

Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Physicochemical and Sensory Characteristics of Chili Sauce

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Abstract: Oil palm fronds are abundant agricultural biomass with high cellulose content that can be converted into carboxymethyl cellulose (CMC) as a natural food thickener. This study aimed to evaluate the effect of oil palm frond-derived CMC on the physicochemical and sensory characteristics of chili sauce and to determine the optimum CMC concentration. A completely randomized design was applied using four CMC concentrations (0, 0.5, 1.0, and 1.5%) with three replications for each treatment. The evaluated parameters included moisture content, pH, crude fiber, texture, vitamin C, viscosity, aroma, and taste. Data were analyzed using one-way analysis of variance followed by Duncan's multiple range test at a 5% significance level. The results showed that increasing CMC concentration significantly reduced moisture content from 84.55% to 83.30% while increasing pH from 3.97 to 4.15, crude fiber from 1.24% to 1.72%, texture from 1.33 to 2.14 N, vitamin C from 22.81 to 24.44 mg/100 g, and viscosity from 2,334.33 to 4,275.00 cP ($p < 0.05$). Sensory evaluation also showed significant differences, with the 1.0% CMC treatment receiving the highest aroma (4.80) and taste (4.90) scores. These findings indicate that oil palm frond-derived CMC can serve as an effective natural thickening agent for chili sauce, with a concentration of 1.0% providing the best balance between physicochemical quality and consumer acceptance.

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INTRODUCTION

Indonesia is the world's largest producer of oil palm (*Elaeis guineensis*), making the commodity a strategic contributor to the national economy. According to the Indonesian Ministry of Agriculture, the country's oil palm plantation area reached approximately 16.83 million hectares in 2023. The implementation of Presidential Instruction No. 8 of 2018 concerning the Moratorium and Evaluation of Oil Palm Plantation Licensing, which was extended until 2023, has resulted in relatively stable plantation expansion. Consequently, increasing productivity and maximizing the utilization of oil palm biomass have become important priorities for supporting the sustainability of the palm oil industry (BPDP, 2024).

One of the most abundant by-products generated from oil palm cultivation is the oil palm frond. Large quantities of fronds are produced during routine pruning and replanting activities, yet most of this biomass remains underutilized. Oil palm fronds contain a high proportion of cellulose, making them a promising renewable raw material for producing cellulose derivatives with higher economic value. The physical characteristics of the fronds, including moisture content, density, and specific gravity,

significantly influence cellulose quality and should therefore be considered during further processing (Wulandari & Erwinsyah, 2020).

Carboxymethyl cellulose (CMC) is one of the most important water-soluble cellulose derivatives. Owing to its excellent viscosity, rheological properties, mechanical strength, and tunable hydrophilicity, CMC has been extensively applied in various industries, including food, pharmaceutical, textile, paper, cosmetic, and biomedical industries. In food systems, CMC functions as a thickener, stabilizer, emulsifier, adhesive stabilizer, and moisture binder, contributing to improved texture, stability, and overall product quality (Rahman et al., 2021). Although commercial carboxymethyl cellulose (CMC) is traditionally produced from wood-based cellulose, recent studies have demonstrated that various lignocellulosic agricultural residues can serve as alternative cellulose sources for CMC production. Agricultural biomass offers abundant renewable raw materials for producing CMC with desirable physicochemical and rheological properties suitable for food and other industrial applications (Rahman et al., 2021). Likewise, Lestari et al., (2020). demonstrated that CMC synthesized from agricultural biomass possesses physicochemical properties approaching industrial quality standards, making it a promising environmentally friendly alternative for food applications.

In the food industry, CMC is extensively utilized as a hydrocolloid to improve viscosity, enhance texture, stabilize emulsions, reduce phase separation, and extend product shelf life. Its ability to maintain product consistency makes CMC one of the most important functional ingredients in processed foods. Ahmed et al., (2018) reported that CMC significantly improves texture and storage stability in various liquid and semi-solid food products by strengthening the internal gel network and maintaining product homogeneity.

