Effect of Porang Starch Edible Coating with CMC and Ginger Extract on Red Chilli Quality

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Abstract. Curly red chili is susceptible to postharvest deterioration; edible coatings are applied to maintain quality. A composite coating formulated from porang starch, carboxymethyl cellulose (CMC), and ginger extract shows promising functional properties. This study evaluated the effect of porang starch–based edible coatings with different CMC concentrations and ginger extract addition on curly red chili quality during 12 days of room temperature storage. Analyses using a Completely Randomized Design with CMC concentrations (6%, 9%, 12%, 15%, 18%). Data were analyzed using One-Way ANOVA. Panelists preferred sample 18% CMC color and texture over other samples throughout storage. Sample 15% CMC had the lowest weight loss. Moisture content increased with higher CMC concentrations. Sample 18% CMC retained vitamin C better than others. At the end of storage, the control had the highest microbial count (9.65×10^3 CFU/mL), while sample 6% CMC had the lowest (7.08×10^3 CFU/mL). The edible film's water uptake, solubility, and WVTR decreased as CMC concentration increased. Sample 18% CMC was identified as the best treatment with the highest productivity from day 0 to day 12. Thus, porang starch-based edible coatings containing CMC and ginger extract can effectively extend the shelf life of curly red chili providing a sustainable postharvest solution.

1 Introduction

Curly red chili (*Capsicum annuum* L.) is a widely used ingredient in Indonesian cuisine. Due to its plentiful supply, many local farmers tend to overlook the significance of proper postharvest handling. Farmers believe that the harvest of curly red chili will always sell out in the market with minimal waste. In practice, improper handling of chilies often results in significant waste at the market level, as many become unsellable due to premature spoilage or excessive drying. This not only leads to financial losses but also reduces the availability of fresh produce for consumers. The deterioration of chilies can be triggered by various factors, including microbiological contamination, chemical reactions, or physical and physiological damage during handling and storage. Proper postharvest treatment is therefore crucial to minimize waste and extend the shelf life of this valuable commodity [1]. In recent years, coating technology for fruits has proven both effective and relatively economical for enhancing the quality and shelf life of various commodities. Edible coatings, which are thin

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layers applied to the surface of food products, are made from natural, edible ingredients. These coatings protect the product from moisture, gases, and mechanical damage, helping preserve freshness and prolong shelf life. Additionally, they can be infused with natural additives, such as antioxidants or antimicrobials, to enhance the product's resistance to spoilage further and extend its usability.

Porang starch (*Amorphophallus muelleri*) is increasingly utilized in the development of edible coatings due to its ability to form transparent, oxygen-resistant films. One challenge in developing edible coatings is ensuring the resulting layer has good flexibility and durability. In this context, starch-based materials are often used for their natural, eco-friendly properties and safety for consumption. However, starch-based edible coatings are generally brittle and lack elasticity, requiring the addition of plasticizers to enhance flexibility and reduce brittleness [2]. Carboxymethyl cellulose (CMC) is a derivative of cellulose known for its ability to bind water and is commonly used to create smooth textures. Due to its gelling and thickening properties, CMC is widely utilized in various food and pharmaceutical applications [3]. In edible coatings, CMC serves as a hydrophilic colloid, stabilizer, binder, and texturizer, collectively enhancing the mechanical properties of the coating. Rather than acting as an emulsifier in a hydrocolloid emulsion system, CMC functions primarily as a stabilizer. It helps suspend particles within the system, ensuring they remain evenly distributed and do not settle under gravity, thereby maintaining the consistency and effectiveness of the coating. This ability to prevent separation is crucial in achieving a uniform and durable edible film. The addition of CMC improves the stability of starch-based edible coatings and enhances their elasticity, allowing the coating to better adhere to the surface and mold to the shape of the fruit, such as curly red chili. This results in a uniform, flexible layer that effectively protects the chili, helping to maintain its quality and extend shelf life [4].

