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Carnauba Wax Applied to the Shell Surface of Chicken Eggs Improved the Shelf Life and Internal Quality of the Eggs

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Abstract

The egg is a nutrient-rich food, essential for human health, containing proteins, vitamins, and minerals. However, it is perishable and begins to lose internal quality shortly after being laid. The quality of eggs deteriorates due to the loss of water and carbon dioxide, which is more pronounced at higher temperatures. Therefore, the aim of this study was to investigate the effect of coating eggs with a semi-solid product formulated with carnauba wax on the preservation and internal quality of eggs during a 28-day storage period at room temperature. 144 white eggs from 50-week-old hens were used, divided into three groups: eggs coated with carnauba wax, eggs coated with mineral oil (positive control), and a control group without coating (negative control). The results were subjected to analysis of variance (ANOVA), followed by the comparison of means through the *Tukey* test at a significance level of 5% ($p<0.05$), using the statistical program SISVAR. Eggs coated with carnauba wax showed less weight loss throughout the storage period, lower pH in both the yolk and albumen, higher yolk index and higher *Haugh* Unit compared to uncoated eggs and eggs coated with mineral oil. This suggests a significant improvement in the quality of coated eggs. Therefore, the use of carnauba wax coating can be an effective solution for extending the shelf life and preserving the quality of eggs, especially in regions where refrigerated storage cannot be guaranteed.

Keywords: Albumen; Carnauba wax; Coating; Haugh Unit; Yolk

Introduction

Eggs stand out as a food with high nutritional value. Their composition includes essential nutrients such as lipids, proteins, and trace elements, as well as a variety of vitamins, including vitamin A, iron, vitamin B12, riboflavin, choline, zinc, and calcium, in addition to several biologically active components [1]. In addition to being a moderately calorie source, with approximately 140 kcal per 100g, eggs are accessible to society due to their low economic cost. The structure of eggs comprises the shell, membranes, egg white, yolk, chalaza, and an air sac. In terms of nutrient distribution, both the egg white and yolk are rich in proteins, with an average of 12.5g in 100g of raw fresh egg. The total lipid content in the egg is relatively stable, ranging from 8.7g to 11.2g in 100g of whole egg, with most of these lipids concentrated in the yolk and low carbohydrate content [1].

According to the Food and Agriculture Organization of the United Nations (FAO) estimate in 2016, global egg production reached 1.387 billion units, roughly equating to nearly one egg for every two individuals daily. According to the International Egg Commission (IEC) in 2018, the average consumption was reported at 161 eggs per person per year [2,3].

The quality of eggs is influenced by various factors, both extrinsic and intrinsic. Key elements associated with egg deterioration include environmental conditions such as temperature and relative humidity. Handling and storage also play a role in compromising egg quality. During the storage period, it's observed that certain characteristics of the egg white, yolk, and membrane can be altered, leading to a decline in egg quality [4]. The internal quality deterioration of eggs occurs due to the gradual loss of water and carbon dioxide over the storage period, with this degradation being directly impacted by rising temperatures. In Brazil, it is common for the majority of commercially available eggs to be stored at room temperature, which reduces their shelf life and, consequently, shortens their shelf life. This is a common practice in the marketing of low-quality eggs. The average temperature in Brazil can vary from 10°C to 30°C or more, depending on the region and time of the year [5]. The pursuit of alternative methods to extend the shelf life of eggs has been under study for some time. There is a growing interest in the development of effective methods to preserve the internal quality of eggs. In this context, edible coatings have emerged as a technology used and applied in various products to control moisture, gas exchange, and oxidation processes [6].

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Carnauba wax is derived from the leaves of the Brazilian palm tree, known as *Copernicia prunifera* (Miller) H.E. Moore, which is abundant in the arid regions of northeastern Brazil. This wax is renowned for its highly hydrophobic nature, making it a suitable choice as a coating for fruits and vegetables, imparting a shine and safeguarding against water loss [7]. This attribute contributes to the extension of the shelf life of perishable foods. It is essential to emphasize that carnauba wax is regarded as safe for food use and is widely employed as an edible coating on fruits with peels [8]. In the food industry, wax is employed as a coating agent, acidity regulator, carrier, and anti-caking agent in surface treatments, as highlighted by Freitas *et al.* [9].