Chili sauce is one of the most popular condiment products consumed in Indonesia and has become an essential component of daily meals. Besides providing a distinctive spicy flavor, high-quality chili sauce should exhibit appropriate viscosity, homogeneous texture, stable emulsion, and resistance to phase separation during storage. Therefore, the incorporation of suitable thickening agents is essential to maintain product quality. (Aisyi et al., (2019) stated that hydrocolloids play an important role in improving the physical stability, texture, and overall consumer acceptance of chili sauce products.

Despite the widespread use of commercial CMC in the food industry, studies investigating CMC derived from oil palm fronds as a natural thickening agent for chili sauce remain limited. Most food manufacturers still rely on imported or commercially produced CMC, whereas locally sourced CMC from oil palm biomass has considerable potential to reduce production costs, increase the economic value of agricultural waste, and support sustainable resource utilization. The conversion of oil palm fronds into food-grade CMC also represents an innovative approach to promoting circular economy principles within the palm oil industry.

Although numerous studies have reported the utilization of commercial Carboxymethyl Cellulose (CMC) as a thickening and stabilizing agent in food products, limited attention has been given to the development of CMC derived from oil palm fronds as an alternative food-grade hydrocolloid. Previous studies have primarily focused on the extraction and physicochemical characterization of CMC from agricultural biomass, while only a few have evaluated its functional performance in complex food systems such as chili sauce. Moreover, comprehensive investigations simultaneously assessing physicochemical quality attributes, including moisture content, pH, crude fiber, vitamin C, texture,

viscosity, and sensory acceptance, remain scarce. Consequently, the practical feasibility of utilizing oil palm frond-derived CMC in processed food products has not been fully established.

The novelty of this study lies in the application of food-grade Carboxymethyl Cellulose synthesized from oil palm fronds as a natural thickening agent for chili sauce. Unlike previous studies that mainly evaluated the production or physicochemical characteristics of CMC itself, this research comprehensively investigates its influence on the physicochemical and sensory quality of chili sauce using different CMC concentrations. Furthermore, this study demonstrates the potential of converting underutilized oil palm biomass into a value-added food ingredient, thereby supporting sustainable biomass utilization and circular economy practices within the palm oil industry.

Therefore, this study aimed to evaluate the effects of different concentrations of oil palm frond-derived Carboxymethyl Cellulose (CMC) on the physicochemical and sensory characteristics of chili sauce. The study also sought to determine the optimum CMC concentration capable of improving product quality while promoting the utilization of oil palm biomass as a sustainable and value-added food ingredient. The findings are expected to provide scientific evidence supporting the development of environmentally friendly hydrocolloids for food applications and to expand the utilization of oil palm biomass in the food industry.

RESEARCH METHOD

The experiment was carried out at the Laboratory of Plantation Product Processing Technology, Institut Teknologi Sawit Indonesia (ITSI), Deli Serdang, North Sumatra, Indonesia, during the period of April–May 2026. An experimental research design was applied to investigate the influence of Carboxymethyl Cellulose (CMC) derived from oil palm fronds on the physicochemical properties and sensory quality of chili sauce.

A Completely Randomized Design (CRD) with a single factor was applied, consisting of four concentrations of oil palm frond-derived CMC, namely 0% (control), 0.5%, 1.0%, and 1.5%. Each treatment was performed in triplicate, resulting in a total of twelve experimental units. The independent variable was the concentration of CMC, while the dependent variables included moisture content, vitamin C content, pH, crude fiber content, texture, viscosity, aroma, and taste of the chili sauce.

The materials used in this study included Carboxymethyl Cellulose extracted from oil palm fronds, bird's eye chili (*Capsicum frutescens*), curly chili (*Capsicum annum*), tomatoes, garlic, shallots, refined salt, granulated sugar, and vegetable oil. The equipment consisted of a blender, digital balance, knife, gas stove, frying pan, stirring spoon, thermometer, pH meter, viscometer, TA-XT Plus Texture Analyzer (Stable Micro Systems, UK), and standard laboratory glassware.