Ginger is rich in bioactive compounds, including phenols, flavonoids, terpenoids, and essential oils, all of which contribute to its antimicrobial properties. These secondary metabolites in ginger are particularly effective in inhibiting the growth of various pathogens. One specific variety, *Zingiber officinale* var. Roscoe is especially recognized for its potent antimicrobial activity. Ginger extract has demonstrated antimicrobial activity against a broad spectrum of pathogenic microorganisms, including *Escherichia coli*, *Salmonella typhi*, *Bacillus subtilis*, and the yeast *Candida albicans* [5]. The antimicrobial activity of the edible film made from kimpul starch with ginger extract against *E. coli* and *S. aureus* increased with increasing ginger extract concentration. For both types of bacteria, increasing the concentration of ginger extract resulted in larger inhibition zones, with the 20% red ginger combination yielding the best results. These findings indicate that ginger extract, which contains bioactive compounds (phenols, flavonoids, terpenoids, and essential oils), is effective in inhibiting microbial growth and can be used to extend the shelf life of food products [5]. The study aimed to investigate the effect of varying concentrations of CMC in the application of edible coating made from porang starch with ginger extract on the chemical, physical, and microbiological quality of curly red chili during 12 days of storage at room temperature, as well as to determine the optimal concentration of CMC

2 Material And Methods

2.1 Materials

This study used porang starch (*Amorphophallus muelleri*) obtained from the Ikarie Organic SME, Bantul, Yogyakarta, Indonesia , curly red chili, and elephant ginger were bought at

Pasar Gede, Surakarta, Indonesia. Other supporting materials, including CMC, glycerol, 70% alcohol, and distilled water, were purchased from Merck (Germany).

2.2 Methods

2.2.1 Ginger extraction

The ginger extraction process was begins with peeling and washing the ginger, followed by slicing it into 0.2–0.3 cm-thick pieces to facilitate crushing with a chopper (Phillips, Netherlands). The ground ginger is then filtered and squeezed using a filter cloth.

2.2.2 Edible coating preparation

The procedure begins by mixing and homogenizing 5 grams of porang starch with 500 mL of distilled water using a hot plate stirrer (Heidolph, Germany), heating the solution to 60°C. Next, CMC, previously dissolved, is added at varying concentrations for each sample: 6%, 9%, 12%, 15%, and 18% (w/w) relative to the porang starch. Immediately thereafter, 2.5 mL of glycerol and 8% ginger extract (v/v) are added, based on the volume of distilled water. The final step involves stirring and heating the mixture on the hot plate stirrer (Heidolph, Germany) at 85°C and 1000 rpm for 30 min.

2.2.3 Application of edible coating on curly red chili

The application of an edible coating on curly red chili was began with washing the chili peppers, followed by brief draining. To prevent bacterial contamination, the peppers are then sprayed with 70% alcohol on their surface. Once dry, the peppers are dipped into the edible coating solution for 30 seconds, with the solution maintained at 40–60°C. The chili is held by the stem, ensuring the entire surface is coated while leaving the stem exposed. The coating is considered dry when the surface transitions from glossy to matte, after which the peppers are stored in BPA-free clear plastic containers at room temperature for 12 days. Physical and chemical characterization were conducted every 3 days, specifically on days 0, 3, 6, 9, and 12. Meanwhile, microbiological analysis was performed on day 0 and day 12.

2.2.4 Edible film preparation

The edible coating solution is poured into a 20×20 cm baking tray, using 150 mL per tray. After the edible film is cast, allowed to cool, and set, it is dried in an oven at 50°C for 10 h. The finished edible film derived from the edible coating solution applied to the curly red chili is then analyzed for its mechanical characteristics, including water uptake, solubility, and water vapor transmission rate (WVTR).

2.2.5 Characterization of sensory, physical, chemical, microbiological, and mechanical properties

The analysis of curly red chili quality based on the application effect of porang starch edible coating with the addition of CMC and ginger extract was conducted by several tests: sensory analysis using hedonic test for color and texture parameters, weight loss analysis via gravimetric method, moisture content using thermogravimetric method, vitamin C using iodometric titration, total plate count using the pour plate method, water uptake using swelling test, solubility via the gravimetric method, and water vapor transmission rate measurement using the gravimetric method. The preference scale used the following parameters: 1 = dislike very much; 2 = dislike; 3 = slightly dislike; 4 = neutral; 5 = slightly like; 6 = like; and 7 = like very much.

2.2.6 Statistical analysis

The experimental design of this study used a Completely Randomized Design (CRD) with a single factor, variation in CMC concentration levels (6%, 9%, 12%, 15%, and 18%). Each concentration is repeated 3 times and then analyzed using One-Way Analysis of Variance (ANOVA) to determine whether there are significant differences among the sample concentrations. The analysis is then followed by Duncan's Multiple Range Test (DMRT) at a significance level of α = 5% if differences are found in the treatments tested. Table 1 provides data the variation in CMC concentration in porang starch-based edible coating.

