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The Production of Coating Film with Sweet Potato Starch and Carboxymethylcellulose from Water Hyacinth on Storage Life Extension of Mango (*Mangifera indica* L.)

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Abstract

The objective of this research was to study the production of coating films with sweet potato starch (SPS) and carboxymethyl cellulose (CMC) from water hyacinth and to study the effect of the coating on the storage life extension of mangoes. The coating film was prepared by dissolving sweet potato starch in water at a concentration of 5 % w/v and adding CMC from water hyacinth at 5 different concentrations: 0, 5, 10, 15, and 20 % based on the weight of the starch. Glycerol was added as a plasticizer at 20 % of the weight of the starch solution. The mixture was then dried at 65 °C for 18 h. The study found that the thickness of the film decreased with higher concentrations of CMC from water hyacinth. The water activity (a_w) ranged from 0.35 to 0.42, and the solubility and water vapor permeability of the film decreased with increasing CMC concentration. In the degradation study, it was observed that the films could biodegrade from 42 to 100 % for 8 weeks, with degradation rates decreasing as the amount of CMC from water hyacinth increased. Coating Mango with 10 % w/w CMC helped delay weight loss, skin color changes, and extended the shelf life of mango for up to 18 days at room temperature (28 ± 2 °C, 65 ± 2 % RH), compared to the control group with a shelf life of 12 days. These results indicate that films made from SPS/CMC from water hyacinth, with glycerol as the plasticizer, can effectively be used for preserving fruits and creating biodegradable films.

Keywords: Sweet potato starch, Carboxymethylcellulose, Water hyacinth, Coating film, Preservation fruit, Biodegradation, Shelf life

Introduction

Mango (*Mangifera indica* L.), also known as the king of fruits, is popular for consumption and available in the market throughout the year in Thailand. Post-harvest, mangoes have a limited shelf life and are prone to physiological and biochemical deterioration [1], primarily due to processes like respiration, and transpiration, resulting in losses in nutrition and sensory qualities [2]. The application of coatings is utilized to preserve the quality of fruits and vegetables [3]. This process can decrease the movement of gases and water vapor, resulting in a slower respiration rate in fruits, reduced weight loss, and the prevention of microbial growth. Consequently, the overall result is an extension of the shelf life of fresh fruits [4]. Conventional coatings are based on synthetic waxes or chemical fungicides, which can be harmful to consumer health and environmentally polluting [5]. Recently, the coating films are produced from renewable natural and biodegradable polymeric materials such as polysaccharides [6], proteins [7], lipids [8], or a combination of these components [2,9]. Coatings produced from starch are particularly intriguing due to several advantages. For instance, starch is readily available locally, biodegradable, and consumable. In addition, starch coatings exhibit superior characteristics compared to other biopolymers in various aspects, such as odorless, colorless and permeability of flavoring agents [10]. In this context, starch is an ideal and sustainable alternative to petroleum-based plastics.

Sweet potato (*Ipomea batatas* (L.) Lam) is one of the most important crops due to its abundance, renewability, biodegradability, non-toxicity and low cost [11]. Its root tuber is rich in starch [12]. However, coating fruits with only one type of starch may result in high water permeability, and brittleness, limiting their processability and applicability [13]. Therefore, the properties of the starch films have been enhanced by blending the starch with other biopolymers, resulting in new blends that exhibit superior properties.

Carboxymethylcellulose (CMC) is a water-soluble derivative of cellulose which exhibits excellent film-forming ability. Due to chemical compatibility, CMC is used for blending with starch to enhance the

mechanical and moisture resistance of the film [14]. In literature, CMC was produced from cellulose from agricultural waste sources, including rice straw [15], durian peel [16] and corn cobs [17]. Alternative to the mentioned sources, water hyacinth (*Eichhornia crassipes*) is of interest as a raw material for the synthesis of CMC. Water hyacinth is a high-potential raw material for producing CMC from its high cellulose content (72.63 %) and abundance in the natural water body [18]. Numerous studies have used CMC to extend the shelf life of fresh produce, including avocado, peach, pear, mango and cucumber [19]. Consequently, it is a promising material for mixing with starch to create fruit-coating materials. However, if the coating contains only starch and CMC, it may lack flexibility and adhesion. Therefore, the addition of plasticizers to the starch and CMC solution can reduce the intermolecular forces between polymer chain segments, increasing flexibility, cohesion, and overall performance [20]. Plasticizers commonly used are sorbitol [21] and glycerol [22]. Glycerol is commonly used as a plasticizer for starch films due to its compatibility with amylose, which enhances its mechanical properties. A study conducted by Ballesteros-Mártinez *et al.* [22] investigated the effect of glycerol and sorbitol on sweet potato starch film. The research revealed that glycerol was a more effective plasticizer with low water solubility, good tensile strength, and higher elongation compared to sorbitol.

