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Carboxymethyl Cellulose from Banana Rachis: A Potential Edible Coating to Extend the Shelf Life of Strawberry Fruit

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Abstract: Cellulose derivatives, as edible coating for fruits and vegetables, have been broadly applied due to their availability, stability, solubility, safety, and low price. Therefore, this study was conducted to (1) extract cellulose from the banana plant rachis, (2) convert it into carboxymethyl (CMC), and (3) use the produced CMC as an edible coating to retard senescence and prolong the storage life of strawberry fruit. Preparation of CMC was accomplished by an etherification process, utilizing sodium hydroxide and monochloroacetic acid (MCA), with ethanol as a supporting medium. Characterization of CMC was done by analyzing the spectra of FTIR, degree of substitution (DS), ash content, CMC yield, water and oil holding capacity, in addition to physical characteristics. A storage study with CMC as an edible coating was conducted to investigate its impact on the shelf life of stored strawberry fruits. High purity food-grade CMC was successfully produced. CMC showed a yield of 156.25% with a DS of 0.78, a water holding capacity of 11.24 g/g, and an oil holding capacity of 1.60 g/g. The resulted CMC was well suited for edible coating preparation and was used effectively to prolong the shelf life of stored strawberry fruits at 22 °C to 6 days and to 16 days for that stored at 4 °C. Weight loss, total soluble solids (TSS), decay percentage, pH, anthocyanin content, ascorbic acid content, firmness, and sensory characteristics of CMC coated strawberry fruit stored at 4 °C were better than those stored at 22 °C. Thus, CMC edible coating prepared from banana rachis could be recommended as a potential postharvest treatment to delay postharvest senescence and maintain the quality of ambient and cold stored fruits.

Keywords: cellulose; banana rachis; etherification; edible coating; shelf life; strawberry

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1. Introduction

Bananas are one of the most significant crops in the world, with 116 million tons produced globally in 2017–2019, valued at about USD 31 billion according to FAO 2020 [1]. Banana crops generate a series of waste that needs to be managed [2].

One of the most significant byproducts of the banana plant's fruit harvesting operation is banana rachis [3]. Among the materials that can be obtained from plant waste is cellulose. Recently, numerous studies have been focusing on valuing the ligno-cellulosic fractions of agro-industrial green waste produced by biorefinery. Since lignin and cellulose comprise mostly of this waste, it is generally referred to as cellulosic waste. In one respect, lignocellulosic waste is recognized as a limitless source of raw materials for producing valuable products [4]. Cellulose is a linear homo-polysaccharide of β-1,4-D-glucopyranose. The monomer has hydroxyl groups that can make hydrogen bonds, providing cellulose with a variety of characteristics, including (i) the multi-scale microfibrillar structure, (ii) the presence of amorphous regions as opposed to crystalline regions, and (iii) natural high cohesiveness indicated by a glass transition temperature greater than the breakdown temperature [5].

The extraction and modification of cellulose is straightforward, leading to an array of cellulose derivatives with varied characteristics. Carboxymethyl cellulose (CMC) is a cellulose derivative formed by reacting cellulose with chloroacetic acids and sodium hydroxide [6]. Environmental sustainability is a vital basis for the creation of new materials, goods, and processes. The use of biodegradable products and those made from biomass increases the value of agricultural waste and fosters innovation in science and technology [7,8]. In this regard, underutilized materials, byproducts, or waste from the agri-food sector gained a significant recognition as alternatives in creating new packaging [9,10].

Banana byproducts have also been identified as one of the major biomass agro-resources [11]. Additionally, the banana crop suffers significant losses; postharvest losses for green bananas are rejected due to defects and not being exportable (between 5 and 10%) [8,10,12]. In this context, the stem, peel, and rachis are parts of the banana plant that are removed and not used but contain a lot of cellulose.

CMC is a water-soluble polysaccharide with suitable biodegradable and appealing film-forming qualities and can be obtained in huge quantities at a low cost from a variety of sources [13]. It has a pH of between 6 and 8.5, is tasteless, odorless, and non-toxic. It also contains 4–5.5% moisture. This film has outstanding performance as a protective colloid and adhesive [13,14], as well as shear stability. It also has a thickening ability. Edible coatings have gained recognition in recent years owing to their positive impact on the storage life of vegetables and fruits [15,16]. Furthermore, once edible coatings are applied on fresh fruit surface, they afford an internal environment that reduces respiration and decelerates the ripening stage and quality alteration [17,18]. Polysaccharides, particularly cellulose and chitosan derivatives, are becoming increasingly popular as edible materials [18–20]. Several studies have applied CMC for prolonging the shelf life of fresh products such as avocado [21], peach and pear [22], mango [23], and cucumber [24].

Strawberry (*Fragaria ananassa* L.) is recognized as one of the most consumed delicate fruits around the world. The shelf life of strawberries is relatively short due to their susceptibility to moisture loss, mechanical injury, and fungal growth that significantly reduce the fruit quality and marketability [25]. Several approaches have been suggested to control microbial growth and physiological processes of fruit. One suggested approach is the use of simple and sustainable bio-based technology, such as edible coatings that could control these processes by modifying the internal atmosphere in tissues. A positive effect against inhibition of fruit pathogens was obtained by the employing of chitosan beads that liberated lavender and red thyme EOs. Layer-by-layer edible coating was effective in eliminating the loss of strawberry hardness and fragrance volatiles, while having no impact on total acidity and total soluble solid content [26]. This coating maintains strawberry quality by depressing metabolite levels after eight days of storage.

There have been attempts to develop edible coatings based on polysaccharides and cellulose derivatives such carboxymethyl cellulose (CMC). However, to the best of our knowledge, there is no information available on carboxymethyl cellulose from banana rachis as a potential edible coating to extend the shelf life of strawberry fruit. Therefore, this study was conducted to (1) extract cellulose from the banana plant rachis, (2) convert it into carboxymethyl, and (3) use produced CMC as an edible coating to retard senescence and prolong the shelf life of strawberry fruit.