Table 1. Variation of CMC concentration in porang starch-based edible coating

Samples	**Porang starch (g)**	**CMC (%)**	**Ginger extract (%)**	**Glycerol (g)**	**Aquadest (g)**
Control	-	-	-	-	-
6% CMC	5	6	8	2.5	500
9% CMC	5	9	8	2.5	500
12% CMC	5	12	8	2.5	500
15% CMC	5	15	8	2.5	500
18% CMC	5	18	8	2.5	500

3 Results and discussion

3.1 Sensory characteristics

The sensory analysis results for curly red chili are presented in Table 2, highlighting the color and texture parameters. The research indicates a decline in the panelists' preference scores for the color of the curly red chili as storage time increased. Preference scores tended to iCMC concentrations in the edible coating. Samples 15% CMC and 18% were generally preferred by the panelists and showed significantly higher scores compared to the control sample (uncoated), which had lower scores across all storage times. This can be attributed to uncoated samples experiencing color degradation due to postharvest respiration, which diminishes fruit freshness and quality, resulting in a faded appearance. Damaged fruit cells release internal fluids that interact with oxygen, causing darkening [6]. The higher the CMC concentration, the more stable the coating adheres to the fruit, forming a thicker layer that slows respiration rate. Thus, since color properties in fresh fruit are critical for determining quality, which affects consumer preference and acceptance, using edible coatings made from polysaccharides and biopolymers, such as porang starch and CMC, is an effective solution to slow the deterioration of curly red chili and other fruits and vegetables during storage [7].

Table 2. Preference test score for color and texture parameter

Samples	Average preference test score for color parameter				
	Day-0	Day-3	Day-6	Day-9	Day-12
Control	5.96 ± 1.02^{a}	5.12 ± 1.01^{a}	3.40 ± 1.38^{a}	2.64 ± 1.29^{a}	1.80 ± 1.15^{a}
6% CMC	6.04 ± 0.79^{a}	5.16 ± 1.37^{ab}	3.80 ± 1.44^{ab}	3.00 ± 1.61^{abc}	2.20 ± 1.47^{a}
9% CMC	6.36 ± 0.76^{ab}	5.56 ± 1.16^{abc}	4.36 ± 1.35^{bc}	2.88 ± 1.62^{ab}	2.20 ± 1.50^{a}
12% CMC	6.44 ± 0.65^{ab}	5.88 ± 0.93^{bc}	4.36 ± 1.29^{bc}	3.40 ± 1.29^{bc}	2.32 ± 1.18^{a}
15% CMC	6.08 ± 0.76^{a}	6.04 ± 0.93^{c}	4.84 ± 1.11^{cd}	3.64 ± 1.11^{c}	2.28 ± 1.21^{ab}

Samples	Average preference test score for texture parameter				
18% CMC	6.72 ± 0.54^{bc}	6.00 ± 0.82^{c}	5.20 ± 0.91^{d}	3.76 ± 1.30^{c}	3.00 ± 1.47^{b}
	Day-0	Day-3	Day-6	Day-9	Day-12
Control	5.92 ± 0.10^{a}	3.76 ± 1.39^{a}	2.36 ± 1.19^{a}	1.60 ± 0.87^{a}	1.32 ± 0.63^{a}
6% CMC	5.44 ± 1.36^{a}	3.88 ± 1.54^{ab}	2.68 ± 1.41^{a}	1.68 ± 0.75^{a}	1.40 ± 0.71^{a}
9% CMC	5.72 ± 1.02^{a}	4.20 ± 1.22^{b}	3.08 ± 1.41^{ab}	1.84 ± 1.03^{a}	1.36 ± 0.76^{a}
12% CMC	5.72 ± 1.14^{a}	4.64 ± 1.41^{bc}	3.00 ± 1.22^{ab}	2.36 ± 0.99^{b}	1.44 ± 0.77^{a}
15% CMC	5.80 ± 1.00^{a}	4.76 ± 1.01^{bc}	3.48 ± 1.05^{b}	2.72 ± 1.06^{b}	1.76 ± 1.01^{ab}
18% CMC	6.48 ± 0.77^{b}	5.00 ± 1.12^{d}	3.80 ± 1.32^{c}	2.80 ± 0.91^{b}	2.00 ± 1.26^{b}

Note: Values with the same superscripts are not significantly different (p>0.05).

