Slight increases in the count were observed in both coated treatments, 4.8 log [CFU/mL] and 3.7 log [CFU/mL], respectively. Based on the data collected, the use of herbal extract was shown to play a very significant role in improving the effectiveness of edible coatings. Hashemi et al. [16] observed the positive effect of starch-based edible coating with *Adiantum capillus veneris* extracts (0, 0.1, 0.2 and 0.3% *v*/*v*) which were reported to enhance their antioxidant load and decrease microbial contamination.

When fruit is cut, it loses its natural skin barrier and its tissues are exposed to external conditions. As cut fruit and vegetables are consumed raw, their microbiological safety is a concern for both producers and consumers. An active coating with antimicrobial properties can safeguard produce from microbial spoilage and extend the shelf life of cut fruit and vegetables [26].

No major mold growth was seen throughout the experiment in the coated samples. Mold growth was observed on day 9 on the surface of the control samples. Mold growth developed rapidly on the control samples after that, while in case of the coated samples only a slight change in color was observed. On day 12, browning of the control samples was observed with texture values demonstrating tissue softening. The coated samples showed no sign of mold growth or browning.

7. Physico-Chemical Properties

7.1. Color

Since alginate coating creates a semi-permeable barrier that controls gas exchange, reducing the contact of the exposed fruit surface to oxygen, the combined effect of coating plus ascorbic acid resulted in an effective way to control browning in cut pear samples. Moreover, the addition of citric acid enhanced the anti-browning capacity of the sodium alginate. Color was influenced by the sodium alginate-based edible coating on fresh-cut fruit, and color retention in the coated samples was better when compared with the control samples [33]. Enzymatic browning, which is caused by the enzyme polyphenol oxidase that is found in many fruits, is frequently the major limiting factor on the shelf life of fresh-cut fruit such as pear and apples. After some days of storage, the control samples started to lose lightness, whereas tissue browning was significantly delayed in the samples coated with SACC and SAGEO. Sharma & Rao [34] and Xiao et al. [35] reported that enzymatic browning was delayed in fresh-cut pears coated with essential oils as the polyphenol oxidase reaction was inhibited.

Natural anti-browning agents play a very important role and help in the modification of the internal gaseous atmosphere in the fruit when they are coated. Ascorbic acid is a well-known antioxidant that has been successfully used to reduce enzymatic browning in pome fruits [36,37]. A decrease in L values indicates the emergence of browning/darkening in samples and an increase in a* values (positive) indicates that the samples are turning more brown/red which reflects the ripening status of the fruits.

7.2. L Value

The same L value was recorded on day 0 for all three samples. The L value decreased to 73.7 from 74.4 in the control samples and to 74.1 from 75.6 in the samples coated with SACC and SAGEO. A slight decrease in the L value from 75.6 to 74.8 was seen in the SAGEO samples by day 3. A rapid decrease in the L value of the control samples was observed by day 6, reaching 66.4, but no significant decrease was seen with either of the coated treatments (SACC and SAGEO). L values of 72.5 and 73.5 were recorded, respectively. A similar trend was observed in a previous study carried out by Passafiume et al. [14] on cut Italian pears using an aloe vera-based edible coating. The coated samples did not show a notable decrease in L value compared to the control samples on day 9 and 12, with L values of 59.5 and 57.0 observed in the control samples on these days, respectively. The addition of citric acid showed a positive impact on preserving the lightness of cut pears [38,39]. One-way ANOVA showed no significant difference in the L value of the control and coated

samples ($p \geq 0.05$). On day 15, the control samples recorded the lowest L value of 54.6, and the coated treatments (SACC and SAGEO) had L values of 67.4 and 68.2, respectively. Figure 2a shows the data collected during the study. A high L value was observed in samples with edible coating containing ginger essential oil during the storage period, and the same trend was also observed in the study carried out by Chiabrando & Giacalone [28] on cut apple samples treated with a coating containing rosemary essential oil.

