



Coatings based on corn starch, gelatin, and cinnamon essential oil for postharvest preservation of strawberries

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Submitted: 09/29/2025; Accepted: 03/09/2026; Published: 04/15/2026.

ABSTRACT: The strawberry (*Fragaria × ananassa* Duch., cv. Albion) is a fruit of high nutritional and commercial value, whose post-harvest shelf life is limited by its non-climacteric nature. This study aimed to develop an edible coating based on corn starch (*Zea mays* L.), gelatin, and cinnamon essential oil (*Cinnamomum zeylanicum*) to prolong the shelf life of refrigerated strawberries. Commercial corn starches, avocado seed (*Persea americana* cv. Fuerte), and banana (*Musa* AAA cv. Cavendish) were evaluated, with corn starch being highlighted for its greater swelling capacity at temperatures below 60 °C, although it exhibited lower solubility. Cinnamon essential oil, obtained by distillation, yielded 1.56% and had a density of 1.048 g mL⁻¹. Using a 32-response surface design, the concentrations of gelatin (2, 3.5, 5 % w/v) and essential oil (0.3, 0.4, 0.5 % w/v) were optimized, determining that the combination of 2 % gelatin and 0.5 % essential oil significantly reduced the weight loss of strawberries ($p \leq 0.05$). The adjusted model explained 96.05% of the variability ($R^2 = 97.09$). Under these conditions, a 14.7% reduction in weight loss was achieved, and quality parameters were better preserved for 15 days at 2 °C and 50% humidity, demonstrating the effectiveness of the coating as a sustainable conservation strategy.

Keywords: edible coatings; corn starch; cinnamon essential oil; gelatin; Albion strawberry; post-harvest preservation.

Revestimentos à base de amido de milho, gelatina e óleo essencial de canela para conservação pós-colheita de morangos

RESUMO: O morango (*Fragaria × ananassa* Duch., cv. Albion) é uma fruta de alto valor nutricional e comercial, cuja vida útil pós-colheita é limitada por sua natureza não climatérica. Este estudo teve como objetivo desenvolver uma cobertura comestível à base de amido de milho (*Zea mays* L.), gelatina e óleo essencial de canela (*Cinnamomum zeylanicum*) para prolongar a vida útil de morangos refrigerados. Foram avaliados amidos de milho comerciais, sementes de abacate (*Persea americana* cv. Fuerte) e banana (*Musa* AAA cv. Cavendish), destacando-se o amido de milho por sua maior capacidade de intumescimento em temperaturas inferiores a 60 °C, embora tenha apresentado menor solubilidade. O óleo essencial de canela, obtido por destilação, apresentou rendimento de 1,56% e densidade de 1,048 g mL⁻¹. Utilizando um delineamento de superfície com 32 respostas, as concentrações de gelatina (2; 3,5; 5% p/v) e de óleo essencial (0,3; 0,4; 0,5% p/v) foram otimizadas, determinando-se que a combinação de 2% de gelatina e 0,5% de óleo essencial reduziu significativamente a perda de peso dos morangos ($p \leq 0,05$). O modelo ajustado explicou 96,05% da variabilidade ($R^2 = 97,09$). Nessas condições, obteve-se uma redução de 14,7% na perda de peso, e os parâmetros de qualidade foram melhor preservados por 15 dias a 2 °C e 50% de umidade, o que demonstra a eficácia do revestimento como estratégia de conservação sustentável.

Palavras-chave: revestimentos comestíveis; amido de milho; óleo essencial de canela; gelatina; morango Albion; preservação pós-colheita.

1. INTRODUCTION

The use of edible coatings on fresh fruits and vegetables has been established as an effective strategy to extend their post-harvest shelf life (Díaz et al., 2010), as they function as a semipermeable barrier to gas and moisture exchange, reducing firmness loss and oxidative deterioration (KAHRAMANOĞLU et al., 2022). These coatings are made from natural polymers such as carbohydrates, proteins, and

lipids, which, when applied to the fruit surface, act as primary packaging.

The strawberry (*Fragaria × ananassa* Duch.), especially the Albion variety, stands out for its richness in vitamins (A, E, B5, B6, and C), minerals (Ca, Fe, Mg, K, Se), anthocyanins, and phenolic compounds with antioxidant capacity, which also give it its characteristic red color (GARCÍA et al., 2012; WANG et al., 2019; FIERASCU et al., 2020). In Ecuador,

strawberry production has shown sustained growth, increasing from 500 tons in 1999 to 15,000 tons in 2013 (BARRAZUETA-ROJAS et al., 2018). However, its delicate external structure and the absence of a protective shell make it a highly perishable product, prone to water loss, oxidative decomposition, and a decrease in sensory quality in a short time (SAPPER, CHIRALT, 2018).

Several studies have highlighted that starch-based coatings, in combination with plasticizers, offer an effective barrier against oxygen and carbon dioxide, allowing the regulation of enzymatic activity and maintaining quality during storage (DÍAZ-GALINDO et al., 2020; LUCIANO et al., 2022). However, their hydrophilic nature represents a limitation in terms of resistance to moisture passage (SAPPER; CHIRALT, 2018). For this reason, the use of mixtures with hydrophobic biopolymers, such as gelatin, and functional additives such as essential oils, which not only improve the barrier properties but also provide antimicrobial and antioxidant properties to the coating, has been proposed.