Carboxymethyl Cellulose (CMC) was synthesized from oil palm fronds through cellulose isolation followed by alkalization and carboxymethylation. Fresh oil palm fronds were washed, cut into small pieces, oven-dried, and ground into powder. The powdered material underwent delignification to remove lignin and hemicellulose, yielding purified cellulose. The cellulose was then treated with sodium hydroxide (NaOH) to produce alkali cellulose, followed by reaction with sodium monochloroacetate under controlled temperature to introduce carboxymethyl groups into the cellulose backbone. The resulting CMC was repeatedly washed with ethanol and distilled water until

neutral pH was achieved, oven-dried, milled into fine powder, and stored in airtight containers until further use as a thickening agent in chili sauce formulation.

The synthesized CMC was visually evaluated to ensure uniform color and powder consistency before being incorporated into the chili sauce formulation. The produced CMC was subsequently applied as a thickening agent at concentrations of 0, 0.5, 1.0, and 1.5% (w/w) according to the experimental design.

Fresh bird's eye chili, curly chili, tomatoes, garlic, and shallots were washed thoroughly before being blended into a homogeneous paste. The paste was cooked together with vegetable oil, granulated sugar, and refined salt under continuous stirring. Oil palm frond-derived CMC was gradually added according to each treatment concentration while stirring continuously to ensure complete hydration and homogeneous dispersion. Heating was continued until the desired consistency was achieved, after which the chili sauce was cooled to room temperature and transferred into sterile containers prior to physicochemical and sensory analyses.

The physicochemical properties of the chili sauce were evaluated by determining moisture content, vitamin C, pH, crude fiber, viscosity, and texture. The moisture content of the samples was determined by the oven-drying method following the Indonesian National Standard (SNI). Sample pH was measured using a calibrated digital pH meter, whereas viscosity was evaluated with a rotational viscometer under ambient temperature conditions. Texture analysis was conducted using a TA.XT Plus Texture Analyzer according to the protocol described by Lis et al. (2021). Crude fiber was determined using the gravimetric method, while vitamin C content was analyzed in accordance with the official methods of the Association of Official Analytical Chemists (AOAC).

Moisture content was determined using the oven-drying method following the Indonesian National Standard (SNI). The pH value was measured using a calibrated digital pH meter. Crude fiber content was determined by the gravimetric method, while vitamin C content was analyzed using the AOAC standard method. Texture was evaluated using a TA.XT Plus Texture Analyzer, and viscosity was measured using a rotational viscometer under ambient temperature conditions. Sensory evaluation involving 30 untrained panelists was conducted using a five-point hedonic scale to assess aroma and taste.

Sensory evaluation was conducted by thirty untrained panelists to assess the aroma and taste of the chili sauce samples. Each sample was assigned a random three-digit code and presented in a randomized order. The panelists evaluated the samples using a five-point hedonic scale, where a score of 1 indicated "dislike very much" and a score of 5 indicated "like very much." Drinking water was provided to cleanse the palate between sample evaluations to minimize carry-over effects.

All experimental data were statistically analyzed using one-way Analysis of Variance (ANOVA) to determine the effect of CMC concentration on the physicochemical and sensory characteristics of chili sauce. When significant differences were detected ($p < 0.05$), Duncan's Multiple Range Test (DMRT) was performed to compare treatment means. In addition, simple linear regression analysis was employed to evaluate the relationship between CMC concentration and the measured quality parameters. Statistical analyses were performed using IBM SPSS Statistics software with a significance level of 95%.