Therefore, the objectives of this research are to investigate the production of coating films from sweet potato starch (SPS) / CMC from water hyacinth at different concentrations, using glycerol as a plasticizer. The physicochemical and mechanical properties were evaluated. The film-coating solution with different concentration of CMC was further applied on mango fruits and the changes in physical properties of the formed films was examined.

Materials and methods

Materials

Sweet potato tubers, with uniform size and shape, were obtained from a local farm (Lop Buri, Thailand). The water hyacinth was taken from Khok Samrong River, Lop Buri, Thailand, cleaned and dried under sunlight before usage. All the reagents and chemicals such as NaOH (technical grade), isopropyl alcohol (technical grade), sodium chloroacetate (Na-CA, Merck), Ethanol (96 %), CH_3COOH (technical grade) and glycerol (technical pure).

Instrument

Film thickness was determined using a micrometer (Mitutoyo, Japan) with an accuracy and precision of 0.001 mm. The color of films was employed using a Hunter Lab colorimeter (Color Flex Z2, USA). Water Activity (a_w) was performed on a water activity meter (Aqualab model series 4, Decagon device Inc, USA). FTIR was conducted using Spectrum 100, Perkin Elmer, equipped with an Attenuated Total Reflectance (ATR) cell device.

Methods

Preparation of sweet potato starch (SPS)

Sweet potato tubers were cleaned with water and then cropped. First, sweet potatoes were ground into a slurry by adding water. Then, the slurry was filtered through a filter cloth. The filtrate was left to settle overnight without shaking to recover the sediment as starch. The starch was rinsed 3 times with water and dried at 50 °C for 8 h using a hot air oven (Memmert, UN 110, Germany). Afterward, it was finely ground into a powder and sifted through a 150-mesh sieve before being stored in a moisture-controlled container.

Preparation of carboxymethyl cellulose (CMC) from water hyacinth (WH)

CMC was prepared following the method previously described by Elma *et al.* [23], with some modifications. Water hyacinth stems are cleaned and cut into small pieces. These pieces are subsequently baked in a hot air oven at a temperature of 55 °C for 24 h. Afterward, WH was ground and sieved with a size ranging from 80 mesh. Alkalization process, 15 g of WH powder was mixed with 450 cm^3 of isopropyl alcohol for 30 min at room temperature. Next, 50 cm^3 of 30 % NaOH solution was added to the mixture, and it was stirred for 1 h. In the carboxymethylation process, the solution was combined with 18 g of sodium chloroacetate and stirred at 55 °C for 3 h. The pH of the solution was neutralized with CH_3COOH. After that, the solution was washed 3 times with 96 % ethanol (200 cm^3 each time). Finally, the mixture was filtered and the residue obtained was dried in an oven at a temperature of 60 °C for 2 h. CMC characterizations are carried out. The CMC yield is calculated using Eq. (1) [24].

$$Yield(\%) = \frac{Weight\ of\ CMC\ (g)}{Weight\ of\ cellulose\ (g)} \times 100 \quad (1)$$

Film preparation

SPS/CMC from water hyacinth films was prepared through the cast casting technique, as previously described by Romani *et al.* [25]. The SPS (3 % w/v) was homogenized in distilled water using a mechanical stirrer for 10 min at room temperature. Subsequently, the solution was heated to 100 °C and stirred for over 30 min until the starch completely dissolved, resulting in a clear and viscous mixture. After gelatinization, CMC was added at different concentrations (0, 5, 10, 15 and 20 % w/w by the starch weight). Then, the plasticizer (glycerol) was added (20 %, w/v) under mechanical agitation (20 min). Thus, the filmogenic solution (20 mL) was on glass plates (10 cm in diameter) and allowed to dry at 65 °C for 18 h in a hot air oven (**Figure 1)**. After drying, the films were placed in desiccators for 24 h before evaluation.