In this context, this study proposes the development and optimization of an edible coating based on corn starch, gelatin, and cinnamon essential oil, aimed at prolonging the shelf life of Albion variety strawberries through the evaluation of physicochemical parameters and their impact on weight loss during refrigerated storage.

2. MATERIAL AND METHODS

2.1. Isolation of starches from banana, avocado seed, and corn

Starches were obtained from banana (*Musa* AAA cv. Cavendish), avocado seed (Fuerte variety), and commercial corn. The bananas were purchased during the 12th week of harvest, green, with a ripeness level of 1 according to the Von der Werke scale, and a caliber of 39 to 42 cm, as specified in standard NTE INEN 2801 (2013).

The avocado seeds, previously washed, were dried at room temperature. Starch extraction was performed according to the methodology described by Vargas et al. (2016). Both the fruits and the seeds were peeled and cut into 3 × 3 cm pieces, then immersed in a homogeneous solution of 0.3% (w/v) sodium metabisulfite at a 1:1.5 ratio. The pieces were subsequently ground using a domestic blender at maximum speed (3600 rpm) for two minutes. The mixture was filtered using a 345 μm mesh, and successive washes were performed until the obtained liquid was clear. The liquid was left to stand for 4 hours to allow for sedimentation, and the resulting sediment was subjected to centrifugation at 2500 rpm in a Corning LSE centrifuge. Subsequently, the material was dried in an oven (Mermert) at 50 °C for 24 hours until it reached a constant weight. Finally, the dried material was sieved using a #60 mesh screen to homogenize the particle size. The starch yield was calculated using the equation proposed by Pascoal et al. (2013):

$$\text{Starch yield (\%)} = \frac{\text{Dry starch (g)}}{\text{Banana pulp (g)}} \times 100 \quad (01)$$

2.2. Evaluation of the proximate composition of starches

Commercial corn starch purchased at a local market in the city of Machala was compared with starches extracted from Fuerte avocado seeds and Cavendish banana seeds. Proximate analysis was used to characterize the three starches

using standardized analytical procedures. Fiber content was determined using the Weende method (WOLTERS et al., 1992), while the lipid fraction was evaluated according to the AOAC 2003.06 (2005). Protein quantification was performed by high-temperature combustion using the Dumas method (AOAC 968.06, 2005). Ash content was determined by controlled-temperature calcination (AOAC 923.03, 2005), and moisture content was determined by oven drying according to AOAC 925.10 (2005). Carbohydrate content was calculated by difference, considering the proportion remaining after subtracting the major components. All analyses were performed in triplicate. The results were subjected to analysis of variance (ANOVA) to identify statistically significant differences between the mean values for each component.

2.3. Infrared spectroscopy analysis

Starch spectra were obtained using Fourier transform infrared spectroscopy (FTIR) with an FT/IR-6X spectrometer (JASCO) equipped with an attenuated total reflection (ATR) accessory. Thirty-two scans were performed in the wavelength range 4000 to 600 cm⁻¹.

2.4. Functional evaluation of starches

To determine the swelling power (SP), water solubility index (WSI), and water absorption rate (WAI) of banana, avocado, and corn starches, the methodology proposed by Cedeño et al. (2024) was used with modifications. One gram of starch (dry basis) was weighed into previously oven-dried centrifuge tubes at 60 °C for 16 hours and then tared. Then, 25 mL of distilled water preheated to specific temperatures (50, 60, 70, and 80 °C) was added. The tubes were placed in a water bath inside a 1-L beaker on a hot plate (DLAB MS7-H550-S) for 30 minutes. During the first third of heating, the samples were manually shaken to homogenize them. Subsequently, they were centrifuged in a centrifuge (Hermle) at 2500 rpm for 15 minutes. The supernatant (soluble starch) was removed, and the total volume was measured. Then, 10 mL was placed in pre-weighed Petri dishes and dried in an oven at 105 °C for 16 hours. Both the remaining gel and the dishes were weighed using an analytical balance (Radwag). The Petri dishes were finally dried in an oven (Mermert) at 70 °C for 16 hours. All analyses were performed in triplicate. ISA, IAA, and PH values were calculated using equations 2, 3, and 4. The results were analyzed using analysis of variance (ANOVA), with a significance level of $p \leq 0.05$, to identify statistically significant differences between treatments.

$$\text{IAA} = \frac{\text{Gel mass (g)}}{\text{Sample mass on a dry basis (g)}} \quad (02)$$

$$\text{ISA} = \frac{\text{Soluble mass (g)} \times \frac{V}{10}}{\text{Sample mass on a dry basis (g)}} \quad (03)$$

$$\text{PH} = \frac{\text{Gel mass (g)}}{\text{Sample mass on a dry basis} - \text{Solubl mass (g)}} \quad (04)$$

