Revista Ensaios e Ciência
ISSN 1415-6938 e ISSN 2178-695X

DOI: https://doi.org/10.17921/1415-6938.2026v30n2p258-279

The Efficiency of Coating in the Preservation of Palmer Variety Mangoes

Eficiência do Revestimento na Conservação de Mangas cv. Palmer

Received: February 2026
Accepted: June 2026

Rutinéia Martins Freitas: Empresa Brasileira de Serviços Hospitalares. RN, Brazil. Instituto Federal Goiano. GO, Brazil. E-mail: nutrirutifreitas@gmail.com

Lucas Silva Peixoto: Instituto Federal Goiano. GO, Brazil.

Hygor Rodrigues de Oliveira: Instituto Federal de Mato Grosso do Sul. MS, Brazil.

Geovana Rocha Plácido: Instituto Federal Goiano. GO, Brazil.

Osvaldo Resende: Instituto Federal Goiano, GO, Brazil.

Alex Fonseca Souza: Instituto Federal de Mato Grosso do Sul, MS, Brazil.

Viviane Patrícia Romani: Instituto Federal do Paraná, PR, Brazil.

Danilo Tófoli: Instituto Federal de Mato Grosso do Sul, MS, Brazil.

Abstract

Mango, a climacteric fruit, experiences losses throughout the supply chain due to mechanical injuries and physiological changes that negatively affect its color, aroma, flavor, and texture. Among commercially cultivated varieties, the Palmer cultivar stands out because of its market acceptance and post-harvest potential. This study addresses challenges related to the post-harvest quality of mangoes, aiming to improve preservation technologies, maintain fruit quality, and reduce unnecessary waste of natural resources. To achieve this objective, edible coatings formulated with cornstarch and enriched with natural waxes, including beeswax, candelilla wax, and carnauba wax, were applied to freshly harvested fruits. After harvest, mangoes were sanitized, coated, and stored at an average temperature of 29°C under controlled conditions. In triplicate experiments, a total of 108 Palmer mangoes were evaluated every two days for weight loss, peel coloration, firmness, pH, titratable acidity, soluble solids, respiratory rate, and ultrastructural characteristics using electron microscopy. These analyses provided a comprehensive understanding of preservation efficiency and coating performance. Results demonstrated that coatings significantly extended shelf life and preserved sensory and physicochemical properties. Coated mangoes maintained integrity for 12 days, while uncoated fruits lasted only 8 days. Beeswax showed superior effectiveness, followed by candelilla and carnauba waxes, highlighting advances for sustainable post-harvest management and industry applications.

Keywords: Edible Coating. Mangifera Indica. Waste. Supply Chain.

Resumo

A manga, fruto climatérico, apresenta perdas significativas ao longo da cadeia de suprimentos devido a danos físicos ou alterações que comprometem sua cor, aroma, sabor e textura. Entre as variedades comercialmente disponíveis, destaca-se a cultivar Palmer. O estudo aborda desafios relacionados à qualidade pós-colheita da manga, fruta tropical amplamente cultivada, com o objetivo de aprimorar tecnologias pós-colheita para preservar a qualidade e reduzir o desperdício de recursos naturais. Para isso, foram aplicados revestimentos comestíveis à base de amido de milho combinados com ceras naturais (cera de abelha, cera de candelila e cera de carnaúba). Após a colheita, as mangas foram higienizadas, revestidas e armazenadas a uma temperatura média de 29 °C. Em triplicata, 108 mangas da variedade Palmer foram analisadas a cada dois dias quanto à perda de massa, coloração, textura, pH, acidez, sólidos solúveis, taxa respiratória e microscopia eletrônica, a fim de obter uma visão abrangente sobre a conservação pós-colheita e a qualidade dos frutos revestidos, evidenciando a eficiência dos revestimentos aplicados. Os revestimentos prolongaram a vida útil de armazenamento, mantendo as propriedades químicas e sensoriais. As mangas revestidas mantiveram sua integridade por 12 dias, enquanto as não revestidas apresentaram conservação de oito dias. A cera de abelha mostrou-se mais eficaz, seguida pela cera de candelila e pela cera de carnaúba, indicando avanços na conservação pós-colheita com benefícios para a indústria de alimentos.

Palavras-chave: Revestimento Comestível. Mangifera Indica. Desperdício. Cadeia de Suprimentos.

1 Introduction

Mangoes are climacteric fruits, widely consumed in Brazil due to their texture, taste, and rich nutritional composition (Li *et al.*, 2022). In 2024, 1,838,706 tons of mangoes were produced, generating approximately R$3.626.601.600,00. About 272,500 tons of mangoes were exported, making it the leading fruit in exports in 2021. The main varieties exported by Brazil are Tommy Atkins for the American market and Kent, Keitt, and Palmer for the European market (EMBRAPA, 2022; IBGE, 2025). According to Sebrae (2022), mangoes, such as the Palmer variety, are gaining more prominence in the domestic market due to their flavor.

Tropical fruits like mangoes are sensitive to cold and can be damaged by various bacteria and fungi. The loss of food, including fruits like mangoes, necessitates the production sector to control deterioration to conserve environmental resources (Taïbi *et al.*, 2022). Annually, approximately 31% of the global production is wasted from the harvesting process to the final consumer. Additionally, food waste also contributes to the climate crisis, accounting for 10% of the global greenhouse gas emissions (ONU, 2022).

During storage, fruits and vegetables undergo the respiratory process, leading to substrate metabolism and carbohydrate degradation. Consequently, various senescence and physiological changes occur, diminishing the quality for commercialization, such as ethylene production, water loss, and color alteration. Additionally, fruits and vegetables are susceptible to mechanical injuries during storage and transportation, accelerating the senescence process (Oyom *et al.*, 2022).

New post-harvest technologies, including irradiation, salt application, thermal treatments, and edible coatings, are being studied and applied to extend the shelf life of various fresh products (Osae *et al.*, 2022). Coatings that adhere to the fruit surface emerge as a promising and sustainable technology. This not only benefits the economy by increasing the shelf life of post-harvest mangoes but also enhances the quality and safety of the fruit (Sousa *et al.*, 2021).

Films and coatings made from proteins and polysaccharides offer promising mechanical characteristics. However, the hydrophilic region makes the film susceptible to moisture loss. On the other hand, lipids provide greater protection against moisture due to their hydrophobic nature (Blancas-Benitez *et al*., 2022). Lipid coatings have been used for centuries to protect fresh foods. Among lipids, waxes create the best water vapor barriers, although they produce brittle and fragile films due to their hardness, necessitating the addition of substances to enhance flexibility and elasticity. Beeswax, candelilla, and carnauba waxes are extensively studied in the development of post-harvest technologies for fruit preservation (Galus and Kadzinska *et al*., 2015).

Despite advances in edible coating technologies, studies comparing the effectiveness of different natural waxes incorporated into starch-based coatings for the preservation of Palmer mangoes are still scarce. Therefore, the present study evaluated the effect of corn starch coatings enriched with beeswax, candelilla wax, and carnauba wax on the postharvest quality and shelf life of Palmer mangoes stored at ambient temperature.