2. Materials and Methods

The raw materials at green stage were collected from the rachis of banana fruit (*Musa sapientum* L. cv. Mali-Ong) obtained from a commercial farm in Qena governorate, Egypt. Strawberry fruits were obtained from the local market.

2.1. Extraction of Cellulose

Cellulose was extracted from banana rachis utilizing the method proposed by Flores-Velázquez et al. [27]. Banana rachis were peeled from the green layer and then cut into small pieces 5–6 cm. The rachis pieces were washed with water and dried in the sun. Then, the dried rachis was ground and soaked in toluene—ethanol (2:1 *v*/*v*) for 2 days. The mixture was filtrated and washed 5 times with distilled water to eliminate low molecular weight organic compounds in the raw material. The remaining part was treated with aqueous 1.5% H_2O_2 and the pH of the solution was adjusted to 12 utilizing 12 M NaOH and stirred at 45 °C for 14 h. After filtration and washing with distilled water and absolute ethanol, the remaining insoluble substance was treated with a mixture of 70% (*v*/*v*) nitric acid and 80% (*v*/*v*) acetic acid at 120 °C for 15 min. Finally, it was washed with ethanol and distilled water, then the cellulose fibers were dried and ground.

2.2. Carboxymethyl Cellulose (CMC) Synthesis

CMC was produced from the extracted cellulose as described by Mondal et al. [28]. CMC was formed by two reactions; in the first reaction alkaline NaOH solution 30% (*w*/*v*) was added into 5 g of pure cellulose at room temperature. Ratio 1:2.7 cellulose: alkaline solution was formed with mechanical stirring for one hour. A volume of 150 mL ethanol was utilized as a solvent in this step. The second reaction was etherification; a treatment with monochloroacetic acid 120% (*w*/*v*). The acid was added drop by drop under continuous stirring for 30 min. Ratio 1:1.2 cellulose: monochloroacetic acid was taken for 3.5 h at 55 °C. After the interaction was over, the solution was filtered, and 200 mL of methanol was added. Then, glacial acetic acid was added to the slurry to neutralize the acidity. The sample was washed with 70% ethanol four times and then with absolute ethanol. Finally, the sample was filtered and dried at room temperature.

2.3. Characterization of CMC

Properties of CMC, including CMC yield, moisture, ash, degree of substitution, water holding capacity, and oil holding capacity, were determined. Moisture content was determined by a drying oven (BJPX-Summer) at 104 °C. Ash content was determined according to the standard method [29] in a muffle furnace at 600 °C using porcelain crucibles.

For the water holding capacity (WHC) and oil holding capacity (OHC) determination, 1 g (W1) of dry material was mixed with 25 mL of distilled water or commercial olive oil for 1 h at 40 °C. The supernatant from centrifugation was weighed (W0), then WHC and OHC were determined as gram of water or oil per gram of dry sample, respectively [30], and were calculated using the following equation:

$$\text{WHC or OHC (g/g)} = \frac{\text{W0} - \text{W1}}{\text{W1}}$$

Dry sodium CMC (0.5 g) was gently heated between 450 °C and 550 °C in a muffle furnace for 24 h to evaluate the degree of substitution, and then it was dissolved in 100 mL of distilled water, using methyl red as an indicator and 20 mL of this solution was titrated with 0.1 N sulfuric acid. The solution was heated and titrated to a sharp end point after the initial endpoint. The degree of substitution was used to calculate the carboxymethyl content [31], as follows:

$$\text{Degree of substitution } = \frac{0.162 \times \text{ B}}{1 - 0.08 \times \text{ B}} \text{B} = \frac{0.1 \times \text{ b}}{\text{G}}$$

where, B is millimoles of acid per gram of CMC, b is the volume (in mL) of 0.1 N sulfuric acid, and G is the mass of pure CMC in grams.

2.4. Identification of Functional Groups of the CMC Using FTIR Spectroscopy

The IR spectra of the produced compounds were recorded using a KBr disc on a JASCO FTIR-4100 (JASCO Co., Tokyo, Japan). 0.2 mg of CMC samples was used to make the pellets, which were then crushed with 2 mg of KBr. The transmission was measured were obtained within the 4000–400 cm^{-1} range.

2.5. Coating Preparation and Storage Experiment

2.5.1. Preparation of Carboxymethyl Cellulose and Thyme Essential Oil (CMC/TEO) Composite Edible Coatings

The CMC/TEO edible coating was formed by dissolving 2 g of CMC in 200 mL distilled water under stirring at 70 °C for 45 min. Then, the solution was completed (1% w/v) with distilled water up to 200 mL. Following, 1 mL glycerol was added as a plasticizer with continuous stirring for 10 min at 70 °C. Thyme essential oil 2 mL (TEO) was added to the coating solution at a concentration of 1% (v/v) as antimicrobial and antioxidant agents, with continuing stirring at room temperature. Tween 20% was mixed with the coating solution at a concentration of 0.1% (v/v) as a surfactant and the solution was heated at 60 °C in a water bath for 2 h [32].

2.5.2. Coating Application

Strawberry fruits were immersed in 2% sodium hypochlorite solution for 2 min and then dried at room temperature for one hour. Following, fruits were dipped in coating solution for 30 s then put on shelves to dry at room temperature for 2 h. Uncoated fruits dipped in water were used as a control treatment. After that, coated and uncoated fruits were placed in perforated polypropylene plastic boxes and stored at two different temperatures (4 °C and 22 °C) with relative humidity (45–50% RH) and (50–55% RH), respectively. A group of 120 fruits was used for each treatment with three replicates. For different analyses, the fruit was withdrawn from the storage after 2, 4 and 6 at 22 °C, and after 5, 10 and 15 days of storage at 4 °C.