2.5. Obtaining and characterizing cinnamon essential oil

Commercial cinnamon bark samples were purchased from a market, with a single brand and lot number selected to ensure uniformity. The essential oil extraction was carried out using the hydrodistillation method with a Clevenger-type apparatus, according to the methodology described by Sontakke et al. (2019) with modifications. 200 g of crushed

bark were placed in a 5 L flask along with 1 L of distilled water. The mixture was distilled in 4-hour cycles for a total of five cycles. The oil was collected every 2 hours in amber bottles and stored at 4 °C. The oil yield was calculated following the equation described by Fernández et al. (2024):

$$\text{Yield (\%)} = \frac{\text{Volume of essential oil (mL)}}{\text{Mass of plant material (g)}} \times 100 \quad (05)$$

The density of the oil was determined using a 10 mL pycnometer, which had been previously dried at 105 °C for 3 hours in a MEMMERT oven and stored in a desiccator until use. The empty pycnometer was weighed, then filled with distilled water at 20 °C, and finally with the essential oil also at 20 °C, using a RADWAG analytical balance. The procedure was performed in triplicate, and the density was calculated based on the mass difference, as described by Echeverría; Porta (2021).

$$\rho_{20^{\circ}\text{C}} = \left(\frac{P_2 - P}{P_1 - P} \right) \quad (06)$$

where: ρ , density; P_2 , mass of the pycnometer plus that of the sample (20 °C); P_1 , mass of the pycnometer plus that of the distilled water (20 °C); P , mass of the pycnometer.

The chemical composition of the oil was analyzed using gas chromatography-mass spectrometry (GC-MS), with an Agilent Technologies 7890A chromatograph and a 5977A mass detector. A total of 0.2 μL of neat oil was injected at a 50:1 split ratio. The injector temperature was set at 250 °C, using helium as the carrier gas at 7.1 PSI. The column used was an HP-5MS (30 m \times 0.25 mm \times 0.25 μm). The temperature program started at 40 °C, increasing at 4 °C/min to 260 °C, with a 10-minute hold, and a post-run to 290 °C for 1 minute. Compound identification was performed using the NIST 14 library.

2.6. Preparation of coating-forming solutions

The coating-forming solutions were formulated based on a 3² response surface design, executed in two blocks with replication at the central point and completely randomized, using Statgraphics XIX.III program. The effect of different levels of gelatin (2, 3.5, and 5% w/v) and cinnamon essential oil (0.3, 0.4, and 0.5% w/v) on the weight loss of strawberries (*Fragaria* \times *ananassa* Duch., var. Albion) was evaluated, following the methodology of Fakhouri et al. (2015). The gelatin solutions were prepared according to the treatments, while the commercial corn starch solution and glycerol were kept constant at 5% (w/v) and 3% (w/v), respectively. Both solutions were heated separately: the starch solution at 70 °C for 30 minutes and the gelatin solution at 80 °C for 10 minutes, using a DLAB MS7-H550-S hotplate with magnetic stirring. The solutions were mixed at 55 °C with constant stirring for 5 minutes. Glycerol was then added, and stirring continued for 3 minutes. The temperature was then lowered to 40 °C using a water bath, and Tween 80 was added as needed. Finally, cinnamon essential oil was added and stirred vigorously for 10 minutes at room temperature until a homogeneous solution was obtained.

2.7. Coating application and storage

Strawberries were selected for their uniformity of shape, size, absence of mechanical damage, and level of maturity (color 4). They were washed and disinfected by immersion in

a sodium hypochlorite solution (5 mg) for 2 minutes. The peduncle and sepal were removed and immersed in the coating-forming solutions for 2 minutes. They were then left to drain on a mesh with sterile gauze for 4 hours and dried in the air for 24 hours. Each treatment was applied in two immersions. The mass of the coated strawberries was recorded as the initial weight using an analytical balance. The samples were stored in coded polypropylene trays with five 0.45 mm diameter perforations to maintain an internal atmosphere at approximately 2 °C and 50% relative humidity, as described by Zavaleta et al. (2020).

2.8. Evaluation of the effect of coating on the preservation of strawberries

A total of 144 strawberries were divided into two groups: 72 fruits were coated with the optimal formulation (2% w/v gelatin and 0.5% w/v essential oil). At the same time, the remaining 72 were used as a control, immersed only in distilled water. The samples were stored under the same conditions mentioned above. Measurements were taken every 3 days for 15 days to evaluate weight loss, total soluble solids (TSS), pH, and titratable acidity. Each analysis was performed in triplicate, following the procedures described by García et al. (2012) and Zavaleta et al. (2020).

3. RESULTS

3.1. Starch extraction yield

The starch yield obtained from banana was 26.56 \pm 3.45%, while that extracted from avocado seed was 20.5 \pm 2.2%, using the wet milling method. These values are in agreement with those reported by Pascoal et al. (2013) and Wang et al. (2022). In the case of avocado seed starch, similar results were reported by Builders et al. (2010), who obtained a yield of 20.5%, and by Martins et al. (2022) and Kowalski et al. (2017), who recorded yields of 19.54% and 20.1%, respectively. The differences between the values obtained can be attributed to various factors, including the extraction method, botanical variety, physiological state of the material, its freshness, and the duration of separation and washing.