Although some studies have demonstrated the effectiveness of these coatings in preserving perishable products deemed safe for human consumption, there is still a significant research gap regarding their application to eggs. Therefore, the objective of this study is to evaluate the effectiveness of a semi-solid product formulated with carnauba wax (applied to the surface of chicken eggshells) in preserving the internal quality and prolonging the shelf life of these eggs during a four-week storage period at room temperature. In addition to contributing to the economic sector, the environment, and the scientific community, this study aims to assess the physical-chemical quality (through weekly evaluations of weight loss, yolk and albumen pH, yolk and albumen percentages, yolk index, and *Haugh* Unit) of eggs coated with carnauba wax, with the goal of minimizing food waste.

Materials and Methods

Eggs

Unwashed white eggs from laying hens of the same commercial batch (Hisex White lineage, at 50 weeks of age, fed with a specific balanced diet for laying hens based on corn, soybean meal, and vegetable oil) were used. A total of 96 fresh, unfertilized whole eggs (no more than one day from laying) were utilized for the experiment. The eggs were acquired from a commercial farm (Brambilla) located in the city of Americana, SP, Brazil. The experiment took place at the Food Technology Laboratory of FAM – Faculdade de Americana, (550 meters of altitude, 22°42' South latitude and 47°18' West longitude), Americana, SP, Brazil.

Treatments

The treatments consisted of a control group with no treatment (negative control); a group treated with mineral oil (positive control), and a group treated with a semi-solid product containing carnauba wax. The formulation of the semi-solid product involved the dissolution of 30% pure carnauba wax flakes (100%) (purchased from the industry PolyStar Comércio de essencias Ltda - manufactured in Brazil), 20% of solid vaseline (pharmaceutical grade Needs®), and 50% of liquid mineral oil (pharmaceutical grade Needs®), under constant stirring at a temperature of 80ºC. On the same day as laying, all eggs were transported to the laboratory. On day zero (same day as egg collection), these eggs were weighed, numbered and their weight was noted on the shell with a pencil.

The eggs were divided between the three treatments according to their average weight, and after cooling, the semi-solid carnauba wax-based product was applied individually to the surface of each eggshell, manually, with the aid of a brush, forming the film of coating. The same procedure was performed with the positive control, mineral oil. An average of 170 mg of the product was applied per egg. Following the coating, the eggs were placed in cardboard trays, each capable of holding 30 units (one tray per treatment) and stored at room temperature. The production cost of 100 g of the product was $ 1.05 sufficient to treat 588 eggs (using approximately 170 mg of product per egg), resulting in a cost of $ 0.0018 per treated egg.

The temperature and relative humidity in the environment were monitored daily during the storage period using a digital thermo-hygrometer (Incoterm®).

The average maximum and minimum temperatures varied within the range of 27.8°C±2.9°C and 20.4°C±3.1°C, respectively. The variation in average maximum and minimum humidity was 70.8%±6.5% and 53.7%±7.6%, respectively.

The eggs were distributed in a completely randomized design with twelve eggs per treatment, divided into three replicates of four eggs each.

Assessment of Egg Quality

The analyses to assess the internal quality of the eggs were conducted at 7, 14, 21, and 28 days, corresponding to the storage duration of the eggs at room temperature. The variables under study included: egg weight loss (%), yolk percentage, egg white percentage, yolk pH, egg white pH, yolk index, and *Haugh* unit.

The weight of whole eggs was measured on a digital electronic scale (AG200 Gehaka). The weight of the eggs was assessed on day 0 (the day of coating) and subsequently on days 7, 14, 21, and 28 of storage at room temperature. The percentage weight loss of both control eggs (uncoated and coated with mineral oil) and the group coated with carnauba wax was calculated using the following equation described by Yüceer et al. [10].

% weight loss of egg = ([initial whole egg weight (g) after coating at day 0 - whole egg weight (g) after storage] / initial whole egg weight (g) after coating at day 0) x100)

The Haugh Unit (HU) was calculated according to the equation described by Haugh [11]: HU=100 log (h+7.57-1.7w 0.37), where h corresponds to the height of the egg white in millimeters, and w is the weight of the egg in grams.

The yolk index was calculated as the ratio of the height (mm) to the diameter of the yolk (mm). To do this, the eggs were cracked on a flat glass surface, and using a micrometer, the height of the dense egg white and the yolk diameter were measured. The yolks were manually separated from the egg whites, and the eggshells were washed and dried at room temperature for 7 days and then weighed.