Soil Biodegradability of films

The biodegradability of the films was evaluated according to the method described by Charles *et al.* [26], with modifications. Film samples (2×3 cm^2) were buried in a container measuring 20.3×48.5×14.3 cm^3, and they were embedded in natural soil to a depth of 8 - 10 cm at a temperature of 30 ± 2 °C. The samples were sprayed with water (20 mL). A control set using polyethylene plastic (PP) films was employed, and then the degradation of film samples was weighed every 2 weeks at 8-week intervals by removing the samples, brushing them to remove soil, and drying them at 50 °C for 2 h. The percentage weight loss during degradation was calculated using Eq. (2) [27].

$$Weightloss(\%) = \frac{(m_0 - m_1)}{m_0} \times 100 \quad (2)$$

where m_0 is the initial film weight, and m_1 is post degradation weight.

Application of the film coatings

The film-forming solutions were applied to the surface of the mango coating to investigate their impact on weight loss and internal appearance during storage, according to the adapted methodology of Martins da Costa *et al.* [28]. A similar-sized mango was selected and washed to dry at room temperature. The Mango was dipped in the film-forming solution, SPS/CMC 0 %, SPS/CMC 5 %, SPS/CMC 10 %, SPS/CMC 15 % and SPS/CMC 20 %, until they were fully coated and dried in an incubator at room temperature (28 ± 2 °C) (**Figure 1)**. Mangoes without any coating were used as a control group and placed under the same conditions. The Mango was weighed for 20 days. The weight loss (%) could be Eq. 3 [29].

$$weightloss(\%) = \frac{(W_0 - W_1)}{W_0} \times 100 \quad (3)$$

where W_0 is the initial weight, and W_1 is the weight after the test.

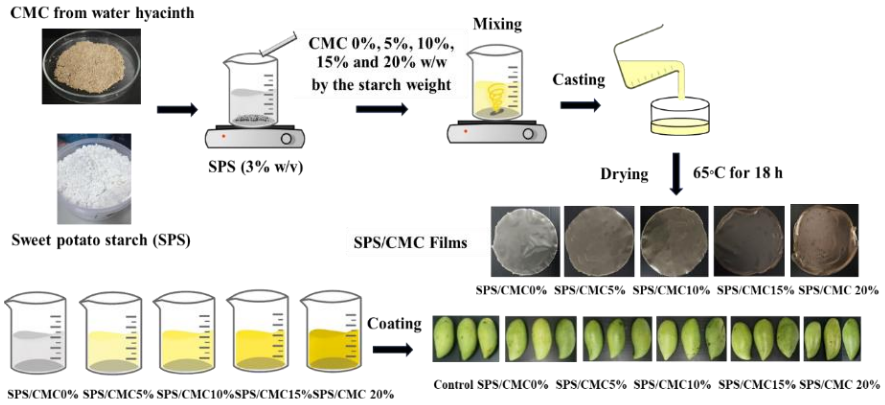


Figure 1 Representative scheme of the production of coating films with SPS/CMC from water hyacinth at different concentrations and applied on mango fruits.

Films properties evaluation

Thickness, water activity (a_w) and color properties

The thickness (nm) was used to measure at 5 different positions for film samples and their average value was calculated.

The color of films was employed using a Hunter Lab colorimeter. The parameters analyzed in this color system are L^* (lightness/brightness), a^* (redness/greenness), and b^* (yellowness/blueness). Film samples sized at 1.5×1.5 cm^2 were cut, and the color values were measured, repeating the process 3 times.

Water Activity (a_w) of films is important to determine in terms of microbial and chemical stability. High a_w (> 0.9) is susceptible to microbial growth while low a_w (< 0.5) is stable and has a longer shelf-life. The a_w values of the films were determined using a water activity meter. Film samples sized at 1.0×1.0 cm^2 were cut and the test was done in triplicates [30].

