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The Effect of Sodium Alginate-Calcium Chloride Coating on the Quality Parameters and Shelf Life of Strawberry Cut Fruits

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Abstract: Strawberry fruits have a short shelf life after harvesting due the physiological factors that enhances ripening such as respiration and transpiration. Sensory properties including color, texture, odor, and flavor are the main factors that makes fresh produce appealing to consumers, and they change very rapidly upon harvest. For this reason, quality preservation is essential during post-harvest handling and storage of strawberry fruits. Quality deterioration rates are higher in strawberry fruit cuts due to the mechanical damage and the loss of their natural protective barriers, resulting in an increase in moisture loss, respiration rates, and the deterioration of their sensory properties. The effect of a sodium alginate-calcium chloride edible coating on quality preservation and shelf life extension of strawberry cut fruits stored at 4 °C was studied. Control samples had mold growth initiated after one week of storage at 4 °C, while the coated fruit samples had a mold free shelf life extension for up to 15 days. The sodium alginate-calcium chloride edible coating was effective in reducing respiration and transpiration rates and delayed the increase of the pH and soluble solid content. Furthermore, the coating delayed surface mold growth for up to 15 days and preserved the sensory properties of the cut fruits such as color and texture.

Keywords: strawberry; edible coating; cut fruits; post-harvest; storage; quality

1. Introduction

Different methods have been used to reduce food losses and extend the shelf life of fresh fruits and vegetables including conventional refrigerated storage, modified atmosphere packaging (MAP), and controlled atmosphere storage [1]. Active packaging is also a method that has been used to reduce post-harvest losses, and it consists of using synthetic packages with variable active functions such as oxygen scavengers, carbon dioxide absorbents, and ethylene absorbents. Moreover, edible film and coating is a preservation method that has become very popular in the last few decades due its effectiveness in the extension of the post-harvest shelf life of the fresh produce [2].

An edible coating is a thin layer of adhesive material that must be applied on the surface of the food product in a liquid form by brushing, spraying, or complete immersion, forming a protective coating that can be consumed together with the food product, while an edible film is a self-standing material that can be used to wrap the food products or cover them. Edible films and coatings extend the shelf life of fresh produce and protect them from the external environmental damages in addition to the physical, chemical, and biological changes [3]. Research studies have shown that edible films can act as natural barriers against moisture loss, gas exchange, lipids, and flavor compounds losses [4]. Additionally, edible coatings create an internal atmosphere when applied on the surface of the fresh produce, which reduces the respiration and transpiration rates and delays quality deterioration and ripening [5].

Research is focused today on developing eco-friendly and biodegradable food packaging to replace synthetic packaging materials [6]. In the past several decades, scientists have been able to identify different types of natural polymers that can be used in the production of edible films and coatings. These polymers can be derived from multiple sources such as plants, animals, and microorganisms and are divided into three different categories. The hydrocolloid category including proteins and polysaccharides; the lipid category; and composites [3]. Composites are made of a combination of hydrocolloids and lipids to produce edible films and coatings with shared advantages from two different categories [5]. The thermo-physical and mechanical spectral properties of these special composite materials have also been extensively studied to determine their suitability for different applications with the desired adhesive, water vapor and gas permeability control respiration, and transpiration rates of perishable produce [7,8].

Polysaccharides are polymers of monosaccharides connected to each other by glycocidic bonds and used in the production of edible films and coatings. Polysaccharides are suitable for use in the coating of fruits and vegetables due to their effective gas barriers. Their selective permeability to O_2 and CO_2 gases allows for the creation of a modified atmosphere. Other advantages are their low cost and their high availability since they are mainly found in plants and seaweeds. However, polysaccharides are hydrophilic with a high-water vapor permeability [9]. Cellulose derivatives, starches, alginates, pectin, chitosan, pullulan, and carrageenan are the most commonly used polysaccharides in the production of edible films and coatings [3].

Pullulan is a water soluble microbial exopolysaccharide obtained from the yeast-like fungus *Aureobasidium pullulans* and can be used in the production of thin, colorless, odorless, and tasteless edible films [6]. Moreover, alginates are polysaccharides naturally produced by brown marine algae or seaweeds such as *Laminaria hyperborean* and *Macrocystis pyrifera*. Alginates can also be produced by some bacteria such as *Azotobacter vinelandii,* which were first discovered in 1881. Alginates are considered as generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA) and were used as thickening agents and stabilizers. In addition, they are an approved food additive by the European Commission (EC). Water soluble sodium alginate is commonly used in the making of edible films and coatings and should be mixed with divalent ions to reduce its water solubility. The addition of divalent ions such as calcium allows for the formation of divalent salt bridges due to the binding of calcium ions between two chains, which provides rigid and dense gels [10].

According to the Food and Agriculture Organization report (FAO, 2011), over 4.5 million tons of strawberries were harvested each year around the world, mainly in Spain, Egypt, the USA, and Mexico [11]. Several studies have focused on strawberry fruits due to their high perishability. The effect of a chitosan-based edible coating on the shelf life extension of strawberry cut fruits was reported [12]. Additionally, the effect of a gellan-based edible coating on the quality parameters of strawberry cut fruits was studied. Their soft texture makes them more susceptible to mechanical damage and quality loss during post-harvest storage [13].

With the increased interest in ready to eat and nutritious snacks, cut fruits have become more popular and widely available in supermarkets, cafeterias, airline catering, universities, and schools [10]. Cut fruits and vegetables are wounded tissues with a shorter shelf life than the intact fruits due to the induced mechanical damages. The internal tissues in cut fruits are exposed to the external environment, which increases respiration and transpiration rates, oxidative browning, and microbial growth [14].