7.3. a Value*

Figure 2b shows the a* values of all three treatments during storage. It was observed that the storage time significantly influenced the change in parameter a*. Negative a* values were observed on day 0 in the control samples as well as in the coated samples as the fruit samples were freshly cut and negative values show a high proportion of green color [18]. The a* value of the control samples increased to 1.01 on day 3, and a negative a* value in the coated samples of the SACC and SAGEO treatments was noted. A slight decrease was seen in the control samples on day 6, and a slight increase in a* value was observed with the SACC samples, whereas the SAGEO samples still showed negative a* values. The presence of citric acid as an anti-browning agent prevented cut fruits darkening during storage. On day 9, the a* value increased to 2.45 in the control samples but only a slight increase in the coated samples was recorded, with a* values of 1.01 and 0.03 in the samples coated with SACC and SAGEO, respectively. One-way ANOVA showed a significant difference ($p < 0.05$) in the a* value of the control samples and the coated samples during storage. The a* value of the control samples increased to 2.8 and 2.8 on days 12 and 15, respectively, whereas the SACC coated samples showed values of 2.2 and 2.3. The lowest a* values of 1.18 and 1.76 were observed with the SAGEO samples.

7.4. b Value*

The value of the b* parameter (yellow and blue) for all samples was positive. No significant ($p > 0.5$) difference between the b* values of the control samples and the coated samples was observed during the 15 days storage time. The control samples showed a higher b* value of 16.9 on day 0, and the coated treatments showed similar data with a b value of 11.9. The b* value of the control samples and the two coated samples increased to 18.5, 14.3 and 15.0, respectively on day 3. On day 6 and day 9, the b* value of the control samples decreased to 18.0 and 16.0, respectively, while a slight increase to 15.8 and 15.7 was observed in the samples coated with SACC. For the samples coated with SAGEO there was an increase to 16.6 and 16.9.

An increase in the b* value was recorded in the coated samples on days 12 and 15, with the samples coated with SACC having b* values of 18.2 and 22.2. In the case of SAGEO treatment, b* values of 18.4 and 18.0 were observed. On day 15, the control samples showed an increase in b* value to 18.9. Progressive change in color was seen in this parameter which had the highest value in the case of the tests carried out on the cut fruits without the addition of ginger essential oil. The type of coating used did not lead to any significant statistical differences between the b* value for the coatings. One-way ANOVA showed no significant difference between the control samples and the samples coated with SACC and SAGEO during the storage time ($p > 0.05$). Figure 2c shows the data for the 15 days.

8. Physio-Chemical and Textural Properties

8.1. pH

pH was measured during the 15-day experiment, and the results showed that the control samples had a larger increase in pH than the coated samples. The control samples and the samples only coated with sodium alginate and calcium chloride showed similar readings, while the samples coated with sodium alginate incorporating the essential oil showed a much lower change in the pH reading on day 0 due to the presence of citric acid.