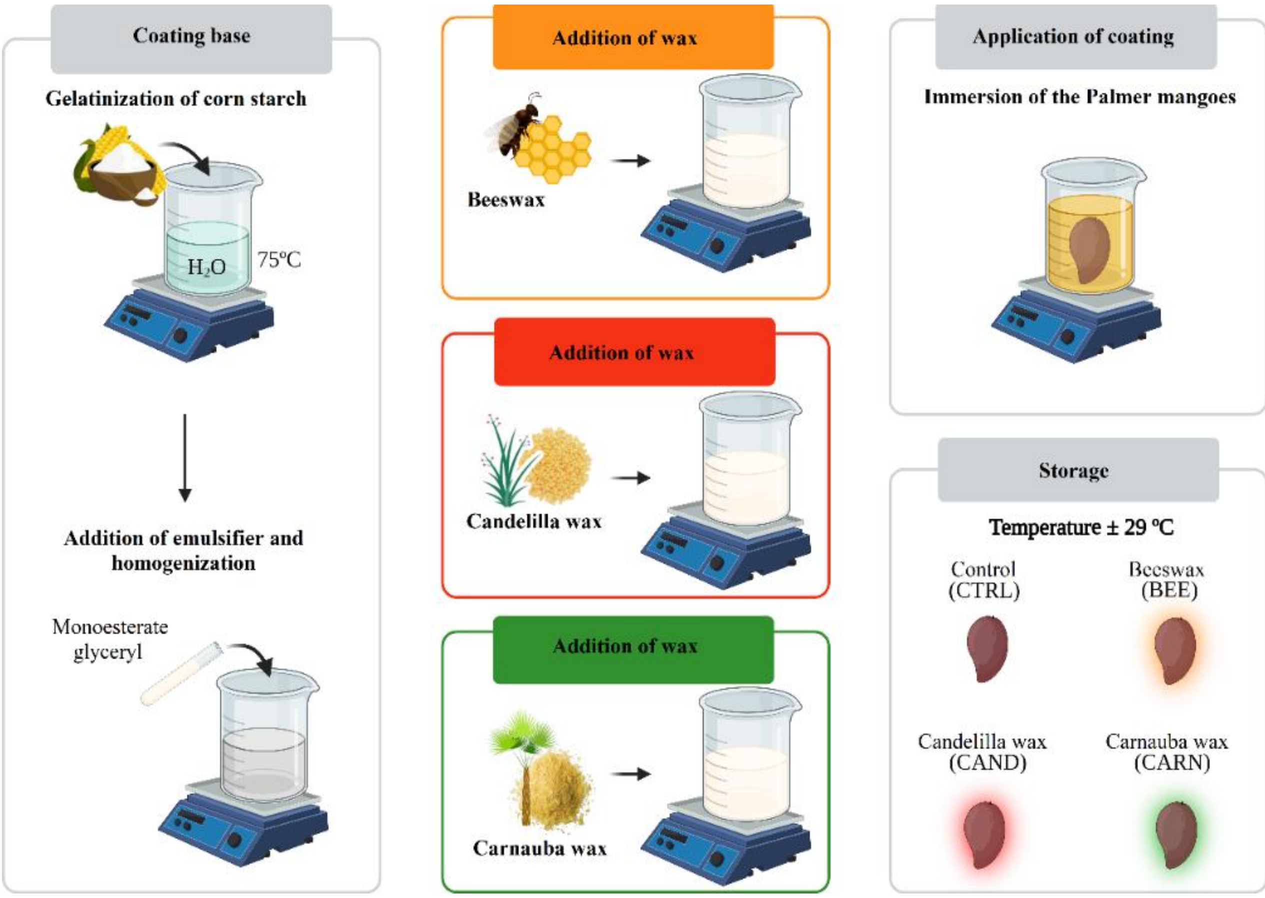
2 Material and Methods

2.1 Edible coating

Three different waxes were acquired from GM Indústria Comércio e Representação de Ceras and used in corn starch coatings. These waxes included beeswax (Epicharis flava, GM Comércio de Ceras e Derivados Ltda, Brazil), candelilla (Euphorbia Cerifera Cera, GM Comércio de Ceras e Derivados Ltda, Brazil), and carnauba (Copernicia Cerifera Cera, GM Comércio de Ceras e Derivados Ltda, Brazil). The control group consisted of uncoated fruits. Formulations were prepared at Laboratory of Chemistry Nº 91, Instituto Federal do Mato Grosso do Sul (IFMS) campus Coxim. The procedure followed the method adopted by Chiumarelli and Hubinger (2014) with adaptations. In the experimental procedure, we adhered to the protocol established by Chiumarelli and Hubinger (2014), with some modifications. The choice of using corn starch over cassava starch was justified due to the widespread availability and cost-effectiveness of the former. We opted to use glyceryl monostearate as a substitute for stearic acid, combined with glycerol, based on its composition as an ester resulting from the combination of glycerol and stearic acid. This selection was grounded in the chemical structure of glyceryl monostearate, which naturally incorporates the necessary components, representing an effective approach to obtaining the emulsifying agent needed for the purposes of this research.

Sixty grams of corn starch (3% w/w) (Starch, Unilever Brasil Industrial Ltda, Brazil) were added to ultrapure water (2,000 ml) at 75 ºC using a heating plate (DB-IVA Heating Plate, Warmnest) under constant stirring with a magnetic stirrer (0851/Q, Lucadema Científica, Brazil). After starch gelatinization, 46 g (1% w/w) of the emulsifier glyceryl monostearate (CAS: 31566-31-1, Allimentari Comércio de Produtos Alimentícios e Serviços, Brazil) was added and homogenized using a mixer (063201003, Britânia Eletrodomésticos, China) in the corn starch suspension for 4 minutes at 11,200 rpm. Subsequently, 10 g of each wax was added separately according to the treatment and homogenized for 3 minutes. The emulsion was then cooled to room temperature in a BOD incubator (SL-200/90, Solab Científica, Brazil) (Figure 1).

Figure 1 - Preparation and application of edible coatings



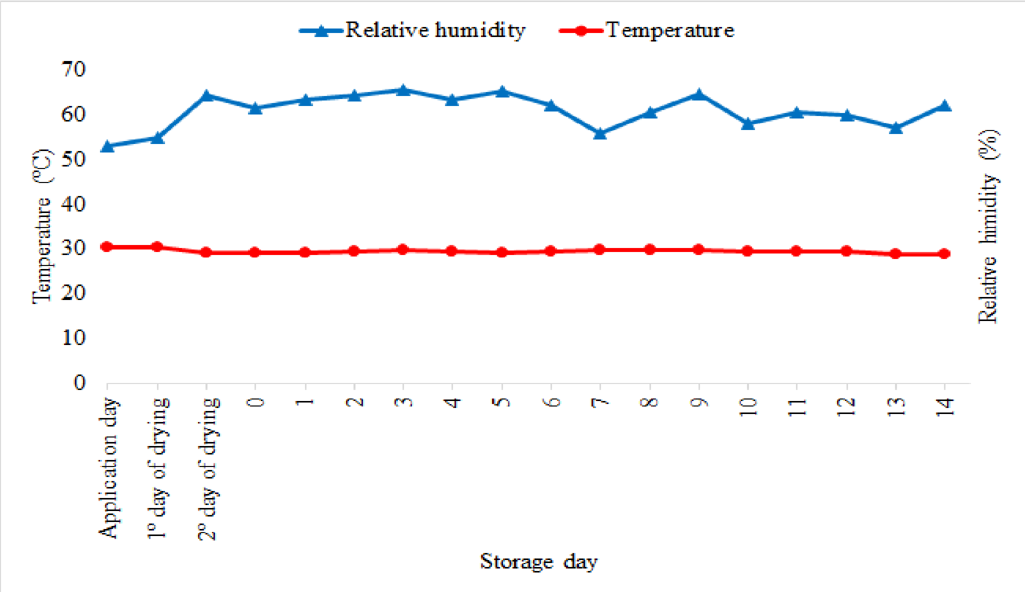
Source: the authors.

2.2 Coating and storage of mangoes

The mangoes were coated by immersion in the emulsion at 20 ºC, applying three different formulations, and one sample remained uncoated (control). Immersion took place for 30 seconds until complete coverage of the surface. After the coating application, the mangoes were subjected to air drying at room temperature for 48 hours.

The coated fruits were stored in fruit crates in Laboratory Nº 89 at IFMS - Campus Coxim, at a controlled temperature according to the conditions presented in Figure 2. Given that Palmer variety mangoes have a shelf life of 22 days at a temperature of 12 ºC (Thakur *et al.*, 2022), and considering that storage temperatures would be higher, a storage period of 14 days was established.

Figure 2 - Temperature and relative humidity of the air during the storage of mangoes with coating application from the beginning to the end of the analysis period



Source: research data.