Minimally processed fruits and vegetables usually show uneven responses to edible coatings due to the differences in their tissue structures, surface texture, turgidity, and metabolic activity. However, a successful adhesion of the coating solution on the fruit surfaces can extend their shelf life and provide a fresh-like appearance [15].

Several studies have been carried out to evaluate the best coating composition to extend the shelf life of cut fruits. A whey protein-calcium caseinate-based edible coating has been credited with a beneficial effect in preventing oxidative browning in apple and potato cuts. However, whey proteins have low mechanical properties, which makes them not very suitable for use on the surfaces of fresh fruit and vegetables [14]. It has also been reported that a methyl cellulose and sodium alginate-based edible coating extended the shelf life of peaches stored at 15 °C, up to 21 and 24 days compared with 15 days in the control samples. This edible coating reduced the respiration and transpiration rates and delayed the increase in total soluble solids content [7,8]. It was also reported that the chitosan-based edible coating significantly reduced the weight loss of fresh strawberries and red raspberries during storage at 2 °C and 88% relative humidity (RH) compared to the control [16]. The sodium alginate composites provide some additional advantages because of their ability to complex with calcium chloride [17]. Calcium chloride has been widely used as a texture firming agent for fruits and vegetables for a long time since it can form complexes with low methoxyl pectin present in the produce tissue, thereby facilitating texture firming [18,19]. A similar benefit can potentially be realized with the combination of sodium alginate-calcium chloride combinations [17].

The objective of this study was to evaluate the effect of a sodium alginate-calcium chloride-based edible coating on the quality parameters and the shelf life extension of cut strawberry fruits stored for two weeks at 4 °C was evaluated. The available information of edible coating for cut fruits is very scanty.

2. Materials and Methods

2.1. Sample Preparation

Four kg of strawberry fruits were purchased fresh from the market and chosen based on similar degrees of maturity and stored at 4 °C overnight until use the next day. Strawberries were washed with tap water to remove the external impurities and cut into 1-cm thicknesses along their longitudinal axis. Cut fruits were drained for 10 min after washing and before coating.

2.2. Coating Solution Preparation

Calcium chloride salt was used in the study due to its effect as a firming agent and high-water solubility. Distilled water was used to prepare the coating solutions of 2% (*w*/*w*) sodium alginate (Sigma, Oakville, ON, Canada) and 2% (*w*/*w*) calcium chloride (Sigma, Oakville, ON, Canada). To prepare the sodium alginate coating solution, sodium alginate powder was added to distilled water and the beaker was placed on a magnetic stirring rod at 300 rpm with no heat until the sodium alginate powder was completely dissolved at room temperature. To prepare the calcium chloride solution, calcium chloride salts were added in a volumetric flask with distilled water and shaken to completely dissolve the salt.

2.3. Control Sample Preparation

For the preparation of control samples, two kg of strawberry fruits were only washed with tap water, cut into 1 cm thicknesses, drained for 10 min at room temperature, and stored in plastic containers at 4 °C. Fruit samples were covered with polyvinyl chloride stretch film (PVC films) [20].

2.4. Sample Coating

Sodium alginate and calcium chloride solutions were poured in to the plastic containers and the strawberry cut fruits were placed in a fabric mesh and dipped completely into the sodium alginate solution for 5 min, removed, and drained for 1 min in a plastic mesh, dipped again this time in the calcium chloride solution for 5 min, removed, drained, and left on filter paper for 10 min at room temperature (22 °C) to remove the surface excess of the coating solution. Two kg of strawberry cut fruits were coated with the sodium alginate-calcium chloride-based edible coating [21].

2.5. Sample Storage

Coated and control samples were stored in plastic containers (each container contained six to seven fruit samples) and covered with polyvinyl chloride stretch film (PVC film). Small four to five holes were made in the PVC film (1–2 mm each) to maintain the atmospheric composition of air within the container (Figure 1). Plastic containers were stored in the refrigerator at 4 °C for two weeks and tests were done on both the control and coated samples every three days (days 0, 3, 6, 9, 12, and 15) with quality monitoring on a daily basis [20].

Figure 1. Sample storage in plastic containers covered with polyvinyl chloride (PVC) films.

2.6. Respiration Rate

Control and coated strawberry cut fruits (150 g) were placed for 2 h in an airtight Plexi-glass chamber (18 cm × 12 cm × 27 cm) at room temperature (22 °C). The glass chamber was connected to a CO_2 sensor (ACR Systems Inc, St-Laurent, QC, Canada) that transferred the results to a data acquisition system (Smart Reader plus 7). The CO_2 concentration was collected every 1 min over a 2 h period. Respiration rates were obtained from the regression slope of CO_2 concentration versus time and evaluated as mL CO_2 kg^{-1} h^{-1} [7,8].

2.7. Transpiration/Weight Loss

Weight loss was measured by periodically weighing fruit samples using a digital balance (Denver instrument, APX-323, NY, USA). The difference between the initial weight on day 0, and the final weight measured every three days was considered as the weight loss and expressed as a percentage of the initial weight. The test was done in triplicate every three days during storage using 200 g of uncoated fruit samples and 200 g of coated fruit samples stored in multiple plastic containers (six to seven fruit samples per container) [22].