Based on Table 2, the panelists' preference scores for the texture of curly red chili decreased across all samples as storage time increased. The scores tended to improve with higher CMC concentrations, with sample 18% CMC showing a significantly higher average across all storage times than the control sample (uncoated), which had lower scores. In this study, texture changes on the surface of curly red chili are closely linked to transpiration and respiration, consistent with previous color attributes. Higher CMC concentrations lead to a thicker coating, reducing water loss and minimizing wrinkling, hollowness, and softness. Increasing CMC concentration enhances coating adhesion, resulting in a thicker layer. The higher the CMC concentration, the greater the water retention, promoting molecular swelling during gel formation, resulting in a compact, strong, and stable coating. Texture changes are also closely tied to fruit quality because they reflect freshness and firmness, which are key indicators of quality. Loss of moisture and cell integrity during storage leads to undesirable texture changes, reducing the fruit's overall appeal [6] [8]

3.2 Physical characteristics

The data in Table 3 showed that curly red chili experienced increased weight loss as storage days progressed. However, the application of porang starch edible coating combined with CMC and ginger extract effectively reduced weight loss during the 12-day storage period at room temperature compared to the control (uncoated) samples. The study data indicate that Sample 15% CMC had the lowest weight loss among all samples. Sample using 15% CMC, was the most effective at minimizing weight loss during 12 days of room-temperature storage, followed by the sample treated with 18% CMC.

Table 3. Weight loss value of curly red chili

Samples	Weight loss (%)				
	Day-0	Day-3	Day-6	Day-9	Day-12
Control	0.00 ± 0.00^{a}	13.36 ± 1.05^{c}	29.35 ± 1.31^{d}	49.38 ± 0.96^{e}	74.87 ± 2.78^{e}
6% CMC	0.00 ± 0.00^{a}	11.73 ± 0.55^{b}	27.14 ± 2.31^{c}	45.84 ± 1.46^{d}	67.61 ± 3.42^{d}
9% CMC	0.00 ± 0.00^{a}	11.73 ± 1.20^{b}	26.86 ± 2.03^{bc}	42.33 ± 1.96^{c}	62.93 ± 2.24^{c}
12% CMC	0.00 ± 0.00^{a}	11.36 ± 0.88^{b}	24.77 ± 2.09^{ab}	40.96 ± 1.58^{b}	59.25 ± 1.31^{b}
15% CMC	0.00 ± 0.00^{a}	9.48 ± 0.51^{a}	23.21 ± 2.35^{a}	38.09 ± 2.04^{a}	53.01 ± 1.67^{ab}
18% CMC	0.00 ± 0.00^{a}	11.11 ± 1.10^{b}	25.53 ± 1.13^{b}	39.62 ± 1.17^{ab}	52.61 ± 2.33^{a}

Note: Values with the same superscripts are not significantly different (p>0.05).

Based on Table 3 data, the addition of CMC stabilized the edible coating solution, effectively preventing sedimentation under gravity. Consequently, the coating layer adhered more consistently and securely to the surface of the curly red chili, creating a thicker protective barrier that significantly reduced respiration and transpiration rates in the fruit. Weight loss in curly red chilies indicates a decline in quality due to water loss and the loss of vital nutrients. After harvest, ongoing respiration and transpiration cause moisture loss, reducing the fruit's weight. These processes dry out the fruit's tissues, leading to a loss of freshness and accelerating spoilage [8]. In this study, the use of an edible coating on curly red chili effectively reduced weight loss. This result supports previous research suggesting that postharvest treatments with edible coatings made from polysaccharide starch and biopolymers help maintain the quality of curly red chili, particularly by reducing weight loss. The coating works by creating a selective barrier that limits the movement of gases, water vapor, and soluble materials, thus preventing moisture loss [9].