3.2. Proximate composition of starches

Analyses showed that the proximate composition of starches varied significantly among the three sources ($p \leq 0.05$) (Table 1). Commercial corn starch had the highest carbohydrate content (88.16 \pm 0.01%), compared to avocado seed starch (86.15 \pm 0.092%) and banana seed starch (83.80% \pm 0.0529%). These results align with those reported by Hernández-Medina et al. (2008), who state that corn kernels contain between 61 and 78% starch, and with Zhang et al. (2021), who also highlight that corn contains non-starch polysaccharides.

Regarding fat content, avocado seed starch recorded the highest value (0.3511 \pm 0.02%), which is consistent with its good lipid profile, including linoleic, oleic, and palmitic acids (NASCIMENTO et al., 2025). In contrast, corn starch showed the lowest fat content (0.0231 \pm 0.005%), which can be attributed to industrial processing that removes the germ of the grain, where the oil and protein are concentrated (COLONIA, 2013; GONGORA et al., 2025). Regarding fiber, protein, and ash content, banana starch had the highest values: 1.526 \pm 0.0941% (fiber), 1.936 \pm 0.0112% (protein), and 1.216 \pm 0.066% (ash). These results are consistent with the reports of Olatunde et al. (2017) and Montoya-López et

al. (2014), who linked high ash content with the presence of minerals such as calcium, potassium, and magnesium. Humidity also showed significant differences: banana starch recorded the highest value ($11.44 \pm 0.0518\%$), followed by

corn starch ($10.826 \pm 0.061\%$), and avocado seed starch the lowest ($8.793 \pm 0.0102\%$). These variations could be due to differences in the drying methods used (JIMÉNEZ et al., 2021).

Table 1. Proximate characterization of three varieties of starches.
Tabela 1. Caracterização aproximada de três variedades de amidos.

Component	Starch		
	Commercial corn	Avocado seeds	Cavendish banana
Fiber (%)	0.23 ± 0.0264^a	0.6 ± 0.0205^b	1.526 ± 0.0941^c
Fats (%)	0.0231 ± 0.005^a	0.3511 ± 0.02^b	0.08 ± 0.0100^a
Proteins (%)	0.723 ± 0.0406^a	3.63 ± 0.01^b	1.936 ± 0.0112^c
Carbohydrates (%)	88.161 ± 0.01^a	86.153 ± 0.092^b	83.8 ± 0.0529^c
Ash (%)	0.036 ± 0.0573^a	0.473 ± 0.0517^b	1.216 ± 0.066^c
Humidity (%)	10.826 ± 0.061^a	8.793 ± 0.0102^b	11.44 ± 0.0518^a

Mean \pm standard error; n=3.

Means in a column with a different letter are significantly different ($p \leq 0.05$).

3.3. FTIR analysis of starches

Figure 1 shows the Fourier transform infrared (FTIR) spectra of the three starches evaluated, in which characteristic polysaccharide bands were identified. FTIR spectra showed that all three starches exhibited bands characteristic of polysaccharides. Stretching vibrations were observed at approximately 3300 cm^{-1} , corresponding to the -OH groups of amylose and amylopectin (WANG et al., 2021). A band at 2934 cm^{-1} was related to glucose units, and a bending vibration at 1639 cm^{-1} corresponded to -OH groups in the amorphous regions. In the fingerprint region, bands were identified at 1150 cm^{-1} (CO of ethers), at 1041 and 995 cm^{-1} (crystalline regions), and at 1011 cm^{-1} (amorphous region), with varying intensities. In addition, signals were observed at 860 and 762 cm^{-1} corresponding to α -glycosidic bonds (COC and COH) (BASILIO-CORTÉS et al., 2019; NWAKEGO et al., 2022).

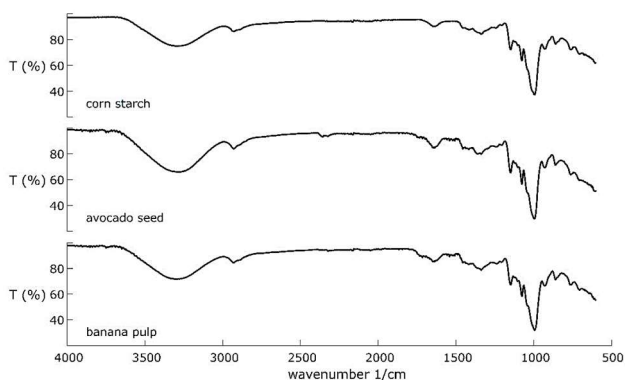


Figure 1. FTIR spectra of commercial corn starch, avocado seed starch, and banana pulp starch.

Figura 1. Espectros de FTIR de amido de milho comercial, de semente de abacate e de polpa de banana.

3.4. Functional properties of starches

In all the starches evaluated, the swelling power (PH) increased with temperature (Figure 2a). Corn starch showed a greater swelling capacity at $60 \text{ }^\circ\text{C}$, reaching a value of $9.453 \text{ g water g}^{-1} \text{ starch}$ at $90 \text{ }^\circ\text{C}$.

Avocado and banana seed starches showed a progressive increase from $70 \text{ }^\circ\text{C}$, reaching 12.115 and 14.157 g g^{-1} , respectively, at $90 \text{ }^\circ\text{C}$. This behavior is attributed to their lower amylose content and higher gelatinization temperatures (CHEL-GUERRERO et al., 2016; OLATUNDE et al., 2017; UTRILLA-COELLO et al., 2014).