The egg yolks were weighed to determine the percentage of yolk in relation to the egg's weight. The weight of the egg white was determined by the difference between the weight of the whole egg and the weights of the yolk and shell after drying, and its percentage in the total weight was estimated. The pH of the yolk and egg white was measured with a digital pH meter (Mpa-210A).

Egg classification: The egg quality was classified based on the United States Individual Shell Egg Quality Standards as follows: AA (albumen and yolk firmness = Haugh unit above 72); A (reasonably firm = 71 to 60); and B (weak and watery = below 60) [12].

Statistical Analysis

The eggs were distributed in a completely randomized design with twelve eggs per treatment, divided into three replicates of four eggs each. For each treatment there was a surplus of 15 eggs in case of accidental breakage. Statistical analysis was conducted using analysis of variance (ANOVA), considering each egg an experimental unit; followed by the comparison of means through the Tukey test at a significance level of 5% ($p<0.05$) using the statistical program SISVAR as described by Ferreira [13]. Information was collected in 12 eggs per treatment. Statistical models included the effects of treatments (coating types) ($P<0.05$), storage periods (weeks) ($P<0.05$) and interaction (treatments by storage periods) ($P<0.05$).

Results and Discussion

In general, on almost every storage day, there was a significant difference ($p\leq0.05$) between the group treated with carnauba wax when compared to the negative control (untreated) and positive control (mineral oil) for the variables under study, such as egg weight loss (%), yolk pH, albumen pH, yolk index, and *Haugh* Unit. There were no significant differences ($p>0.05$) observed in the evaluated parameters of albumen percentage and yolk percentage between the control group and the treated group during the 4-week storage period (Table 1).

Table 1: Internal quality comparison of eggs from commercial laying chickens externally coated with a semi-solid product based on carnauba wax versus control groups (negative control without coating) and positive control (mineral oil), stored for 28 days at room temperature.

Shell Surface Treatment	Storage time (days)			
	07	14	21	28
Weigth loss (%)				
Carnaúba wax	0.30±0.07^{Aa}	0.37±0.06^{Aa}	0.77±0.14^{Aab}	1.28±0.12^{Ab}
Mineral oil	0.34±0.07^{Aa}	0.39±0.13^{Aa}	0.86±0.22^{Bb}	1.69±0.15^{Bc}
Control	1.71±0.11^{Ba}	2.91±0.09^{Ba}	6.28±0.21^{Cb}	6.56±0.22^{Cb}
Egg Yolk pH				
Carnaúba wax	6.00±0.07^{Aa}	6.04±0.01^{Aa}	6.05±0.08^{Aa}	6.06±0.04^{Aa}
Mineral oil	6.13±0.02^{Ba}	6.18±0.05^{Bb}	6.17±0.01^{Bb}	6.21±0.02^{BCbc}
Control	6.19±0.02^{Ca}	6.37±0.03^{Ca}	6.35±0.06^{Ca}	6.26±0.01^{Ca}
Albumen pH				
Carnaúba wax	8.35±0.04 ^{Ab}	8.53±0.02^{Ab}	8.62±0.04^{Ab}	8.76±0.05^{Aa}
Mineral oil	9.09±0.05^{BCa}	9.12±0.09^{Ba}	9.21±0.02^{Bb}	9.29±0.03^{Bb}
Control	9.17±0.03^{Ca}	9.27±0.04^{Cb}	9.36±0.03^{Cc}	9.56±0.03^{Cd}
Albumen percentage (%)				
Carnaúba wax	60.31±0.01	59.70±0.03	58.02±0.02	55.25±0.01
Mineral oil	60.33±0.01	58.47±0.04	57.32±0.04	55.87±0.02
Control	60.28±0.01	57.44±0.03	56.12±0.03	56.19±0.03
Yolk percentage (%)				
Carnaúba wax	29.87±0.03	30.61±0.02	32.06±0.01	34.78±0.04
Mineral oil	29.82±0.06	31.57±0.02	32.45±0.02	33.46±0.03
Control	29.76 ± 0.12	32.81±0.02	33.69±0.04	33.62±0.05
Yolk index				
Carnaúba wax	0.37±0.04^{Aa}	0.33±0.01^{Aa}	0.29±0.01^{Ab}	0.22±0.02^{Ac}
Mineral oil	0.33±0.05^{BCa}	0.29±0.01^{Ba}	0.25±0.01^{ABab}	0.19±0.02^{ABc}
Control	0.30±0.01^{Ca}	0.23±0.02^{Cb}	0.18±0.03^{Cc}	0.16±0.02^{Cc}
***Haugh* unit (HU)**				
Carnaúba wax	78.31(AA) ± 0.76^{Aa}	68.30 (A)±0.56^{Ab}	60.39 (A)±0.98^{Abc}	60.17 (A)±0.96^{Ac}
Mineral oil	60.32 (A) ± 0.94^{Ba}	55.75 (B)±0.80^{Ba}	54.77 (B)±1.09^{Bab}	52.31(B)±1.17^{BCb}
Control	54.22 (B) ± 1.12^{Ca}	50.53 (B)±1.81^{Ca}	50.12 (B)±1.00^{Ca}	49.20 (B)±1.29^{Ca}
Data are expressed as Means ± standard deviations.				

