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Active Carboxymethyl Cellulose-Based Edible Coatings for the Extension of Fresh Goldenberries Shelf-Life †

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Abstract: Edible coatings based on natural sources are a good alternative to protect and increase the shelf-life of the fruits. In this work, active carboxymethyl cellulose (CMC)-based edible coatings enriched with functional ingredients, extracted from spent coffee grounds (SCG), were produced and used to increase the shelf-life of fresh goldenberries. Thus, three different treatments were tested on fresh goldenberries: (i) coating CMC (CMC-based edible coating); (ii) coating CMC-A (CMC-based edible coating with 0.2% (*w*/*v*) of polysaccharide-rich extract from SCG); and (iii) coating CMC-B (CMC-based edible coating with 0.2% (*w*/*v*) of polysaccharide-rich extract, and 0.2% (*w*/*v*) of phenolic compounds encapsulated from SCG), being compared with uncoated goldenberries. Physicochemical and microbiological properties of the fruits were evaluated throughout 12 and 28 days of storing at 20 °C and 65% relative humidity and 4 °C and 95% RH, respectively. The results showed that the temperature and relative humidity significantly influenced the quality of goldenberries, increasing their shelf-life almost two-fold when stored at 4 °C and 95% RH. Both CMC-A and CMC-B coatings controlled weight loss and decreased the gas transfer rates (O_2, CO_2, and C_2H_4), mainly when goldenberries were stored at 20 °C and 65% RH. Moreover, coating CMC-A was better for delaying microbial growth, while the edible coating CMC-B gave an extra content of phenolic compounds to goldenberries, increasing thus their antioxidant potential.

Keywords: carboxymethyl cellulose; spend coffee grounds; polysaccharides; phenolic compounds; edible coatings; shelf-life; goldenberry

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1. Introduction

The quality of fresh fruits, after harvesting, can be affected by several factors, such as microbiological contamination, chilling, temperature, and relative humidity, leading to a significant reduction in their quality and shelf-life, which become an obstacle to the commercialization of such products. On the other hand, customers are looking for food of high quality and as far as possible, free of synthetic preservatives and chemical additives.

In this sense, postharvest treatments play an important role in food preservation and their commercialization, especially if they require large storage periods. Edible coatings obtained from natural sources have been shown as a great alternative to supply the existing needs, protecting and increasing the shelf-life of fresh and processed food, particularly vegetables and fruits [1–5]. Thus, edible coatings can act as a barrier to avoid fruit dehydration, reduce microbial contamination, and maintain the organoleptic and nutritional properties safe for a longer time [6–8]. They can also be used as potential carriers of bioactive compounds (e.g., antimicrobials, antioxidants, and anti-browning agents) to support or even improve the nutritional and sensory characteristics of products [9–11].

Among the most used biopolymers to produce edible coatings are polysaccharides, proteins, lipids, or waxes. Other relevant components include surfactants and food-grade plasticizers. These coatings can be developed from a unique component, or a mixture of polymers, if required more structured or complex matrices.

Polysaccharide-based coatings, for example, provide a good gas barrier due to their hydrophilic nature and some studies have highlighted their use to modify the internal environment of the system and decrease the respiration rate of vegetables and fruits [4,7,8,12]. One of the most common and commercial cellulose derivatives is carboxymethyl cellulose (CMC). It has been widely used in food and is generally recognized as safe (GRAS). CMC provides excellent coating-forming characteristics due to its biocompatibility with other water-soluble materials [13,14]. CMC-based coatings are usually tasteless and odorless, flexible, and transparent. They offer barriers to oil and moisture transfer and help to maintain the firmness and crispness of fruits [8].

Nowadays, the production of edible coatings containing functional materials extracted from agro-industrial wastes has been widely studied. Thus, spent coffee grounds (SCG), which are the main solid residues generated during the processing of soluble coffee, were considered in this work due to their high content of polysaccharides [15–17] and phenolic compounds [18,19] and multiple properties including antioxidant and antimicrobial activities [15,16,18,19].

On the other hand, *Physalis peruviana* L., also known as goldenberry, is a native plant from the South American Andes (usually harvested in Colombia, Peru, and Ecuador) and exported to different European countries. Goldenberry is a climacteric yellow-orange waxy skin fruit with a high nutritional value [6,20,21]. It is a juicy berry similar in size, shape, and structure to a cherry tomato. Goldenberry is naturally wrapped by a papery husk or calyx whose function is to protect it during harvest and postharvest. However, the calyx occupies a large volume, becoming a disadvantage when fruit storing and commercialized. Similarly, some countries require calyx removal from goldenberry for its exportation to avoid phytosanitary problems [6,20,22], which in turn, can compromise quality the quality and shelf-life of goldenberry. In fact, the shelf-life of goldenberry with calyx is estimated at 30 days, while without calyx can be decreased to 5 days when stored at room temperature [20,23]. However, it can be extended up to 45 days when goldenberry without calyx is kept between 3 and 7 °C [24].

Edible coatings application is considered one of the most suitable treatments for conserving and improving the shelf-life of fresh products. Despite being a well-known and studied technology, it continues to attract great attention from research and industry food. For instance, edible coatings have been successfully tested on strawberries [25], tomatoes [11], cherries [26], red Crimson grapes [27], and fresh-cut fruits [28], with some of them already used commercially.

A few studies have reported the application of edible coatings on goldenberries [6,20,22,24]. However, to the best of our knowledge, there is not any study on the utilization of CMC-based edible coatings blended with functional ingredients obtained from SCG to extend the goldenberries' shelf-life. Therefore, the main objective of this study was to produce CMC-based edible coatings enriched with SCG extracts containing polysaccharides and phenolic compounds encapsulated to increase the shelf-life of goldenberries. For that, physicochemical and microbiological properties, as well as the gas exchange rates of goldenberries, were evaluated when subjected to three different treatments: (i) coating CMC (CMC-based edible coating); (ii) coating CMC-A (CMC-based edible coating with SCG extracts rich in polysaccharides); and (iii) coating CMC-B (CMC-based edible coating with SCG extracts rich in polysaccharides and phenolic compounds encapsulated), being compared with uncoated goldenberries throughout 12 and 28 days of storing at 20 °C and 65% relative humidity (RH) and 4 °C and 95% RH, respectively.

2. Materials and Methods

2.1. Raw Material and Chemicals

SCG were supplied by the Portuguese coffee industry Nova Delta-Comércio e Indústria de Cafés S.A. (Campo Maior, Portugal). After the reception, the material was dried in an oven at 60 °C until 5% moisture content and processed to obtain: (i) a polysaccharide-rich extract as described by Ballesteros et al. [15], and (ii) phenolic compounds encapsulated as proposed by Ballesteros et al. [18]. Carboxymethylcellulose (CMC) (Blanose, 7M65) was obtained from Ashland Inc. (Düsseldorf, Germany), and analytical reagent grade glycerol 99.5% was purchased from Himedia (Mumbai, India). All the chemicals used were analytical grade, purchased from Sigma–Aldrich (Chemie GmbH, Steinheim, Germany), Panreac Química (Barcelona, Spain), Merck (Darmstadt, Germany), and Fisher Scientific (Leicestershire, UK). Ultrapure water from a Milli-Q System (Millipore Inc., Bay City, MI, USA) was used. Goldenberries were harvested in Colombia and purchased from a Portuguese company "Nativa, sabores de outro mundo", which exported the fruits and packaged them on the same date.

2.2. Coating Production

CMC-based coatings were made according to Ballesteros et al. [13]. Briefly, CMC was dissolved in ultrapure water at 70 °C for 4 h at constant agitation (300 rpm) using a magnetic stirrer. Subsequently, glycerol was added to CMC and the mixture was maintained under the same conditions for one more hour. On the other hand, different concentrations (0.05%, 0.1%, and 0.2%, *w*/*v*) of the polysaccharides and phenolic compounds encapsulated extracted from SCG were dissolved in ultrapure water and kept at 20 °C for 3 h with magnetic agitation. Each of the polysaccharides and phenolic compounds solutions was slowly added to the CMC-glycerol mixtures and then sterilized at 70 °C for 30 min. The coating solutions were prepared considering the desired components and final concentrations of each one. Thus, coating CMC was made with 1.5% of CMC and 0.5% of glycerol, while coatings CMC-A were composed by 1.5% of CMC and 0.5% of glycerol with increasing concentrations of the polysaccharide-rich extract (0.05%, 0.1%, and 0.2%, *w*/*v*). Finally, coatings CMC-B were composed by 1.5% of CMC, 0.5% of glycerol, and 0.2% of polysaccharide-rich extract with increasing concentrations of phenolic compound-rich extract (0.05%, 0.1%, and 0.2%, *w*/*v*).

All the coating solutions were stored at 4 °C until further analyses were carried out to select the best coating from CMC-A and CMC-B groups, which were applied together with the coating CMC on the goldenberries.

2.3. Surface Tension and Critical Surface Tension of Goldenberry Skin

The surface tension was determined by using the Young–Dupré equation according to Van Oss et al. [29]. For a pure liquid, if polar $\left(\gamma_L^p\right)$ and dispersive $\left(\gamma_L^d\right)$ interactions are known, and if θ is the contact angle between that liquid and a solid, the interaction can be described in terms of the reversible $\left(\gamma_L^d\right)$ work of adhesion (W_a), as shown in Equation (1), where γ_S^p and γ_S^d represent the polar and dispersive contributions of the surface of the solid studied.

$$W_a = W_a^d + W_a^p \Leftrightarrow W_a = 2\left(\sqrt{\gamma_s^d \cdot \gamma_L^d} + \sqrt{\gamma_s^p \cdot \gamma_L^p}\right) = \gamma_L(1 + \cos\theta) \quad (1)$$

Rearranging Equation (1), Equation (2) is obtained:

$$\frac{1 + \cos\theta}{2} \cdot \frac{\gamma_L}{\sqrt{\gamma_L^d}} = \sqrt{\gamma_s^p} \cdot \sqrt{\frac{\gamma_L^p}{\gamma_L^d}} + \sqrt{\gamma_s^d} \quad (2)$$

The contact angle (θ) formed on the surface of the fruit (goldenberry skin) was evaluated using three pure liquid compounds, including bromonaphthalene, formamide, and ultrapure water. All measurement were performed at 20.5 ± 0.5 °C with 10 replicates for each pure liquid used. The obtained contact angles combined with the values of each dispersive and polar component values of the pure liquids were used to calculate the variables of Equation (2).