2.3 Experimental design

The experiment was conducted in a completely randomized design (CRD) using a 4 × 8 factorial arrangement, consisting of four coating treatments and eight storage periods. The treatments were: uncoated fruit (control), corn starch coating containing beeswax, corn starch coating containing candelilla wax, and corn starch coating containing carnauba wax. The storage periods corresponded to evaluations performed every two days during 14 days of storage.

Each treatment was evaluated in triplicate, and the experimental unit consisted of a group of fruits subjected to the same coating treatment and storage period. A total of 108 Palmer mangoes were used throughout the experiment.

2.4 Physicochemical analysis

On each day of analysis, a set of twelve fruits was used, distributed into three groups for each treatment, except for one group of twelve fruits allocated to assess the respiratory rate on all analysis days. Consequently, the study of edible coatings involved a total of 108 fruits, and all analyses were conducted in triplicate using the equipment and materials available in Chemistry Laboratories Nº 91 and Food Laboratories Nº 95 and 96 at IFMS - Campus Coxim. The analyses were performed every two days after the drying of the applied coatings, following the methodology proposed by Formiga *et al*. (2019).

2.5 Visual characteristics

A assessment of fruit ripeness and the occurrence of damage during the mango storage period were evaluated through visual analysis of the external appearance of the fruit. The use of the ripening index on a scale from 2 to 4, within a broader scale of 1 to 5, was adopted to examine variations in the visual characteristics of the mango during the storage period. In this context, a ripening index of 2 represents a stage where the fruit is predominantly green, index 3 indicates an onset of ripening with visible differences in color, and index 4 signifies a complete change in fruit color. This approach allows for a more detailed assessment of the evolution of mango ripening throughout storage, providing valuable information about the visual changes that occur as the fruits progress from one ripening stage to another.

2.6 Respiratory rate

A analysis of the respiratory rate was conducted following the method described by Deliza *et al.* (2008). The first titration (Digitrate Pro, Jencons Scientific LLC, United Kingdom) was performed after the coating drying. On the titration day, the samples were placed in airtight containers following the protocol, and after 2 hours, they were stored again in fruit crates. The analysis took place every two days.

2.7 Mass loss

The mass loss was calculated using the non-destructive weighing method described by Xu and Wu (2021). Every two days, the mangoes were weighed on a semi-analytical balance (BL3200H, Shimadzu Corporation, Japan) to calculate the percentage of mass loss.

2.8 Pulp firmness

The pulp firmness of the mango was evaluated by the maximum penetration force using a texturometer (TA.XTplus, Stable Micro Systems, United Kingdom) following the method by Klangmuang and Sothornvit (2018). The fruit peel was removed using a fruit peeler, and the penetration force into the pulp was measured at three points in the equatorial zone of the mango using a cylindrical probe of 2 mm at a speed of 10 mm/min until reaching a depth of 5 mm. Data collection was performed using the TexturePro CT software (TexturePro CT, Brookfield

Engineering Labs, United States of America).

2.9 pH and titrable acidity

The pH was measured using an electronic titrator (848 Titrino plus, Metrohm, Switzerland) according to the manufacturer's method M41, with the electrodes calibrated using pH 4 buffer solution (CAS: 77-92-9, Dinâmica Química Contemporânea Ltda, Brazil) and pH 7 buffer solution (CAS: 7758-79-4, Dinâmica Química Contemporânea Ltda, Brazil) (Metrohm, 2012). The titratable acidity was determined by potentiometric titration and expressed in citric acid equivalents. Titratable acidity was measured using 0.1N NaOH solution (CAS: 1310-73-2, Neon Comercial Reagentes Analíticos Ltda, Brazil). Ten grams of crushed pulp boiled in 90 ml of ultrapure water, and after cooling, titrated until reaching pH 8.5.

2.10 Total soluble solids

The total soluble solids were determined following the Adolfo Lutz Institute method (2008) using a portable refractometer (VX0-90, Vodex). Three to four drops of the filtered homogenized sample were transferred to the refractometer prism using filter paper. After one minute, the reading was taken on the Brix scale.

2.11 Scanning electron microscopy

Surface analysis was performed using Scanning Electron Microscopy (SEM) with the JSM-6610 equipment from Jeol, Japan, at the High-Resolution Microscopy Multi-User Laboratory (LabMic) of the Federal University of Goiás. Samples were prepared following the laboratory protocol, desiccated with a 2 cm diameter on the day of the final analysis, and fixed with double-sided tape on sample holders before being sent for analysis.

2.12 Colorimetric parameters

The peel and pulp of the mango were colorimetrically evaluated using a portable colorimeter (CR-410, Konica Minolta Sensing Americas, Japan) previously calibrated on the calibration plate (CR A-44, Konica Minolta Sensing Americas, Japan) utilizing the CIELab system. The CIELab color space is designed to identify colors similarly to the human eye, where L* corresponds to luminosity, a* to redness, and b* to yellowness (Villaseñor-Aguilar *et al*., 2021).

2.13 Statical analyses

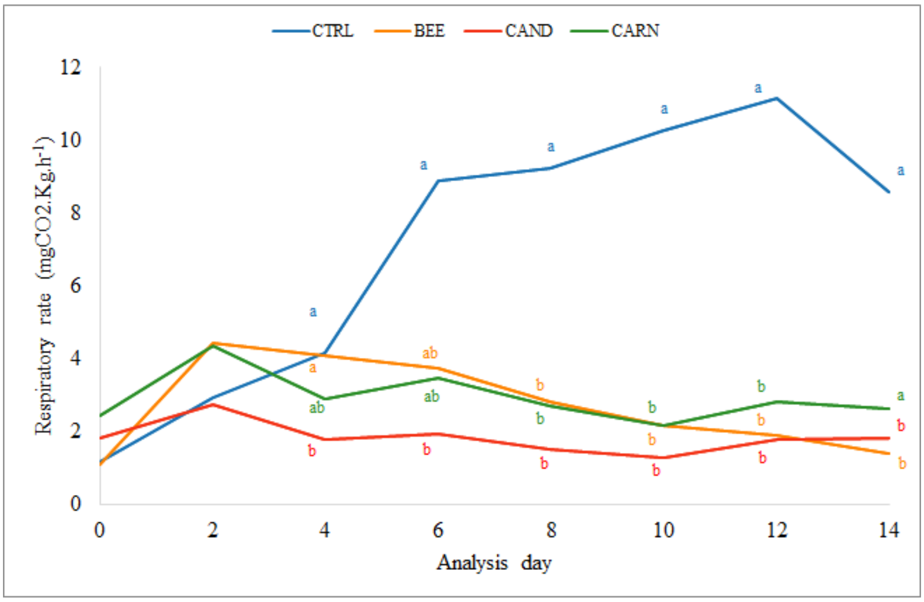
The experiment was conducted in a completely randomized design (CRD) with a 4 x 8 factorial arrangement, meaning four treatments at eight storage times. Linear and quadratic effects were calculated, and their significance was assessed through analysis of variance (p-value at a 95% confidence level). Additionally, the adjusted models were considered suitable if lack of fit was not significant at the same confidence level. Statistical analyses were carried out using the free software R, version 4.3.0.

3 Results and Discussion

3.1 Respiratory rate

The control treatment exhibited a constant increase in the respiratory rate until the 12th day of analysis when it showed a respiratory rate more than twice as high compared to the other treatments on all analysis days (Figure 3). The fruits coated with cornstarch-based coating added with wax showed the least variation in the respiratory rate, followed by those coated with carnauba and beeswax.

Figure 3 - Respiratory rate of Palmer mangoes. CTRL: Control treatment; BEE: Treatment with beeswax coating; CAND: Treatment with candelilla wax; CARN: Treatment with carnauba wax. Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the samples, according to Tukey's test ($p < 0.05$). CV = 61.23%



Source: research data.

Sousa *et al.* conducted an analysis of mangoes from the cv. Palmer variety, which were subjected to coatings composed of HPMC with the addition of 10% and 20% beeswax. These fruits maintained a lower respiratory frequency compared to the control group (Sousa *et al.*, 2021). In another study, Ranjith *et al.* (2022) observed that all coated fruits exhibited lower respiratory rates than the uncoated ones, also noting differences in oxygen consumption and carbon dioxide production.