3.3 Chemical characteristics

The chemical characteristics of curly red chili are presented in Table 4. The data show that the moisture content of curly red chili decreased continuously with increasing storage time across all samples. On the 3rd, 6th, 9th, and 12th test days, the moisture content of curly red chili increased with higher CMC concentrations. The highest values on these test days were observed in sample 18% CMC: 74.98%, 69.65%, 63.43%, and 57.89%, respectively. These values were significantly different from the control sample, which had the lowest values at 71.06%, 57.26%, 41.80%, and 29.94%, respectively. The study concluded that higher CMC concentrations result in a thicker edible coating layer, leading to higher viscosity. This, in turn, hinders the transfer of water vapor from the cells during storage, thereby retaining moisture content. The thicker coating acts as a barrier, slowing water evaporation and helping maintain moisture levels. The increased viscosity and thickness provided by the CMC also help protect the agricultural product from oxidative damage, which is crucial for preserving its bioactive content [10].

Table 4. Moisture and vitamin C contents of curly red chili

Samples	Average moisture content of curly red chili (%)				
	Day-0	Day-3	Day-6	Day-9	Day-12
Control	83.07 ± 0.70^{c}	71.06 ± 0.51^{a}	57.26 ± 0.32^{a}	41.80 ± 0.04^{a}	29.94 ± 1.18^{a}
6% CMC	82.04 ± 0.09^{b}	72.45 ± 0.23^{b}	60.32 ± 0.33^{b}	47.09 ± 1.12^{b}	37.30 ± 1.28^{b}
9% CMC	81.57 ± 0.85^{a}	71.99 ± 0.85^{ab}	62.17 ± 0.29^{c}	50.43 ± 0.18^{c}	41.38 ± 0.74^{c}
12% CMC	82.36 ± 2.05^{b}	73.62 ± 2.19^{c}	64.29 ± 0.23^{d}	54.52 ± 2.43^{d}	46.90 ± 2.37^{d}
15% CMC	81.34 ± 1.23^{a}	73.52 ± 1.28^{c}	66.96 ± 0.78^{e}	58.99 ± 0.92^{e}	52.65 ± 0.48^{e}
18% CMC	82.29 ± 2.34^{b}	74.98 ± 1.74^{d}	69.65 ± 0.42^{f}	63.43 ± 1.79^{f}	57.89 ± 1.39^{f}
Samples	Average vitamin C content of curly red chili (%)				
	Day-0	Day-3	Day-6	Day-9	Day-12
Control	25.38 ± 0.58^{c}	20.69 ± 0.76^{ab}	15.37 ± 1.50^{a}	13.37 ± 1.86^{a}	10.80 ± 1.86^{a}
6% CMC	23.55 ± 3.59^{b}	19.95 ± 2.04^{a}	16.51 ± 0.36^{b}	15.14 ± 0.36^{b}	13.69 ± 0.36^{b}
9% CMC	23.74 ± 2.52^{bc}	20.84 ± 0.60^{ab}	18.11 ± 1.71^{c}	16.90 ± 1.41^{c}	15.65 ± 1.41^{c}
12% CMC	23.31 ± 1.96^{b}	21.43 ± 1.46^{b}	19.24 ± 1.41^{d}	17.60 ± 1.41^{d}	17.13 ± 1.41^{d}
15% CMC	21.86 ± 1.53^{a}	21.75 ± 0.53^{b}	19.55 ± 1.12^{d}	18.07 ± 1.23^{e}	17.79 ± 1.23^{d}
18% CMC	24.17 ± 2.45^{c}	23.00 ± 0.40^{c}	20.77 ± 2.42^{e}	19.12 ± 2.35^{f}	19.01 ± 2.35^{e}

Note: Values with the same superscripts are not significantly different ($p>0.05$).

The findings in Table 4 reveal that the vitamin C content in curly red chili decreases with prolonged storage time but improves with increased CMC concentration in the edible coating. However, vitamin C levels across all treatments remained lower than those in the control sample on day 0 (fresh condition). Sample 18% CMC exhibited significantly better retention of vitamin C than other samples (6, 9, and 12) % CMC across all storage days, with the smallest reductions recorded at 24.17%, 23.00%, 20.77%, 19.12%, and 19.01%, respectively. The sample with the highest decrease in vitamin C content was the control sample. This significant reduction occurred across all storage days, highlighting the impact of not using an edible coating for protection.