On the other hand, critical surface tension (γ_c) was estimated according to Cerqueira et al. [4]. In systems where the surface tension is lower than 100 mN/m (low-energy surfaces), the contact angle formed by a drop of liquid on a solid surface is considered a linear function of the surface tension of the liquid (γ_{LV}), where phase V is air saturated with the vapor of liquid, L.

Zisman plot extrapolation [30], used to characterize the low-energy surfaces wettability, was obtained by plotting the cosine of the contact angle of the pure liquid compounds, that were evaluated on the surface of the fruit (goldenberry skin), against the surface tension of each compound. The intercept of this curve with cos θ = 1 is known as the critical surface tension (γ_c) and defined in Equation (3).

$$\gamma_c = \lim \gamma_{LV} \; as \; \theta \rightarrow 0 \tag{3}$$

2.4. Selection of Coating Solutions

In the initial stage, the wettability and antimicrobial activity of CMC-based solutions containing different concentrations of polysaccharides and phenolic compounds from SCG were determined. The coating from each CMC-A and CMC-B group with the best properties was selected and then applied to the fresh goldenberry to evaluate its shelf-life.

2.4.1. Wettability

The wettability of coating solutions on goldenberry skin was studied by determining the values of spreading coefficient (W_s), work of adhesion (W_a), and cohesion (W_c), according to Cerqueira et al. [4].The adhesive forces promote the liquid spreading on a solid surface and the cohesive forces promote their contraction. The wetting behavior of the solutions mainly depends on the balance between these forces.

The contact angle *(θ)* of a liquid drop on a solid surface is defined by the mechanical equilibrium of the drop under the action of three interfacial tensions: solid-vapor (γ_{SV}), solid-liquid (γ_{LV}) and liquid-vapor (γ_{LV}). The spreading coefficient (W_s) is defined by Equation (4) [31] and can only be negative or zero.

$$W_s = W_a - W_c = \gamma_{SV} - \gamma_{LV} - \gamma_{SL} \tag{4}$$

where W_a and W_c are defined by Equations (5) and (6), respectively.

$$W_a = \gamma_{LV} + \gamma_{SV} - \gamma_{SL} \tag{5}$$

$$W_C = 2\gamma_{LV} \tag{6}$$

The surface tension of the coating solutions (γ_{LV}) was measured using a tensiometer (Force tensiometer—K20, krüss, Switzerland) at 20.5 ± 0.5 °C. Five replicates were made for each sample. On the other hand, the contact angle of the coating solutions on the goldenberry surface was carried out according to the sessile drop method [32] as previously described by Ballesteros et al. [13]. Measurements were made in less than 5 s at 20.5 ± 0.5 °C and ten replicates were obtained for each coating solution.

2.4.2. Antimicrobial Activity

The antimicrobial potential of the coating solutions was evaluated against six fungi that drastically influence the postharvest quality of the fruits such as *Alternaria* sp. MUM 02.42, *Cladosporium cladosporioides* MUM 97.06, *Phoma violacea* MUM 97.08, *Botrytis cinerea* MUM 97.08, *Fusarium culmorum* MUM 97.01, and *Penicillium expansum* MUM 02.14. The fungi

were obtained from the collection of the Mycology Laboratory (MUM) of the University of Minho, Portugal, and cultured according to Ballesteros et al. [15].

The antimicrobial test was carried out by using the agar diffusion method as reported by Hili et al. [33] and Scorzoni et al. [34] in combination with some modifications. Briefly, 100 µL of inoculum suspension (1×10^6–5×10^6 CFU/mL) were spread with sterile swabs on Petri dishes (90 mm) containing approximately 25 mL of potato dextrose agar (PDA) and then a 10 µL drop of the coating solution was placed on contaminated agar and incubated at 25 °C for 48 h. The growth or no-growth of the fungi was qualitatively evaluated (by the naked eye). In addition, Natamycin and Fluconazole were used as positive controls and distilled water as a negative control to verify the effectiveness of the method. Each coating solution was evaluated in triplicate and repeated at least in two independent assays.

2.5. Application of the Coating on Goldenberries

Firstly, the papery husks or calyxes that covered the goldenberries were removed. Subsequently, the fresh fruits were checked and selected, and then discarded those that presented injuries or a higher degree of ripeness when assessed by the naked eye. For the fruit shelf-life evaluation, the goldenberries were subjected to three different treatments: (i) coating CMC (CMC-based edible coating); (ii) coating CMC-A (CMC-based edible coating with SCG extracts rich in polysaccharides); and (iii) coating CMC-B (CMC-based edible coating with SCG extracts rich in polysaccharides and phenolic compounds encapsulated). The coated fruits were compared with uncoated goldenberries, which were used as the control.

The process consisted of placing the goldenberries duly separated on a plastic mesh, and then the coating solutions were sprayed on fresh fruits with a sprayer gun (Elckner handheld spray gun, Lezennes, France) equipped with compressed air. The fruits were placed in a drying chamber at 33 °C for 2 min. After that, they were sprayed again, and the process was repeated two more times.

The different groups of coated and uncoated goldenberries were subdivided into aluminum boxes (about 40 g per box) that were later placed inside plastic containers. These containers were closed and stored in controlled RH chambers. Thus, the physicochemical, and microbiological parameters of the goldenberries were evaluated throughout 12 and 28 days of storing at 20 °C and 65% RH and at 4 °C and 95% RH, respectively, to determine the influence of these variables on the shelf-life of coated and uncoated goldenberries.

2.6. Gas Exchange Rates

Measurements of oxygen (O_2), carbon dioxide (CO_2), and ethylene (C_2H_4) exchange rates of goldenberries (coated and uncoated) were carried out using a closed system method with air as the initial atmosphere according to Cerqueira et al. [4] with some modifications. Briefly, the experiments were carried out in glass containers of 2 L, used as reactors to evaluate the gas exchange of the samples. The RH was simulated by using saturated salt solutions such as sodium nitrite (65% RH) and potassium sulfate (95% RH), which were put on the bottom of the containers. Later, 136 g of goldenberry were placed inside each reactor, separated from the saturated salt solution by a stainless-steel mesh. The systems were closed and stored at 4 °C and 95% RH as well as at 20 °C and 65% RH. The concentrations of O_2, CO_2, and C_2H_4 inside the containers were measured by drawing gas samples with a 500 µL syringe (Hamilton, Bonaduz, Switzerland) suitable for gas chromatography through a silicone septum fitted in the container lids. The samples were analyzed in duplicate, taking three injections from each one at the measurement moment. The gas exchange (O_2, CO_2, and C_2H_4) was measured daily until it was kept constant.

The C_2H_4 content in the glass containers was determined using a gas chromatograph (Varian Star 3400 CX, Palo Alto, CA, USA) equipped with a flame ionization detector (FID) at 280 °C, a non-polar column Varian and Helium (1 mL/min) as carrier gas. A standard C_2H_4 sample (500 ppm) was used for calibration. On the other hand, O_2 and CO_2 contents were analyzed through a gas chromatograph (Bruker Scion 456, Markham, ON, Canada),

equipped with a thermal conductivity detector (TCD) at 130 °C, and two independent channels to separate O_2 and CO_2. Thus, a Molsieve column and Argon (30 mL/min) as the carrier gas were used to separate O_2, while a Poraplot column and Helium (15 mL/min) as the carrier gas for CO_2. A mixture containing 70% N_2, 20% O_2, and 10% CO_2 was used as a standard sample for calibration.

The O_2 consumption rate was calculated through Equation (7), while CO_2 and C_2H_4 production rates were determined by applying Equation (8), according to Salvador et al. [35]. These models were developed for a closed system impermeable to gases, where R_{O_2}, R_{CO_2}, and $R_{C_2H_4}$ represent the O_2 consumption rate and CO_2 and C_2H_4 production rates (cm^3/Kg h), respectively, w_{GB} is the weight of the fruit (Kg), and V_f represents the free volume of the container (mL).

$$dy_{O_2} = -R_{O_2}\frac{w_{GB}}{V_f}dt \quad (7)$$

$$dy_{C_2H_4/CO_2} = R_{C_2H_4/CO_2}\frac{w_{GB}}{V_f}dt \quad (8)$$

The free volume was calculated by Equation (9), where V_C the total volume of the container (mL), w_{GB} is the weight of the fruit (kg), and ρ_{GB} is the density of goldenberry.

$$V_f = V_C - \frac{w_{GB}}{\rho GB} \quad (9)$$

The graphs of O_2 consumed, and CO_2 and C_2H_4 produced as a function of time, were used to calculate the slopes, which correspond to the derivatives, dy/dt, of each gas.