- Weight Loss

Weight loss was determined by weighing each strawberry box (n = 5) before and after storage period. Weight loss percentage was estimated as per the following equation:

$$\text{Weight loss (\%)} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

- Decay Percentage

Decay percentage was recorded during storage using 15 strawberries for each treatment and calculated as follows:

$$\text{Decay (\%)} = (\text{decayed fruits}/\text{total fruits}) \times 100$$

- Fruit pH

Five strawberries (for each treatment) were homogenized using a homogenizer (HG-15A, Wonju, Republic of Korea) and filtered by a cheesecloth. The pH was recorded in fruit juice by a pH-meter (AD1030, ADWA Instruments Inc., Romania).

- Total Soluble Solid (TSS)

Strawberries (5 fruits for each treatment) were cut into small pieces and 10 g was weighed. Then, the sample was homogenized with 30 mL distilled water and filtered by a cheesecloth. TSS was recorded using a handheld refractometer (Atago PAL-1, Japan) [33].

- Anthocyanins Content

Five grams of strawberries were obtained from 5 fruits and mixed with 40 mL of ethanol-1.5 mol/L HCl solution using a homogenizer (HG-15A, Wonju, Republic of Korea) for 1 min. The mixture was filtered and the filtrate was completed to 100 mL by distilled water. Absorbance was measured at 535 nm using a spectrometer (T80 UV/VIS spectrophotometer). Anthocyanin content was calculated according to the following equation:

$$\text{Total anthocyinan } \left(\text{mg cyanidin } 100 \text{ g}^{-1}\right) = \frac{\text{Absorbance } \times \text{ dilution factor}}{98.2} \times 100$$

- Ascorbic Acid Content

Ascorbic acid content was assessed according to the standard method of AOAC [34] with some modification. The sample (5 g) was mixed with 40 mL 3% (w/v) metaphosphoric-glacial acetic acid solution using a homogenizer (HG-15A, Wonju, Republic of Korea) and centrifuged at 4000 rpm for 20 min. Then, the sample was titrated with 2,6-dichloro phenol indophenol [35].

- Fruit Firmness

The strawberries' firmness was determined by using a handheld texture analyzer (FB200 S/N: 344, Tarnowskie Góry, Poland). The probe was inserted into the fruit and recorded punching force to penetrate 4 mm of fruit.

- Sensory Evaluation of Stored Strawberry

Sensory evaluation was carried out by 20 panelists (10 women and 10 men, between 25–35 years old). Sensory attributes evaluated included taste, texture, color, flavor, and overall acceptability. The evaluation was taken after 2, 4 and 6 days of storage at 22 °C and after 5, 10 and 15 days of storage at 4 °C.

2.6. Statistical Analysis

Statistical analyses were conducted using SAS software (version 913). Data analyses were handled by analysis of variance (ANOVA). Duncan's multiple comparison test was utilized to compare the differences between means at level $p \leq 0.05$.

3. Results and Discussion

3.1. Physicochemical Characteristics of CMC Produced from Banana Rachis

The chemical and physical characteristics of the CMC produced from alkali treatment of banana rachis cellulose are presented in Table 1. In this study, the yield of the CMC product is 156.25%. According to Silva et al. [36], the yield depends on how much material is lost during the dialysis process. When more extreme reaction conditions (higher temperature, SMCA concentration, and NaOH) were used, more degradation occurred, and lower molecular weight material was produced. This will lead to less carboxymethylated polymeric product being left over for drying to recover. Higher CMC yield, 121–128% from water hyacinth and 141% from the pod husk of Cacao, has been reported [37,38]. The difference in CMC yield from different sources could be attributed to the concentration of NaOH, temperature of the reaction and monochloroacetic acid (MCA) utilized during synthesis.

The degree of substitution (DS) is one of the most significant characteristics of CMC. The DS refers to the average number of hydroxyl groups substituted by the substituent in every anhydro glucose unit in the chain, and in commercial products it can range from 0.4 to 1.526 [37]. For banana pseudo stem, Adinugraha and Marseno [38] reported that the DS range was 0.26–0.76. When the DS is higher than 0.4, the CMC is entirely soluble and its hydro-affinity increases with rising DS value, while below this value, the CMC is swellable but insoluble [39]. The accessibility of reactants and the availability of the activated hydroxyl groups are the key determinants of etherification [40]. Since the CMC derived from banana rachis has a DS value of 0.78, it is completely soluble in water and its solubility will rise with increasing temperature. Therefore, the DS value obtained in this work satisfies the DS requirement for the CMC product (DS = 0.3). The variation between different products is due to the employment of various substances and different experimental settings.

The results for moisture content, ash content, WHC, and OHC of CMC are presented in Table 1. The moisture content, ash content, WHC, and OHC of the prepared CMC were greater than standard CMC, that were 2.22%, 14.23%, 4.12 g/g, and 1.58 g/g, respectively.

The high WHC suggests that the prepared CMC is highly hydrophilic. During etherification, more hydroxyl groups were substituted by carboxymethyl groups, which are hydrophilic; as a result, an increase of DS improves the ability of CMC to immobilize water in the system [41]. The high ash content indicates high DS, possibly because more hydroxyl groups were substituted by sodium salts of carboxymethyl groups via the etherification reaction. These results infer high reactivity.