Higher concentrations of CMC in the edible coating effectively slow oxygen diffusion into chili tissues, thereby reducing oxidation processes that lead to vitamin C degradation. In contrast, the control sample, lacking any protective coating, allows unrestricted oxygen diffusion, accelerating the degradation of vitamin C. This difference underscores the protective role of CMC coatings in preserving vitamin content by limiting oxidative damage during storage. Edible coatings on food products can extend shelf life and maintain quality by delaying oxidation and respiration processes [10] [11].

3.4 Microbiological characteristics

The microbiological analysis of curly red chili using the Total Plate Count method, as shown in Table 5, revealed that on day 0, all samples (including the control) had microbial counts below 250 colonies. By the end of the storage period, the control sample (uncoated) exhibited the highest microbial count at 9.65×10^3 CFU/mL, while the lowest count was observed in Sample 6% CMC at 7.08×10^3 CFU/mL, with a total microbial growth of 6.96×10^3 CFU/mL. The data indicate that while microbial counts generally increased with higher CMC concentrations (from Samples 6% -18% CMC), they remained below those of the control, except for Samples 15 and 18 % CMC which had the highest CMC concentrations.

Table 5. Total plate count value of curly red chili

Samples	Average frequency of total microbial count (CFU/mL)		Microbial growth (CFU/mL)
	Day-0	Day-12	
Control	<100	9.65×10^3	9.65×10^3
6% CMC	1.17×10^2	7.08×10^3	6.96×10^3
9% CMC	1.61×10^2	7.45×10^3	7.29×10^3
12% CMC	<100	8.20×10^3	8.20×10^3
15% CMC	1.95×10^2	1.32×10^4	1.30×10^4
18% CMC	2.12×10^2	1.37×10^4	1.35×10^4

This study suggests that lower concentrations of CMC (around 6%) are more effective in controlling microbial growth. Higher concentrations of CMC create thicker barriers that reduce oxygen diffusion, but they might also trap moisture, providing a more favorable environment for microbial growth. Conversely, thinner coatings (as in Sample 6% CMC) may strike a balance between reducing oxygen exposure and preventing excessive moisture retention, thereby limiting microbial proliferation during storage. It is important to note that CMC itself is known to lack strong antibacterial properties and is less sensitive to microbial contamination. Therefore, the inclusion of ginger extract in this study aimed to enhance the antimicrobial activity of the edible coating. However, as suspected, the concentration of ginger extract used was likely too low to overcome the lack of antimicrobial properties of CMC, allowing other materials with more dominant properties to have a greater effect [12] [13].

If the ginger extract concentration had been optimized, the combination of its antimicrobial bioactive compounds (alkaloids, saponins, flavonoids, and terpenoids) with CMC's oxygen-reducing properties would likely have led to a greater reduction in microbial growth. This synergy would limit the exposure of curly red chili to external contaminants, reducing microbial proliferation during storage. Properly balanced concentrations of both CMC and ginger extract would enhance the antimicrobial effectiveness of the edible coating [9].

3.5 Mechanical characteristics

The physical tests for the edible film include solubility, water uptake, and water vapor transmission rate (WVTR). The research results for these tests are shown in Table 6. Based on the study data, the concentration of CMC in all samples significantly affected the water uptake, solubility, and water vapor transmission rate (WVTR) of the edible film used for coating the curly red chili. The values for all analyses decreased as the CMC concentration increased. The highest values for water uptake, solubility, and WVTR were observed in Sample 6% CMC, with values of 25.56%, 29.84%, and 46.12 g/m²/hr, respectively. In contrast, Sample 18% CMC exhibited the lowest values, with water uptake, solubility, and WVTR at 16.20%, 16.03%, and 20.25 g/m²/hour, respectively. These results indicate that CMC concentration plays a key role in controlling the film's moisture-related properties and barrier performance, both critical for food preservation.

Table 6. Mechanical characteristics of edible film through water uptake, solubility, and WVTR value

Samples	Water uptake (%)	Solubility (%)	Water vapor transmission rate (WVTR) (g/m²/hr)
6% CMC	25.56 ± 2.80^{e}	29.84 ± 2.00^{e}	46.12 ± 2.12^{e}
9% CMC	22.33 ± 1.41^{d}	26.57 ± 1.23^{d}	23.93 ± 2.78^{c}
12% CMC	19.57 ± 5.06^{c}	21.68 ± 2.31^{c}	25.26 ± 2.62^{d}
15% CMC	18.95 ± 1.28^{b}	20.62 ± 1.55^{b}	21.76 ± 1.05^{b}
18% CMC	16.20 ± 4.99^{a}	16.03 ± 1.40^{a}	20.25 ± 4.51^{a}

Note: Values with the same superscripts are not significantly different (p>0.05).