2.7. Physicochemical and Microbiological Properties

Physicochemical properties such as weight loss, pH, acidity, total soluble solids, browning, ascorbic acid, and total phenolic and flavonoid contents, as well as microbiological analyses, were determined along the storage time. The different groups of stored coated and uncoated goldenberries at 20 °C and 65% RH were evaluated at 0, 2, 4, 6, 9, and 12 days, while the fruits left at 4 °C and 95% RH were analyzed at 0, 3, 7, 11, 15, 22, and 28 days of storing. For the tests, two homogenates from each group of samples were prepared. The content of an aluminum box with approximately 40 g of goldenberries was put into a sterile plastic bag, crushed using a rolling pin, and then vigorously stirred. Later, the homogenates were reserved in Falcon tubes until the analyses.

2.7.1. Weight Loss

Weight loss was carried out by gravimetric analysis using an analytical balance (Kern ABS-N/ABJ-NM, Balingen, Germany). The uncoated and coated goldenberries were weighted at the beginning of the experiment and during the days which the fruits were evaluated. Weight loss was expressed in percentage (%). Three replicates were weighted from each treatment.

2.7.2. pH

For the pH determination of the coated and uncoated samples, the electrode of a pH meter (Hanna Instruments HI 2221 digital, Szeged, Hungary) was immersed in a 15–20 g of goldenberry homogenate. Two replicates were performed for each homogenate.

2.7.3. Acidity

For titratable acidity measurement of goldenberries (coated and uncoated), 5 g of fruit homogenate were diluted in 50 mL of distilled water. The mixture was vortexed and then centrifuged for 15 min at 1800× g. The supernatant was recovered and used for titration. Hence, the sample, containing 3 drops of phenolphthalein, was titrated with 0.1 N NaOH solution until the change of color was observed (faint pink) and the pH value achieved 8.2.

A standard sample of citric acid (2 mg of citric acid per mL distilled water) was freshly prepared each day, in which the titratable acidity was evaluated to determine of citric acid factor. The results were expressed as milligrams of citric acid per 100 g of fruit (mg citric acid/100 fruit). Two replicates were obtained for each homogenate.

2.7.4. Total Soluble Solids

Total soluble solids of coated and uncoated goldenberries were determined using a digital refractometer (Hanna Instruments HI 96801, Szeged, Hungary). In brief, 2 g of fruit homogenate were centrifuged at 1792× *g* for 5 min, and then 200 µL of supernatant were collected and measured in the refractometer. Total soluble solids were expressed as °Brix (g fructose/100 g fruit juice). Three replicates were obtained for each homogenate.

2.7.5. Browning

The browning of goldenberries was measured using the colorimetric method described by Li et al. [2]. Briefly, 2 g of fruit homogenate were mixed with 5 mL of ethanol at 95%, vortexed, and then centrifuged for 20 min at 1792 g and room temperature. The supernatant was collected and filtrated through 0.22 mm membranes. The absorbance was measured at 420 nm in a spectrophotometer V-560 (Jasco, Tokyo, Japan) against distilled water used as a blank. The browning values were expressed as the absorbance at 420 nm. Two replicates were obtained for each homogenate.

2.7.6. Vitamin C

The ascorbic acid content in coated and uncoated goldenberries was measured by 2,6-dichlorophenolindophenol (DCPIP) reagent titration. In brief, 5 mL of oxalic acid at 4% (*w*/*v*) were mixed with 2 mL of fruit juice (previously centrifuged) and 2 mL of distilled water. The mixture was vortexed and then titrated to a permanent pink color using a DCPIP solution (0.24 mg DCPIP per mL of distilled water). An ascorbic acid standard sample (0.2 mg of ascorbic acid per mL of distilled water) was freshly prepared each day of the measurement to determine of vitamin C factor. The results were expressed as milligrams of ascorbic acid per 100 milliliters of fruit juice (mg ascorbic acid/100 mL fruit juice). Two replicates were obtained from each homogenate.

2.7.7. Phenolic Compounds and Flavonoids

Total phenolic compounds (PC) and flavonoids (FLA) were sequentially extracted from goldenberries as described by Giovanelli et al. [36], with some modifications. In brief, 5 g of fruit homogenate, were put into a Falcon plastic tube with 15 mL of acidic methanol (methanol: HCl, 99:1, *v*/*v*). The mixture was stirred in the dark for 1 h, and then centrifuged at 1010× *g* and 10 °C for 10 min. The supernatant was separated and reserved, and the solid part was shaken again in the dark two more times with 15 and 10 mL of acidic methanol, each time for 15 min, and centrifuged under the same conditions above mentioned. The extracts (supernatants) were joined and made up to 50 mL with the same solvent. Subsequently, they were filtered through Whatman qualitative filter papers (Grade 1).

PC and FLA were determined as described by Ballesteros et al. [37] and expressed as milligrams of gallic acid equivalent per grams of fruit (mg GAE/g fruit) and milligram of quercetin equivalent per grams of fruit (mg QE/g fruit), respectively. For both PC and FLA assays, ten replicates were obtained from each homogenate.

2.7.8. Microbiological Analysis

Total mesophilic count and mold and yeast growth [38] were conducted to determine the microbiological quality of the goldenberries. For that, 1 mL of fruit homogenate was mixed with 9 mL of peptone water (0.1%, *w*/*v*). The mixture was previously vortexed, and then a series of appropriate dilutions (10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4}) were prepared, in duplicate. Subsequently, 1 mL of each dilution was transferred to a Petri dish containing

Plate Count Agar (PCA) medium or Rose Bengal Chloramphenicol Agar (DRBC) medium at 45–50 °C.

PCA was used to evaluate the total mesophilic count, while DRBC to determine the mold and yeast growth in the coated and uncoated goldenberries. Once the dilution sample was in contact with the medium, the Petri dishes were rotated to obtain evenly dispersed colonies. After complete solidification, the dishes were closed with parafilm, inverted, and incubated. PCA dishes were incubated at 35 °C for 2 days, in contrast to DRBC plates, which were set at 25 °C for 5–7 days.

Two homogenates were prepared for each group of samples. The results were expressed in Log colony forming units per milliliters of fruit juice (Log CFU/mL fruit juice).

2.8. Sensorial Analysis

The sensorial analysis of the goldenberries was carried out by using a Triangle sensory test, which is a discriminative method to determine if there is a sensory difference between two products. In brief, a set of three goldenberries was evaluated by 25 untrained panelists.

Each set was composed of one goldenberry coated with one of the coatings (i.e., coating CMC, coating CMC-A, or coating CMC-B), while the other two samples were uncoated goldenberries. The panelists, based on the appearance, aroma, taste, and texture of the samples, selected one goldenberry from each set as the different sample. Results were analyzed with a significance level of 95%, using the appropriate interpretation table for the Triangle sensory test (for 25 panelists, the number of correct answers to establish a significant difference should be $\geq$13). The sensory analysis was made on the goldenberries stored at 4 °C and 95% RH, after 15 days of packing, being this period considered safe for their consumption.

2.9. Statistical Analysis

GraphPad Prism (V6.1 by Dotmatics, San Diego, CA, USA) was used to carry out a one-way analysis of variance (ANOVA) and Tukey's multiple comparisons test to calculate the significant differences ($p < 0.05$) among the different groups of samples when were evaluated in the same storage day.

3. Results

3.1. Surface Tension and Critical Surface Tension of Goldenberry Skin

The surface tension, and critical surface tension, were determined to characterize the goldenberry skin surface. Goldenberries presented a surface tension of 30.78 $\pm$ 2.81 mN/m, while the value for the critical surface tension was 24.95 $\pm$ 1.37 mN/m. The critical surface tension values obtained in this study for the goldenberry are similar to those reported in the literature for the grapefruit (23.00 mN/m) [39], cajá (23.92 mN/m), and mango (22.68 mN/m) [4].

Additionally, the fruit surface, being a low-energy surface (<100 mN/m), presented a high dispersive component (29.26 $\pm$ 1.39 mN/m), which indicates the ability of the fruit surface to participate in non-polar interactions, while presenting a very low polar component (1.52 $\pm$ 0.40 mN/m). A surface with these characteristics interacts with liquid mostly by dispersion forces, influencing the effective spreading of the coating-forming solution on the goldenberry skin. Thus, the polarity compatibility (apolar or polar) between the fruit surface and the coating solutions plays a key role in the wettability of the surface since after drying, the edible coating should possess appropriate adhesion, and cohesion, as well as remain intact along the time.

3.2. Selection of Coating Solutions

The wettability and antimicrobial activity were determined for CMC-based coating solutions containing different concentrations (0.00%, 0.05%, 0.10%, and 0.20%, w/v) of polysaccharide-rich extract and phenolic compounds encapsulated (obtained from SCG).

Finally, the coatings from each CMC-A and CMC-B group with the best properties were selected and tested on fresh goldenberries.

3.2.1. Wettability

Wettability is one of the most important parameters when evaluating the capacity of a solution to coat a desired foodstuff surface. It was studied by determining the values of the spreading coefficient (W_s). In practical terms, the closer the values are to zero, the better a surface will be coated [40]. Table 1 presents the W_s values of the CMC-based coating solutions that were tested on fresh goldenberry skin.

Table 1. Spreading coefficient (W_s) of the CMC-based coating solutions tested on fresh goldenberry surface.

Sample	Concentration of Polysaccharide-Rich Extract and Phenolic Compound-Rich Extract in the Coating Solutions		(W_s) (mN/m)
	Polysaccharides (%, *w*/*v*)	Phenolic Compounds (%, *w*/*v*)	
Coating CMC	—	—	-81.69 ± 3.36 [a]
Coatings CMC-A	0.05	—	-44.96 ± 4.21 [b]
	0.10	—	-59.81 ± 5.84 [c]
	0.20	—	**-35.72 ± 3.82 [d]**
Coatings CMC-B	0.20	0.05	-58.02 ± 2.30 [b]
	0.20	0.10	-51.76 ± 4.87 [b]
	0.20	0.20	**-44.13 ± 3.94**[c]

All coating solutions were produced with 1.50% (*w*/*v*) CMC and 0.50% (*w*/*v*) glycerol with different concentrations (0.00%, 0.05%, 0.10%, and 0.20%, *w*/*v*) of extracts rich in polysaccharides and phenolic compounds. Results are expressed as mean ± SD (n = 10). Different letters within each group (coatings CMC-A or coatings CMC-B) indicate a statistically significant difference (Tukey test $p < 0.05$). The data in bold represent the best-obtained values for coatings CMC-A and coatings CMC-B.