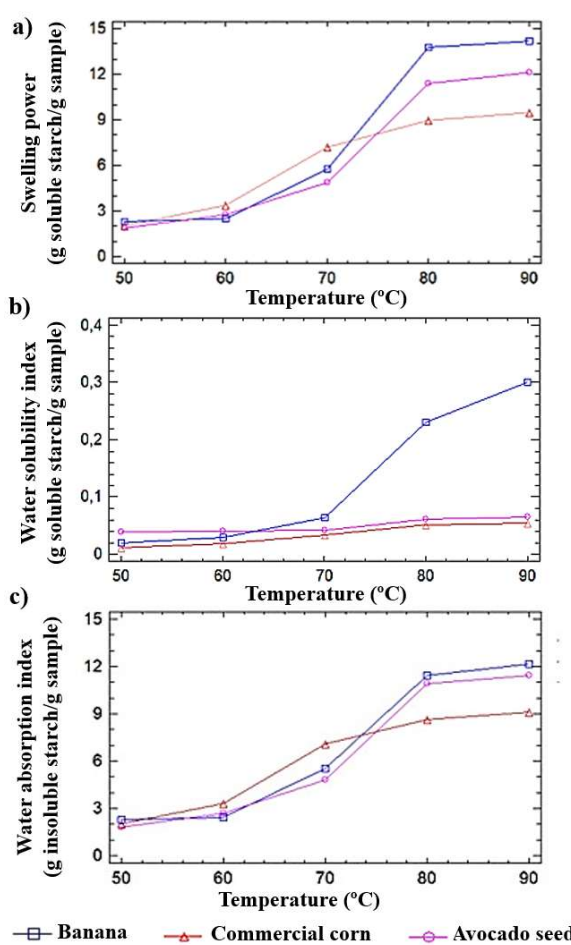


Figure 2. Functional properties of commercial corn starch, avocado seed starch, and banana pulp starch: a) swelling power; b) water solubility index; and c) water absorption index.

Figura 2. Propriedades funcionais do amido de milho comercial, amido de semente de abacate e amido de polpa de banana: a) poder de intumescimento; b) índice de solubilidade em água; e c) índice de absorção de água.

The water solubility index (ISA) also increased with temperature (Figure 2b). At $70 \text{ }^\circ\text{C}$, corn starch had a value of 0.0185 g g^{-1} , significantly lower than that of avocado (0.0415 g g^{-1}) and banana (0.0634 g g^{-1}). The lower solubility of corn starch may be attributed to its higher amylose content and distinct molecular organization (TARAHY et al., 2022;

DHULL et al., 2021). The water absorption index (IAA) values reflected a similar trend to the PH (Figure 2c). At 90 °C, avocado and banana starches reached 11.45 and 12.15 g g⁻¹, respectively, while corn starch reached only 9.123 g g⁻¹. These results confirm the greater absorption capacity of starches with higher amylopectin content (CHEL-GUERRERO et al., 2016; TARAHI et al., 2022).

3.5. Characterization of cinnamon essential oil

The average yield of cinnamon essential oil obtained was 1.56 ± 0.09%, with a density of 1.048 ± 0.003 g mL⁻¹. These

results are similar to those reported by Echeverría; Porta (2021). GC-MS analysis (Figure 3) revealed 1-(E)-cinnamaldehyde (87.66%) as the majority compound, followed by 2-cis-cinnamaldehyde (1.16%), 3-benzenepropanal (1.88%), cinnamyl ester acetic acid (3.24%), benzaldehyde (0.64%), and alpha-copaene (0.44%).

These findings are consistent with those reported by Cantó; Blázquez (2017) and Black-Solís et al. (2017), who also reported cinnamaldehyde as the predominant compound.

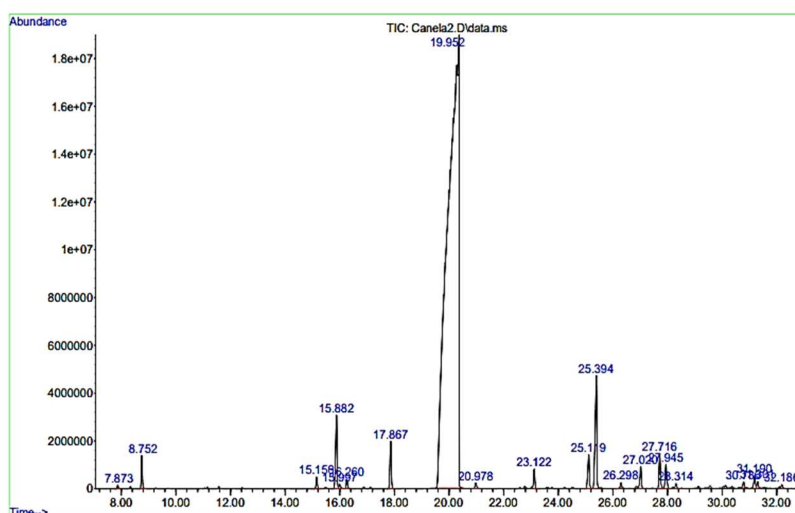


Figure 3. Chromatogram of cinnamon essential oil.