$^{a-d}$Means with different lowercase letters within a row are significantly different after Tukey's test (P<0,05).

$^{A-C}$Means with different capital letters within a column are significantly different after Tukey's test (P<0,05).

Egg grades: AA, HU>72; A, HU=71–60; B, HU=59–31; C, HU<30 - (Designated after each mean, in the parenthesis)

Effects of Coating and Storing Eggs with Carnauba Wax on Variable Weight Loss

Regardless of the storage period, commercial eggs in the control group stored at room temperature significantly lost more weight ($p\leq0.05$) compared to the treated group that received the carnauba wax coating and mineral oil treatment. The weight loss increased over the 4 weeks of storage for both the negative and positive control groups, as well as for the group treated with carnauba wax. The percentage of weight loss in the negative control group was initially 1.71% and increased to 6.56% after 4 weeks of storage. In the mineral oil-treated group, the weight loss was 0.34% in the first week, increasing to 1.69% in the last week of evaluation, while the carnauba wax-treated group showed an initial weight loss of 0.30%, increasing to 1.28%, demonstrating the effectiveness of the product in egg preservation.

Eggs sold in the Brazilian retail market are typically stored at room temperature, which varies between 25°C and 27°C. In contrast, in other countries like the United States, eggs are stored at a temperature of 4°C [14]. However, it's important to note that depending on the season and region of the country, this temperature can vary significantly, which can directly impact the quality of commercial eggs. Given the variations in storage temperatures, this study opted to use room temperature, which better reflects the reality of the Brazilian market. In Brazil, regulations require that eggs be washed before they are sold. This is done to ensure food safety and reduce the risk of bacterial contamination that may be present on the egg's surface. Egg washing, as highlighted by Gole *et al*. [15], can damage the shell cuticle and expose pores, resulting in moisture loss and a deterioration of internal quality. These insights may help explain the differences observed between the control group without coating and the group treated with the semi-solid product based on carnauba wax and mineral oil regarding the observed weight loss in our study.

The weight reduction of eggs over the storage period provides important information about the quality and shelf life of fresh eggs. Weight loss during storage is a natural process influenced by the movement of water and gases (carbon dioxide) through the eggshell, as highlighted by Wardy *et al.* [16]. Egg weight loss mainly occurs due to the transfer of moisture from the albumen to the external environment through the shell's pores. In our study, it was observed that eggs coated with carnauba wax formed an impermeable protective layer similar to the natural cuticle covering the shell of fresh eggs. This natural cuticle plays a crucial role in protecting the pores on the shell, making it difficult for water to escape and preventing the entry of bacteria through these pores, as observed by Muñoz *et al.* [17] and Pires *et al.* [18]. Based on these results, we hypothesize that the waxy coating seals these pores and reduces the evaporation process.

Pushpakumara *et al.* [20] evaluated mineral oil and two other variations of vegetable waxes as coatings for chicken eggs stored at room temperature (27±2°C) for five weeks. They observed a lower weight loss in coated eggs compared to the control group without any coating, highlighting the effectiveness of these coatings in egg preservation. This finding is consistent with the results obtained in our study. However, we observed an even greater efficacy in preserving eggs coated with carnauba wax compared to mineral oil, which already has well-established results. In our study, it was observed that eggs coated with carnauba wax formed an impermeable protective layer similar to the natural cuticle that covers the shell. This highlights the effectiveness of the carnauba wax-based product in providing a more robust barrier compared to mineral oil coating. Carnauba wax, derived from the leaves of the Brazilian palm tree *Copernicia prunifera*, is known for its highly hydrophobic nature, imparting waterproof properties. In contrast, coating with mineral oil may not offer as effective a barrier, making carnauba wax a superior choice for egg preservation.