The best wettability value (-35.72 ± 3.82 mN/m) was achieved with the CMC-based edible coating containing 0.20% (*w*/*v*) of the polysaccharide-rich extract. This sample was statistically different ($p < 0.05$) from the other samples from the same group (coatings CMC-A), which contained lower quantities of polysaccharide extract.

On the other hand, the sample with the best spreading coefficient value (-44.13 ± 3.94 mN/m) from the coatings CMC-B group was the CMC-based edible coating with 0.20% (*w*/*v*) of the polysaccharide-rich extract and 0.20% (*w*/*v*) of the encapsulated phenolic compound-rich extract (Table 1), while the other coatings CMC-B did not show significant changes ($p < 0.05$).

In conclusion, the results show that the W_s values were closer to zero when the concentrations of polysaccharides and phenolic compounds increased in the CMC-based coating solutions. Thus, solutions containing the highest quantities of polysaccharides and phenolic compounds (data in bold) are the most suitable for use on goldenberries thanks to their relevant wettability characteristics.

3.2.2. Antimicrobial Activity

Table 2 shows the antimicrobial test results obtained with the coating solutions, which contain different concentrations (0.00%, 0.05%, 0.10%, and 0.20%, *w*/*v*) of polysaccharide-rich extracts and encapsulated phenolic compound-rich extracts. The coating were proved against six food pathogenic fungi (*Alternaria* sp., *Phoma violacea*, *Penicillium expansum*, *Cladosporium cladosporioides*, *Fusarium culmorum*, and *Botrytis cinerea*) that drastically affect the quality and safety of postharvest fruit [41].

Table 2. Antimicrobial activity of the CMC-based coating solutions against the growth of different microbial strains.

Sample	Concentration of Polysaccharide-Rich Extract and Phenolic Compound-Rich Extract in the Coating Solutions		*Alternaria* sp.	*Phoma violacea*	*Penicillium expansum*	*Cladosporium cladosporioides*	*Fusarium culmorum*	*Botrytiscinerea*
	Polysaccharides (%, *w*/*v*)	**Phenolic Compounds (%, *w*/*v*)**						
Coating CMC	—	—						
Coatings CMC-A	0.05	—		X			X	X
	0.10	—			X	X	X	
	0.20	—	X	X	X	X	X	X
Coatings CMC-B	0.20	0.05		X			X	
	0.20	0.10		X	X			
	0.20	0.20		X		X	X	

X: Represents the coating solution that had an antimicrobial effect against a specific microbial strain. All coating solutions were produced with 1.50% (w/v) CMC and 0.50% (w/v) glycerol with different concentrations (0.00%, 0.05%, 0.10%, and 0.20%, w/v) of extracts rich in polysaccharides and phenolic compounds. Results are expressed as mean ± SD (n = 8).

The results were based on a qualitative test (naked eye) and the X symbol in Table 2 represents the coating-forming solutions that had an antimicrobial effect against the tested fungi.

All coating solutions from the CMC-A and CMC-B groups (Table 2) showed antimicrobial activity against at least one of the strains. However, the best results were obtained with the CMC-based coating solution containing 0.20% (w/v) of the polysaccharide-rich extract, achieving thus, delaying the growth of all the fungi.

On the other hand, the solutions of the coatings CMC-B group showed antimicrobial effect against two or three fungi, being the CMC-based coating solution with 0.20% (w/v) of polysaccharide-rich extract, and 0.20% (w/v) of phenolic compound-rich extract, the one that presented higher antimicrobial potential (Table 2). As expected, Natamycin and Fluconazole (known as antifungal agents and used as positive controls) revealed antimicrobial behavior against the tested fungi, while the distilled water (negative control) allowed their growth.

These findings suggest that the antimicrobial effect could be related to the concentration of polysaccharides and phenolic compounds in the coating-forming solutions. Some authors have reported that the polysaccharide might act as an external barrier, obstructing the essential nutrients for the microorganisms, and delaying their growth [42]. Usually, this barrier behavior increases when the polysaccharide concentration rises, which was evidenced in this study. In addition, phenolic compounds have been widely known and used for their multiple functionalities, including antimicrobial properties [15,41] as demonstrated.

Consequently, the coatings for evaluating the extension of fresh goldenberries' shelf-life were selected considering the obtained results for the wettability and antimicrobial activity. The coating solutions that presented the best characteristics were the CMC-based edible coating with 0.2% (w/v) of polysaccharide-rich extract (named coating CMC-A), and CMC-based edible coating with 0.2% (w/v) of polysaccharide-rich extract, and 0.2% (w/v) of phenolic compounds encapsulated (named coating CMC-B).

Finally, after choosing the coating solutions, the fresh goldenberries were subjected to three different treatments: (i) coating CMC (CMC-based edible coating); (ii) coating CMC-A (CMC-based edible coating with SCG extracts rich in polysaccharides); and (iii) coating CMC-B (CMC-based edible coating with SCG extracts rich in polysaccharides and phenolic compounds encapsulated), which were compared with uncoated fruits. The fresh goldenberry was evaluated throughout 12 and 28 days of storing at 20 °C and 65% RH and 4 °C and 95% RH, respectively.

3.3. Evaluation of CMC-Based Coatings on Fresh Goldenberry

3.3.1. Gas Exchange Rates

O_2 consumption (R_{O_2}), and CO_2 (R_{CO_2}) and C_2H_4 $(R_{C_2H_4})$ production allow understanding of how the selected edible coatings (coating CMC, coating CMC-A, and coating CMC-B) can influence the gas transfer exchange.

The obtained results for R_{O_2}, R_{CO_2}, and $R_{C_2H_4}$ are shown in Figure 1A–C, respectively. It can be seen that R_{O_2}, R_{CO_2}, and $R_{C_2H_4}$ values increased considerably when the goldenberries (uncoated and coated) were stored at 20 °C and 65% RH, in comparison to the values obtained for goldenberries stored at 4 °C and 95% RH, indicating that the storage conditions affect the respiration rate. Figure 1A shows that at 20 °C and 65% RH, R_{O_2} of goldenberries without coating was significantly higher ($p < 0.05$) than the values achieved for coated goldenberries with the edible coatings CMC, CMC-A, and CMC-B, while all coated goldenberries (regardless the treatment used) did not present significant differences among them. Moreover, R_{O_2} was lower for all samples when stored at 4 °C and 95% RH (Figure 1A). Nonetheless, when the coatings CMC and CMC-A were used, the R_{O_2} was significantly lower ($p < 0.05$) in comparison with the uncoated goldenberries or coated with edible coating CMC-B.

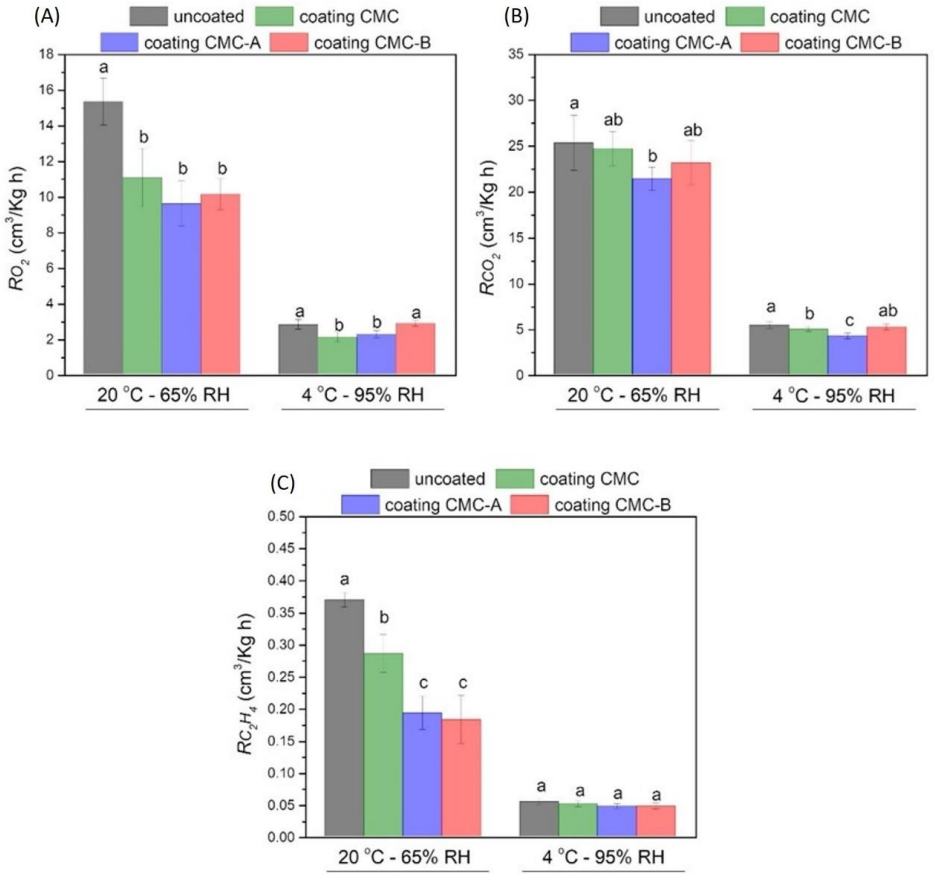


Figure 1. O_2 (**A**), CO_2 (**B**), and C_2H_4 (**C**) transfer rates in fresh goldenberries at 20 °C and 65% RH and 4 °C and 95% RH. Results are expressed as mean ± standard deviation ($n = 6$). Different letters within each temperature and RH group correspond to statistically different values for a 95% confidence level. Sample names correspond to the three treatments tested on fresh goldenberries: (i) coating CMC (CMC-based edible coating); (ii) coating CMC-A (CMC-based edible coating with SCG extracts rich in polysaccharides); and (iii) coating CMC-B (CMC-based edible coating with SCG extracts rich in polysaccharides and phenolic compounds encapsulated). Uncoated corresponds to fruits without coating.