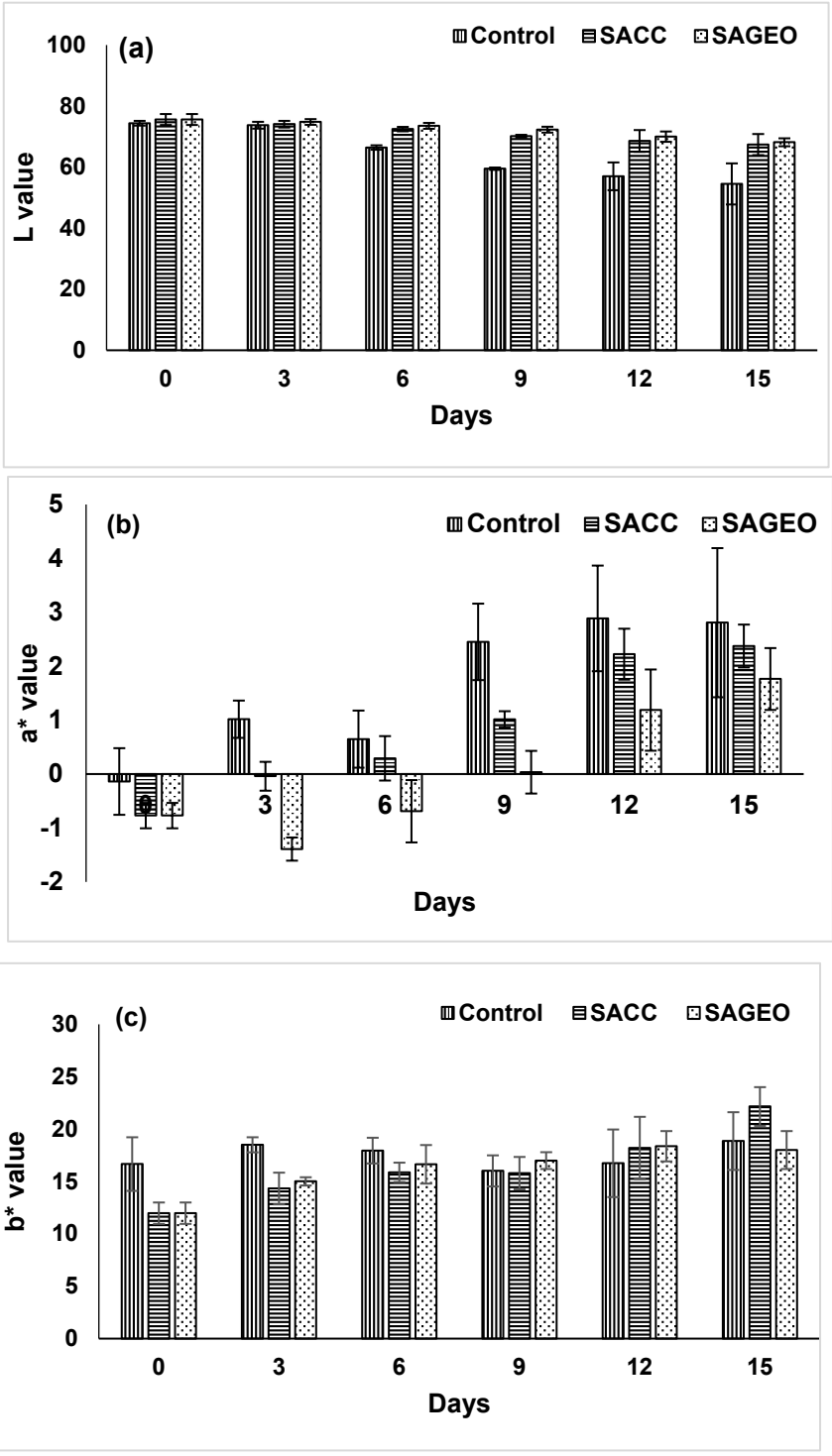

Figure 2. (**a**) Changes in L values, (**b**) changes in a* values, (**c**) changes in b* values during the 15-day storage period. Vertical bars indicate standard deviation (±). **SACC** treatment: samples coated with sodium alginate only; **SAGEO** treatment: samples coated with sodium alginate incorporating ginger essential oil.

On day 3, the pH of control samples increased to 5.0, and the pH then increased to 5.3 and 5.9 on days 6 and day 9, respectively. It then went up to 6.3 and 7.9 on day 12 and day 15, respectively. The increase in pH meant a decrease in the acidity of the samples. The samples coated with SACC did not show a notable increase in pH; on day 3 and day 4 pH levels of 4.53, 4.64 were observed and a very slight increase was found on day 9. The levels

reached 5.0 and 5.2 on day 12 and day 15, respectively. Lower pH and high acidity control mold growth more effectively. There was no significant difference between the pH of the coated treatments (SACC and SAGEO) until day 12 ($p \geq 0.05$).

In comparison with the control samples, there was not any notable increase in the pH of the coated treatments, something which indicated that the sodium alginate coating contributed to the moderation of the pH of the coated samples. One of the studies stated that a low pH could be due to a low maturity stage at the time of minimal processing [34]. Finally, the SAGEO samples showed a relatively low increase in pH level even when compared to the samples coated with sodium alginate without ginger essential oil (SACC). One-way ANOVA showed a significant difference in the pH of the control and coated treatments during the 15 days' storage time ($p < 0.05$). For product quality acceptance, all these values have to be in the 10% limit [40] and this was achieved during experiment (Figure 3a).