Solubility in water, moisture content and water vapor permeability

The solubility in water (SW) of the films was adapted from the method by Romani *et al.* [25] and Tongdeesoontorn *et al.* [31]. Film samples were cut (2.0 cm^2) and dried in a hot air oven (Memmert, UN 110, Germany) at 105 ± 2 °C to establish their initial dry weight. These film samples were placed in 50 mL of distilled water and shaken 120 rpm for 1 h at 25 °C. Subsequently, the films were oven-dried to determine the final dry weight. The SW (%) was calculated as Eq. (4).

$$SW(\%) = \frac{(m_i - m_f)}{m_f} \times 100 \quad (4)$$

where m_i is the dry weight of the film before the test and m_f is the dry weight after the test.

The moisture content (MC) of the films was determined using the method described by Jiang *et al.* [32], with some modifications. Specimens (2.5×7.5 cm^2) from each film were measured after undergoing a 48-hour conditioning period at 28 ± 2 °C (relative humidity 55 ± 2 %). After storage, the film samples were subjected to additional oven drying at 105 °C for 3 h. The moisture content of the film samples was calculated using Eq. (5).

$$MC(\%) = \frac{(M_1 - M_2)}{M_1} \times 100 \quad (5)$$

where M_1 is the initial weight of each film (g); and M_2 is the final weight of each film dried at 105 °C (g).

Water vapor permeability (WVP) was measured according to the ASTM Standard Method E96-00 [33] with some modifications. Film samples were cut (4.0 cm^2) and hermetically sealed on aluminum cups containing silica as desiccant inside. These sealed cups were then placed in desiccators with distilled water at 28 ± 2 °C (relative humidity 75 ± 2 %). The samples were periodically removed and weighed every hour intervals for 8 h. Subsequently, the WVP (g mm m^2 h^{-1} kPa^{-1}) was calculated using Eq. (6) [34].

$$WVP = \frac{(W \times L)}{A \times t \times \Delta P} \times 100 \quad (6)$$

where W is the weight of the permeation cell (g); L is the film thickness (mm); A is the film exposed to permeation (m^2); t is the time of weight (h); and ΔP is the vapor pressure difference (kPa).

Fourier transform infrared spectroscopy (FT-IR)

FT-IR was used to evaluate the molecule structure of CMC from water hyacinth, and starch samples, with and without the addition of the CMC. The analyses were carried out in the wavenumber range of 4,000 - 400 cm^{-1} with a resolution of 4 cm^{-1} by using an FT-IR spectrometer.

Statistical analysis

All physicochemical properties of the films were assessed in triplicate, and the results are presented as mean ± standard deviation. Statistical analysis was carried out using ANOVA and Duncan's multiple range test (SPSS Inc., version 12). Significant differences were determined at $p \leq 0.05$.

Results and discussion

Film appearance

Figure 2 shows films composed of SPS/CMC in various concentrations (0, 5, 10, 15, and 20 % w/w). These films are odorless, transparent and easily removable from the glass plate. They exhibit flexibility and have a smooth texture. An increase in the proportion of CMC results in a transition from transparent yellow to cloudy yellow, which can be attributed to the inherent yellow-brownish hue of the CMC [35].

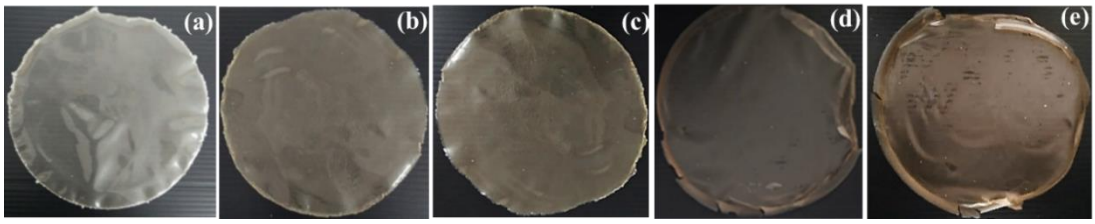


Figure 2 Appearance of SPS film with different CMC 0 % (a), 5 % (b), 10 % (c), 15 % (d), and 20 % w/w (e).