RESULTS AND DISCUSSION

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Moisture Content of Chili Sauce

Table 1. Effect of Oil Palm Frond-Derived CMC Concentration on the Moisture Content of Chili Sauce

CMC Concentration (%)	Moisture Content (%) (Mean $\pm$ SD)
0.0	84.55 $\pm$ 0.07 ^a
0.5	84.15 $\pm$ 0.06 ^b
1.0	83.73 $\pm$ 0.05 ^c
1.5	83.30 $\pm$ 0.05 ^d
ANOVA (F-value)	276.547
Significance (p-value)	<0.001

Note: Data are expressed as mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Table 1 shows that increasing the concentration of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds significantly reduced the moisture content of chili sauce. The control treatment (0% CMC) exhibited the highest moisture content (84.55 $\pm$ 0.07%), whereas the addition of 1.5% CMC produced the lowest moisture content (83.30 $\pm$ 0.05%). Overall, the moisture content decreased by approximately 1.25% as the CMC concentration increased from 0% to 1.5%. The one-way Analysis of Variance (ANOVA) indicated that CMC concentration had a highly significant effect on moisture content ($F = 276.547$; $p < 0.001$). Duncan's Multiple Range Test further demonstrated that each treatment belonged to a different homogeneous subset, indicating that all treatment means differed significantly ($p < 0.05$). These findings suggest that even relatively small increases in CMC concentration substantially influenced the moisture characteristics of the chili sauce.

The decrease in moisture content can be explained by the hydrocolloid characteristics of CMC. Carboxymethyl Cellulose contains numerous hydroxyl (-OH) and carboxymethyl (-CH₂COO⁻) functional groups that possess strong hydrophilic properties. These functional groups readily interact with water molecules through hydrogen bonding, promoting the formation of a three-dimensional polymer network capable of entrapping water within the gel matrix. As the concentration of CMC increased, a greater proportion of water became immobilized within the polymer structure, thereby reducing the amount of free water available for evaporation during oven drying. Consequently, the measured moisture content gradually decreased with increasing CMC concentration. Besides lowering the amount of free water, this mechanism also contributed to improving the physical stability of chili sauce by minimizing water mobility, reducing phase separation, and maintaining product consistency during storage.

The present findings are consistent with previous studies demonstrating that CMC functions as an effective hydrocolloid capable of regulating water distribution in food systems. Li et al. (2022) reported that increasing CMC concentration significantly enhanced water-binding capacity and reduced free water mobility, resulting in improved gel stability and lower measurable moisture content in hydrocolloid-based foods. Similarly, Ahmed et al. (2018) observed that CMC strengthened the internal gel network of semi-solid food products, thereby improving moisture retention and reducing syneresis during storage. Rahman et al. (2021) also explained that cellulose-derived hydrocolloids

improve the stability of food matrices by immobilizing water molecules within polymer chains, leading to enhanced physicochemical stability without adversely affecting product quality. The agreement between the present study and previous reports confirms that CMC synthesized from oil palm fronds exhibits functional properties comparable to those of commercially available CMC, particularly in its ability to regulate water distribution in food products.

From a technological perspective, the reduction in moisture content observed after CMC addition is advantageous for chili sauce manufacture. Lower free water availability may contribute to improved microbial stability, reduced water activity, and better resistance to physical deterioration such as serum separation during storage. Although water activity was not measured in the present study, the observed reduction in moisture content, together with the increase in viscosity and texture, indicates that oil palm frond-derived CMC effectively enhanced the structural integrity of chili sauce. Therefore, utilizing CMC produced from oil palm fronds not only improves product quality but also represents a sustainable strategy for converting abundant oil palm biomass into a value-added food ingredient, thereby supporting the development of environmentally friendly hydrocolloid applications in the food industry.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the pH of Chili Sauce

Table 2. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the pH of Chili Sauce

CMC Concentration (%)	pH (Mean $\pm$ SD)
0.0	3.97 $\pm$ 0.01 ^a
0.5	4.02 $\pm$ 0.01 ^b
1.0	4.09 $\pm$ 0.01 ^c
1.5	4.15 $\pm$ 0.01 ^d
ANOVA (F-value)	186.750
Significance (p-value)	< 0.001

Note: Data are expressed as mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