Although R_{CO_2} was higher than R_{O_2} for all coated and uncoated samples, the lowest R_{CO_2} (4.18 ± 0.32 cm^3/Kg h) at 4 °C and 95% RH was achieved when the edible coating CMC-A was used, being statistically different to the other samples (Figure 1B). Similar behavior was observed at 20 °C and 65% RH, where R_{CO_2} of the goldenberries with the coating CMC-A was significantly lower ($p < 0.05$) than the reported values for the goldenberries treated with the edible coating CMC or without coating. However, the coated fruits with the coating CMC-A did not show statistical differences in terms of R_{CO_2} when compared to the coated goldenberries with the edible coating CMC-B stored at 20 °C and 65% RH (Figure 1B).

On the other hand, $R_{C_2H_4}$ at 20 °C and 65% RH was significantly lower ($p < 0.05$) for all coated goldenberries, especially for those fruits coated with the edible coatings CMC-A and CMC-B, when compared with the uncoated goldenberries. However, at 4 °C and 95% RH, no significant difference was noted between the uncoated and coated goldenberries (Figure 1C). Goldenberry can be classified as a fruit highly climacteric that after physiological maturity presents an increased respiratory rate [43].

The obtained values for the ethylene production and respiration rate of the goldenberry agree to those reported by Carvalho et al. [22] when the fruits were stored at 20 °C.

Although the low temperatures reduce the gas exchange (O_2, CO_2, and C_2H_4) of the fresh goldenberries [44], results show that the application of the developed coatings decrease this exchange at different storage conditions, being more effective at a higher temperature and a lower RH. This can be explained by the fact that CMC-based coatings containing polysaccharide-rich extract and phenolic compound-rich extract increase the goldenberry skin resistance to gas diffusion by blocking the pores on the fruit surface, resulting in a modified internal atmosphere of relatively high CO_2 and low O_2.

3.3.2. Weight Loss

Weight loss in fruits is mainly related to the decrease in their water content during postharvest storage, leading to changes in texture, flavor, and appearance [8]. Figure 2A shows the weight loss for coated and uncoated fresh goldenberries when stored for 12 days at 20 °C and 65% RH, while Figure 2B indicates the obtained results for the fresh goldenberries maintained at 4 °C and 95% RH during 28 days of storage. For both storage periods, all coated and uncoated fruits showed weight losses, which increased along storage time, being the higher weight losses observed for the uncoated fresh goldenberries ($p < 0.05$), independently of temperature and RH used. Similar behavior were reported by other studies that evaluated edible coatings for controlling weight loss in tomatoes [11], goldenberries [6,20], and fresh cut-mangoes [3].

Although the uncoated fruits were the most affected by weight loss, the goldenberries treated with the other treatments (coating CMC, coating CMC-A, and coating CMC-B) also suffered a weight loss higher when stored at 20 °C and 65% RH, as expected, since the fruit quality is greatly affected when the storage temperature and RH are increased. The experiments show that from the 9th day of storage at 20 °C and 65% RH, the weight loss values of uncoated fruits were statistically different ($p < 0.05$) than those values found for the coated goldenberries; however, there were no significant differences ($p < 0.05$) when was used coating CMC, coating CMC-A, or coating CMC-B. At the end of the 12th day of storage (Figure 2A), the weight loss for uncoated fruits was 26.48%, while for coated fresh goldenberries with coating CMC, coating CMC-A, and coating CMC-B was 17.88%, 15.31%, and 15.73%, respectively, demonstrating thus that goldenberries coated, independently of the treatment used ($p < 0.05$), lost less weight than uncoated fruits when stored at high temperatures and RH.

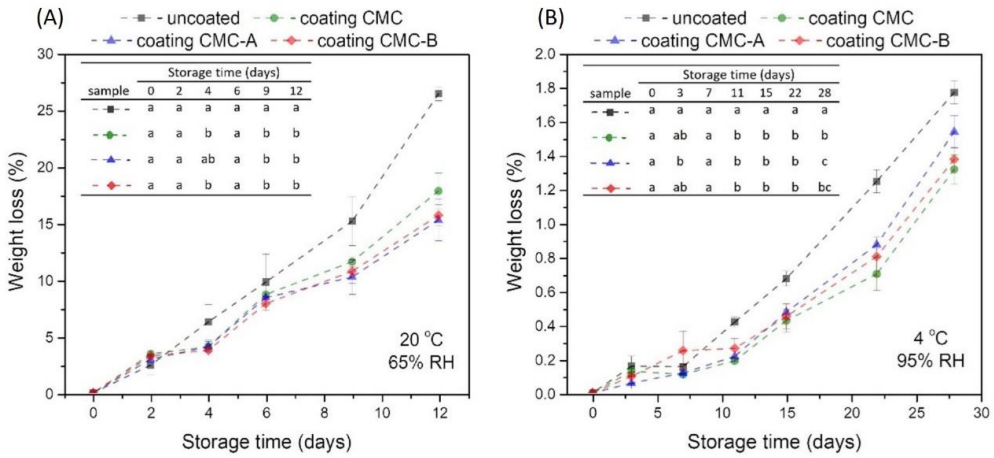


Figure 2. Weight loss of the coated and uncoated fresh goldenberries during storage at 20 °C and 65% RH (**A**) and 4 °C and 95% RH (**B**). Results are expressed as mean ± standard deviation (n = 3). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

The fruits stored at 4 °C and 95% RH for 28 days (Figure 2B) also showed significant differences ($p < 0.05$) among the uncoated goldenberries and those coated (independently of the treatment used). The largest weight loss for the uncoated goldenberries started from the 11th day of storage. It was maintained until the end of the storing.

In both storage conditions, the treatments tested presented the same behavior. However, the weight loss of the goldenberries subjected to 4 °C and 95% RH was lower in comparison with the fruits stored at 20 °C and 65% RH, revealing a reduction of mass loss of 1.77% for uncoated goldenberries, and 1.32%, 1.54%, and 1.37 % for goldenberries using coating CMC, coating CMC-A, and coating CMC-B, respectively. These findings reveal a delay in weight loss between 25 and 14 % in comparison with the goldenberries subjected to the higher conditions.

Therefore, the conditions of storage influence on weight loss of goldenberries, and the CMC, CMC-A, and CMC-B coatings proved to decrease the mass loss. It can be explained by the water vapor barrier provided by the coatings used on goldenberries, which decrease moisture loss during storage and, thus, a lower weight loss.

3.3.3. pH and Acidity

The pH values for uncoated and coated fresh goldenberries stored at 20 °C and 65% RH as well as those stored at 4 °C and 95% RH are presented in Figure 3A, B, respectively. Some pH variations (3.50–3.77) can be observed concerning the obtained initial values in each sample, indicating differences ($p < 0.05$) in the degree of maturity of the fruits. The pH values of the coated and uncoated goldenberries placed at 20 °C and 65% RH did not show significant changes ($p > 0.05$) from the 4th day of storage; however, the pH values of all samples were increased during the storage time. The pH rise is explained by the fruit ripening and decomposition process caused by hydrolysis, oxidation, or fermentation that modifies the concentration of hydrogen ions [3].

On the other hand, the fruits stored at 4 °C and 95% RH maintained the pH values constant along storage days, except for the uncoated goldenberries, in which the pH values increased. Results suggest that the coatings helped to maintain the initial pH values when the fruits were left at 4 °C and 95% RH during 28 days of storage, delaying the fruit ripening and ensuring a controlled microbial growth. This behavior is explained by the fact that the coated fruits maintained a more acidic pH, which is favorable to inhibiting bacterial growth [45].

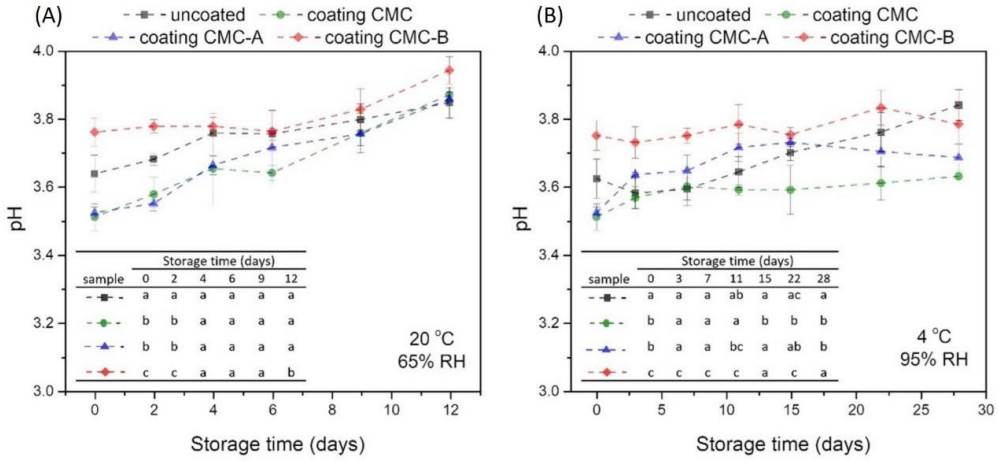


Figure 3. pH of the fresh goldenberries (coated and uncoated) during storing at 20 °C and 65% RH (**A**) and 4 °C and 95% RH (**B**). Results are expressed as mean ± standard deviation (n = 4). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

The rise in pH values is directly related to the decrease in acidity occurring in the fruits [46]. Goldenberry is rich in organic acids, mainly citric acid. During the maturity phase, this organic acid is usually degraded or consumed, since it is considered a respiratory substrate [3], affecting thus the shelf-life of goldenberry. Figure 4A, B show that all the samples evaluated (uncoated, coating CMC, coating CMC-A, and coating CMC-B) presented the same behavior when subjected to different temperatures (20 and 4 °C), RH (65 and 95%) and storage times (12 and 28 days).