The physicochemical properties of CMC prepared from banana rachis are presented in Table 1. The solubility of the CMC sample was tested and was found to be soluble in water and insoluble in ethanol. The results showed that CMC was fine powdered, off-white in color, tasteless, and odorless. A solution with 1% CMC had a pH of 6.80 and no layer of foam was observed after shaking 0.1% solution of the sample. No reddish-brown or blue color of CMC were developed in an iodine solution or red color with acidified phloroglucinol. These examinations indicate the absence of organic impurities such as starch and dextrin in the produced CMC. The Joint FAO/WHO Expert Committee on Food Additives [42] has recommended some standards for purity and identification of CMC. In this study, the prepared CMC fulfills these requirements.

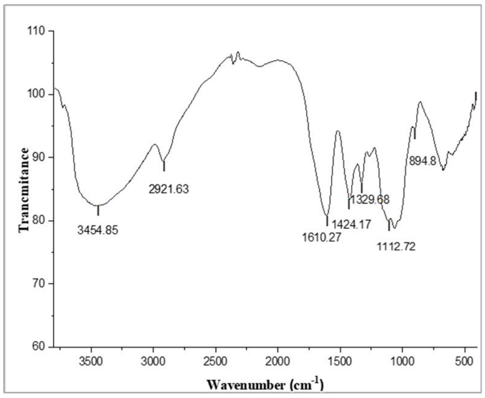
CMC is a powder that ranges in color from white to off-white and dissolves in water. It is soluble at concentrations of up to 50 mg/mL, but heat may be needed. The properties of CMC rely on the cellulose chain length and the degree of substitution [43].

Table 1. Physicochemical characteristics of CMC prepared from banana rachis.

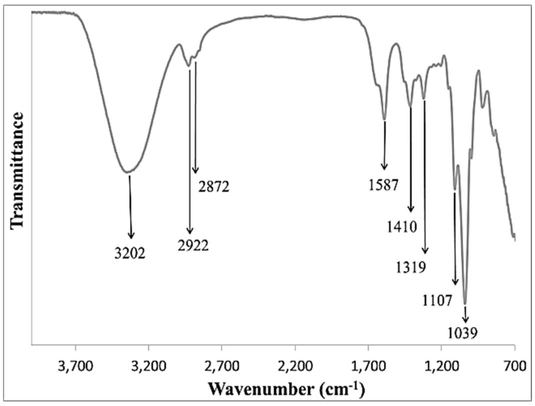
Formula	$\mathbf{(C_6H_7O_2(OH)_2COONa)_n}$
Yield	156.25%
Color	Light brown or off-white
Moisture	8.44%
Ash	19.50%
Water holding capacity	11.24
Oil holding capacity	1.60
Degree of substitution	0.78
pH	6.8
Solubility in water	Soluble in water
Film formability	Able to form film
Form	Powder
Organoleptic	Odorless, tasteless, white and with free-flowing powder
Foam	Shaking a 0.1% solution produces no layer of foam
Starch and dextrins	With iodine solution, there is no blue or reddish-brown color
Organic impurities	With acidified phloroglucinol, there is no red color

3.2. Identification of Functional Groups of CMC Using FTIR

The infrared spectra of the prepared CMC are shown in Figure 1. A broad absorption band at 3454 cm^{-1} is caused by the OH group's stretching frequency, and a band at 2921 cm^{-1} is caused by the C–H group's stretching vibration. The stretching vibration of carboxyl groups (COO) is confirmed by the occurrence of a new and strong absorption band at 1610 cm^{-1}, and the carboxyl groups' salts are assigned to 1424 cm^{-1} [6]. The vibrations of –OH bending and C–O–C stretching are attributed to the bands near 1329 cm^{-1} and 112 cm^{-1}, respectively. Detection of 1,4-glycoside of cellulose at wavelength 894 cm^{-1} was made.



(**a**)



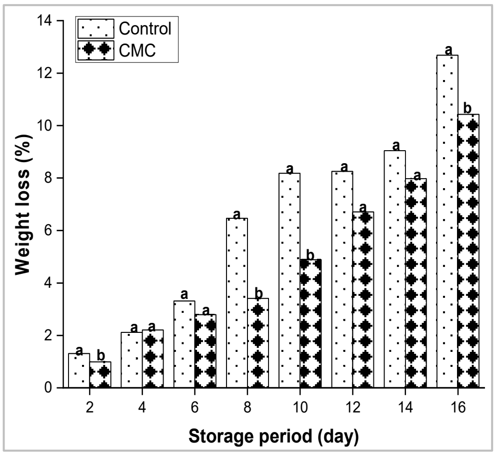
(**b**)

Figure 1. (**a**) FTIR spectra of CMC prepared from banana rachis (DS = 0.78), (**b**) FTIR spectra of pure CMC [39].

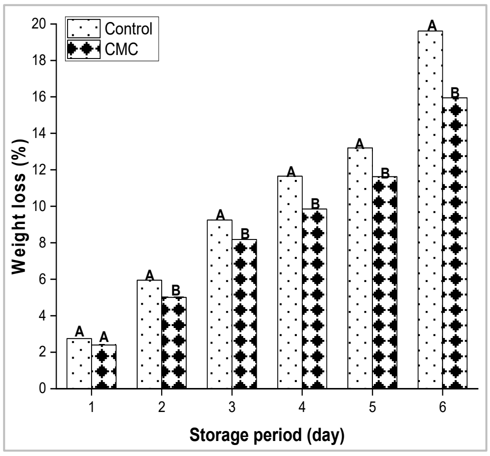
3.3. Chemical and Physical Characteristics of Stored Strawberries

3.3.1. Weight Loss

The weight loss percentage of strawberry fruit during storage time at 4 °C and 22 °C is shown in Figure 2a,b. The weight loss percentage significantly increased ($p \leq 0.05$) during the storage period for both coated and uncoated fruits. Weight loss showed a significant variation between coated and uncoated fruit. Edible coating reduced moisture evaporation from fruits, as coating treatment (CMC) produced (10.34%) weight loss percentage which was smaller than that of the control treatment (12.68%). At the end of the storage experiment at 4 °C (16 days) and at 22 °C (6 days), coated treatment (CMC) had lower (15.95%) weight loss percentage than the control treatment (17.37%). These results indicate that the coating material worked as barrier for water loss.