2.8. Color

The color characteristics of strawberry cut fruits were measured using a calorimeter, a tristimulus Minolta Chroma Meter (Minolta Corp, Ramsey, NJ, USA), to determine the L value (lightness), a * (green-red chromaticity), and b * (yellow-blue chromaticity), Chroma, and Hue angle. The calorimeter was calibrated using a white standard. Readings were done at room temperature on five to six samples of the control and coated samples [7,8].

2.9. Texture

Seven to ten samples from each lot (control and coated) were subjected to a puncture test using a Texture Analyzer (Model TA XT Plus, Texture Technologies Corporation, Scarsdale, NY, USA/Stable Micro Systems, Godalming, Surrey, UK) fitted with a 25 mm diameter round tipped puncture probe with a speed of 10 mm/s. The force deformation and firmness of the fruit samples were measured based on the force–deformation curve. Measurements are in Newton (N) [7].

2.10. pH

The pH was measured with a standard calibrated pH meter (Brinkman Co., Mississauga, ON, Canada). pH measurements were made by blending for 1 min and 50 g of the strawberry cut fruits with 150 mL of distilled water. A pH meter calibration was done with variable standard solutions at pH 7 and 10.

2.11. Titratable Acidity

Titratable acidity (TA) was measured using the Association of Official Analytical Chemists (AOAC) titrimetric method for fruits [23] by titrating 10 mL of strawberry juice with 0.1 mol/L NaOH using phenolphthalein as an indicator. The tests were done in triplicate on coated and uncoated samples. The results are expressed in citric acid (%).

$$\text{Titratable acidity }(\%) = \frac{\mathrm{V(NaOH)(0.1)(0.064)}}{\mathrm{m}} \times 100 \tag{1}$$

where $V_{(NaOH)}$ is the mL of NaOH used during titration; (0.1) is the molarity of the NaOH solution used; (0.064) is the conversion factor for citric acid, which is the main acid in strawberries; and (m) is the mass of the strawberry samples used during the test [24].

2.12. Total Soluble Solids (TSS)

Total soluble solids (TSS) were measured using a hand refractometer (ATAGO N1, Kirkland, DC, USA) and expressed in °Brix scale. Tests were done in triplicate for both the coated and control samples [22].

2.13. Total Aerobic Count of Microorganisms

Total aerobic counts of microorganisms were analyzed using the plate count method. Ten grams of different control and coated samples were transferred to a blender with 90 mL of saline peptone water (0.1 g peptone/100 mL water). After blending, a serial dilution was done and pour-plated onto plate count agar (PCA). Plates were incubated for five days at 25 °C for counting of total aerobic microorganisms. Colony count was expressed as Log CFU/g of strawberries. Tests were done every three days in triplicate on both the control and coated samples [25].

2.14. Appearance

The appearance of samples was evaluated based on the color and surface mold growth. Three plastic containers of control samples and three plastic containers of coated samples (each container containing six to seven fruit samples) were stored at 4 °C and used to evaluate the appearance of the control and coated strawberry cut fruits during the experiment.

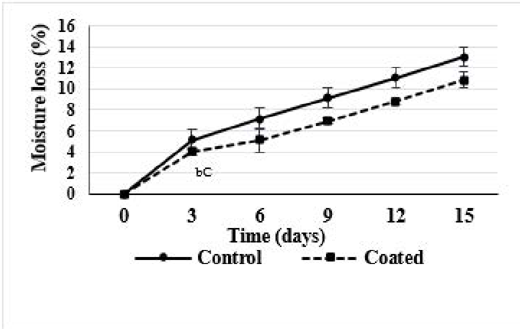
2.15. Statistical Analysis

A statistical analysis system (Analysis ToolPak in Excel) was used to conduct one-way Analysis of Variance (ANOVA) at 95% level of confidence and 5% level of significance. The significance level used was ($p < 0.05$). Tukey's method was used to indicate the significant difference between the control and coated samples during storage as well as between the different storage times for both the control and coated. The effect of the edible coating on pH, moisture loss, respiration, TSS, titratable acidity, firmness, color, and microbiological count on strawberry cut fruits was evaluated [7,8].

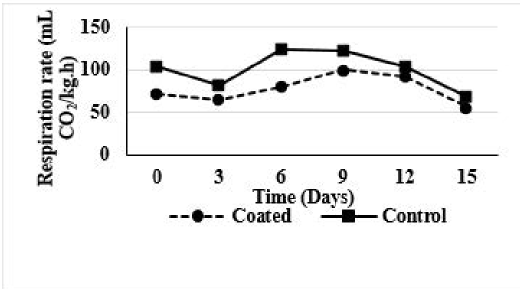
3. Results and Discussion

3.1. Transpiration/Weight Loss

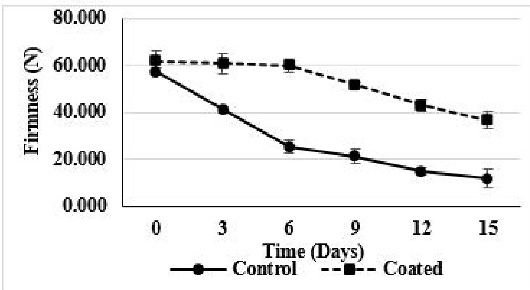
The transpiration rates (expressed as percentage moisture loss) measured for fruit samples stored at 4 °C are shown in Figure 2a. Weight loss was measured every three days during storage in triplicate using 200 g of the control samples and 200 g of the coated samples stored in multiple plastic containers. During the 15 days of the experiment, overall, the moisture loss percentages in the coated samples were significantly lower ($p < 0.05$) than in the control samples. The weight loss in the control samples after three days of storage was 5.2%, slightly higher than 4.0% in the coated samples. Transpiration rates increased in both the control and coated samples during the experiment. On the final day 15, moisture loss in the control samples reached 13% while in the coated samples, it was 11%. Differences between the coated and uncoated samples were clear from day 3 onward. Moisture loss was reduced due to the water vapor barrier formed by the sodium alginate-calcium chloride edible coating on the fruit's surface (Figure 2a).