On the other hand, Ali *et al.* (2022a) identified an increase in respiratory rate and ethylene production throughout the storage period, highlighting that fruits coated with CMC demonstrated a higher respiratory rate on the 16th day.

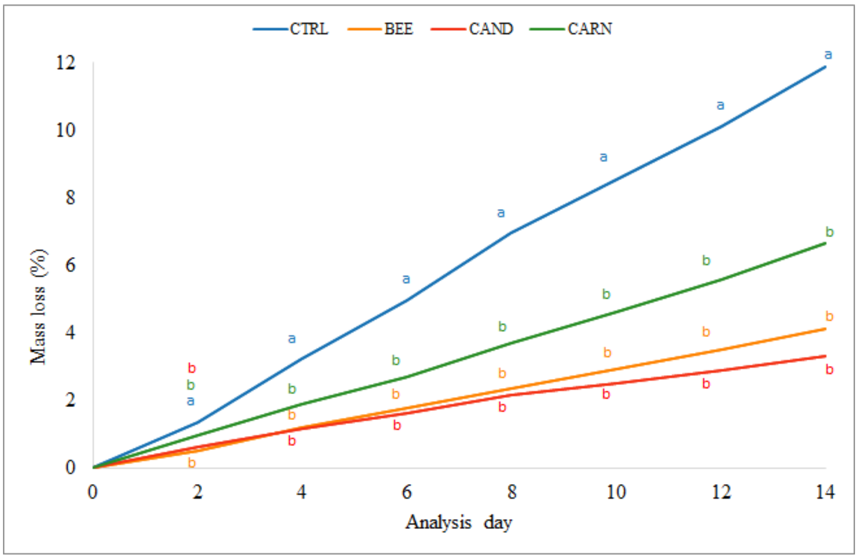
The fluctuation in the respiratory rate observed in our study may be due to differences in internal heat dissipation and metabolic activities due to heterogeneous sizes of the fruits, even when stored under the same conditions. It is important to consider the method for this assessment, as respiratory rate determination can involve the use of a respiration analyzer, ethylene, and gas chromatography. In our study, we used an estimation method, similar to Ma *et al.* (2021).

Although the waxes have distinct compositions, the respiratory rate of the coated fruits showed no differences among them from the sixth day of observation. This suggests that the hydrophobic barrier formed by the material applied on the mangoes resulted in a reduction in the respiratory rate, leading to a decrease in physiological processes in the fruit.

3.2 Mass loss

The mass loss in fruits is a physiological process that occurs through the peel due to respiration and transpiration processes, leading to fruit ripening and softening. The application of different coatings formed a barrier, delaying these processes (Figure 4).

Figure 4 - Mass loss of fruits over the storage period. CTRL: Control treatment ($R^2 = 0.9988$); BEE: Treatment with beeswax coating ($R^2 = 0.9992$); CAND: Treatment with candelilla wax ($R^2 = 0.9917$); CARN: Treatment with carnauba wax ($R^2 = 0.9992$). Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



Source: research data.

As expected, mass loss gradually increased in all evaluated treatments; however, it was three times higher in the control treatment compared to the treatment with candelilla wax coating. The results indicated that fruits coated with wax showed lower mass loss compared to uncoated fruits, which is related to the observed lower respiratory rate.

In the study conducted by Ranjith *et al*. (2022), it was observed that coated mangoes exhibited a reduction in weight loss compared to uncoated mangoes, which could be attributed to lower respiratory rates.

Khaliq *et al.* (2015) also noted that all mangoes experienced a gradual weight loss during storage, with significantly lower loss in fruits that received an arabic gum coating after 14 days of storage.

Additionally, Ali *et al.* (2022b) conducted a study with mangoes coated with tragacanth gum, and the results demonstrated significantly lower mass loss in coated mangoes compared to the control group.

Eshetu et al. (2019) also researched the topic and found that the application of coatings based on beeswax and chitosan resulted in a significant reduction ($p < 0.05$) in weight loss, with a concentration of 2% beeswax being the most effective for both apple-type mangoes and Tommy Atkins-type mangoes.

Similar to observations by other researchers, the edible coatings used in our study showed significantly lower mass loss, starting from the second day of analysis.

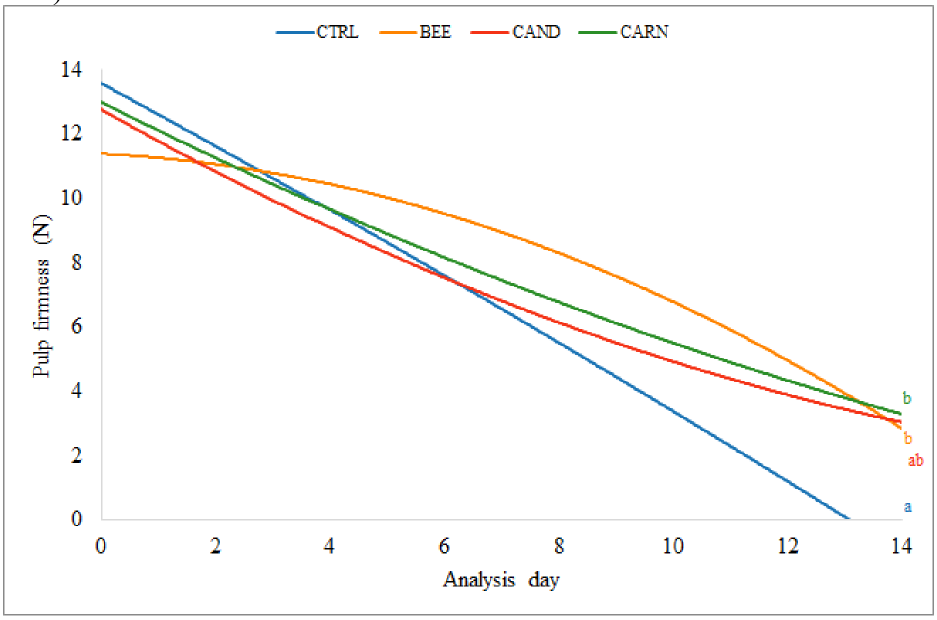
This result may be attributed to the presence of corn starch in the coating, which could have enhanced hydrogen interactions between the hydroxyl group and hydrophilic substances present in the fruit.

Furthermore, the incorporation of waxes increased hydrophobicity and reduced moisture loss, while stearic acid promoted the dispersion of lipid molecules. Therefore, the importance of combining molecules with different characteristics in the formulation of coatings is emphasized, enabling improved performance.

3.3 Pulp firmness

The results obtained in this study revealed a significantly similar loss of firmness in all treatments. On the 14th day, fruits coated with beeswax and carnauba wax showed a significantly lower ($p < 0.05$) reduction in firmness, while the treatment with candelilla wax, despite demonstrating a lower loss of firmness, did not show a statistically significant difference ($p > 0.05$) (Figure 5).

Figure - Fruit pulp firmness obtained through penetration force evaluation. CTRL: Control treatment (R^2 = 0.9015); BEE: Treatment with beeswax coating (R^2 = 0.9552); CAND: Treatment with candelilla wax (R^2 = 0.8433); CARN: Treatment with carnauba wax (R^2 = 9744). Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



Source: research data.