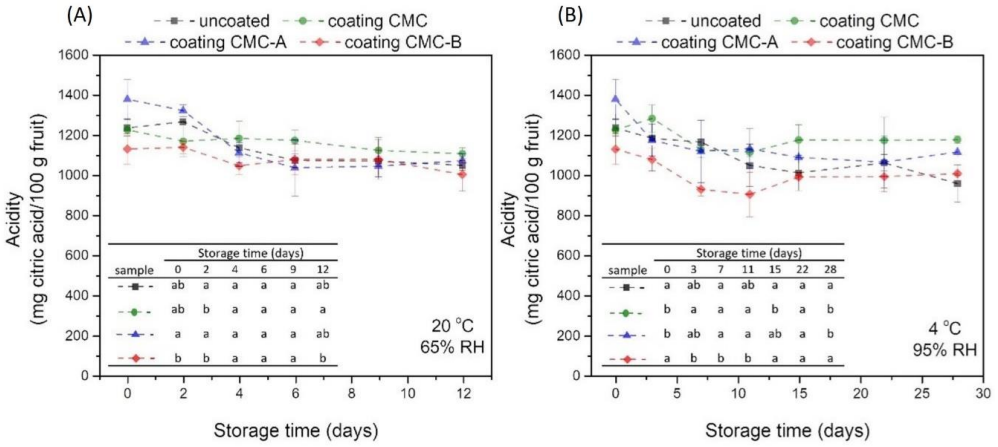


Figure 4. Titratable acidity of the fresh goldenberries (coated and uncoated) as a function of storage time: (**A**) 20 °C and 65% RH; and (**B**) 4 °C and 95% RH. Results are expressed as mean ± standard deviation (n = 4). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

At the beginning of the analyses, the acidity values of all samples were between 1200 and 1400 mg acid citric per 100 g fruit and decreased along with the storage time. However, it can be noted that from the 15th day of storage at 4 °C and 95% RH (Figure 4B), the acidity values were more stable for coated goldenberries than for uncoated goldenberries. Similar results were reported for goldenberries coated with an alginate-based coating at 2 °C during 21 days of storage [22].

3.3.4. Total Soluble Solids and Browning

In the fruits, the total soluble solids represent water-soluble substances such as sugars, acids, and vitamin C, among others. However, this parameter is currently used as an indicator of total sugar content since 90% of the soluble solids present in the fruits correspond to the sugars [47]. The initial values of total soluble solids for uncoated and coated goldenberries ranged between 14 and 15 °Brix. During storage at 20 °C and 65% RH (Figure 5A), the total soluble solids increased for all the samples (coated and uncoated goldenberries) achieving at the end of the 12th day of storage a value of approximately 18.5 °Brix without significant differences between the samples ($p > 0.05$).

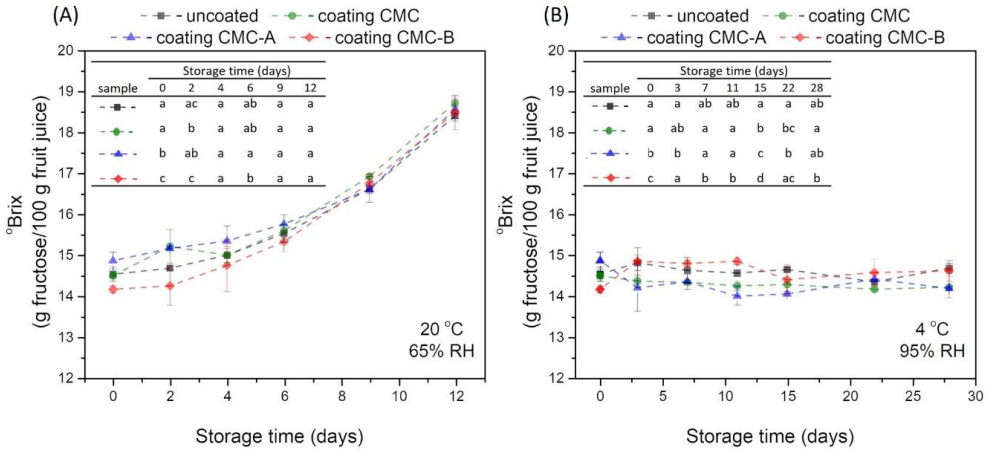


Figure 5. Total soluble solids of uncoated and coated fresh goldenberries as a function of storage time: (**A**) 20 °C and 65% RH and (**B**) 4 °C and 95% RH. Results are expressed as mean ± standard deviation ($n = 6$). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

Usually, total soluble solids rise during fruit ripening due to the gradual degradation of starch and cell wall materials [3], resulting in an increase in the sugar content. On the contrary, the total soluble solid values of the uncoated and coated goldenberries were maintained constant for 28 days when stored at 4 °C and 95% RH (Figure 5B). Although all the treatments (fruits coated with CMC, CMC-A and CMC-B coatings) and uncoated goldenberries presented the same behavior without statistically significant changes when stored at different temperatures and RH, it can be noted that fruits placed at 4 °C and 95% RH had a reduction of metabolic activity, which agrees with the results obtained for gases transfer rate.

Another important parameter to evaluate the quality of the fresh goldenberries during storage is the browning rate (Figure 6). The obtained results showed that the browning of the uncoated goldenberries and those coated with different treatments, and then subjected to dissimilar temperatures and RH, had the same behavior previously reported for the total soluble solids. Consequently, the browning rate of the uncoated and coated fruits stored at 20 °C and 65% RH increased as a function of storage time (Figure 6A), but without significant differences between the samples ($p > 0.05$).

The browning rate to all the goldenberries uncoated and coated with CMC, CMC-A, and CMC-B coatings and placed at 4 °C and 95% RH remained constant during the storage time (Figure 6B) and neither presented significant statistical differences ($p > 0.05$) among the samples. However, the results showed that at 4 °C and 95% RH, the browning rate can be prevented, which is possibly related to a lower O_2 transfer rate, avoiding thus the browning caused by oxidative or enzymatic processes [3].

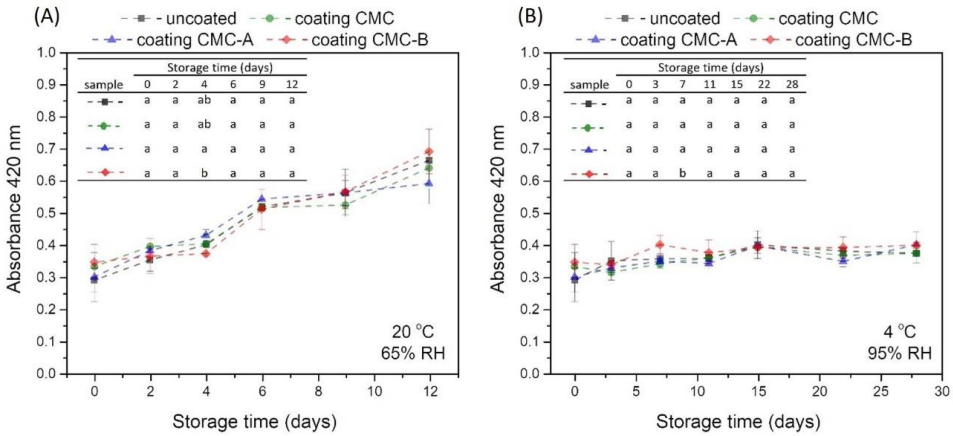


Figure 6. Browning rate of the fresh goldenberries (coated and uncoated) as a function of storing: (**A**) 20 °C and 65% RH and (**B**) 4 °C and 95% RH. Results are expressed as mean ± standard deviation (n = 4). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

3.3.5. Vitamin C, Phenolic Compounds and Flavonoids

Vitamin C, also known as ascorbic acid, is an important constituent of fresh fruits and vegetables. It is classified as a hydro-soluble vitamin, being abundant in fruits where the content water exceeds 50% [23,48]. It would explain the high level of ascorbic acid in goldenberry when compared with other fruits since 79% of its composition is water. The obtained values at 0 days of storage for coated and uncoated goldenberries ranged around 21–23 mg/100 mL of fruit juice, which agrees with those values reported by Gutierrez et al. [48].

For the goldenberries (uncoated and coated) stored at 20 °C and 65% RH, the content of vitamin C increased over time (Table 3), except for fruits without coating that after 4 days of storage showed a significant reduction in the ascorbic acid content ($p < 0.05$) concerning the coated fruits. For goldenberries (uncoated and coated) stored at 4 °C and 95% RH, the content of ascorbic acid increased for all samples during storage time (Table 4). At the end of the storage, significant changes ($p < 0.05$) were observed among all coated fruits and those without coatings (day 12) when stored at 20 °C and 65% RH, and between the uncoated fruits and those protected with coating CMC and coating CMC-B (day 28) when subjected at 4 °C and 95% RH.