The pH value is an important quality parameter in chili sauce because it influences product stability, microbial safety, shelf life, and sensory characteristics. As shown in Table 2, increasing the concentration of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds resulted in a gradual increase in the pH of chili sauce. The control treatment (0% CMC) exhibited the lowest pH value (3.97 $\pm$ 0.01), while the highest pH (4.15 $\pm$ 0.01) was obtained in the treatment containing 1.5% CMC. The overall mean pH of all treatments was 4.06 $\pm$ 0.07. One-way Analysis of Variance (ANOVA) indicated that CMC concentration had a highly significant effect on the pH of chili sauce ($F = 186.750$; $p < 0.001$). Furthermore, Duncan's Multiple Range Test (DMRT) showed that each treatment belonged to a different homogeneous subset, indicating that all treatment means differed significantly ($p < 0.05$). These findings demonstrate that increasing the concentration of oil palm frond-derived CMC consistently increased the pH value of the chili sauce.

The increase in crude fiber content is primarily associated with the chemical composition of Carboxymethyl Cellulose. CMC is a chemically modified cellulose polymer derived from lignocellulosic

biomass, in which the cellulose backbone remains largely intact after the carboxymethylation process. Since cellulose is classified as an insoluble dietary fiber, increasing the amount of CMC incorporated into the chili sauce proportionally increased the crude fiber fraction of the product. Furthermore, the cellulose polymer exhibits high thermal stability during cooking, allowing its structural integrity to be maintained throughout the processing stage. Consequently, the additional cellulose introduced through CMC was quantified as an increase in crude fiber content in the final product.

Besides improving the nutritional composition, the presence of CMC also contributes to the formation of a more stable food matrix. The long polymer chains of CMC interact with water molecules and dispersed food particles to form a cohesive three-dimensional hydrocolloid network. This network enhances the retention of structural polysaccharides within the sauce, improves emulsion stability, and minimizes the loss of insoluble components during processing. As a result, increasing CMC concentration simultaneously enhanced both the technological functionality and the nutritional quality of the chili sauce.

The findings of the present study are consistent with previous reports on the application of cellulose-derived hydrocolloids in food products. Rahman et al. (2021) explained that CMC derived from lignocellulosic biomass possesses excellent water-binding capacity while contributing to the dietary fiber content of processed foods. Similarly, Handoyo and Suseno (2021) reported that CMC supplementation significantly increased crude fiber content and improved the structural stability of sauce products without negatively affecting their physicochemical quality. Lestari et al. (2020) also demonstrated that agricultural biomass-derived CMC exhibits physicochemical characteristics comparable to commercial CMC, making it a promising sustainable ingredient for food applications. The consistency between the present findings and previous studies confirms that oil palm frond-derived CMC has considerable potential as a renewable source of functional dietary fiber.

From a nutritional perspective, the increase in crude fiber content represents an important added value for chili sauce. Dietary fiber is widely recognized for its beneficial physiological effects, including improving gastrointestinal function, promoting satiety, regulating postprandial glucose absorption, and supporting overall digestive health. Therefore, the utilization of CMC synthesized from oil palm fronds not only improves the technological properties of chili sauce but also enhances its nutritional profile. This dual functionality highlights the potential of converting underutilized oil palm biomass into a sustainable food ingredient capable of providing both technological and health-related benefits, thereby supporting the development of value-added products within the food industry.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Crude Fiber Content of Chili Sauce

Table 3. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Crude Fiber Content

CMC Concentration (%)	Crude Fiber (%) (Mean $\pm$ SD)
0.0	1.24 $\pm$ 0.01 ^a
0.5	1.37 $\pm$ 0.01 ^b
1.0	1.53 $\pm$ 0.02 ^c
1.5	1.72 $\pm$ 0.01 ^d
ANOVA (F-value)	970.063
Significance (p-value)	< 0.001

Note: Data are expressed as mean $\pm$ standard deviation ($n = 3$). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Crude fiber is an important nutritional parameter because it contributes to the physiological benefits of food products while also influencing their physicochemical characteristics. As presented in Table 3, increasing the concentration of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds significantly increased the crude fiber content of the chili sauce. The control treatment (0% CMC) showed the lowest crude fiber content ($1.24 \pm 0.01\%$), whereas the highest value ($1.72 \pm 0.01\%$) was obtained in the treatment containing 1.5% CMC. Overall, the average crude fiber content of all treatments was $1.47 \pm 0.19\%$.