(a)



(b)



(c)

Figure 2. Moisture loss (%) (**a**), respiration rate (**b**), and firmness of control and sodium alginate-calcium chloride coated samples during storage (**c**). Different lowercase letters indicate a significant difference due to storage time ($p < 0.05$). Different uppercase letters indicate a significant difference among the control and coated samples ($p < 0.05$).

One-way ANOVA statistical analysis showed that there was a significant difference in moisture loss among the control samples and among the coated samples during storage ($p < 0.05$). A clear significant difference in moisture loss between the control and coated samples was observed starting from day 6 up to day 15 ($p < 0.05$). Moisture loss was significant with respect to time for both the coated and uncoated cut fruits. Moisture loss is also related to quality loss and the reduction in weight and volume (shrinkage or shriveling) of the fresh produce. It was also reported that the reduction of moisture loss in coated fruits during storage played an important role in the shelf life extension of the strawberry cut fruits. Formation of a layer of the alginate film obviously helped to reduce the moisture loss from the fruit by acting as a barrier [10].

3.2. Respiration Rate

The respiration rates of the control and coated samples were measured over the period of storage. The amounts of CO_2 produced were measured every minute for 2 h using 150 g of both the control and coated strawberry cut fruits. The results were taken during the first hour until the saturation of CO_2 [24]. Based on this methodology, the respiration rates measured (mL CO_2 kg^{-1} h^{-1}) in the control samples were higher than the respiration rates in coated fruit samples over the whole period of the experiment starting from day zero. The sodium alginate-calcium chloride edible coating played an effective role in decreasing the respiration rates in the coated samples by reducing the amounts of CO_2 produced. On day zero, the respiration rate in the control samples was 104 mL CO_2 kg^{-1} h^{-1}, while it was 71.6 mL CO_2 kg^{-1} h^{-1} in the coated samples. Previous studies showed that on day zero, the respiration rates in both the control and coated samples should be high due to the mechanical damage. The respiration rates decreased in the control samples on day 3 to 81.3 mL CO_2 kg^{-1} h^{-1}, while in the coated samples, it decreased to 64.7 mL CO_2 kg^{-1} h^{-1}. On day 6, the respiration rates in the control samples increased to 123.7 mL CO_2 kg^{-1} h^{-1} and stayed stable until day 9, before it decreased to 68.5 mL CO_2 kg^{-1} h^{-1} on day 15. In the coated samples, the respiration rate increased to 99.6 CO_2 kg^{-1} h^{-1} on day 9, before it decreased to 55.5 mL CO_2 kg^{-1} h^{-1} on day 15 (Figure 2b). The sodium alginate-calcium chloride coating reduced the respiration rates in strawberry cut fruits.

One-way ANOVA statistical analysis showed no significant overall difference between the control and coated samples ($p > 0.05$) (because of the consideration of the variation over the entire range rather than a direct one to one comparison). However, the differences were significant in the beginning and between six and 12 days of storage. Other studies have shown that calcium dips can be effective in reducing respiration rates in addition to extending the shelf life of cut fruits. A decrease in the respiration rates in cut cantaloupe dipped in a calcium salt solution and stored 4 °C was reported. This reduction is facilitated by the reduced oxygen and carbon dioxide permeability by the coating. This will not only result in reducing the oxygen tension within the fruit because of the lower infusion of oxygen into the tissue, but at the same time, reduced removal of the CO_2 produced will thereby promote a higher concentration of CO_2 within the tissue and the consequence of both will be a reduced respiration rate [26].

3.3. Texture

The firmness of the strawberry cut fruits was measured using seven to 10 samples of the control and coated samples, the results of which are shown in Figure 2c. Firmness of coated strawberry cut fruits decreased during the 15 days of storage at 4 °C. However, the coated samples showed better results than the control samples. A beneficial effect in the firmness retention was observed in coated samples during the 15 days of the experiment. Since day zero, the texture of the coated samples showed higher values than the control samples due to the added calcium chloride, which acts as firming agents as well as the lowered respiration and transpiration rates. The firmness of the control samples decreased from 57.3 N on day zero to 41.2 N on day 3, while in the coated samples, the firmness was almost stable during the first six days of storage. On day 6, the firmness in the control samples showed a dramatic decrease and declined to 11.8 N at the end of the experiment on day 15. In the coated samples, firmness declined only to 36.6 N on day 15, thus remained firm. Additionally, after 12 days of storage, it was difficult to perform the texture analysis on the control samples due to their extremely soft texture, while coated samples were still in good condition. The results showed the positive effect of the sodium alginate-calcium chloride edible coating on the texture of strawberry cut fruits, since a good texture was maintained over the whole period of the experiment. Values observed in coated fruits were three times higher than in the control samples (Figure 2c).

One-way ANOVA statistical analysis showed a significant difference in the firmness among the control samples after day 0 (i.e., from day 3 to 15) ($p < 0.05$). However, with the coated samples, no significant decline in texture was observed until day 9. Furthermore, a significant difference in the firmness between the control and sodium alginate-calcium chloride coated samples was observed starting from day 3 up to day 15 ($p < 0.05$).