(**a**)



(**b**)

Figure 2. Effect of CMC edible coating prepared from banana rachis on weight loss (%) of strawberries stored at two different temperatures (**a**) at 4 °C and (**b**) at 22 °C. A significant difference between treatment groups within the same analysis day at $p < 0.05$ is indicated by a different letter on each bar.

3.3.2. Decay Percentage

The results in Figures 3 and 4 show the decay percentage of strawberry fruits during storage at 4 °C and 22 °C. The results revealed an increase in decay percentage of strawberry fruits during storage for control and coated treatment (CMC +1%TEO). At the end of storage time at 4 °C, control treatment and coated treatment showed decay percentages of 62.85% and 32.5%, respectively, while at 22 °C it recorded 90.63% and 43.13%, respectively. The decay percentage of strawberries had a significant difference ($p \leq 0.05$) between coated and uncoated fruit. Edible coating (CMC +1%TEO) reduced fruit decay by 30.35% compared with the control treatment at 4 °C and by 47.50% in comparison with the control treatment at 22 °C. These results agreed with a previous report [43], describing that CMC edible coating reduced the decay of strawberries (up to 32.66%) compared with the untreated samples (up to 22.4%) [36]. CMC coating could increase the storage life of strawberries during storage at both storage temperatures (22 °C and 4 °C).

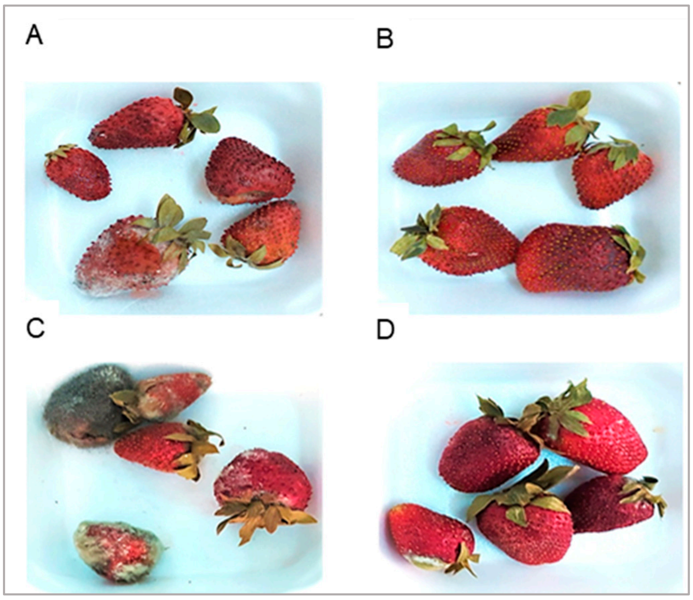


Figure 3. Effect of CMC edible coating prepared from banana rachis on strawberry fruit decay (**A**) uncoated strawberries stored at 4 °C for 16 days, (**B**) coated strawberries with CMC+ TEO stored at 4 °C for 16 days, (**C**) uncoated strawberries stored at 22 °C for 6 days, and (**D**) coated strawberries stored at 22 °C for 6 days.

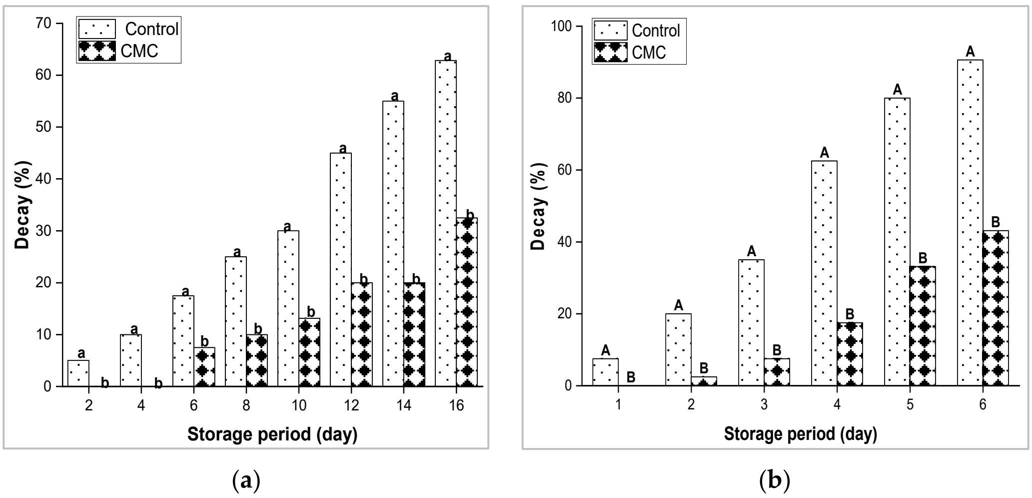
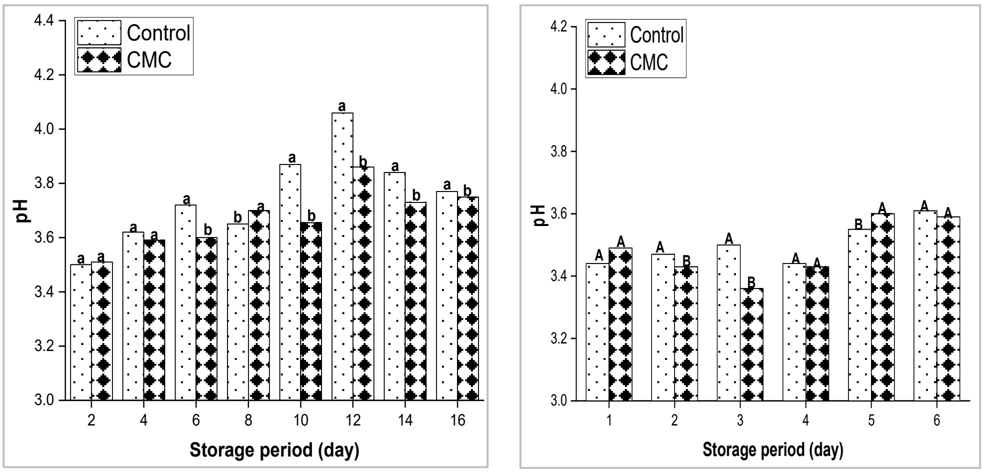