The thickness of all the SPS films with and without CMC, falls within the range of 0.18 - 0.26 mm, as shown in **Table 1**. An increase in CMC levels in the films results in a significant decrease in thickness ($p \leq 0.05$). During film processing and drying, hydrogen bonds within SPS can be replaced by stronger hydrogen bonds between CMC and SPS, resulting in a more compact blend structure and reduced film thickness [36].

The color values for the films are presented in **Table 1**. The color appearance of the sample films was analyzed based on L^* a^* b^* values. From the observed results, it was found that the control film (CMC 0 % w/w) showed a significantly lower L^* (darker) a^* and b^* value than all of the tested films. Additionally, an increase in CMC content led to a significant increase in the L^* and b^* values (yellowness) ($p \leq 0.05$), resulting in a more yellow film. Similar changes were also observed with the value of a^* (redness), indicating the presence of CMC content which has a pale yellow-like appearance in nature. Consequently, the incorporation of CMC into starch films has the potential to enhance their optical properties and produce clearer films. This observation was in agreement with corn starch/CMC blend films as reported by Lan *et al.* [37], where the alteration in film color was attributed to the CMC content.

The water activity (a_w) is a measure of the amount of free water that is conducive to the growth of microorganisms. In this context, a_w values close to 1 suggest a susceptibility to both microbiological and physicochemical alterations, while low a_w (< 0.6) suggests stability against microbial growth. From the observed results in **Table 1**, the films presented a_w values ranging from 0.35 - 0.42, which shows a significant difference ($p \leq 0.05$). In this study, a low a_w value could be crucial for storage, as this parameter may be influenced when in contact with a food product [38].

Table 1 Physical properties of SPS film with different concentrations of CMC.

Amount of CMC (%w/w)	Thickness (mm)	Color			a_w
		L^*	a^*	b^*	
0	0.26 ± 0.01^{a}	19.36 ± 0.42^{e}	-0.33 ± 0.03^{e}	0.21 ± 0.04^{d}	0.42 ± 0.01^{d}
5	0.24 ± 0.01^{a}	21.21 ± 0.61^{d}	-0.22 ± 0.02^{d}	0.28 ± 0.02^{d}	0.41 ± 0.01^{c}
10	0.23 ± 0.01^{bc}	23.55 ± 0.97^{c}	-0.05 ± 0.02^{c}	0.72 ± 0.10^{c}	0.40 ± 0.01^{b}
15	0.22 ± 0.01^{c}	26.17 ± 0.66^{b}	0.28 ± 0.06^{b}	1.04 ± 0.02^{b}	0.37 ± 0.01^{ab}
20	0.18 ± 0.01^{d}	28.12 ± 0.74^{a}	0.47 ± 0.04^{a}	2.43 ± 0.27^{a}	0.35 ± 0.01^{a}

[a - e]Means ± standard deviation in the same column with different letters are significantly different ($p \leq 0.05$)

Solubility in water, moisture content and water vapor permeability

The water solubility of the SPS films at various CMC concentrations is shown in **Table 2**. The addition of CMC at all concentrations resulted in reduced water solubility of the films. The samples without CMC film had a % SW of 26.86 %. However, a significant decrease ($p \leq 0.05$) in solubility was observed

at higher CMC levels. Specifically, at a CMC concentration of 20 % w/w, the films exhibited the lowest % SW values at 21.77 %. The decreased solubility of water indicated that intermolecular interaction occurred between hydroxyl groups on starch and the carboxyl groups of CMC, forming hydrogen bonds and ester bonds, which enhance cohesiveness and reduce water solubility. These results are consistent with similar investigations by Tongdeesoontorn *et al.* [39].

Table 2 shows the moisture absorption of the SPS films at various CMC concentrations. It was observed that SPS/CMC films exhibited lower moisture absorption than SPS without CMC film. These results suggest that the addition of CMC improved the water resistance because starch can form hydrogen bonds with the hydroxyl and carboxyl groups of the CMC molecules, hindering water diffusion. Similar results have been reported by other researchers who also observed reduced water absorption in corn starch blends containing CMC [40].

The WVP of the SPS films decreased with the increase of CMC content as can be seen in **Table 2**. Generally, water permeates through the amorphous zones within the films. The reduced WVP of the films can be attributed to their high crystallinity which promotes strong intra- and inter-molecular hydrogen bonding, thus reducing the available intermolecular space for water to enter the network, in agreement with the results of Jha *et al.* [41].