The improvement in texture can be attributed to the hydrocolloid properties of Carboxymethyl Cellulose. CMC is a high-molecular-weight polysaccharide capable of absorbing large amounts of water and forming a continuous three-dimensional polymer network within the food matrix. During hydration, the hydroxyl and carboxymethyl functional groups interact extensively with water molecules through hydrogen bonding, causing the polymer chains to swell and become highly entangled. This entanglement increases intermolecular interactions, reduces water mobility, and strengthens the viscoelastic structure of the chili sauce. Consequently, greater force is required to deform the product, resulting in higher texture values as the concentration of CMC increases.

Furthermore, the increase in texture is closely associated with the enhanced water-holding capacity of CMC. As more water becomes immobilized within the hydrocolloid matrix, the dispersed particles of chili, tomato, and other ingredients are more effectively suspended, producing a homogeneous and stable semi-solid system. This mechanism minimizes phase separation during storage and improves the consistency and spreadability of the chili sauce. The formation of a stronger gel network also contributes to maintaining structural integrity under mechanical stress, thereby improving the overall quality and consumer acceptability of the product.

The findings of this study are in agreement with previous research on the functional role of CMC in food systems. Ahmed et al. (2018) reported that increasing CMC concentration significantly improved the firmness and structural stability of sauce products by reinforcing the internal gel network. Likewise, Lestari et al. (2020) demonstrated that biomass-derived CMC enhanced gel strength and consistency owing to its high water-binding capacity and excellent rheological properties. Pratiwi et al. (2023) further observed that the incorporation of CMC increased hardness and cohesiveness in semi-solid food products while maintaining product homogeneity during storage. These consistent findings suggest that CMC synthesized from oil palm fronds exhibits technological performance comparable to commercially available CMC in improving the textural characteristics of food products.

From a technological perspective, improved texture is an essential quality attribute because it influences product handling, stability, and consumer perception. A sauce with appropriate firmness and consistency is generally preferred because it spreads evenly, adheres well to food surfaces, and exhibits greater resistance to serum separation during storage. The present findings therefore demonstrate that oil palm frond-derived CMC has considerable potential as a sustainable hydrocolloid capable of enhancing both the physical quality and commercial value of chili sauce. In addition to improving product texture, the utilization of CMC derived from oil palm biomass supports the

development of renewable, environmentally friendly food additives that contribute to sustainable food processing practices.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Texture of Chili Sauce

Table 4. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Texture of Chili Sauce

CMC Concentration (%)	Texture (N) (Mean $\pm$ SD)
0.0	1.33 $\pm$ 0.02 ^a
0.5	1.58 $\pm$ 0.02 ^b
1.0	1.86 $\pm$ 0.02 ^c
1.5	2.14 $\pm$ 0.02 ^d
ANOVA (F-value)	1018.140
Significance (p-value)	< 0.001

Note: Data are expressed as mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Texture is one of the most important quality attributes of chili sauce because it directly influences product consistency, spreadability, and consumer acceptance. As shown in Table 4, increasing the concentration of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds significantly enhanced the texture of the chili sauce. The control treatment (0% CMC) exhibited the lowest texture value (1.33 $\pm$ 0.02 N), whereas the highest value (2.14 $\pm$ 0.02 N) was observed in the treatment containing 1.5% CMC. The overall mean texture value of all treatments was 1.73 $\pm$ 0.32 N, indicating a progressive increase in gel strength as the concentration of CMC increased. The one-way Analysis of Variance (ANOVA) indicated that CMC concentration had a highly significant effect on the texture of chili sauce ($F = 1018.140$; $p < 0.001$). Duncan's Multiple Range Test (DMRT) further showed that each treatment belonged to a different homogeneous subset, indicating significant differences among all treatments ($p < 0.05$). These results demonstrate that increasing the concentration of CMC effectively improved the mechanical properties of chili sauce.