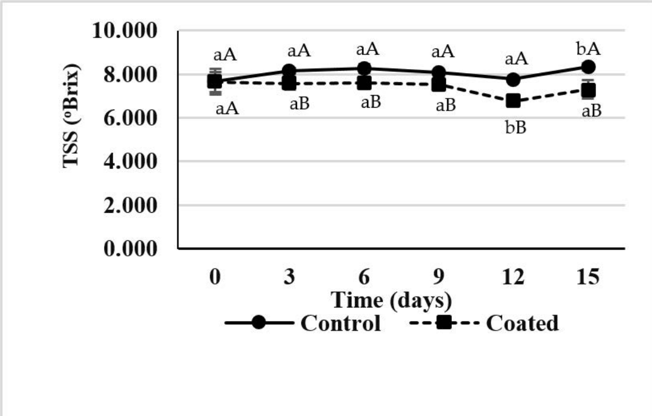
Fruit softening during maturation is caused by the biochemical changes in the cell turgidity and the cell wall compositions. The changes are shown by a degradation of the middle lamella of the cortical parenchyma cells, and a decrease in the pectin content [24]. The addition of calcium chloride salts was reported to play an effective role in maintaining the firmness of the coated samples during storage, acting as firming agents [9].

3.4. Total Soluble Solids

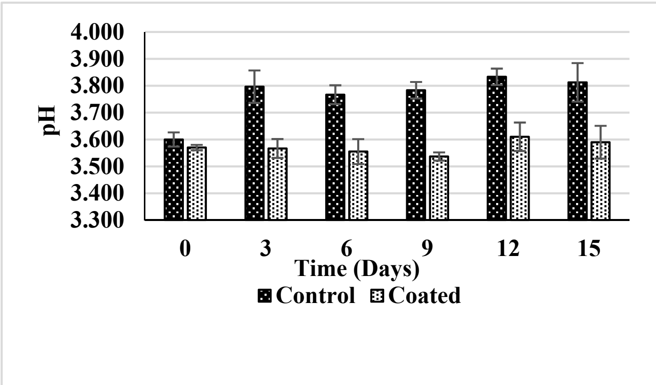
Total soluble solids (°Brix) is used as an indicator of fruit maturity and is measured in fruits to study their maturation rates. Based on different studies, the total soluble solids content (TSS) in fruits increased during storage. The edible coating could reduce the TSS content by delaying the fruits ripening [27]. During the 15 days of storage, the TSS in the control samples was higher than in the coated samples, which suggests that sugars are synthesized at a slower rate due to the sodium alginate-calcium chloride coating. On day zero, the values of TSS were 7.7 in the control samples and 7.6 in the coated samples. TSS in the control samples increased to 8.3 on day 6, while in the coated samples, the TSS remained almost stable from day 0 until day 6 with a value of 7.6. The edible coating reduced the rates of carbohydrate breakdown and delayed fruit maturation (Figure 3a). The decrease in the TSS content at the end of the experiment is an important indicator of fruit maturation since it can indicate fruits over ripening [28]. One-way ANOVA statistical analysis showed an overall significant difference between the control and sodium alginate-calcium chloride coated samples during the experiment ($p < 0.05$). However, no significant difference was observed among the control samples or among the coated samples during storage ($p > 0.05$). The increase in TSS is related, first, to moisture loss and the increase in the soluble solid concentration. Moreover, it is related to the breakdown of complex carbohydrates into soluble solids due to the respiration and ripening of fruits. Starch is degraded rapidly into sugars such as sucrose, glucose, and fructose due to the activity of amylases, starch phosphorylase and 1,6-glucosidase enzymes [27].

3.5. pH

A significant increase in the pH of the control samples over the period of storage was observed. The pH of the control sample was higher than in the coated sample during the 15 days of the experiment. On day zero, the pH of the control and coated samples was 3.6. The pH of the control samples gradually increased and reached 3.8 on day 12, while in the coated sample, the pH was almost stable from day zero until day 12. The sodium alginate-calcium chloride edible coating reduced the pH of the coated samples in comparison with the control samples. Additionally, it delayed the increase in the pH values during storage (Figure 3b). One-way ANOVA statistical analysis showed a significant difference between the control and sodium alginate-calcium chloride coated samples during the 15 days of storage, especially day 3 onward ($p < 0.05$). The pH of the coated fruits remained higher than in the control samples throughout the study. A delay in the increase of the pH of strawberries coated with carboxyl methyl cellulose (CMC) was reported [22]. It has also been reported that the sodium alginate-based edible coating delayed the increase in the pH of the fruit samples, which delayed fruit ripening and mold growth by maintaining the acidity of the fruits [27].



(**a**)



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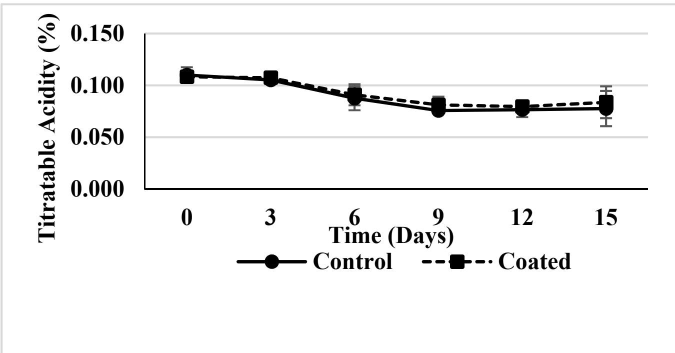

(**c**)

Figure 3. Changes in total soluble solids (TSS) (**a**), pH change (**b**), and titratable acidity of the control and coated samples during storage (**c**). Different lowercase letters indicate a significant difference due to storage time ($p < 0.05$). Different uppercase letters indicate a significant difference among the control and coated samples ($p < 0.05$).