8.2. Total Soluble Solids (° Brix)

On day 0, both the control samples and the samples coated with sodium alginate showed similar readings, whereas the TSS of the samples treated with SAGEO was 7.1° Brix. On day 3 there was no notable increase in the TSS content of either the control samples or the coated samples. A rapid increase in TSS content of the control samples was seen as it rose to 9.3° Brix, whereas the coated samples showed no increase in TSS value until day 9, and this increase was less in the samples treated with SAGEO emulsion. On day 12, the TSS content of the control samples reached 12° Brix and increased to 16.5° Brix on day 15. The coated samples showed a <10° Brix increase in TSS content until day 12. An increase in TSS is not associated with the influence of coatings or essential oils in the coatings [26]. A slight increase was recorded in the samples coated with SACC, whereas the samples with SAGEO coating showed considerably less increase in TSS. One-way ANOVA showed a significant difference in TSS between the control samples and both the coated samples ($p \leq 0.05$) but showed no significant difference in TSS between the two coated treatments until day 12.

The edible coatings slowed down the deteriorative biochemical changes as compared with the control samples by lowering the metabolic activity of the cut fruit and preventing the increase in sugar content at 4 °C during the 15 days of storage time [14,15]. The edible coating prevented an increase in the TSS content of the coated samples by lowering the metabolic activity of the cut fruit and prevented an increase in sugar content at 4 °C during the 15 days of storage time (Figure 3b). A study carried out by Gomes et al. and Souza et al. [24,41], proved that increases in TSS are associated with moisture loss during storage. One-way ANOVA showed a significant difference between the TSS of the control and coated treatments during the 15 days of storage time ($p < 0.05$).

8.3. Titratable Acidity

One-way ANOVA showed no significant difference in titratable acidity (TA) on coated treatments ($p \geq 0.05$) until day 9. TA is related to the presence of acids in the fruit, the conversion of organic acids into sugars, and the development of microbial activity on fruit. A higher acid content lowers the growth potential of molds and yeast [26]. There are several studies which report the effects of essential oils on the chemical composition of fruit. The Hosseini et al. study [42], which was carried out on kumquat fruit treated with chitosan incorporating essential oils in different combinations, showed a similar decrease in the acidity of fruit.

Even on day 0, all three treatments showed some small distribution in data, something which is a natural representation of fruit-to-fruit variability. Slightly higher TA was observed in pears coated with SAGEO edible coating due to the presence of citric acid. A similar trend was observed in another study by Pleșoianu and Nour [15] where it was observed that the addition of ascorbic acid and citric acid with chemical dip resulted in

significantly higher TA in cut pears during 15 days of storage. The authors reported that the addition of preservative delayed the fermentation process in the fruit.