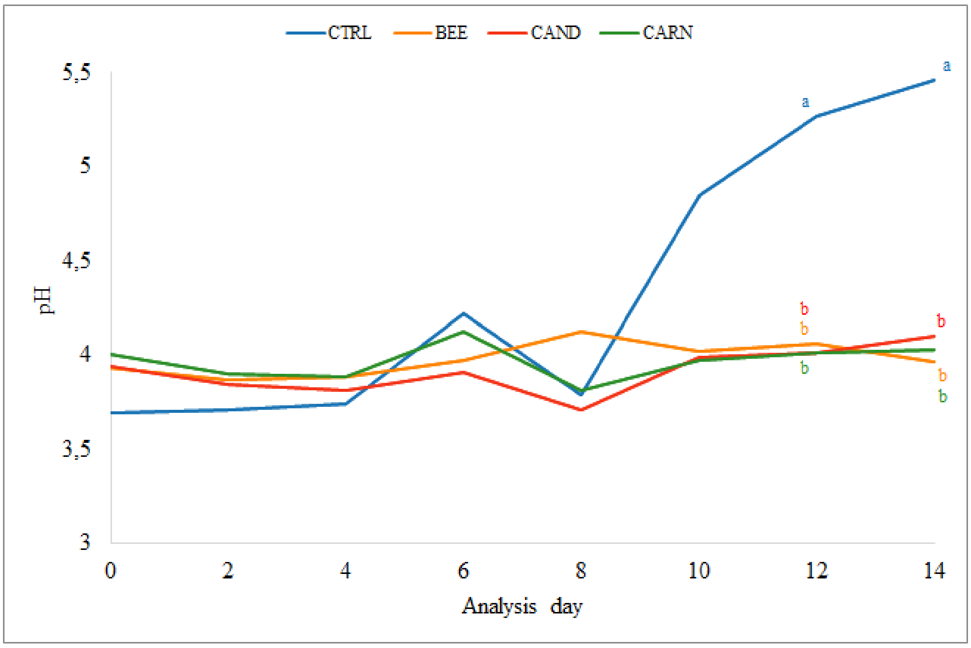
In the study conducted by Ranjith *et al*. (2022), it was observed that all fruits with antifungal coating showed a reduction in pulp firmness loss from the third day of storage. In the research carried out by Khaliq *et al.* (2015), fruits treated with 10% arabic gum and 3% calcium chloride, as well as those subjected only to 10% arabic gum, exhibited significantly higher pulp firmness from the 14th day of storage compared to the control. According to the study by Eshetu et al. (2019), firmness loss showed a decreasing trend in all treatments as the concentration of the edible coating increased.

In our research, we chose not to use antifungals and other functional substances that could influence the ability to suppress enzyme activity. As a result of this choice, our data showed significant results from the fourteenth day of analysis.

3.4 pH and titrable acidity

The fruits from the control treatment showed a greater fluctuation in pH compared to the other treatments (Figure 6), increasing during storage. Throughout the storage of fruits, variations in pH were recorded due to metabolic processes, such as an increase in soluble solids and a reduction in organic acids. However, the coatings have the ability to attenuate these changes, reducing the fluctuation. From the twelfth day of analysis onwards, the pH values of uncoated fruits began to differ from the values observed in coated fruits.

Figure 6 - pH of the analyzed samples. CV = 10.83%. Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



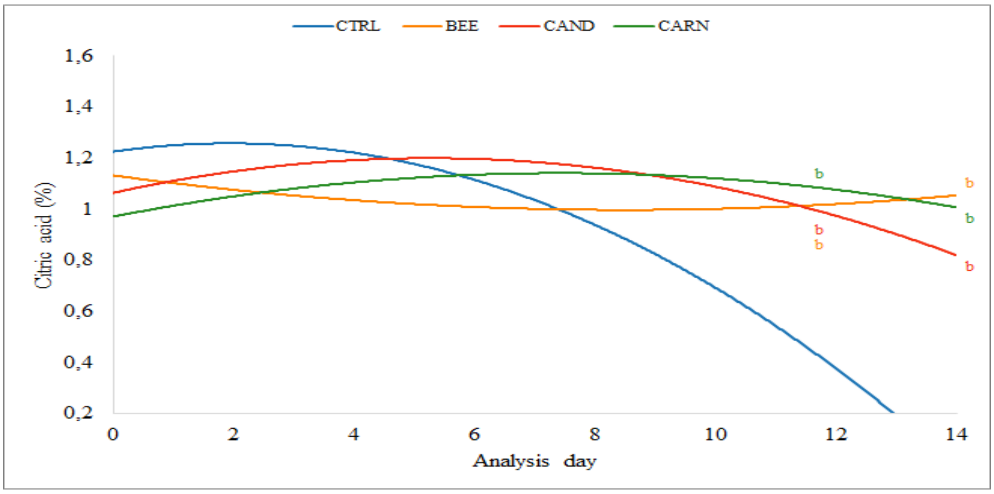
Source: research data.

In a study conducted by Eshetu *et al*. 2019 which investigated various treatments applied to Apple and Tommy Atkins mangoes (including fruits without coating, with chitosan coating at concentrations of 0.5%, 1%, and 1.5%, and beeswax coating at the same concentrations), a consistent increase in fruit pH was observed over the storage period, regardless of the treatment conditions.

In the study conducted by Ebrahimi and Rastegar, it was noted that the average pH of the fruits was significantly influenced by the storage period. However, no statistically significant differences were identified among the treatments over this time interval. The evaluated treatments included fruits without coating, fruits with 2% guar gum, and fruits with 2% guar gum enriched with aloe vera gel (Ebrahimi; Rastegar, 2020).

The control treatment showed a greater decline in citric acid during the storage period, while coated fruits remained more stable (Figure 7). The procedure employed in our research involves sample heating followed by cooling for analysis purposes. However, it is important to note that thermal variations can influence the chemical characteristics of the juice, potentially leading to the degradation of present acids, which, in turn, could affect the fidelity of the results obtained in relation to reality.

Figure 7 - Citric acid expressed as a percentage (mg per 100g). CTRL: Control treatment ($R^2 = 0.8359$); BEE: Treatment with beeswax coating ($R^2 = 0.2138$); CAND: Treatment with candelilla wax ($R^2 = 0.5760$); CARN: Treatment with carnauba wax ($R^2 = 0.1501$). Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



Source: research data.

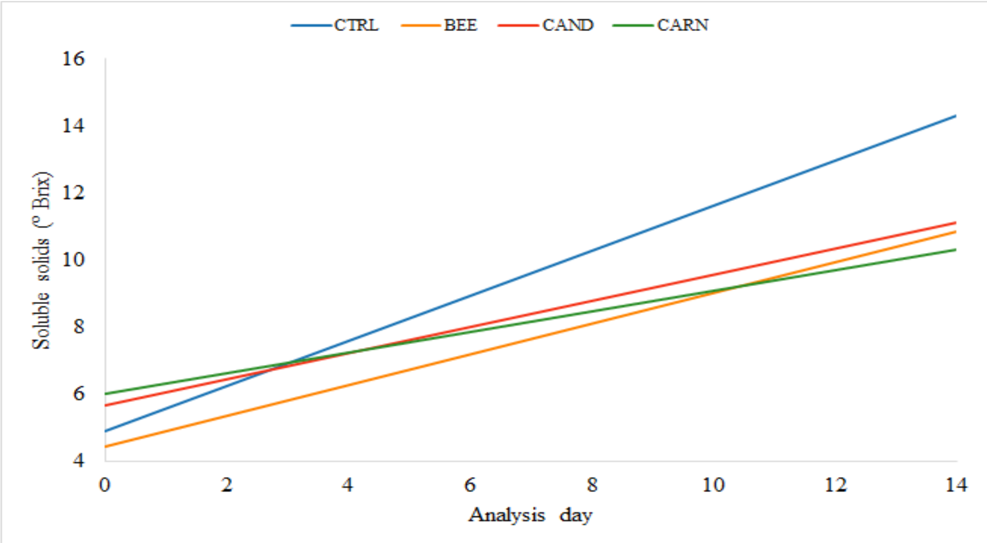
Sousa *et al.* (2021) observed that titratable acidity became higher than that of uncoated fruits from the ninth day of storage. Khaliq *et al.* (2015) concluded that the use of arabic gum coating at 10% may have preserved organic acid, reducing respiratory rate, and inhibiting the oxidation of this compound. Eshetu *et al.* (2019) recorded that the maximum value of titratable acidity was observed in mangoes treated with 2% beeswax and 2% chitosan, while the minimum value was found in the control treatment at the end of the storage period. Additionally, acidity decreased with increasing storage time in all treatments.