3.6. Titratable Acidity

Titratable acidity (TA) was measured and expressed in citric acid (%). Based on the test results, the coated fruits had a higher citric acid (%) than the uncoated samples. On day zero, the titratable acidity was the same in both the control and coated samples. The acidity decreased at a slightly lower rate in the coated samples during the 15 days of storage. On day 6, a significant decrease in TA was observed in the control samples and the value reached 0.088%, while in the coated samples, it decreased to 0.091%. On day 9, the TA decreased in the coated samples to 0.081% and stayed steady up to day 15. Additionally, in the control samples, TA declined on day 9 to 0.076% and stayed steady thereafter until day 15 with a value of 0.078% (Figure 3c). Coated fruits had a higher TA (%) during the 15 days of the experiment. The sodium alginate-calcium chloride edible coating minimized the reduction of fruit acidity compared to the control. However, one-way ANOVA statistical analysis did not show a significant difference in TA (%) between the control and coated samples ($p > 0.05$).

Titratable acidity is related to the organic acid content in strawberries. Acidity decreases at the late stages of fruit ripening due to the use of organic acids during respiration. Coating of strawberries with CMC and hydroxypropyl methylcellulose (HPMC) showed a delay in the decrease in TA (%) in strawberries. The edible coating reduced the loss of ascorbic acid during the 16 days of storage by reducing oxygen diffusion and respiration rates, which caused ascorbic acid retention [22]. Slower rates of decreased acidity were also observed in pectin coated cherry tomatoes stored at different temperatures [27]. Moreover, methyl cellulose coated peaches showed a delayed reduction in the titratable acidity [7,8].

3.7. Color

The color of strawberry cut fruits was affected by the sodium alginate-calcium chloride edible coating and storage time. The color parameters L value, a * value, and Chroma were evaluated as the other parameters of b * value and hue angle did not show any differences between the control and coated samples.

3.8. L Value

The decrease in L value is an indicator of surface darkening [14]. On day zero, both the control and coated samples had similar values. The L value in the control samples showed a dramatic decrease starting from day 3 and declined from 31.6 on day zero to 20.8 on day 15. In the coated samples, the L value was almost stable until day 6. The L value decreased on day 9 and reached 26.7 on day 15. The L value was higher in the coated samples than in the control samples during the whole period of the experiment, which indicates that the sodium alginate-calcium chloride coating prevented oxidative enzymatic browning (Table 1). One-way ANOVA statistical analysis showed a significant difference in the L value between the control and sodium alginate-calcium chloride coated samples ($p < 0.05$) as well as a gradual decrease with storage time, while it reduced more rapidly in the control samples.

Table 1. Color parameters L value, a * value, and C value of the control and coated samples during storage.

	Samples	Day 0	Day 3	Day 6	Day 9	Day 12	Day 15
L values	Control	$31.6 \pm 1.1^{a,A}$	$26.9 \pm 0.8^{b,B}$	$25.6 \pm 1.6^{b,C}$	$24.0 \pm 1.5^{c,C}$	$22.5 \pm 1.5^{c,D}$	$20.8 \pm 2.8^{d,E}$
	Coated	$31.3 \pm 1.0^{a,A}$	$30.8 \pm 0.8^{a,C}$	$30.6 \pm 0.2^{a,D}$	$29.9 \pm 1.4^{b,D}$	$27.1 \pm 0.3^{b,E}$	$26.7 \pm 0.5^{b,F}$
a * values	Control	$32.4 \pm 0.2^{a,A}$	$31.2 \pm 0.9^{a,A}$	$30.3 \pm 2.6^{b,A}$	$29.3 \pm 0.8^{c,A}$	$27.4 \pm 1.9^{d,B}$	$26.4 \pm 2.6^{e,C}$
	Coated	$32.6 \pm 1.3^{a,A}$	$31.3 \pm 0.7^{b,A}$	$29.3 \pm 2.0^{c,A}$	$29.0 \pm 2.0^{c,A}$	$30.0 \pm 2.1^{b,B}$	$32.0 \pm 0.6^{a,D}$
C values	Control	$37.8 \pm 0.4^{a,A}$	$35.7 \pm 1.0^{b,A}$	$34.8 \pm 3.8^{b,A}$	$33.7 \pm 1.0^{b,A}$	$31.9 \pm 3.4^{c,A}$	$29.9 \pm 3.7^{c,B}$
	Coated	$38.3 \pm 1.1^{a,A}$	$34.0 \pm 1.1^{b,A}$	$35.1 \pm 3.9^{b,A}$	$33.9 \pm 2.1^{b,A}$	$34.6 \pm 2.6^{b,A}$	$36.2 \pm 1.3^{b,C}$

Different lowercase letters within a row indicate a significant difference due to storage time ($p < 0.05$). Different uppercase letters indicate a significant difference among the control and coated samples ($p < 0.05$).

It has been reported that the L value decreased in the uncoated cherry tomatoes, pectin coated cherry tomatoes, and alginate coated cherry tomatoes stored at different temperatures (4 °C and 12 °C). However, the L value was higher in the coated samples than in the control samples over the 21 days of storage [27].