A study conducted by Eyng *et al*. [21], which also used carnauba wax as a coating for chicken eggs at different concentrations (12% and 15%) and temperatures (10ºC and 25ºC), demonstrated that during the storage period of the study, the weight loss in eggs coated with wax, at both concentrations and temperatures, was lower compared to the uncoated group. This indicates that regardless of temperature and concentration, the waxy coating on eggshells can preserve the internal quality of the eggs. In the study by Rachtanapun *et al*. [22], the authors used a mixture of paraffin and beeswax (0.5%) and found that this compound had the lowest weight loss after 4 weeks of storage at 25ºC.

The Effects of Coating Eggs with 30% Carnauba Wax and Storage on Egg White pH and Yolk pH

Throughout all storage days, both the yolk pH and albumen pH in the untreated control group were significantly higher ($p<0.05$) compared to the group coated with carnauba wax and mineral oil for both analyzed variables. However, the yolk and albumen pH in the mineral oil-treated group were significantly higher ($p<0.05$) than in the wax-treated group.

In our study, the yolk pH in the untreated control group ranged from 6.19 to 6.37, and the positive control group treated with mineral oil ranged from 6.13 to 6.21. Both control groups showed a larger variation in yolk pH compared to the group treated with carnauba wax, which had a very small variation, ranging from 6.0 to 6.06 over the storage days. As for albumen pH, there was a range of 9.17 to 9.56 for the untreated control group (negative control), the albumen pH of the mineral oil-coated group (positive control) ranged from 9.9 to 9.29 over the storage days, while the albumen pH of the wax-coated group varied from 8.35 to 8.75, showing lower pH levels compared to both negative and positive controls. Overall, all groups experienced an increase in pH as the storage time at room temperature increased.

Albumen pH can be used to determine the freshness of the egg white (Scott & Silversides [22]. Eggs coated with carnauba wax showed significantly lower pH values than the control group during the storage period. Albumen pH can also be used as a measure to indicate egg quality. A newly laid egg contains

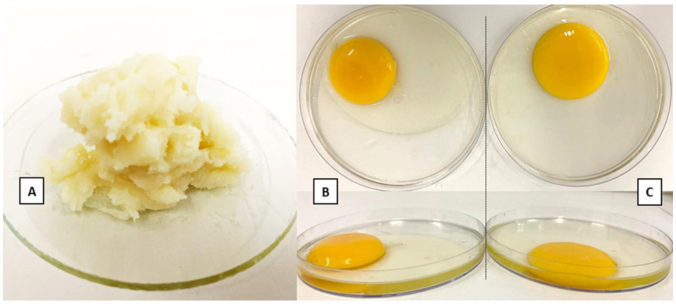

Figure 1: Internal quality of coated and uncoated eggs after 28 days of storage at room temperature. **(A)**: Semi-solid product based on carnauba wax formulated for surface coating of eggshells. **(B)**: Egg treated with carnauba wax: intact yolk and visible dense albumen; **(C)**: Uncoated control egg: the dense albumen is liquefied, and the yolk is flaccid and flat.

about 1.44 to 2.05 mg of dissolved CO_2 (in the form of carbonate), resulting in a pH between 7.6 to 8.7 [22]. Thus, during the storage period, this CO_2 and water are released through the pores in the eggshell, which increases the albumen pH, ranging from 8.9 to 9.4 [19,23]. These results suggest that the carnauba wax coating may delay the loss of carbon dioxide through the eggshell pores, acting as an effective gas barrier. In the study by Souza [24], the author tested a 6.25% carnauba wax emulsion compared to the untreated control group and a group of eggs coated with mineral oil. The conclusion was that eggs coated with mineral oil had a lower albumen pH (8.99) than the group treated with carnauba wax (albumen pH=9.38) after 35 days of storage at room temperature. It seems that the low concentration of carnauba wax in the emulsion couldn't protect the eggs as effectively as mineral oil did. A higher concentration of carnauba wax appears to better preserve the internal quality of the eggs, as found in our study. Pires *et al*. [18] also observed that at the end of the storage period, only mineral oil was able to maintain the albumen pH below the values observed in untreated eggs.