Qambrani *et al.* (2022) indicated that the presence of guar gum and castor oil were the main factors influencing titratable acidity, showing a reduction over the storage period, with a greater impact on untreated fruits. Guerra *et al.* (2023) found that citric acid reduced acidity in all treatments. On the other hand, Silva *et al.* (2017) did not identify significant changes in titratable acidity due to the use of chitosan coating. In the present study, from the twelfth day of analysis onward, a statistically significant difference ($p < 0.05$) in citric acid composition was observed. However, all treatments, except for carnauba wax coating, showed a decrease in citric acid content over time. The difference in the observed behavior of carnauba wax coating over time may be related to differences in the initial conditions of the fruits.

3.5 Soluble solids

Sugars in the juice of fruits represent the total amount of dissolved substances, known as soluble solids. This value is used to assess the quality of fruits, indicating their level of sweetness and ripeness. The higher the quantity of soluble solids, the sweeter and more mature the fruit is considered (Sousa *et al*., 2021). All evaluated treatments showed an increase in the soluble solids content during storage (Figure 8).

Figure 8 - Total soluble solids (ºBrix). CTRL: Control treatment (R^2 = 0.8147); BEE: Treatment with beeswax coating (R^2 = 0.5696); CAND: Treatment with candelilla wax (R^2 = 0.5331); CARN: Treatment with carnauba wax (R^2 = 0.5632). There is no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



Source: research data.

Sousa *et al.* (2021) observed an increase in soluble solids content throughout the storage period in all treatments. However, coated fruits showed lower levels of soluble solids compared to the control group. On the 12th day of storage, uncoated fruits had up to 50% more soluble solids than those with coating.

As reported by Silva *et al.* (2017), the concentration of soluble solids in mango pulp was significantly higher in uncoated fruits compared to coated ones, and the reduction in soluble solids was directly related to chitosan concentrations.

In the study conducted by Ebrahimi and Rastegar (2020), the average soluble solids content gradually increased during storage, reaching the maximum level at the end of the storage period. Ali *et al.* (2022a) found that mangoes coated with 1.5% tragacanth gum showed a delay in the increase of soluble solids compared to the control group. Regarding the study by Eshetu *et al.* (2019), mangoes coated with 2% beeswax had lower levels of soluble solids than the other treatments, while the control group showed a higher content of soluble solids. In the study conducted by Guerra *et al.* (2023), differences in soluble solids content compared to the control were observed from the third day of storage.

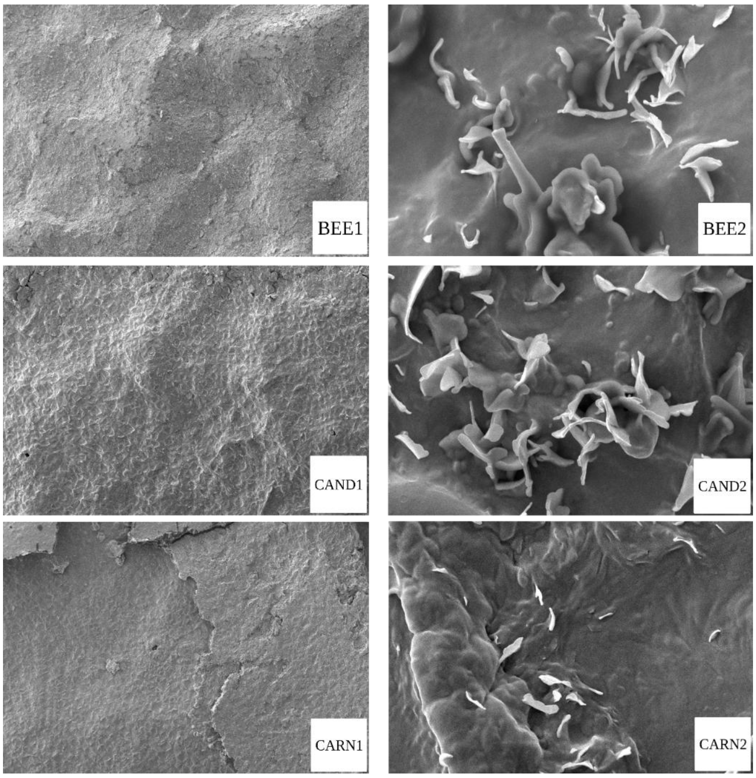
Although soluble solids increased during the analysis period of this study, no statistically significant difference ($p > 0.05$) was observed between the treatments.

3.6 Scanning Electron Microscopy

Through Scanning Electron Microscopy (SEM), the images revealed that in the treatments where the coatings were applied (Figure 9), the fruit surface exhibited non-uniform structures. This indicates that the coating components were not consistently and evenly distributed across the entire fruit surface.

Additionally, the presence of pores and reliefs on the surface was noted, suggesting an irregular texture in the coating itself.

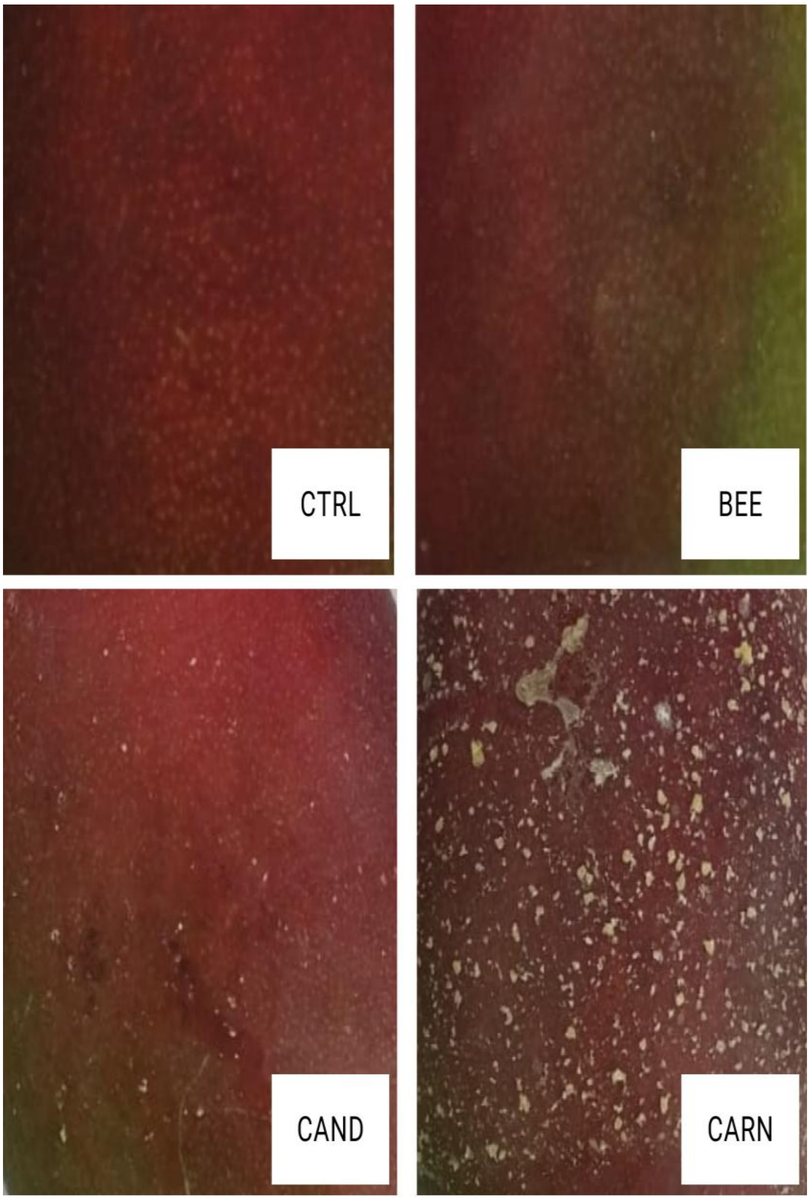
Figure 9 - Images of scanning electron microscopy of the surface of the peel with applied coatings. BEE: Treatment with beeswax coating; CAND: Treatment with candelilla wax; CARN: Treatment with carnauba wax; 1: 70× - 200µm; 2: 5,000× - 5µm



Source: research data.