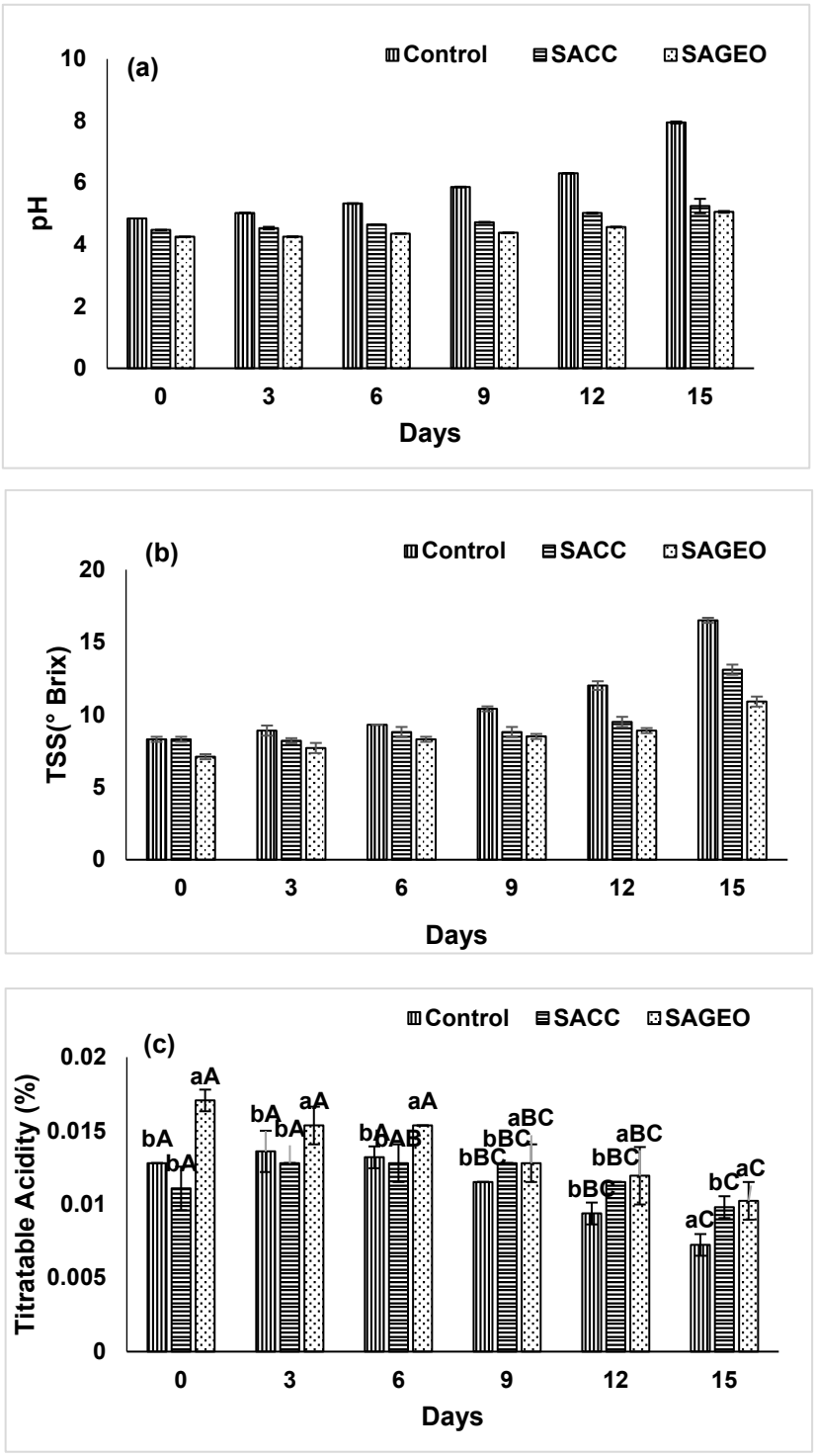

Figure 3. (**a**) Changes in pH, (**b**) changes in (TSS) total soluble solids (**c**) changes in TA value during the 15-day storage period. Vertical bars indicate standard deviation (±). (**SACC**) treatment: samples coated with sodium alginate only; (**SAGEO**) treatment: samples coated with sodium alginate incorporating ginger essential oil. Different letters in lower case indicate a significant difference between the treatments. Different letters in upper case indicate values within the same storage day are significantly different ($p \leq 0.05$).

A slightly higher TA was recorded in the control samples compared to the samples coated with SACC. A gradual decrease in TA levels was observed in the control samples, with 0.014% on day 3 and 0.013% on day 6. The coated samples showed a TA of 0.013% and this remained same until day 9. A slight decrease in TA was recorded in the SAGEO treatment samples compared to the control samples. On day 12, titratable acidity decreased to 0.0094% in the control samples, to 0.012% in the SACC treatment samples and to 0.012% in the SAGEO samples. On day 15, TA in the control samples decreased to 0.0073%, whereas the coated treatment samples showed a lower decrease in TA. Figure 3c shows the difference in TA recorded during the experiment. One-way ANOVA showed no significant difference between SACC treatment and SAGEO ($p \geq 0.05$). One-way ANOVA also showed no significant difference between the control samples and the coated samples during 15 days of storage ($p \geq 0.05$).