Figure 4. Effect of CMC edible coating on decay percentage of strawberries stored (**a**) at 4 °C for 16 days, and (**b**) at 22 °C. Different letters of each bar indicate a significant difference between treatment groups within the same analysis day at $p < 0.05$.

3.3.3. Fruit pH

The impact of CMC edible coating on the strawberries' pH as compared with the control samples is shown in Figure 5. The pH value showed an increase during the storage period for both storage temperatures (4 °C and 22 °C). After 16 days of cold storage at 4 °C, there was a significant variation ($p \leq 0.05$) in the pH values between coated and uncoated fruits. In contrast, fruits stored at 22 °C did not show a significant difference ($p \geq 0.05$)

between coated and uncoated samples at 1, 4, and 6 days of storage. Whereas significant ($p \leq 0.05$) variation between coated and uncoated fruits was detected starting from the 5th day of storage time. The observed increase in pH values could be due to the oxidation of organic acid with the passing of time, and the coating layers could reduce the oxidation processes of the organic acids. CMC coating could reduce the increase in pH of strawberry fruits during the storage period at 4 °C [44].



(**a**) (**b**)

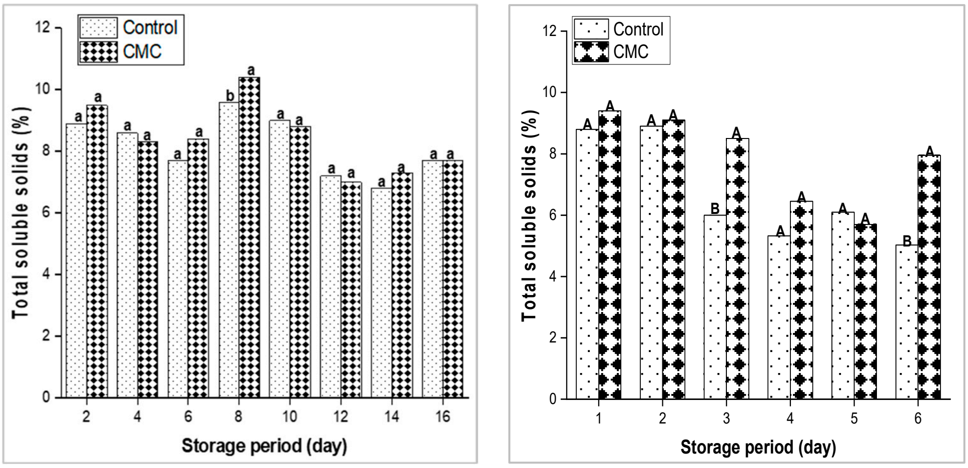
Figure 5. Effect of edible coating of carboxymethyl cellulose prepared from banana rachis on pH of strawberries stored at two different temperatures (**a**) at 4 °C and (**b**) at 22 °C. A significant difference between treatment groups within the same analysis day at $p < 0.05$ is indicated by a different letter on each bar.

3.3.4. Total Soluble Solid

The impact of CMC coating on TSS of strawberry fruits is presented in Figure 6. At the end of the storage period, it was observed that all treatments had a decrease in TSS content. This decrease may be due to the growth of fungi that led to the exhaustion of TSS contents. These results agree with those showed by Rozali et al. and Khodaei et al. [44,45], who observed a decrease in TSS of strawberry fruits at the end of storage (4 °C and 22 °C). At the same time TSS increased at the beginning of storage and this increase could be due to moisture loss and polysaccharide breakdown. At the end of storage time, there was no significant variation between coated and uncoated fruits in TSS content for fruits stored at 4 °C, while fruits stored at 22 °C showed a significant ($p \leq 0.05$) variation between coated and uncoated samples at the end of storage.

3.3.5. Anthocyanin Content

Anthocyanin content in strawberries during storage time is shown in Figure 7. The results indicated that anthocyanin content increased with ambient storage 22 °C in the first two days, with 25.67 mg/100 g for control and 28.65 mg/100 g CMC for coated fruits. Then, anthocyanin content decreased again until the end of storage (6 days), with 14.56 mg/100 g for control and 19.7 mg/100 g for CMC coated fruits. The cold storage at 4 °C followed the same manner. A slight increase was observed at the first 8 days of storage for control (18.44%) and CMC coated fruits (29.43%), then the anthocyanin content decreased starting from the 12th day up to the end of storage time (16 days). These results agreed with previous reports [46,47]. Edible coating could play a role as a barrier to O_2 and to delay anthocyanins synthesis throughout the storage period [48]. In this study, it was observed that strawberries developed a dark red color due to synthesis of anthocyanins at the beginning of the storage period, then the anthocyanins may break down during storage causing a significant decrease in anthocyanin content. At the end of the storage period, coated strawberries stored at 22 °C and 4 °C had significantly ($p \leq 0.05$) higher anthocyanin content, with 19.7% and 19.33% for storage at 22 °C and 4 °C, respectively, compared with the control at 22 °C and 4 °C, with 14.56% and 10.91%.