Table 2 Solubility in water (SW), moisture content (MC) and water vapor permeability (WVP) of films.

Amount of CMC (% w/w)	SW (%)	MC (%)	WVP (g mm m^2 h^{-1} kPa^{-1})
0	26.86 ± 0.54^{a}	7.78 ± 0.67^{a}	0.00034 ± 0.0002^{a}
5	24.94 ± 0.52^{ab}	7.38 ± 0.58^{b}	0.00031 ± 0.0001^{b}
10	23.48 ± 0.53^{b}	6.02 ± 0.38^{c}	0.00028 ± 0.0001^{c}
15	22.49 ± 0.80^{c}	4.03 ± 0.29^{d}	0.00025 ± 0.0002^{d}
20	21.77 ± 0.26^{d}	2.33 ± 0.27^{d}	0.00022 ± 0.0001^{e}

[a - e]Means ± standard deviation in the same column with different letters are significantly different ($p \leq 0.05$)
In this study, CMC was synthesized from water hyacinth (WH) cellulose, resulting in a percent yield of 147 %. This value is higher than that of CMC derived from palm bunch (135.78 %), bagasse (142.41 %) [42] and rice husk (89.33 %) [24].

The cellulose and CMC were selected to determine the evidence of carboxymethyl substituents. The FT-IR spectra of cellulose and CMC from water hyacinth are displayed in **Figure 3**. The presence of cellulose (**Figure 3(a)**) exhibited a broad band at 3,300 - 3,600 cm^{-1}, attributed to the stretching vibration of hydroxyl groups (OH), with an additional band at 2,930 cm^{-1} indicating C-H stretching vibration. The bands at 1,450 and 997 cm^{-1} correspond to -CH_2 scissoring and C-O stretching, respectively. The band at around 1,590 cm^{-1} is attributed to C=O stretching. The CMC spectra were similar to each other but distinct from those of cellulose. The differences were observed at 1,603 and 1,480 cm^{-1} (**Figure 3(b)**). These differences indicate the presence of carboxymethyl substituents in the absorption bands, specifically COO- and CH_2, respectively, which are consistent with those observed by Rachtanapun *et al.* [43]. The addition of various concentrations of CMC to SPS films resulted in the FT-IR spectra shown in **Figures 3(c) - 3(f)**. These changes indicate that the O-H band of the films shifted to 3,294 cm^{-1}, attributed to O-H stretching and the formation of intermolecular/intramolecular hydrogen bonds [44]. The C=O band shifted to 1,642 cm^{-1} with CMC addition. These results are in agreement with the FT-IR spectra of cassava starch-CMC blended films, which reported cross-linking of ester bonds between the hydroxyl groups in the branches of starch and the carboxylic acid groups of CMC [39].