Some studies have stated a decrease in ascorbic acid content in fresh-cut mangoes [3], Chinese jujube [2], apple, and tomato [49] during storage time. However, other authors have reported an increase in vitamin C and polyphenol contents in Japanese quince [50] and goldenberries [43,51]. For example, Gutierrez et al. [43] evaluated the ascorbic acid content in the goldenberry during four different stages of maturity and proved that ascorbic acid raises when the goldenberry becomes more mature. After achieving total maturity, it is expected that starts vitamin C loss. Valdenegro et al. [51] also noted an increment in the vitamin C and polyphenol contents in goldenberries along ripening, achieving the maximum values at the ripe stage, and after that, reducing while the ethylene production increased when stored at 20 °C. Thus, the results obtained agree with those statements, suggesting that the CMC, CMC-A, and CMC-B coatings delay the loss of vitamin C and polyphenols when the goldenberries attain the ripe maximum, while they also reduce the ethylene production (as previously shown in Section 3.3.1) when stored at 20 °C and 65% RH.

Table 3. Vitamin C (Vit C), total phenolic compounds (PC), and flavonoids (FLA) values of the coated and uncoated fresh goldenberries stored at 20 °C and 65% RH for 12 days.

Sample	Analysis	Storage Time (Days)					
		0	2	4	6	9	12
Uncoated	Vit C	22.88 ± 0.62 ^{a}	28.23 ± 2.27 ^{a}	30.85 ± 1.05 ^{a}	24.69 ± 1.42 ^{a}	26.78 ± 1.97 ^{a}	27.89 ± 1.97 ^{a}
	PC	1.52 ± 0.04 ^{a}	1.51 ± 0.03 ^{a}	1.53 ± 0.05 ^{a}	1.57 ± 0.02 ^{a}	1.71 ± 0.04 ^{a}	1.72 ± 0.03 ^{a}
	FLA	0.062 ± 0.004 ^{a}	0.067 ± 0.003 ^{ab}	0.067 ± 0.004 ^{a}	0.074 ± 0.002 ^{ac}	0.073 ± 0.004 ^{a}	0.075 ± 0.003 ^{a}
Coating CMC	Vit C	20.91 ± 3.42 ^{a}	24.33 ± 1.95 ^{b}	29.35 ± 2.92 ^{a}	28.46 ± 1.21 ^{b}	33.63 ± 0.40 ^{b}	31.53 ± 0.37 ^{b}
	PC	1.45 ± 0.06 ^{a}	1.44 ± 0.05 ^{a}	1.51 ± 0.07 ^{a}	1.52 ± 0.06 ^{a}	1.60 ± 0.10 ^{a}	1.73 ± 0.08 ^{a}
	FLA	0.062 ± 0.003 ^{a}	0.064 ± 0.002 ^{a}	0.068 ± 0.004 ^{a}	0.067 ± 0.003 ^{b}	0.074 ± 0.005 ^{a}	0.076 ± 0.004 ^{ab}
Coating CMC-A	Vit C	21.78 ± 4.02 ^{a}	22.26 ± 0.22 ^{b}	31.09 ± 0.21 ^{a}	31.74 ± 2.137 ^{b}	34.96 ± 2.77 ^{b}	33.42 ± 1.86 ^{b}
	PC	1.54 ± 0.03 ^{a}	1.53 ± 0.09 ^{a}	1.72 ± 0.04 ^{b}	1.72 ± 0.03 ^{b}	1.75 ± 0.03 ^{a}	1.98 ± 0.03 ^{b}
	FLA	0.067 ± 0.003 ^{b}	0.066 ± 0.009 ^{ab}	0.066 ± 0.004 ^{a}	0.072 ± 0.003 ^{a}	0.076 ± 0.003 ^{ab}	0.081 ± 0.003 ^{b}
Coating CMC-B	Vit C	22.66 ± 2.80 ^{a}	21.57 ± 1.25 ^{b}	30.60 ± 1.05 ^{a}	30.73 ± 1.85 ^{b}	35.81 ± 2.59 ^{b}	32.63 ± 1.98 ^{b}
	PC	1.81 ± 0.03 ^{b}	1.80 ± 0.05 ^{b}	1.73 ± 0.05 ^{b}	1.93 ± 0.03 ^{c}	1.92 ± 0.02 ^{b}	2.07 ± 0.06 ^{b}
	FLA	0.073 ± 0.003 ^{c}	0.072 ± 0.005 ^{b}	0.076 ± 0.005 ^{b}	0.077 ± 0.003 ^{c}	0.079 ± 0.002 ^{b}	0.088 ± 0.006 ^{c}

Vit C results are expressed as mean ± SD (n = 4) and reported as milligrams of ascorbic acid per 100 milliliters of fruit juice (mg ascorbic acid/100 mL fruit juice); PC and FLA results are expressed as mean ± SD (n = 10) and reported as milligrams of gallic acid equivalent per grams of fruit (mg GAE/g fruit) and milligram of quercetin equivalent per grams of fruit (mg QE/g fruit), respectively. Different letters within each analysis in the same storage day correspond to statistically different samples for a 95% confidence level.

Table 4. Vitamin C (Vit C), total phenolic compounds (PC), and flavonoids (FLA) values of the coated and uncoated fresh goldenberries stored at 4 °C and 95% RH for 28 days.

Sample	Analysis	Storage Time (Days)						
		0	3	7	11	15	22	28
Uncoated	Vit C	22.88 ± 0.62 ^{a}	28.11 ± 0.35 ^{a}	30.01 ± 2.67 ^{a}	29.44 ± 1.80 ^{a}	28.93 ± 1.59 ^{a}	34.21 ± 0.74 ^{a}	33.83 ± 1.63 ^{a}
	PC	1.52 ± 0.05 ^{a}	1.19 ± 0.05 ^{a}	1.21 ± 0.07 ^{a}	1.30 ± 0.05 ^{a}	1.56 ± 0.07 ^{a}	1.58 ± 0.06 ^{a}	1.65 ± 0.08 ^{a}
	FLA	0.062 ± 0.004 ^{a}	0.061 ± 0.004 ^{a}	0.058 ± 0.002 ^{a}	0.059 ± 0.002 ^{a}	0.059 ± 0.006 ^{a}	0.054 ± 0.002 ^{a}	0.053 ± 0.003 ^{a}
Coating CMC	Vit C	20.91 ± 3.42 ^{a}	28.61 ± 2.46 ^{a}	32.97 ± 1.06 ^{a}	32.22 ± 0.36 ^{a}	28.17 ± 0.36 ^{a}	37.89 ± 2.98 ^{b}	37.31 ± 2.52 ^{b}
	PC	1.45 ± 0.06 ^{a}	1.16 ± 0.02 ^{a}	1.28 ± 0.05 ^{a}	1.38 ± 0.06 ^{a}	1.65 ± 0.05 ^{b}	1.65 ± 0.09 ^{a}	1.69 ± 0.08 ^{ab}
	FLA	0.062 ± 0.003 ^{a}	0.063 ± 0.006 ^{a}	0.060 ± 0.003 ^{ab}	0.061 ± 0.003 ^{a}	0.057 ± 0.003 ^{a}	0.058 ± 0.002 ^{ab}	0.057 ± 0.004 ^{ab}
Coating CMC-A	Vit C	21.78 ± 2.02 ^{a}	28.85 ± 0.70 ^{a}	32.43 ± 0.06 ^{a}	31.21 ± 1.44 ^{a}	32.48 ± 2.15 ^{b}	38.69 ± 1.12 ^{b}	35.07 ± 0.35 ^{ab}
	PC	1.54 ± 0.03 ^{a}	1.26 ± 0.07 ^{a}	1.41 ± 0.06 ^{b}	1.47 ± 0.08 ^{b}	1.59 ± 0.05 ^{ab}	1.62 ± 0.01 ^{a}	1.75 ± 0.01 ^{b}
	FLA	0.067 ± 0.003 ^{b}	0.062± 0.004 ^{a}	0.061 ± 0.001 ^{b}	0.062 ± 0.003 ^{a}	0.058 ± 0.003 ^{a}	0.059 ± 0.005 ^{bc}	0.061 ± 0.002 ^{bc}
Coating CMC-B	Vit C	22.66 ± 2.80 ^{a}	31.34 ± 2.86 ^{a}	29.73 ± 2.59 ^{a}	32.22 ± 2.66 ^{a}	30.45 ± 0.04 ^{ab}	40.89 ± 0.37 ^{b}	37.31 ± 0.70 ^{b}
	PC	1.81 ± 0.03 ^{b}	1.40 ± 0.03 ^{b}	1.51 ± 0.05 ^{b}	1.59 ± 0.08 ^{c}	1.65 ± 0.08 ^{b}	1.66 ± 0.09 ^{a}	1.93 ± 0.06 ^{c}
	FLA	0.073 ± 0.003 ^{c}	0.065 ± 0.002 ^{a}	0.063 ± 0.003 ^{b}	0.062 ± 0.003 ^{a}	0.062 ± 0.005 ^{a}	0.063 ± 0.003 ^{c}	0.063 ± 0.003 ^{c}

Vit C results are expressed as mean ± SD (n = 4) and reported as milligrams of ascorbic acid per 100 milliliters of fruit juice (mg ascorbic acid/100 mL fruit juice); PC and FLA results are expressed as mean ± SD (n = 10) and reported as milligrams of gallic acid equivalent per grams of fruit (mg GAE/g fruit) and milligram of quercetin equivalent per grams of fruit (mg QE/g fruit), respectively. Different letters within each analysis in the same storage day correspond to statistically different samples for a 95% confidence level.

The content of phenolic compounds of goldenberries (uncoated and coated) when stored at 20 °C and 65% RH is presented in Table 3. As can be seen at 0 days of storage, the goldenberries with the coating CMC-B showed higher phenolic compounds values ($p < 0.05$) than the other samples. It can be explained by the fact that coating CMC-B has an extra content of phenolic compounds, which were incorporated during the production of that coating [CMC-based edible coating with 0.2% (w/v) of polysaccharide-rich extract, and 0.2% (w/v) of phenolic compounds encapsulated].