These findings suggest that, although the coating formulations were initially homogeneously mixed, the drying process played a significant role. During drying, the chemical components of the coating may not have properly stabilized, leading to the separation or segregation of these components in the coating. This uneven distribution observed in the SEM images and visible to the naked eye (Figure 10) could impact the adhesion of the coating to the fruit surface and its ability to protect against external factors.

Figure 10 - Images of the fruit peel obtained with a camera. BEE: Treatment with beeswax coating; CAND: Treatment with candelilla wax; CARN: Treatment with carnauba wax

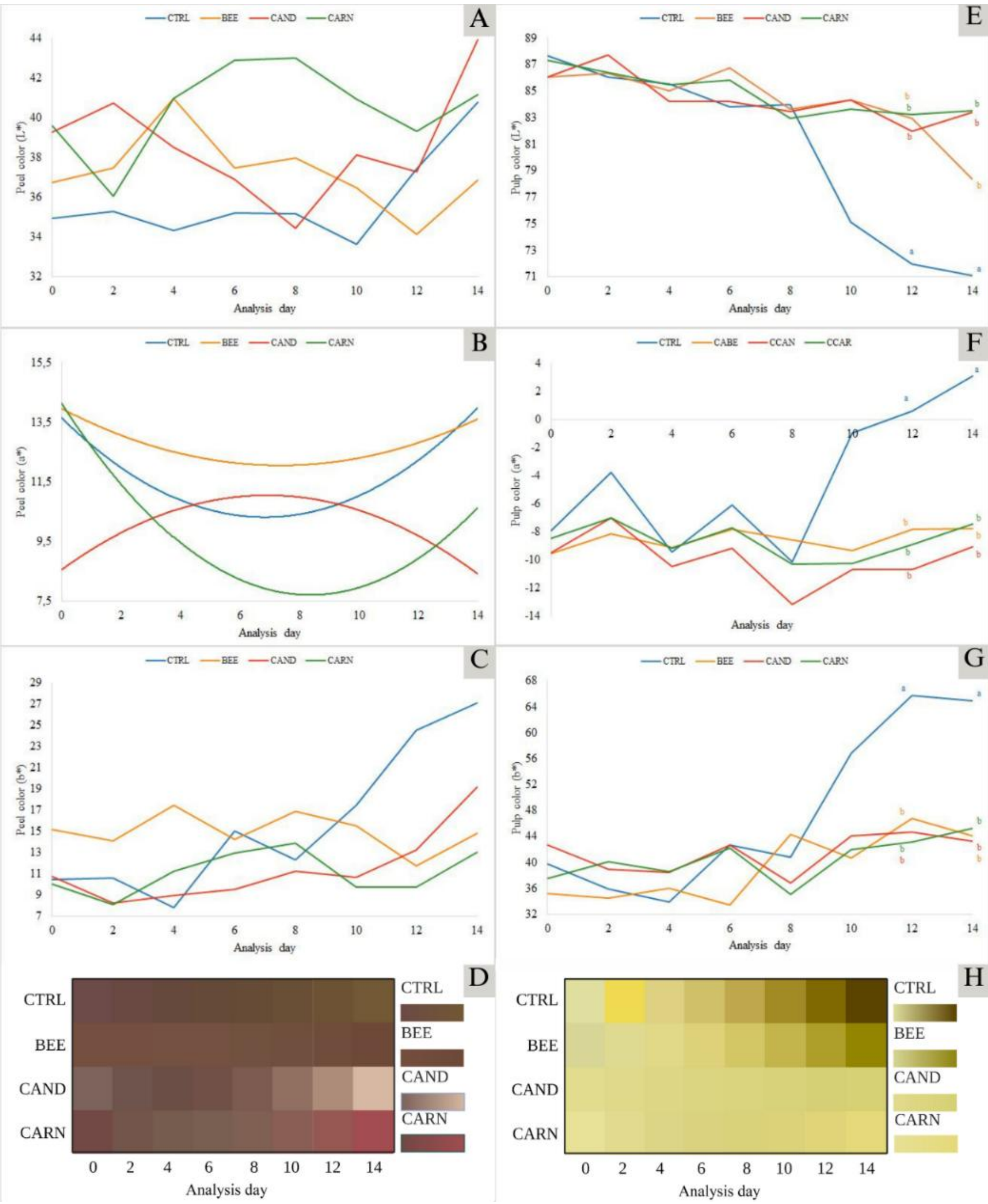


Source: research data.

3.7 Colorimetric Parameters

The Palmer variety of mangoes exhibits a greenish-purple color when unripe, transitioning to a dark red when ripe (CEAGESP, 2022). The expected coloration on the peel and flesh of Palmer mangoes was observed in our study (Figure 11).

Figure 11 - Colorimetric parameters of the peel and pulp of the fruits. CTRL: Control treatment; BEE: Treatment with beeswax coating; CAND: Treatment with candelilla wax; CARN: Treatment with carnauba wax. A: L* of the peel (CV = 9.79%); B: a* of the peel (R^2 CTRL = 0.2564; R^2 BEE = 0.0443; R^2 CAND = 0.2231; R^2 CARN = 0.4082); C: b* of the peel (CV = 42.24%); D: Representation of peel colors over time; E: L* of the pulp (CV = 4.82%); F: a* of the pulp (R^2 CTRL = 0.5175; R^2 BEE = 0.2554; R^2 CAND = 0.109; R^2 CARN = 0.0375); G: b* of the pulp (CV = 21.94%); H: Representation of pulp colors over time. Different letters indicate statistical difference, and the absence of letters indicates no statistical difference between the groups, according to Tukey's test ($p < 0.05$)



Source: research data.

There were no statistically significant differences in peel coloration between coated and uncoated fruits. Therefore, it can be inferred that the application of coatings would not have a discernible impact on consumers' purchasing decisions. However, concerning the pulp, fruits in the control group began to exhibit a darker and more intense color from the tenth day of storage (with higher a* and b* values) compared to coated fruits. This suggests that the coatings were effective in preserving the pulp color during the storage period, possibly due to creating a physical barrier that isolated the fruit surface from external factors such as oxygen, light, and moisture, which contribute to the degradation of pigments responsible for color. They also reduced the respiration rate, delaying fruit ripening and color change.

Silva *et al.* (2017) did not observe significant changes in the peel and pulp color due to coating application. On the other hand, in the study by Ranjith *et al.* (2018), it was found that all fruits with coating maintained their L*, a*, and b* parameters unchanged, attributed to the suppression of respiratory rate and low ethylene production, while the control group showed alterations. Ma *et al.* (2021) noted that the shine of uncoated mangoes quickly disappeared due to ripening and wilting caused by mass loss, although no significant differences were reported between the treatments.

4 Conclusion

When applying edible coatings of corn starch containing beeswax, candelilla wax, or carnauba wax on Palmer mangoes, an increase in shelf life was observed compared to the fresh fruits. This resulted in a prolonged preservation of chemical and organoleptic characteristics. In general, the results indicated that coating with natural waxes, regardless of the type, yielded positive outcomes in fruit preservation. The coated and stored fruits remained intact until the twelfth day of analysis, while the uncoated fruits under the same conditions remained intact only until the eighth day.

However, it is essential to conduct more comprehensive studies with larger samples and extended storage periods to deepen the understanding of the applied formulation and determine the maximum shelf life of coated fruits. Additionally, these studies can dissect the individual effect of each component of the edible coating, contributing to greater uniformity in its application. There is also an opportunity for future research involving sensory evaluation of the coatings to assess consumer acceptance.

References

ALI, S. *et al*. Carboxymethyl cellulose coating delays ripening of harvested mango fruits by regulating softening enzymes activities. *Food Chem.*, v.380, p.131804, 2022a. doi: https://doi.org/10.1016/j.foodchem.2021.131804.

ALI, S. *et al*. Tragacanth gum coating suppresses the disassembly of cell wall polysaccharides and delays softening of harvested mango (Mangifera indica L.) fruit. *Int. J. Biol. Macromol.*, v.222, p.521-532, 2022b. doi: https://doi.org/10.1016/j.ijbiomac.2022.09.159.