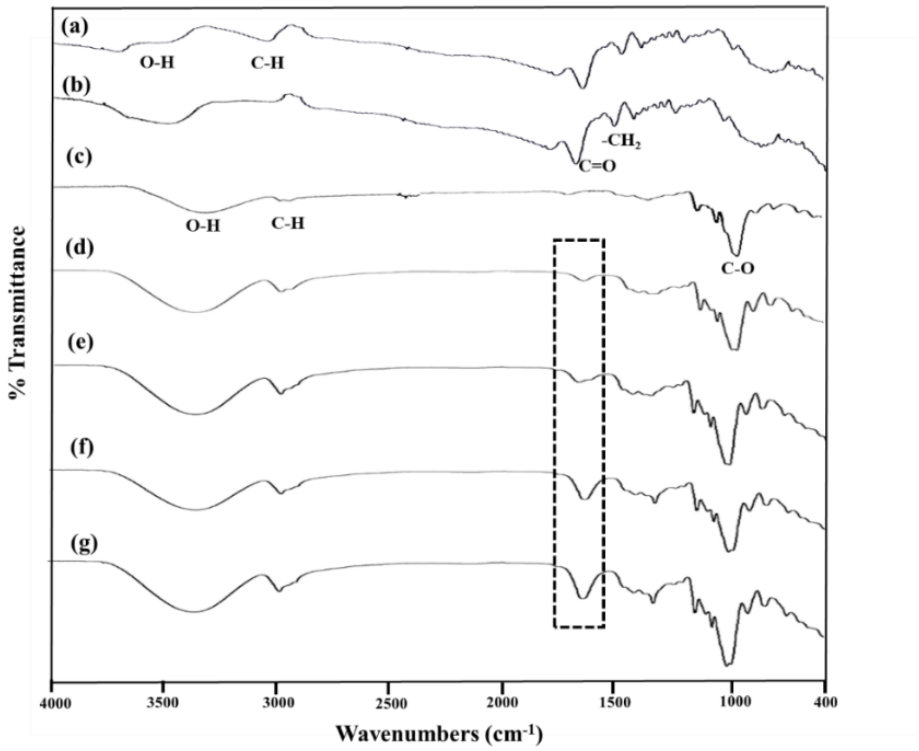
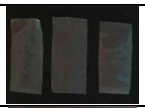
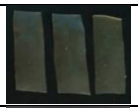
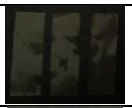
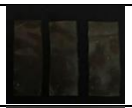
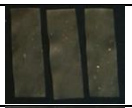
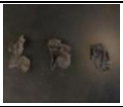
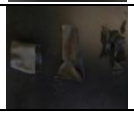
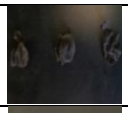
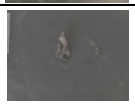


Figure 3 FT-IR spectra of cellulose (a), CMC (b), and SPS film with different CMC 0 % w/w (c), 5 %(d), 10 % (e), 15 % (f), and 20 % w/w (g).

The weight loss during the degradation of various films in the soil is shown in **Table 3**. SPS film (CMC 0 % w/w) exhibited the highest weight loss (100 %), while the other film samples showed a decrease with increasing amounts of CMC, which corresponded with their decreasing water solubility (**Table 2**). This indicates that the addition of CMC reduced the biodegradability of the SPS films, as films with higher water solubility demonstrated accelerated biodegradation. This is significant in an aquatic environment dominated by bacteria. Previous research [13] has also reported that CMC delayed the decomposition of rice starch films. Additionally, an ether linkage on the cellulose backbone is known to be resistant to microorganism attacks [45]. In the study conducted by Charles *et al.* [26], it was observed that the biodegradation rate of potato peel starch films decreased with higher CMC content in the films. In contrast, the control film (polyethylene: PE) showed no signs of degradation. Based on the data presented in **Table 3**, it is likely that the films underwent degradation through the hydro-biodegradation mechanism [46]. Notably, all the films degraded within the recommended time frames, confirming their potential application in postharvest coating, food packaging and pharmaceutical film forming.

Table 3 Biodegradable and weight loss (%) of SPS film with different concentrations of CMC.

Time (Week)	Physical appearance					
	Amount of CMC (% w/w)					
	Control	0 %	5 %	10 %	15 %	20 %
0						
2						
4						

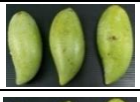
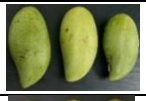
Time (Week)	Physical appearance					
	Amount of CMC (% w/w)					
	Control	**0 %**	**5 %**	**10 %**	**15 %**	**20 %**
6						
8						
weight loss (%)	0.00 ± 0.00^{f}	100 ± 0.00^{a}	84.78 ± 3.21^{b}	78.07 ± 2.12^{c}	59.18 ± 1.83^{d}	42.19 ± 1.42^{e}

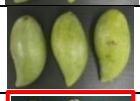
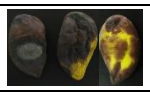
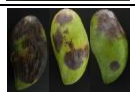
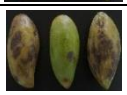
[a - e]Means ± standard deviation in the same column with different letters are significantly different ($p \leq 0.05$).