The yolk pH can vary between 6.4 to 6.9 during storage due to the release of CO_2 and water through the shell. Pushpakumara *et al*. [19] observed in their study that the coatings used on eggs acted as a barrier and helped reduce this evaporation through the shell when compared to uncoated eggs. In our study, the effectiveness of carnauba wax was also evident, as coated eggs had a small variation in pH. Studies have also supported the presence of lower pH values in the albumen and yolk of eggs coated with coatings containing essential oils on the last day of storage [26,27].

Effects of 30% Carnauba Wax Coating and Storage on Yolk Index

There was a significant difference ($p<0.05$) in the yolk index of eggs from the control group and those coated with carnauba wax and mineral oil during the 4-week storage period at room temperature. There was also a significant difference ($p<0.05$) between eggs coated with carnauba wax and eggs coated with mineral oil. After 4 weeks of storage, the yolk index of uncoated eggs decreased from an initial value of 0.3 to 0.16, while that of eggs coated with the 30% semisolid carnauba wax product decreased from 0.37 to 0.22. In general, throughout the storage period, both the uncoated control group (negative control) and the control group treated with mineral oil (positive control), as well as the group treated with the semi-solid waxy product, showed a reduction in egg yolk index. However, it was observed that the egg yolk index in the negative control group decreased more rapidly compared to eggs coated with carnauba wax and mineral oil (positive control). Nevertheless, eggs treated with carnauba wax maintained a significantly higher yolk index (p<0.05) compared to the positive control.

The yolk index is a ratio between the height and width of the yolk and is used as a measure of egg freshness, with a higher yolk index indicating better quality [28]. During the storage period, there is a weakening of the membranes, liquefaction of the egg white, and water absorption by the yolk, resulting in a decrease in the yolk index [18,29]. The results obtained by Pires *et al*. [18] demonstrated that for a period of fewer than 8 weeks, the use of coating was able to preserve the yolk index for a longer time compared to uncoated eggs, which is consistent with our study.

Effects of Coating Chicken Eggs with Carnauba Wax and Storage for the *Haugh* Unit (HU) Variable

Changes in the Haugh unit of eggs from the positive control group (treated with mineral oil); negative control group (no treatment) and eggs coated with carnauba wax during the 4-week storage period can be seen in Table 1.

At room temperature, regardless of the storage time, the eggs in the control group had statistically lower (p<0.05) Haugh unit values compared to the eggs coated with the waxy product. Overall, the Haugh unit decreased with increasing storage periods, as was also observed in the yolk index. However, the Haugh unit of eggs in the control group decreased more rapidly than the eggs coated with the carnauba wax product. It is evident that after the first 7 days of storage, the group of coated eggs maintained a Haugh unit value of 78.31, while the control group showed a much lower value of 54.22.

As the egg is stored, various changes occur in its physical and chemical properties, leading to a gradual deterioration. The decrease in the *Haugh* unit is indicative of this deterioration process. The *Haugh* unit is a metric that assesses egg quality based on albumen height and egg weight. Normally, the Haugh unit decreases as the storage time progresses, which can be attributed to processes such as ovomucin proteolysis, breaking of disulfide bridges, or interactions between α and β ovomucins [20]. The reduction in HU values suggests a change in the texture of the album, making it less thick and more liquid as discussed by Pushpakumara *et al*. 20].

The Haugh Unit, as proposed by Yüceer and Caner [12], serves as a parameter for classifying egg quality. In our study, one week post-storage, eggs treated with carnauba wax were classified as AA (HU: 78.31), indicating high quality; however, this classification dropped to A after 14 days (HU: 68.30) and remained so until 28 days (HU: 60.17), suggesting good quality albeit slightly lower than the initial rating in the first week of room temperature storage. For eggs coated with mineral oil, the Haugh Unit in the first week of storage was (HU: 60.32), classifying the eggs as A. In the second week, the classification of the eggs dropped to B (HU: 55.75), remaining in this category until the end of the experiment at 28 days (HU: 52.31). In contrast, untreated eggs started the first week of storage with a B classification (HU: 54.2) and maintained this classification until the end of the storage period (28 days), with an HU of 49.20 (Table 1). This suggests that the carnauba wax coating had a positive impact on maintaining egg quality over the storage period, as the treated eggs retained a higher classification compared to untreated eggs, which deteriorated in quality more rapidly.