Figura 3. Cromatograma do óleo essencial de canela.

3.6. Evaluation of weight loss in coated strawberries

A 3²-response surface design was employed, with 20 treatments in two blocks and replication at the central point, to assess the impact of gelatin and essential oil concentrations on weight loss (Table 2). Treatments with 2% gelatin and 0.5% essential oil showed the lowest weight losses (6.50–6.55%), while those with 5% gelatin and 0.3% oil showed the highest (up to 17.07%). The effects of the factors and their interaction were significant ($p \leq 0.05$), as indicated by the Pareto diagram. As reported by Cedeño-Sares et al. (2023) and Gómez-Contreras et al. (2021), the essential oil improves the hydrophobicity of the coating, reducing moisture loss. In contrast, gelatin, due to its hydrophilic character, increases water permeability (FAKHOURI et al., 2015; ESPARVARINI et al., 2022).

Runs 3, 4, 13, and 14 (with 2% gelatin and 0.4–0.5% oil) had the lowest losses, while treatments 7, 10, 17, and 20 (with 5% gelatin and ≤0.4% oil) had the highest. The adjusted model yielded an R² coefficient of determination of 97.0901% and an adjusted R² of 96.0508%, confirming the model's high explanatory power.

The optimal levels, which minimized weight loss, were 2% gelatin and 0.5% cinnamon essential oil. The Pareto diagram (Figure 4a) illustrates the significant effects of factors and their interactions on weight loss. The response surface plot (Figure 4b) indicates that a lower gelatin concentration, combined with a higher essential oil content, minimizes weight loss in strawberries.

The adjusted model for weight loss in coated strawberries is expressed as:

$$y = -6,25698 + 6,49002 * x_1 + 33,0933 * x_2 - 0,262462 * x_1^2 - 6,22792x_1x_2 - 36,2614x_2^2 \quad (07)$$

where: y = weight loss (%); x_1 = gelatin (%); x_2 = cinnamon essential oil (%).

Table 2. Percentage of weight loss of strawberries by treatment.

Tabela 2. Percentual de perda de peso de morangos por tratamento.

Run	Gelatin (% w/v)	Cinnamon essential oil (% w/v)	Weight loss (%)
1	3.5	0.5	10.88 ± 0.003 ^b
2	3.5	0.4	11.87 ± 0.006 ^c
3	2.0	0.5	6.50 ± 0.03 ^a
4	2.0	0.4	8.16 ± 0.0002 ^a
5	3.5	0.4	11.88 ± 0.0002 ^c
6	3.5	0.3	12.89 ± 0.0003 ^d
7	5.0	0.3	17.07 ± 0.0004 ^g
8	5.0	0.5	10.87 ± 0.0003 ^c
9	2.0	0.3	8.96 ± 0.0001 ^b
10	5.0	0.4	15.15 ± 0.0002 ^f
11	3.5	0.5	10.87 ± 0.0003 ^c
12	3.5	0.4	11.47 ± 0.0008 ^c
13	2.0	0.5	6.55 ± 0.0003 ^a
14	2.0	0.4	8.16 ± 0.0003 ^a
15	3.5	0.4	11.88 ± 0.0001 ^c
16	3.5	0.3	12.89 ± 0.0003 ^c
17	0.5	0.3	17.07 ± 0.0002 ^g
18	5.0	0.5	10.89 ± 0.0003 ^c
19	2.0	0.3	8.97 ± 0.0001 ^b
20	5.0	0.4	15.15 ± 0.0002 ^f

Mean ± standard error; n= 2.

Different letters indicate significant differences ($p \leq 0.05$).

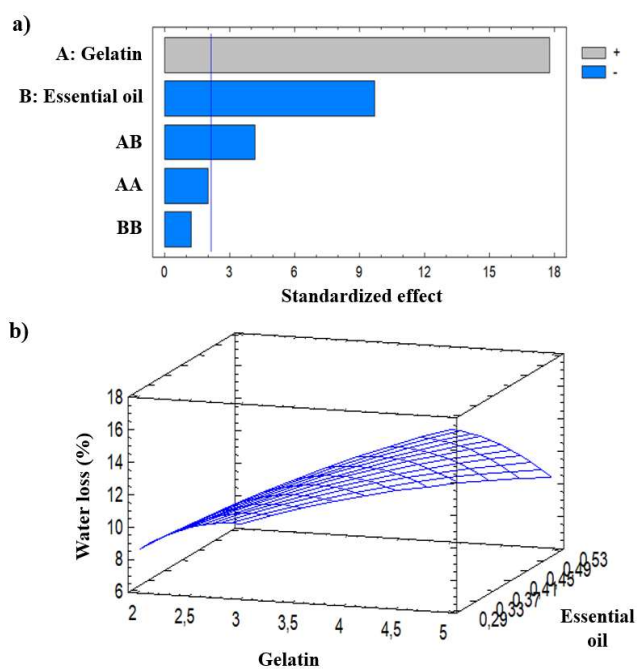


Figure 4. Pareto diagram (a) and response surface plot (b) for weight loss in coated strawberries during storage.