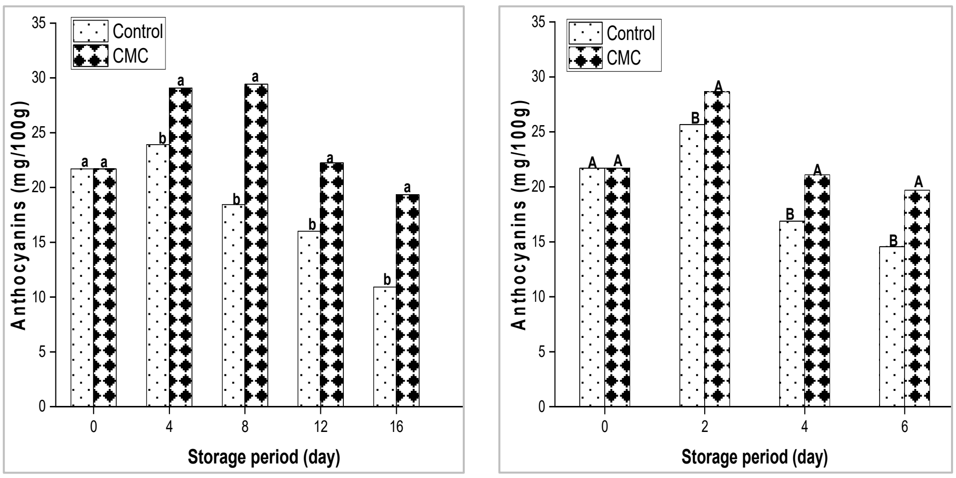


(**a**) (**b**)

Figure 6. Effect of CMC edible coating prepared from banana rachis on total soluble solids of strawberries stored at two different temperatures (**a**) at 4 °C and (**b**) at 22 °C. A significant difference between treatment groups within the same analysis day at $p < 0.05$ is indicated by a different letter on each bar.

3.3.6. Ascorbic Acid

Figure 8 presents ascorbic acid content in strawberries during the storage period. The results showed significant ($p \leq 0.05$) variation between coated and uncoated fruits. At both storage temperatures (4 °C and 22 °C), ascorbic acid content decreased in all treatments during storage time. CMC coated fruits showed the highest content of ascorbic acid at all stages of storage. This could be attributed to the reduction of ascorbic acid oxidation caused by the coating treatment. Ali et al. [49] reported that mango fruits coated with CMC solution showed significantly greater retention of ascorbic acid content in comparison with the control treatment. Guava fruits coated with CMC showed significant differences when compared with the control as reported by Kumar et al. [50]. It was reported that, in response to postharvest treatment, ascorbic acid content in fruits including strawberries was higher in CMC treatment than in control fruits [46,51].



(**a**) (**b**)

Figure 7. Effect of edible CMC coating prepared from banana rachis on anthocyanin content of strawberries stored at two different temperatures (**a**) at 4 °C and (**b**) at 22 °C. A significant difference between treatment groups within the same analysis day at $p < 0.05$ is indicated by a different letter on each bar.

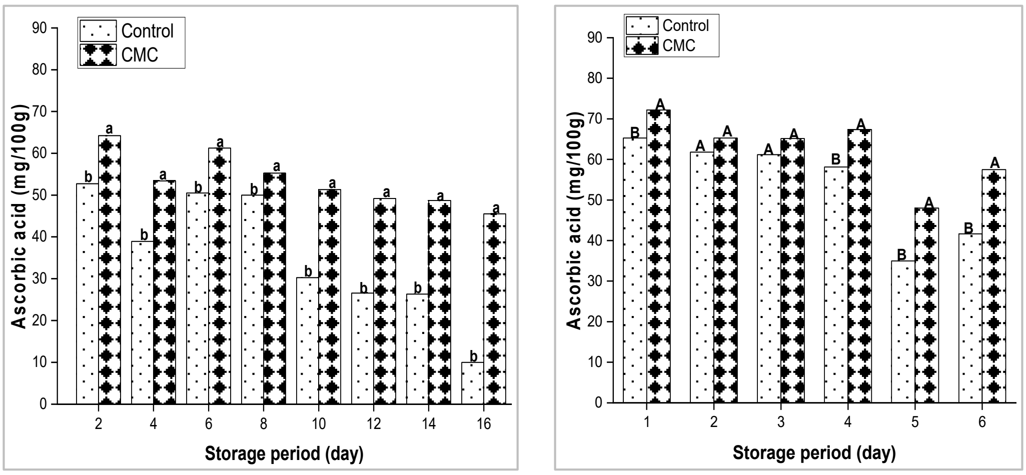
3.3.7. Fruit Firmness

The results of firmness presented in Table 2 demonstrated a decrease in firmness of strawberries during storage at 4 °C and 22 °C. However, coated strawberries showed higher firmness than control ones, but there was no significant difference between CMC treatment and the control ($p \leq 0.05$). These results agree with the previous report by Khodaei et al. [47], who observed a decrease in firmness during the storage. The main reason for the firmness decrease was due to polysaccharide and pectin breakdown in strawberries causing tissue softness.

Table 2. Effect of coating treatment with CMC on firmness (N) of strawberry fruits stored at 22 °C and 4 °C for 6 days and 16 days.