8.4. Texture Firmness

The pear samples treated with sodium alginate showed very good retention of original firmness during the 15 days' storage. Firmness was measured as the maximum force (N) at failure as the probe passes through the fruit tissue. All three treatments showed similar results on day 0, but demonstrating some variability. One-way ANOVA showed no significant difference between the control samples and the coated treatment samples ($p \geq 0.05$). A decrease in the firmness value in the control samples was observed on day 3, with the value falling from 5.6 to 5.1 N. The samples coated with SACC showed a small decrease from 5.5 N on day 0 to 5.3 N on day 3, and in the case of the SAGEO coating the value fell from 5.6 N on day 0 to 5.4 N on day 3. No significant difference was observed between the coated treatments. Coated samples showed high firmness values until day 12 compared to the control samples in which the firmness was reduced to 4.7 N on day 12. Figure 4a shows graphical information on the loss of firmness in all three samples during storage. By day 15, the difference in the firmness value of the control samples and the coated samples was even more clear due to the loss of respiration and transpiration activities, with a firmness of 4.7 N for the control samples versus 5.0 N for the coated samples. The odium alginate coatings lowered the moisture loss and preserved the firmness of the cut-pear samples.

A recent study [43] using chitosan and incorporating trans-cinnamaldehyde in it showed a positive influence on firmness by decreasing the damage by free radical to the membrane structure of cut melons. The study also found that edible coating with essential oil further lowered the respiratory metabolic activity of cut fruits. Oms-Oliu et al. (2008) [13] reported that the texture of the control fresh-cut pears was retained over the storage period and calcium chloride may not even be needed to maintain firmness of cut pears. Somewhat similar results were observed in this study.

Texture is an important factor in determining the quality and shelf life of fresh-cut pears. During the storage period, the feel quality of cut fruits is affected by the softening of tissue and this reduces shelf life. The use of essential oil may promote some protection activity which leads to better firmness retention in cut fruit [26]. One of the primary properties of edible coatings is to preserve the texture by preventing moisture loss and retarding the metabolic activity in cut fruit. The addition of acetic acid to chitosan coating has been beneficial to preserving/maintaining the firmness of cut prickly pears for 12 days [44,45].

8.5. Elasticity

Elasticity plays an important role in cut fruit and vegetables. This parameter was measured, along with firmness, as the distance (mm) the probe travelled into the fruit tissue at the maximum firmness. A small decrease in elasticity values was observed in the coated samples, with values lowered from 9.4 mm to 8.9 mm on day 3, whereas the control samples showed a higher loss from 10 mm from on day 0 to 8.1 mm on day 3. One-way

ANOVA, however, showed no significant difference in the elasticity values of control and coated samples until day 6 ($p \geq 0.05$).

The elasticity value of the control samples was 7.9 mm on day 6, and eventually was further lowered on day 9 to 6.6 mm. There was little loss in elasticity in coated samples compared to the loss in the control samples, 8.3 mm and 8.1 mm elasticity values were observed, respectively. This decreased further to 7.8 mm and 7.5 mm on day 9 in both coated treatments, respectively. Further loss in elasticity was observed in the control samples on day 12, with an elasticity of 5.7 mm, while the SACC and SAGEO samples retained 7.3 mm and 7.5 mm, respectively, which was much higher than the control samples. On day 15, the lowest value of 4.8 mm elasticity was recorded in the control samples, and the SACC and SAGEO samples yielded 6.8 mm and 6.6 mm, respectively. The edible coating with sodium alginate therefore demonstrated a positive impact on preserving the elasticity of cut pears.