Figura 4. Diagrama de Pareto (a) e gráfico de superfície de resposta (b) da perda de peso em morangos revestidos durante o armazenamento.

The coefficient of determination (R^2) was 97.09, while the R^2 adjusted for the degrees of freedom reached 96.05, indicating an adequate fit of the model and a high explanatory capacity of the independent variables on the analyzed response.

3.7 Effect of coating during storage

During the 15 days of storage at approximately 2 °C and 50% RH, coated strawberries exhibited a weight loss of 27.03%, compared to 41.74% for uncoated strawberries, representing a reduction of 14.71% (Figure 5). This result is consistent with that reported by Fakhouri et al. (2015) and Gómez-Contreras et al. (2021), who demonstrated that starch-gelatin coatings with essential oils function as semipermeable barriers, reducing water loss.

The soluble solids content was more stable in the coated strawberries, suggesting lower metabolic activity. This finding is consistent with those of Barrazueta-Rojas et al. (2018) and Kahramanoğlu et al. (2022), who explain that coatings modify the internal atmosphere and slow down respiration.

Likewise, pH increased during storage, while titratable acidity decreased, with less extreme values in coated strawberries. These results suggest that the coating helped preserve organic acids by limiting contact with oxygen, which slows down biochemical ripening processes (WANG et al., 2019; KHODAEI et al., 2021; PAYE et al., 2022; KAHRAMANOĞLU et al., 2022).

The ripening index increased in both groups, but was significantly lower in the coated strawberries. This is related to greater soluble solids retention and a lower decrease in acidity, as documented by Hernández-Muñoz et al. (2008) and Medina (2017).

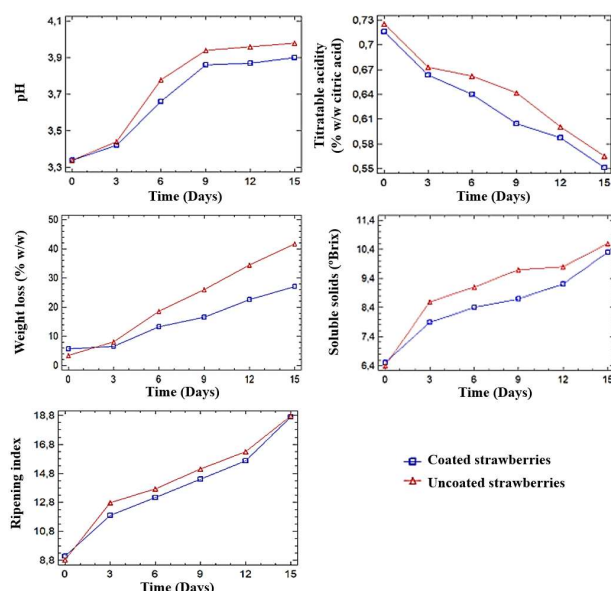


Figure 5. Behavior of physical and chemical indicators of coated (5% (w/v) commercial corn starch, 3% (w/v) glycerol, 2% (w/v) gelatin, and 0.5% (w/v) essential oil) and uncoated strawberries during storage.

Figura 5. Comportamento de indicadores físicos e químicos de morangos revestidos (5% (p/v) de amido de milho comercial, 3% (p/v) de glicerol, 2% (p/v) de gelatina e 0,5% (p/v) de óleo essencial) e não revestidos durante o armazenamento.

5. DISCUSSION

The formulation of an edible coating based on corn starch, gelatin, and cinnamon essential oil is part of the growing trend of using polysaccharide-protein matrices combined with bioactive compounds to extend the shelf life of fresh fruits.

In functional terms, corn starch was chosen due to its swelling behavior and lower relative solubility compared to alternative starches; this finding is consistent with reports on the influence of amylose/amylopectin composition and molecular structure on barrier and gelatinization properties (WANG et al., 2021; TARAHI et al., 2022). Studies on avocado and banana seed starches describe similar functional trends (CHEL-GUERRERO et al., 2016; OLATUNDE et al., 2017), supporting the feasibility of using byproducts as an alternative input, although their performance and thermal behavior may require formulation adjustments (JIMÉNEZ et al., 2021).

The predominance of 1-(E)-cinnamaldehyde in the cinnamon essential oil in the present study is consistent with the literature that identifies this compound as the primary responsible for the oil's antimicrobial and antioxidant activity (BLACK-SOLÍS et al., 2017; CANTÓ; BLÁZQUEZ, 2017). Several studies have shown that the incorporation of cinnamaldehyde or essential oils rich in this compound into polymeric matrices improves microbial resistance and decreases surface oxidation of fruits (WANG et al., 2019; DÍAZ-GALINDO et al., 2020). Therefore, the observation of better preservation of ripening-related parameters (e.g., lower increase in ripening index, preservation of soluble solids, and lower acid loss) is consistent with the mechanism proposed in the literature: the formation of a semipermeable barrier that reduces the rate of gas exchange and, in turn, respiration and oxidative stress (FAKHOURI et al., 2015; KAHRAMANOĞLU et al., 2022).

Comparison with work on weight loss reduction. Previous studies using starch-gelatin coatings and/or starch with essential oils have reported reductions in weight loss and spoilage rates that are consistent with the effects observed in this study. For example, Fakhouri et al. (2015) showed that starch/gelatin coatings reduce mass loss in refrigerated grapes, attributing the effect to the physical synergy between the polysaccharide-protein matrix and the plasticizer.