In a study conducted by Jirangrat *et al*. [29], it was also observed that eggs coated with an oily substance like mineral oil, stored at room temperature for 5 weeks, changed from classification AA to B, while the control group without coating changed from AA to C according to the Caner & Yüceer [30] classification, which is consistent with our findings in this study. The difference between wax-coated eggs and untreated eggs at the end of the 28-day experiment can be seen in Figures 1B and 1C, respectively. The treated eggs exhibit intact yolks and visible dense albumen, in contrast to the control group, where the dense albumen is liquefied, and the yolk appears limp and flattened, indicating signs of deterioration.

Ongoing efforts in food preservation have driven advancements in research and technology in this field. Researchers and scientists are working to develop more effective and sustainable methods for preserving food, much like the studies on eggs discussed earlier. In addition to eggs, fruits are also being coated with different materials such as natural waxes, resins, edible polymers, or combinations of these components to protect and preserve the quality of fresh fruits. According to Blum *et al*. [31], immersing persimmons (*Diospyrus kaki*) in a solution with 12.5% carnauba wax helped maintain ascorbic acid levels and tissue firmness, allowing for storage for up to 49 days. Mota *et al*. [32] found that the use of carnauba wax effectively reduced fresh mass loss and wilting in yellow passion fruits (Passiflora edulis) stored at room temperature. These studies highlight the potential of wax coatings, such as carnauba wax, in preserving the quality and extending the shelf life of various fresh produce items, which is an important aspect of food preservation and reducing food waste.

Our waxy coating product (Figure 1A) appears to have great potential for the egg industry and retail establishments that face challenges in providing refrigeration systems for eggs. This coating material was designed to be environmentally friendly, safe, highly water-resistant, with good mechanical properties, and it offers a cost-effective solution. The use of this technology presents two distinct approaches. The first involves providing the product directly to organic farms and small producers, allowing them to treat the eggs before offering them to end consumers. Alternatively, consumers themselves can purchase fresh eggs and perform the treatment at home. Another option would be to transform the semi-solid product into a liquid formulation, enabling application by spraying directly onto the eggs, following a common practice with mineral oil in some farms.

Conducting more comprehensive studies becomes imperative to assess consumer acceptance and their perception regarding the formed coating film. Understanding how the application of these coatings can influence final consumer prices is essential to balance perceived benefits against additional costs. Furthermore, it is crucial to explore consumer preferences regarding treatment methods, whether directly on farms or at home, aiming for effective implementation aligned with market expectations. This in-depth analysis will provide valuable insights to guide the practical and successful application of this technology in the egg industry.

Food safety is a critical aspect to be considered in future studies, especially concerning the potential for the product to carry pathogenic bacteria through the shell pores into the interior of the eggs. Microbial contamination can result from various factors, such as Salmonella infection in poultry, leading to salmonellosis. Although the study by Rachtanapun *et al.*

[33], demonstrated that coating eggs with a mixture of cassava starch, carboxymethyl cellulose, and paraffin prevented microbial replication during storage at 30ºC, a thorough investigation of these aspects is essential to ensure that the use of the product does not compromise the quality and food safety of the eggs, meeting regulatory standards and instilling confidence in consumers. The incorporation of essential oils into carnauba wax-based egg coating products is a promising avenue of research. This exploration aims to assess potential benefits, including antimicrobial and aromatic properties, among other desirable characteristics. Subsequent studies can delve into the impact of essential oil additions on coating performance, encompassing aspects such as the preservation of internal egg quality, resistance to microorganisms, and potential sensory effects. Notably, Sousa Nali *et a*l. [34] investigated the influence of thymol diluted at 10% in mineral oil on the coating of chicken eggs stored at room temperature for 7, 14, and 21 days, suggesting thymol as a promising alternative for preserving internal egg quality. Additionally, Cui *et al.* [35] study demonstrated the positive effects of low concentrations of thyme oil (rich in thymol), combined with cold nitrogen plasma, in inhibiting bacterial growth on eggshells contaminated with Salmonella.

Conclusion

In conclusion, eggs with shells coated by a semi-solid product based on carnauba wax exhibited superior preservation of internal quality compared to uncoated eggs and those coated with mineral oil. These findings suggest that the waxy semi-solid product may serve as an alternative to extend the shelf life of eggs during a storage period of up to 28 days at room temperature. These discoveries have the potential to assist the egg industry in reducing economic losses during storage. Further studies are recommended, particularly investigating refrigerated egg storage and the use of coatings associated with the presence of active antimicrobial agents to minimize microbial contamination.

Author Statements

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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