Evaluation of fruits during film storage

Finally, SPS films with different CMC were assessed for their ability to preserve a perishable fruit. The film-forming solutions were applied to the coating surface of the mango. Weight loss percentage over the storage period of 20 days for coated and control without coating is shown in **Table 4**. The control mango had the greatest weight loss of 49.73 ± 2.15 %. This is due to postharvest natural respiratory and transpiration processes [28]. Whereas the mango coated with SPS/CMC 10 % w/w resulted in lower weight loss (26.21 ± 1.26 %), followed by SPS/CMC 15 % w/w (33.64 ± 1.18 %), SPS/CMC 20 % w/w (34.68 ± 1.08 %), SPS/CMC 5 % w/w (35.92 ± 1.34 %) and SPS/CMC 0 % w/w (38.65 ± 1.96 %), which regulates selective permeability to O_2, CO_2, and water vapor, thereby delaying the natural physiological ripening process [28]. However, the mangoes coated with CMC at 0 and 5 % w/w exhibit a higher percentage of weight loss, due to the lower amount of CMC interfering with the starch molecules. This facilitated efficient permeation of water vapor and gases, aligning with the values of water vapor permeability [5], which is consistent with the higher water vapor permeability values as shown in **Table 2**. This causes water loss in mangoes over time, resulting in an increased percentage of weight loss. When increasing the amount of CMC (in the content of 15 and 20 % w/w), the percentage of weight loss increases due to mangoes being stored for an extended period, the water molecules trapped within the film cause changes in gas permeability. This results in reduced passage of gases like O_2, CO_2, CH_4, and N_2, leading to the deterioration of the mangoes due to anaerobic respiration [47].

Table 4 Digital photographs of the physical appearance and weight loss of mangoes coated with SPS film with different CMC and without coating.

Time (Day)	Physical appearance of Nam Dok Mai Mango					
	CMC (% w/w)					
	Control	**0**	**5**	**10**	**15**	**20**
`0						
2						
4						
6						
8						

Time (Day)	Physical appearance of Nam Dok Mai Mango					
	CMC (% w/w)					
	Control	**0**	**5**	**10**	**15**	**20**
10						
12						
14						
16						
18						
20						
weight loss (%)	49.73 ± 2.15[a]	38.65 ± 1.96[b]	35.92 ± 1.34[bc]	26.21 ± 1.26[d]	33.64 ± 1.18[c]	34.68 ± 1.08[c]

[a - d]Means ± standard deviation in the same column with different letters are significantly different ($p \leq 0.05$).

From the study on the changes in the skin color and characteristics of mango peel, as shown in **Table 4**, it was observed that during a 12-day storage period at room temperature, uncoated mangoes experienced a transformation in their skin color from green to yellow. With prolonged storage, the mangoes became softer and more susceptible to diseases. In contrast, mangoes coated with SPS/CMC at 10 % w/w extended the shelf life in comparison to all other coatings, with a shelf life of 18 days. Meanwhile, mangoes coated with SPS/CMC at 0, 5, 15 and 20 % w/w had a shelf life of only 14 days. It's worth noting that signs of diseases began to appear on day 14 of storage. As a result, mangoes coated with SPS/CMC at a 10 % w/w concentration could extend the shelf life by approximately 6 days. In a previous study by *Phuangto et al.*, it was reported that chitosan-coated mangoes exhibited an extended shelf life of 14 days [48]. Additionally, *Daisy et al.* demonstrated that a gum Arabic coating can prolong the shelf life of mangoes for up to 15 days [49].

Conclusions

The study investigated the production of coating films using SPS and CMC derived from water hyacinth. The findings revealed that an increase in the concentration of CMC in the SPS film resulted in a denser structure and a smoother surface. As CMC concentrations in the SPS film rose, the thickness, water activity, water solubility, moisture content, and water vapor permeability all decreased. FT-IR spectra indicated intermolecular interactions between SPS and CMC films, noticeable through the shifts in carboxyl (C=O) and OH groups. Additionally, the degradation rate decreased with higher CMC content. Coating films made from SPS and CMC at a 10 % ratio demonstrated exceptional performance in extending the shelf life of mango fruits. These films exhibited superior characteristics throughout the 20-day storage period at room temperature (28 ± 2 °C), resulting in a nearly 6-day extension of mango shelf life compared to uncoated mangoes. This suggests the potential for starch-CMC films to be utilized as edible, biodegradable films. It promotes the application of this coating to extend the shelf life and prevent physical deterioration in mango fruits during storage

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