BLANCAS-BENITEZ, F.J. *et al*. Impact of edible coatings on quality of fruits: a review. *Food Control*, v. 139, p. 109063, 2022. doi: https://doi.org/10.1016/j.foodcont.2022.109063.

CHIUMARELLI, M.; HUBINGER, M.D. *Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid. Food Hydrocol.*, v.38, p.20-27, 2014. doi: https://doi.org/10.1016/j.foodhyd.2013.11.013.

CEAGESP - Companhia de Armazéns Gerais de São Paulo. *Manga.* Disponível em: https://ceagesp.gov.br/hortiescolha/hortipedia/manga/. Acesso em: 10 dez. 2025.

DELIZA, R. *et al. Determinação da taxa respiratória de mamão "Golden"*. Rio de Janeiro: Embrapa Agroindústria de Alimentos, 2008.

EBRAHIMI, F.; RASTEGAR, S. Preservation of mango fruit with guar-based edible coatings enriched with Spirulina platensis and Aloe vera extract during storage at ambient temperature. *Sci. Horticul.*, v.265, p.109258, 2020. doi: https://doi.org/10.1016/j.scienta.2020.109258.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. *Produção integrada de manga: manejo pós-colheita e rastreabilidade (Circular Técnica 89)*. Petrolina: Embrapa Semi-Árido, 2008.

ESHETU, A. *et al.* Effect of beeswax and chitosan treatments on quality and shelf life of selected mango (Mangifera indica L.) cultivars. *Heliyon*, v.5, n.1, p.e01116, 2019. doi: https://doi.org/10.1016/j.heliyon.2018.e01116.

FORMIGA, A.S. *et al.* Use of edible coatings based on hydroxypropyl methylcellulose and beeswax in the conservation of red guava 'Pedro Sato'. *Food Chem.*, v.290, p.144-151, 2019. doi: https://doi.org/10.1016/j.foodchem.2019.03.142.

GALUS, S.; KADZIŃSKA, J. Food applications of emulsion-based edible films and coatings. *Trends Food Sci. Technol.*, v.45, p.273-283, 2015. doi: https://doi.org/10.1016/j.tifs.2015.07.011.

GUERRA, I.C. *et al.* Films and coatings from pequi mesocarp incorporated with nano-ZnO: Properties and capacity to increase mango shelf life. *Ind Crops Prod*, v.195, p.116414, 2023. doi: https://doi.org/10.1016/j.indcrop.2023.116414.

IAL - Instituto Adolfo Lutz. *Normas analíticas do Instituto Adolfo Lutz: métodos químicos e físicos para análise de alimentos.* São Paulo: Instituto Adolfo Lutz, 2008.

IBGE - Instituto Brasileiro de Geografia e Estatística. *Produção de manga.* 2025. Disponível em: https://www.ibge.gov.br/explica/producao-agropecuaria/manga/br. Acesso em: 20 fev. 2026.

KHALIQ, G. *et al*. Effect of gum arabic coating combined with calcium chloride on physico-chemical and qualitative properties of mango (Mangifera indica L.) fruit during low temperature storage. *Sci. Horticul.*, v.190, p.187-194, 2015. doi: https://doi.org/10.1016/j.scienta.2015.04.020.

KLANGMUANG, P.; SOTHORNVIT, R. Active hydroxypropyl methylcellulose-based composite coating powder to maintain the quality of fresh mango. *LWT*, v.91, p.541-548, 2018. doi: https://doi.org/10.1016/j.lwt.2018.01.089.

LI, D. *et al*. Ripening induced degradation of pectin and cellulose affects the far infrared drying kinetics of mangoes. *Carbohydrate Pol.*, v.291, p.119582, 2022. doi: https://doi.org/10.1016/j.carbpol.2022.119582.

MA, J. *et al*. Novel edible coating based on shellac and tannic acid for prolonging postharvest shelf life and improving overall quality of mango. *Food Chem.*, v.354, p.129510, 2021. doi: https://doi.org/10.1016/j.foodchem.2021.129510.

MESA, K. *et al.* Seasonal trends of starch and soluble carbohydrates in fruits and leaves of 'Abbé Fétel' pear trees and their relationship to fruit quality parameters. *Sci. Horticul.*, v.211, p.60-69, 2016. doi: https://doi.org/10.1016/j.scienta.2016.08.008.

METROHM. Food PAC: *Methods for the titrimetric/potentiometric analysis of foodstuffs. Suíça: Metrohm*, 2012. Disponível em: https://img42.chem17.com/5/2008/633640083568438750.pdf. Acesso em: 11 nov. 2025.

ONU - Organização das Nações Unidas. *FAO combate desperdício de frutas e hortaliças*. Disponível em: https://brasil.un.org/pt-br/201527-fao-combate-desperdicio-de-frutas-e-hortalicas. Acesso em: 3 out. 2025.

OSAE, R. *et al*. Influence of shea butter, bee wax and cassava starch coatings on enzyme inactivation, antioxidant properties, phenolic compounds and quality retention of tomato (Solanum lycopersicum) fruits. *Appl. Food Res.*, v.2, p.100041, 2022. doi: https://doi.org/10.1016/j.afres.2022.100041.

OYOM, W. *et al.* Application of starch-based coatings incorporated with antimicrobial agents for preservation of fruits and vegetables: a review. *Prog. Org. Coat.,* v.166, p.106800, 2022. doi: https://doi.org/10.1016/j.porgcoat.2022.106800.

QAMBRANI, S. *et al*. Development of guar gum-based coating with castor oil for improved postharvest quality of fresh mangoes using response surface methodology. *Appl. Food Res.*, v.2, n.2, p.100220, 2022. doi: https://doi.org/10.1016/j.afres.2022.100220.

RANJITH, F.H. *et al.* Influence of natural antifungal coatings produced by Lacto-fermented antifungal substances on respiration, quality, antioxidant attributes, and shelf life of mango (Mangifera indica L.). *Posth. Biol. Technol.*, v.189, p.111904, 2022. doi: https://doi.org/10.1016/j.postharvbio.2022.111904.

SEBRAE - Serviço Brasileiro de Apoio às Micro e Pequenas Empresas. *O cultivo e o mercado da manga.* 2022. Disponível em: https://www.sebrae.com.br/sites/PortalSebrae/artigos/o-cultivo-e-o-mercado-da-manga,90f5438af1c92410VgnVCM100000b272010aRCRD. Acesso em: 10 dez. 2025.

SILVA, G.M.C. *et al.* The chitosan affects severely the carbon metabolism in mango (Mangifera indica L. cv. Palmer) fruit during storage. *Food Chem.*, v.237, p.372-378, 2017. doi: https://doi.org/10.1016/j.foodchem.2017.05.123.

SOUSA, F.F. *et al.* Conservation of 'Palmer' mango with an edible coating of hydroxypropyl methylcellulose and beeswax. *Food Chem.*, v.346, p.128925, 2021. doi: https://doi.org/10.1016/j.foodchem.2020.128925.

TAÏBI, A. *et al.* Dynamics of bacterial and fungal communities of mango: From the tree to readyto-eat products. *Food Microbiol.*, v.108, p.104095, 2022. doi: https://doi.org/10.1016/j.fm.2022.104095.

THAKUR, R.R. *et al.* Effect of harvesting stages and storage temperature on quality attributes and post-harvest shelf-life of mango (Mangifera indica). *South Afr. J. Bot.*, v.83, p.109-116, 2012. doi: https://doi.org/10.1016/j.sajb.2012.08.001.

VILLASEÑOR-AGUILAR, M.-J. *et al*. Current status of optical systems for measuring lycopene content in fruits: review. *Appl Sci.*, v.11, p.9332, 2021. doi: https://doi.org/10.3390/app11199332.

XU, B.; WU, S. Preservation of mango fruit quality using fucoidan coatings. *LWT*, v.143, p.111150, 2021. doi: https://doi.org/10.1016/j.lwt.2021.111150.