3.9. a * Value

The a * value indicates the green/red components. On day zero, a * value was almost the same in the control and coated samples with values of 32.4 and 32.6, respectively. In the control samples, the a * value slowly decreased during storage and reached 26.4 on day 15 ($p < 0.05$). The decrease in the a *value in the control samples might be a response to surface darkening and the formation of a red-brownish color. Additionally, the surface mold growth negatively affected the redness of the fruit samples. The changes in a * value in the sodium alginate-calcium chloride coated samples was not significant ($p > 0.05$) and almost remained steady during the 15 days of the experiment (Table 1). However, one-way ANOVA statistical analysis did not show a significant overall difference in the a * value between the control and sodium alginate-calcium chloride coated samples during storage ($p > 0.05$).

It has been reported that the a * value increased slightly in the sodium alginate coated cherry tomatoes and pectin coated cherry tomatoes stored at 4 °C and 12 °C. In the control samples, the a * value was higher due to the increased redness of the cherry tomatoes during the 21 days of storage [27].

3.10. C Value

The C value, which is the Chroma of the color, was also measured. The C value in the coated samples slightly decreased from 38.3 on day zero to 33.9 on day 9 and increased again on day 12 to finally reach 36.2 on day 15. In the control samples, the C value gradually decreased from 37.8 on day zero to 29.9 on day 15. The C value was lower in the control samples during the whole experiment. The difference between the control and coated samples was mainly observed on days 12 and day 15 due to the fruit maturation, surface browning, and mold growth in the control samples (Table 1). However, as with a * values, one-way ANOVA statistical analysis did not show a significant overall difference in the C values between the control and sodium alginate-calcium chloride coated samples ($p > 0.05$).

A decrease in the Chroma of the uncoated strawberries stored for 8 days at 1 °C was reported. During storage, the color of the fruits became less vivid and was caused by the development of a red-brownish color in the fully ripe strawberries [29]. The edible coating maintained the Chroma of the color during storage of strawberry fruits [22].

3.11. Total Aerobic Count of Microorganisms

A plate count analysis was performed every three days on the control and sodium alginate-calcium chloride coated samples. On day zero, almost similar values were observed in the control and coated samples. After only three days of storage, the number of yeasts and molds in the control samples increased to 5.9 log CFU/g, while in the coated samples, it increased to 5.1 log CFU/g. On day 6, minor mold growth was observed in the control samples and the values increased to 6.15 log CFU/g and reached 6.25 log CFU/g on day 9. After 12 and 15 days of storage, the number of colonies of aerobic microorganisms in the control sample was too large to count (>300 colonies on the least diluted agar plate) using the plate count analysis method; hence, only the total aerobic count of microorganisms for coated samples were shown on day 12 and day 15 (Figure 4).

In the coated samples, the total aerobic count of microorganisms slightly increased to 5.5 log CFU/g on day 6 and reached 5.9 log CFU/g on day 12. On day 15, minor mold growth was observed on the surface of the coated samples and the total aerobic count of microorganisms increased to 6.1 log CFU/g (Figure 4). One-way ANOVA statistical analysis showed a significant increase in total aerobic counts among the control samples starting from day 0 until day 9 (stopped at this stage due to spoilage) and among the sodium alginate-calcium chloride coated samples starting from day 0 until day 15 ($p < 0.05$), although quantitatively slightly less than the coated ones.

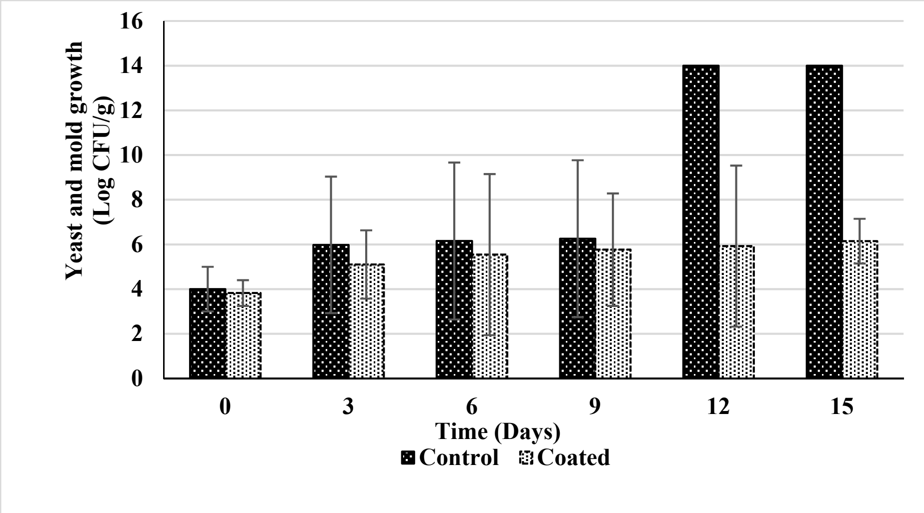

Figure 4. Total aerobic microorganisms count (Log CFU/g) in the control and sodium alginate-calcium chloride coated samples during storage. Error bars are indicated with the points and significance detailed in the text. Different lowercase letters indicate a significant difference due to storage time ($p < 0.05$). Different uppercase letters indicate a significant difference among the control and coated samples ($p < 0.05$). TLC: Too Large to Count.

It has been reported that a chitosan-based edible coating reduced the decay and surface mold growth in strawberry fruits and raspberries stored at 2 °C and 88% RH. Mold growth appeared on the surface of the control samples only after five days of storage, while in the coated samples, the mold growth was delayed [16].