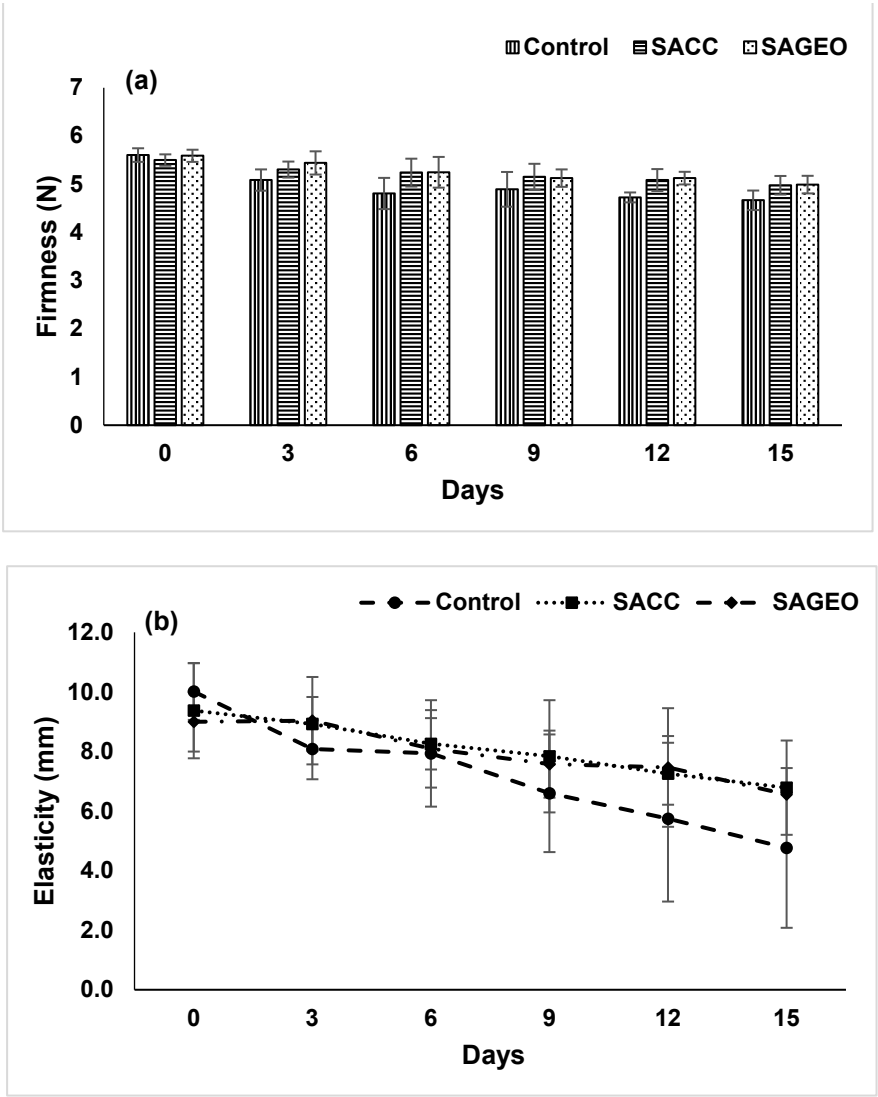

Figure 4. (**a**) Changes in firmness, (**b**) changes elasticity, during the 15 days of storage period. Vertical bars indicate standard deviation (±). (**SACC**) treatment: samples coated with sodium alginate only; (**SAGEO**) treatment: samples coated with sodium alginate incorporating ginger essential oil.

8.6. Appearance Characteristics

Figure 5 shows the appearance of both control and coated samples at time zero and at 15 days of storage. The control samples developed progressive browning to a much

greater extent during storage and showed mold growth whereas the coated SACC and SAGEO samples maintained a better appearance with no mold growth on the cut surfaces. As shown in Figure 5, the incorporation of ginger essential oil enhanced the antimicrobial property of the sodium alginate coating, and the citric acid prevented browning in cut fruits.