The study's results are consistent with the theory [14] that CMC, with its polymer-like structure and relatively high molecular weight, becomes increasingly water-resistant as its concentration increases. This is because a greater amount of water is required to dissolve CMC. Additionally, the starch molecules form hydrogen bonds with the hydroxyl and carboxyl groups of CMC's macromolecules, which helps to slow down water diffusion within the material. These properties enhance the film's barrier performance, reducing moisture transfer and improving its effectiveness in food preservation.

The characteristics, strength, and interactions between the solute and the solvent influence the solubility of a substance in a specific solvent. The results show that as the CMC concentration increases, the film's solubility decreases.

One factor that affects the water vapor transmission rate is the thickness of the edible film. The increase in edible film thickness is due to higher CMC concentrations. The thicker film, resulting from higher CMC concentrations, reduces the rate of water vapor diffusion into the film, thereby lowering the WVTR value [15].

3.6 The determination of the best treatment

In this study, the best treatment was determined using method based on the effectiveness index. The best treatment was selected by comparing each treatment's results using the effectiveness index and weighted test parameters. The sample with the highest Productivity Value (NP) or Effectiveness Value (NE) was considered the best treatment, as it reflects the combined consideration of all variables and parameters that contribute to the quality of the curly red chili product.

The calculation identified the edible coating containing 18% CMC as the optimal treatment, with the highest NP value from day 0 to day 12. This suggests that the chili coating with 18% CMC is the most effective formulation for maintaining the quality of curly red chili, especially when compared to the control sample. Based on the overall results of the chili quality tests (both coating and edible film), the 18% CMC treatment was the best, achieving the highest Productivity Value across all tests. In other words, adding 18% CMC to the edible coating effectively preserved the quality of the curly red chili, supported by the mechanical characteristics of the 18% CMC edible film compared to other treatments.

4 Conclusion

In conclusion, the study demonstrates that porang starch-based edible coatings with higher CMC concentrations, particularly 18%, effectively preserve the quality of curly red chili across several characteristics. The study indicates that, as storage time increased, panelists' preference scores for the color and texture of the curly red chili declined, but preference scores still tended to increase with higher concentrations of CMC in the edible coating. Specifically, sample with 18% CMC was preferred over the control sample, which experienced significant degradation in color and texture due to respiration and water loss. The weight loss of the chili samples increased over time. However, the application of edible coatings, especially sample with 15% CMC concentration, was effective in reducing weight loss compared to the uncoated control. The thicker coating layer created by higher CMC concentrations helps minimize water loss by acting as a barrier, slowing down respiration and transpiration. There was a decline in the chili's moisture content as storage days increased, but higher CMC concentrations, especially at 18% CMC, helped retain more moisture. The CMC coating acts as a barrier to water vapor, preventing excessive dehydration. Sample 18% CMC coating maintained higher vitamin C levels across all storage days, while the control sample experienced a significant decrease. The edible coating helps slow the oxidative degradation of vitamin C by limiting oxygen exposure, demonstrating CMC's protective role in preserving the chili's nutritional content. Microbial growth in the chili samples increased with storage time. The control sample showed the highest microbial count, while samples coated with CMC (especially at lower concentrations, such as 6%) exhibited lower counts. However, higher concentrations of CMC (15% and 18%) created thicker layers that might have trapped moisture, potentially fostering a more favorable environment for microbial growth. The increased CMC concentration reduced the solubility, water uptake, and WVTR of the edible film. Thus, CMC concentration plays a key role in enhancing the film's barrier properties, which are crucial for preserving food. Based on the effectiveness index, sample with an 18% CMC concentration was selected as the optimal treatment, with the highest productivity value. This result highlights the importance of optimizing CMC concentration to achieve optimal preservation. These findings suggest that porang starch-based edible coatings with CMC and ginger extract can serve as an effective solution for extending the shelf life of fruits and vegetables (specifically curly red chili), offering a sustainable approach to postharvest preservation. Future studies should optimize ginger extract concentrations to enhance antimicrobial properties and investigate alternative biopolymers or polysaccharides to improve coating efficacy further.

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