3.12. Appearance

Minor mold growth was apparent on the surface of the control samples on day 6, while in the coated samples, mold growth was observed only on day 15. Control samples stored at 4 °C had an acceptable visual quality during the first six days of storage before the beginning of decay and mold growth. On day zero, both the control and coated strawberry cut fruits showed similar appearances with a bright red color (Figure 5a). After six days of storage, the color of the control samples became darker with a minor appearance of mold growth on the surface. The color of the coated samples became a bit darker after six days with no mold growth (Figure 5b). After nine days of storage, control samples showed some browning, tissue softening, and mold growth while the coated samples showed no darkening and no mold growth (Figure 5c). After 12 days of storage, the control samples had mold growth, very soft texture, and browning, while the coated samples showed no mold growth and a slight darkening in color (Figure 5d). On day 15, the control samples were completely grey with mold growth, and extremely soft with a watery texture. The coated samples showed minor mold growth on the surface of some samples with tissue softening and color darkening (Figure 5e).

The addition of calcium chloride salts helped in enhancing the texture of strawberry cut fruits since they act as firming agents. Additionally, it helps in reducing mold growth, physiological disorders, and oxidative browning [30]. CMC, with the incorporation of probiotic *Lactobacillus plantarum*, was also used to coat strawberries stored at 4 °C for 15 days. A delay in mold surface growth was observed in the coated strawberries [31]. In another study, the chitosan coating reduced mold and yeast growth in fresh cut papaya and reduced mesophilic plate counts [15].

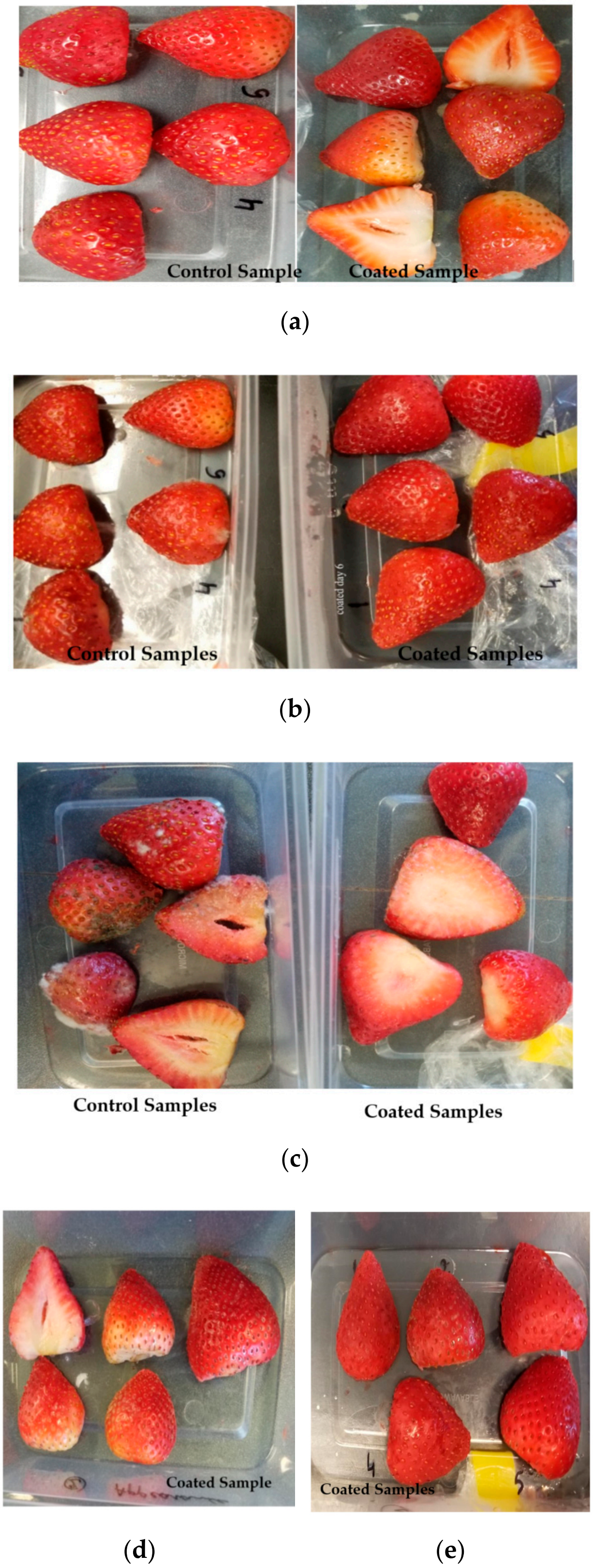

Figure 5. Side by side appearance of the control and coated fruits at day zero (**a**) and after storage for six (**b**) and nine (**c**) days, and only for coated fruits after storage for 12 (**d**) and 15 (**e**) days (extensive mold grown on control samples, not shown).

4. Conclusions

The results demonstrated that the sodium alginate-calcium chloride edible coating extended the shelf life of strawberry cut fruits stored at 4 °C for up to 15 days. The edible coating reduced the transpiration and respiration rates, acting as a protective barrier, which caused the reduction of mold growth and preserved the sensory properties of the cut strawberries. Additionally, the sodium alginate-calcium chloride edible coating delayed the increase in TSS content and the pH of the cut fruits through citric acid retention. The use of a sodium alginate-based edible coating on cut fruits help both consumers and producers reduce food losses and save money.

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