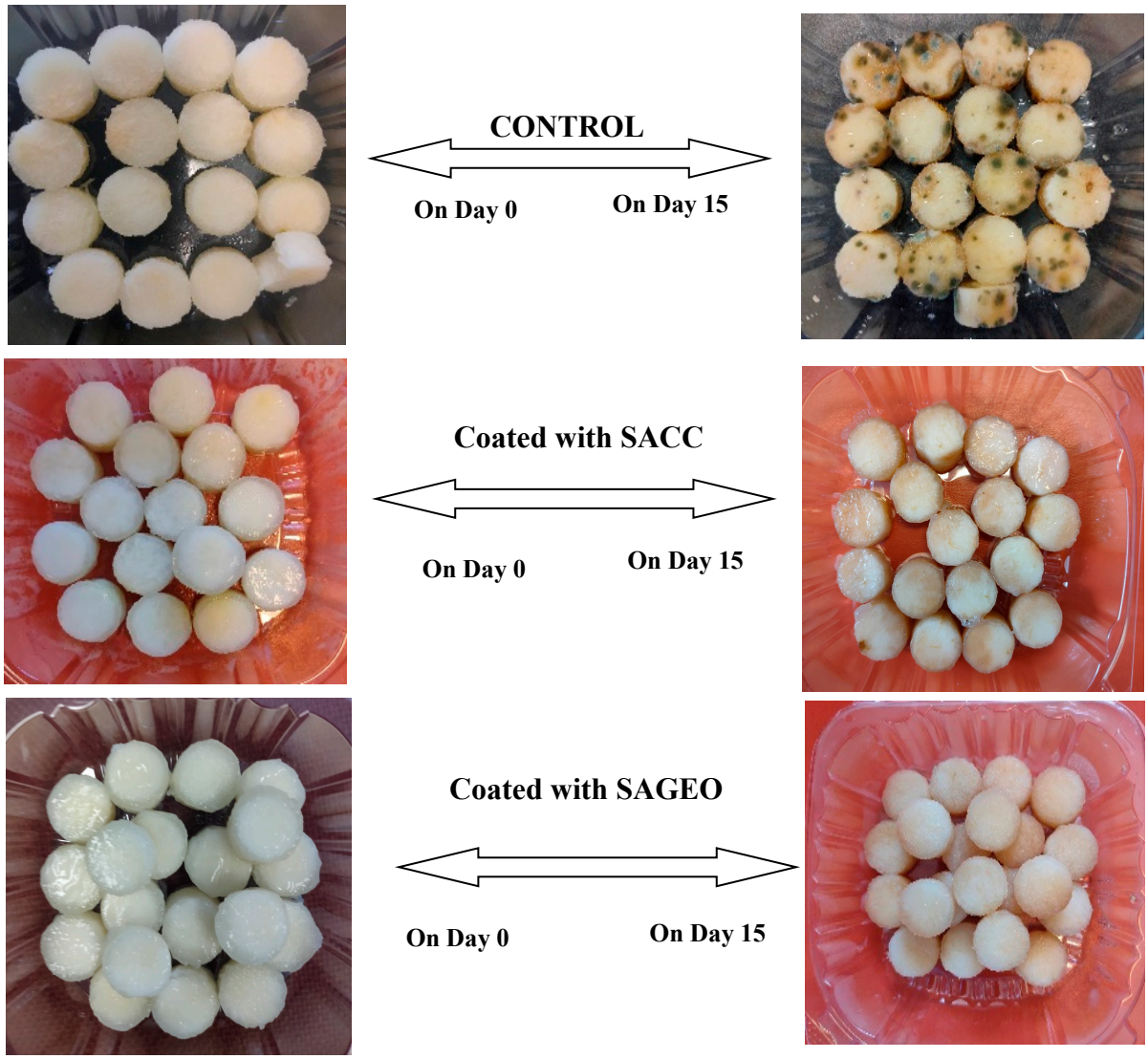

Figure 5. Changes during the 15 days of storage period. (**SACC**) treatment: samples coated with sodium alginate only; (**SAGEO**) treatment: samples coated with sodium alginate incorporating ginger essential oil.

9. Conclusions

This study demonstrated the effect of sodium alginate coating with or without ginger essential oil (SACC and SAGEO) on the extension of the shelf life of cut pears for up to 15 days. This study showed positive results in terms of preserving post-harvest quality parameters. The sodium alginate coating with calcium chloride as a firming agent preserved the texture and color of coated cut pears. The coated samples also showed low respiration rates, low moisture loss, and a smaller change in titratable acidity, pH, and TSS during the 15 days' storage (4 °C). SAGEO showed better performance in controlling the mold growth. Overall, the incorporation of ginger essential oil improved the antimicrobial property of sodium alginate coating and helped to increase the shelf life of cut pears.

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