During storage, uncoated and coated goldenberries, stored at 20 °C and 65% RH, presented a slight increase in the phenolic compound values (Table 3). However, the samples covered with the coating CMC-B showed higher values, being significantly different ($p < 0.05$) than the uncoated goldenberries and those coated with the coating CMC. At the end of storage time, the goldenberries with CMC-A and CMC-B coatings did not present significant differences ($p < 0.05$) regarding the phenolic compound content.

On the other hand, when the goldenberries were stored at 4 °C and 95% RH (Table 4), a decrease with respect to the initial content of phenolic compounds was observed for all the

samples. Some authors have observed this reduction in goldenberries being related to the cold storage [21,22]. After that, the content of phenolic compounds in uncoated and coated goldenberries increased until 15th day of storage and then it was maintained constant.

Nevertheless, significant differences ($p < 0.05$) between goldenberries coated with coating CMC-B and those uncoated or coated with coating CMC were observed over the storage. The results are in agreement with the other studies reporting that the content of phenolic compounds in the fruits increases during ripening [21,51,52].

The content of phenolic compounds obtained for uncoated goldenberries was higher than the values reported by Carvalho et al. [22] and Valdenegro et al. [51]. It can be due to the extraction conditions used in this work (sequential extraction process, solvent, temperature, liquid/solid ratio, and extraction time), as well as to the storage temperature to which the fruit was subjected.

The content of flavonoids of uncoated and coated goldenberries when stored at 20 °C and 65% RH as well as 4 °C and 95% RH are presented in Tables 3 and 4, respectively. Results showed that flavonoids were increasing in all the samples placed at 20 °C and 65% RH, while it decreased for the uncoated and coated goldenberries left at 4 °C and 95% RH. Although all the fruits presented the same behavior when subjected to the same temperature and RH conditions, significant changes ($p < 0.05$) were observed among goldenberries with the coating CMC-B and the others samples, especially at day 0 and at the end of the storage, being the content of flavonoids higher for the fruits coated with the coating CMC-B in both storage conditions, revealing thus a coating CMC-B with antioxidant properties.

3.3.6. Microbiological Analysis

The evolution of mesophilic bacteria, as well as the yeast and mold growth in uncoated and coated goldenberries, are shown in Figure 7.

The lowest values of mesophilic bacteria counts (Log CFU/mL fruit juice), at 20 °C and 65% RH, were achieved when the goldenberries were coated with the coating CMC-A (Figure 7A), being statistically different ($p < 0.05$) than uncoated fruits after 2 days of storage. Additionally, the goldenberries with the coating CMC and CMC-B maintained at the same conditions showed significant changes ($p < 0.05$) when compared to the uncoated goldenberries, mainly after 9 days of storage. Although at 4 °C and 95% RH goldenberries coated with the coating CMC-A also presented lower values of mesophilic bacteria counts (Figure 7B), these were not statistically different ($p < 0.05$) when compared to the other samples.

In the same way, the lower values of yeasts and mold growth at 20 °C and 65% RH were achieved for goldenberries coated with the coating CMC-A, being significantly different than the other samples only at the end of storage (day 12) as shown in Figure 7C. However, at 4°C and 95% RH (Figure 7D), the fruits coated with the coating CMC-A presented statistically different values ($p < 0.05$) when compared to the uncoated goldenberries and those coated with the coating CMC and CMC-B (from 7th to 22nd day of storage).

Other authors have reported the effectiveness of the edible starch-based coatings for delaying or inhibiting the growth of microorganisms in strawberries [53] and goldenberries [20]. The results suggest that coating CMC-A presents antibacterial effects, observed when used at 20 °C and 65% RH, and antifungal effects when used on goldenberries at 4 °C and 95% RH, which agrees with the antimicrobial tests previously carried out. Additionally, the inhibition growth effect of mesophilic bacteria, as well as the yeasts and molds when using the coating CMC-A, may be related to the reduction in the respiration rate of the goldenberries subjected to this treatment as a consequence of lower oxygen permeability [54].

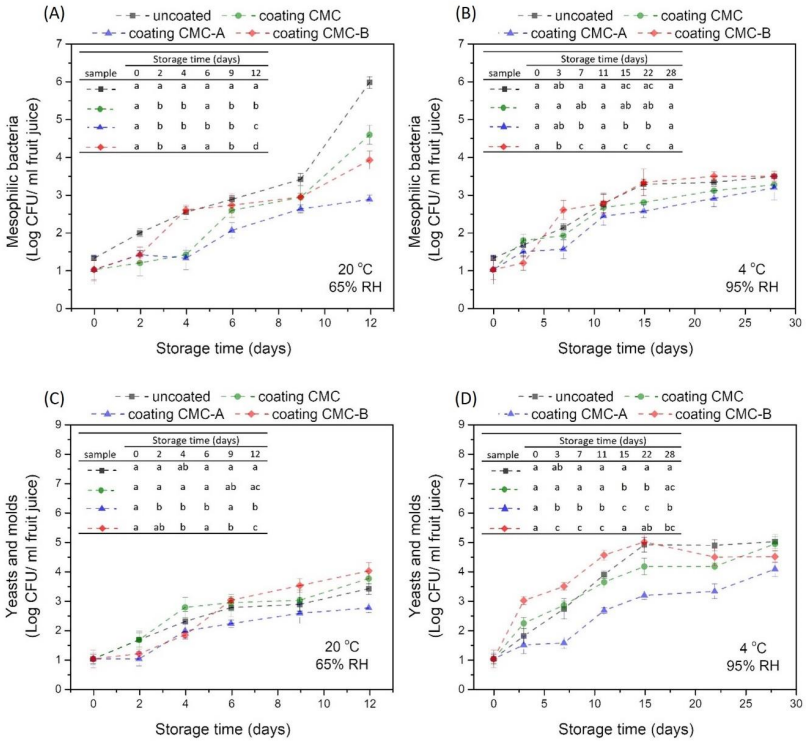


Figure 7. Mesophilic bacteria count (**A**,**B**); and yeasts and molds growth (**C**,**D**) in the uncoated and coated fresh goldenberries when stored at 20 °C and 65% RH and 4 °C and 95% RH. Results are expressed as mean ± standard deviation (n = 4). In the inserted table, different letters on the same analysis day correspond to statistically different values for a 95% confidence level.

3.3.7. Sensorial Analysis

Sensorial analysis was carried out to determine if the coatings influence the sensorial properties of fresh goldenberries. For that, the coated and uncoated goldenberries were stored at 4 °C and 95% RH for 15 days since obtained results about physicochemical and microbiological properties of goldenberries demonstrated that this time is safe for their consumption. Moreover, the sensorial analysis was performed 15 days after goldenberries were stored as usually the fruits stay in the supermarket for some days before being consumed.

Figure 8 shows the results obtained for the Triangle Sensory Test performed by 25 untrained panelists.

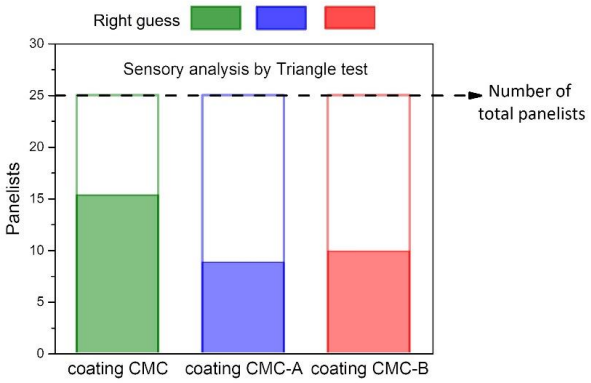


Figure 8. Sensory analysis results of the fresh goldenberries (coated and uncoated) using a Triangle sensory test. According to the test, the number of correct answers to establish a significant difference at a 95% confidence level should be ≥13 for 25 tasters.

The test consisted of selecting, based on the appearance, aroma, taste, and texture of three samples (two uncoated goldenberries and one of them coated with the coating

CMC, coating CMC-A or coating CMC-B), the goldenberry that was considered different. According to the results, 15, 9, and 10 of the untrained panelists made the right choice for the coating CMC, coating CMC-A, and coating CMC-B, respectively. However, for 25 panelists, the number of correct answers to establish a significant difference should be $\geq$13. Thus, the findings indicate that the goldenberries coated with the coating CMC-A and coating CMC-B did not present significant sensorial differences ($p < 0.05$) concerning the uncoated fruits, proving that these two treatments improve or maintain the physicochemical and microbiological properties of goldenberries but without changing their sensory characteristics when compared with the uncoated fruits.

4. Conclusions

Shelf-life parameters of fresh goldenberries were improved when the fruits were coated with the edible coatings CMC-A and CMC-B. Additionally, the temperature and RH used during storage influenced the extension of goldenberries shelf-life. Lower gas transfer rates (O_2, CO_2, and C_2H_4) were obtained for fruits coated with coatings CMC-A and CMC-B in comparison with the uncoated goldenberries when stored at 20 °C and 65% RH. The edible coating CMC-A was better for delaying the microbial growth, while the edible coating CMC-B gave an extra content of phenolic compounds to goldenberries, increasing thus their antioxidant potential. On the other hand, the application of the edible coatings (CMC-A and CMC-B) did not alter the sensorial characteristics of goldenberries. These findings show that CMC-based edible coatings enhanced with polysaccharide-rich extract and encapsulated phenolic compounds-rich extract, obtained from SCG, are a promising alternative for postharvest handling of fresh goldenberries, maintaining their quality and increasing the storage time.

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