Similarly, Díaz-Galindo et al. (2020) and Gómez-Contreras et al. (2021) reported that starch formulations with essential oil emulsions improve surface hydrophobicity and decrease water loss in fruits, supporting the selection of 0.5% (w/v) cinnamon essential oil as a critical factor in the optimization process.

Although the systems (grape, strawberry, other berries) and experimental conditions differ between studies, the convergence in the direction of the effect (improved water retention when incorporating EOs into starch matrices) reinforces the generality of the proposed physicochemical mechanism (GÓMEZ-CONTRERAS et al., 2021; DÍAZ-GALINDO et al., 2020).

Effect of the gelatin-essential oil composition. The observed pattern, greater permeability with increasing gelatin fraction and better behavior with higher essential oil concentrations, is consistent with literature evidence on the duality between the mechanical/structural properties of proteins and the hydrophobicity provided by lipid phases. Gelatin, due to its hydrophilic nature and protein network, can promote the passage of water vapor in the absence of a sufficient hydrophobic component, while essential oils, when arranged in the matrix as dispersed or emulsified phases, increase the tortuosity of the path for vapor diffusion and improve resistance to the passage of water (ESPARVARINI et al., 2022; CEDENO-SARES et al., 2023). These effects have already been described in comparable formulations and explain why the 2% gelatin + 0.5% EO combination was optimal in this experiment (FAKHOURI et al., 2015; ESPARVARINI et al., 2022).

Physicochemical results and postharvest physiology. The relative stabilization of soluble solids and the lower decrease in acidity in coated fruits reflect a decrease in respiration and enzymatic activity associated with ripening; similar findings were reported by Kahramanoğlu et al. (2022) and Khodaei et al. (2021) in strawberries treated with coatings enriched with essential oils and bioactive compounds. These publications also suggest that the modification of the internal atmosphere by the coating can reduce the activity of enzymes such as pectinase and polyphenol oxidase, resulting in less loss of firmness and preservation of sensory attributes—an aspect that, in the present study, requires confirmation through enzymatic assays and sensory tests (HERNÁNDEZ-MUÑOZ et al., 2008; MEDINA, 2017).

Relative and comparative limitations with the literature. Although the comparative evidence indicates that the strategy is robust, it is worth highlighting methodological limitations that frequently appear in the literature and that also apply to the current work. Many published studies complement physicochemical measurements with: (a) quantitative microbiological analyses to confirm the reduction in microbial load and the antifungal activity of EOs; (b) controlled-release assays (release kinetics) to characterize the persistence of the bioactive compound on the surface; and (c) sensory evaluations and migration tests to rule out negative impacts on aroma or flavor (WANG et al., 2019;

DÍAZ-GALINDO et al., 2020; ZAVALETA et al., 2020). The absence of these assays limits quantitative comparability with studies that do include them and therefore suggests clear avenues for follow-up work. Furthermore, variability in storage conditions (temperature, relative humidity), fruit type, and application method makes it difficult to directly extrapolate percentages of weight loss reduction between studies. Even so, the direction of the effects is consistent between authors (FAKHOURI et al., 2015; GÓMEZ-CONTRERAS et al., 2021).

Practical implications and scaling. From an applied perspective, the use of starches from by-products (avocado or banana seeds) could offer economic and environmental advantages, a point explored in several reviews on the valorization of agroindustrial waste (JIMÉNEZ et al., 2021; ZHANG et al., 2021). However, commercial adoption requires characterizing the reproducibility of starch extraction at scale, batch stability, and compatibility with industrial packaging and logistics processes (GINTING et al., 2015). Furthermore, regulation and sensory acceptance must be assessed, as essential oils at functional concentrations can modify the aromatic profile of strawberries and affect consumer acceptance (WANG et al., 2019).

5. CONCLUSIONS

Starches extracted from avocado and banana seeds exhibit physicochemical and functional properties similar to those of commercial corn starch, making them suitable for the development of edible coatings. Furthermore, cinnamon essential oil, rich in 1-E-cinnamaldehyde, demonstrated properties suitable for its incorporation as a functional agent.

The optimal formulation, composed of 2% gelatin and 0.5% essential oil, significantly reduced weight loss in Albion strawberries and improved their physicochemical stability during storage. Together, these results demonstrate the potential of leveraging agro-industrial byproducts and natural compounds in the development of active and sustainable coatings to extend the shelf life of fresh fruits.

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Authors' contributions: L.A.C.S.: conceptualization, acquisition of financing, methodology, investigation or data collection, administration or supervision, writing (original draft), writing (review and editing); S.S.B.E.: methodology, investigation or data collection, writing (original draft); B.G.L.: methodology, investigation or data collection, writing (original draft); A.C.: conceptualization, methodology, validation, writing (original draft), writing (review and editing); M.A.G.: conceptualization, methodology, statistical analysis, validation, writing (review and editing), translation. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Technical University of Machala.

Data availability: Dataset available on request from the corresponding authors.

Conflict of interest: The authors declare that they have no conflict of interest.



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