Storage Period	**2 Days**	**4 Days**	**6 Days**	**8 Days**	**10 Days**	**12 Days**	**14 Days**	**16 Days**
Temperature				4 °C				
Control CMC	3.51 ± 0.25 [a*] 3.85 ± 0.34 [a]	2.96 ± 0.39 [a] 3.53 ± 0.66 [a]	2.69 ± 0.53 [a] 3.4 ± 0.69 [a]	2.76 ± 1.18 [a] 3.37 ± 1.88 [a]	2.46 ± 0.76 [a] 3.358 ± 1.02 [a]	2.23 ± 0.66 [a] 3.29 ± 0.93 [a]	2.21 ± 0.62 [a] 3.02 ± 0.73 [a]	1.87 ± 0.58 [a] 2.73 ± 0.68 [a]
Sample	1 day	2 days	3 days	4 days	5 days	6 days		
Temperature				22 °C				
Control CMC	3.74 ± 1.32 [a] 3.94 ± 1.38 [a]	3.56 ± 1.76 [a] 3.78 ± 1.01 [a]	2.96 ± 0.94 [a] 3.6 ± 1.46 [a]	2.92 ± 1.17 [a] 3.24 ± 0.99 [a]	2.42 ± 0.56 [a] 2.93 ± 0.37 [a]	1.92 ± 1.11 [a] 2.7 ± 0.57 [a]		

Data are mean ± standard deviation. Values in a column followed by different superscript letters are significantly different ($p < 0.05$).



(**a**) (**b**)

Figure 8. Effect of CMC edible coating prepared from banana rachis on ascorbic acid content of strawberries stored at two different temperatures (**a**) at 4 °C and (**b**) strawberries stored at 22° C. A significant difference between treatment groups within the same analysis day at $p < 0.05$ is indicated by a different letter on each bar.

3.4. Sensory Evaluation of Stored Strawberries

The results of sensory evaluation for strawberries are presented in Table 3. Strawberry fruits stored at lower temperatures, 4 °C, showed better sensory properties than those stored at 22 °C for all studied sensory attributes. CMC treated fruits stored at 22 °C and 4 °C had the highest scores in texture, taste, flavor, color and overall acceptability. The storage experiment at 4 °C continued for 15 days, whereas at 22 °C it ended after 6 days. The sensory acceptability of the control samples ended after 4 days, however, for CMC coated fruits it continued for 6 days with good sensory properties and higher scores than those reported for control samples on the 4th day of storage. Strawberry samples stored at 4 °C followed the same trend as those stored at 22 °C; however, the coated samples continued until the end of the storage time (16 days), with good sensory properties, in comparison with the control at 10 days. These results indicate that CMC+ TEO can be used as an edible coating to maintain the quality properties of strawberries during storage.

Table 3. Effect of coating treatment with carboxymethyl cellulose prepared from banana rachis on sensory properties of strawberries fruit stored at 22 °C and 4 °C for 6 days and 16 days.

Temperature	Storage Period	Texture	Taste	Flavor	Color	Overall Acceptability
4 °C	control					
	5 days	6.55 ± 0.52 [b]	5 ± 0.63 [b]	5.27 ± 0.65 [b]	7.09 ± 0.83 [b]	6 ± 0.77 [b]
	10 days	5.82 ± 0.75 [b]	3.73 ± 0.79 [b]	4 ± 0.63 [b]	5.18 ± 0.4 [b]	4.27 ± 0.47 [b]
	15 days				3.64 ± 0.5 [b]	2.64 ± 0.5 [b]
	CMC					
	5 days	7.9 ± 0.3 [a]	6.36 ± 0.5 [a]	6 ± 0.45 [a]	8.73 ± 0.65 [a]	7.45 ± 0.69 [a]
	10 days	6.73 ± 0.47 [a]	5.73 ± 0.65 [a]	5.64 ± 0.81 [a]	7.27 ± 0.47 [a]	6.64 ± 0.5 [a]
	15 days	5.73 ± 0.79 [a]	4.73 ± 0.79 [a]	3.82 ± 0.75 [a]	5.09 ± 0.7 [a]	5.36 ± 0.5 [a]
22 °C	control					
	2 days	7.45 ± 0.52 [b]	7.45 ± 0.52 [b]	7.45 ± 0.52 [b]	7.45 ± 0.52 [b]	7.45 ± 0.52 [b]
	4 days	5.36 ± 0.5 [b]	5.36 ± 0.5 [b]	5.36 ± 0.5 [b]	5.36 ± 0.5 [b]	5.36 ± 0.5 [b]
	6 days					
	CMC					
	2 days	8.36 ± 0.5 [a]	8.36 ± 0.5 [a]	8.36 ± 0.5 [a]	8.36 ± 0.5 [a]	8.36 ± 0.5 [a]
	4 days	6.55 ± 0.52 [a]	6.55 ± 0.52 [a]	6.55 ± 0.52 [a]	6.55 ± 0.52 [a]	6.55 ± 0.52 [a]
	6 days	5.36 ± 0.5	5.36 ± 0.5	5.36 ± 0.5	5.36 ± 0.5	5.36 ± 0.5

Data are mean ± standard deviation (n = 20). Values in a column ([a,b]) followed by different superscript letters are significantly different ($p < 0.05$). Score 9 = excellent; 6–8 = like moderately; 5 = fair; 3–4 = dislike slightly; 0–2 = dislike extremely.

4. Conclusions

Banana rachis is frequently burned or used as animal feed, however, they have not been utilized commercially to generate cellulose. Using cellulose derivative (α-cellulose) extracted from banana rachis, is a sustainable utilization for this byproduct. α-cellulose can be extracted from cellulose by infusion with NaOH and mono-chloroacetic acid (etherification reaction). High-purity food-grade CMC was successfully produced and used effectively as an edible coating to extend the shelf life of stored strawberry fruits, at room temperature (22 °C) or refrigerated storage (4 °C), preserving all physicochemical properties and sensory quality. This postharvest treatment retarded senescence and conserved the quality of ambient and cold stored fruits by inhibiting biochemical or microbiological decays in fruits, as well as physical or textural degeneration; thus, avoiding unfavorable responses such microbial growth and softening in strawberry fruit. CMC may offer significant potential as an edible coating via their protective impact and delivering useful substances like antimicrobials, texture enhancers, and nutraceuticals into their coating matrix.

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