The improvement in texture is attributed to the hydrocolloid characteristics of CMC. Carboxymethyl Cellulose possesses hydrophilic functional groups capable of binding water molecules and forming a three-dimensional network within the food matrix. This polymer network increases resistance to deformation and enhances the consistency of chili sauce. Consequently, higher CMC concentrations produced a firmer texture due to the formation of a stronger gel structure. The increase in texture observed in this study is consistent with the findings of Lestari et al., (2020), who reported that increasing CMC concentration significantly enhanced the gel strength and consistency of processed food products because of its high water-binding capacity. Likewise, Ahmed et al., (2018) found that CMC improved the texture and stability of sauce products by reducing water mobility and strengthening the internal polymer network. Pratiwi et al. (2023) also reported that the addition of CMC increased the hardness and cohesiveness of semi-solid food products while maintaining product homogeneity during storage.

From a technological perspective, improved texture contributes to better product quality because it minimizes liquid separation, enhances product stability, and provides a more desirable

mouthfeel for consumers. Therefore, oil palm frond-derived CMC can serve not only as a thickening agent but also as an effective texture modifier capable of improving the physicochemical quality of chili sauce. Overall, the results indicate that increasing the concentration of oil palm frond-derived CMC significantly improved the texture of chili sauce. Among all treatments, the addition of 1.5% CMC produced the highest texture value (2.14 N), indicating the formation of the strongest gel matrix and the highest structural stability.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Vitamin C Content of Chili Sauce

Table 5. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Vitamin C Content of Chili Sauce

CMC Concentration (%)	Vitamin C (mg/100 g) (Mean $\pm$ SD)
0.0	22.81 $\pm$ 0.12 ^a
0.5	23.30 $\pm$ 0.12 ^b
1.0	23.95 $\pm$ 0.10 ^c
1.5	24.44 $\pm$ 0.08 ^d
ANOVA (F-value)	138.817
Significance (p-value)	< 0.001

Note: Data are expressed as mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Vitamin C is one of the essential nutritional components in chili sauce because it functions as a natural antioxidant and contributes to the nutritional value of the product. As presented in Table 5, increasing the concentration of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds significantly increased the vitamin C content of chili sauce. The control treatment (0% CMC) had the lowest vitamin C content (22.81 $\pm$ 0.12 mg/100 g), while the highest value (24.44 $\pm$ 0.08 mg/100 g) was observed in the treatment containing 1.5% CMC. Overall, the average vitamin C content of all treatments was 23.62 $\pm$ 0.65 mg/100 g. The one-way Analysis of Variance (ANOVA) showed that the concentration of CMC had a highly significant effect on vitamin C content ($F = 138.817$; $p < 0.001$). Duncan's Multiple Range Test (DMRT) further indicated that each treatment belonged to a different homogeneous subset, confirming that all treatment means differed significantly ($p < 0.05$). These findings indicate that increasing the concentration of oil palm frond-derived CMC significantly influenced the retention of vitamin C in chili sauce.

The improved retention of vitamin C can be explained by the protective hydrocolloid matrix formed by CMC during thermal processing. Ascorbic acid is highly susceptible to degradation through oxidation, heat exposure, and contact with dissolved oxygen. When dispersed in the chili sauce matrix, CMC forms a three-dimensional polymer network that immobilizes water molecules and increases the viscosity of the system. This dense network reduces oxygen diffusion and limits molecular mobility, thereby decreasing the exposure of ascorbic acid to oxidative reactions. In addition, the increased viscosity minimizes convective movement within the sauce during heating, reducing the interaction between vitamin C and dissolved oxygen. Consequently, the degradation rate of ascorbic acid is lowered, resulting in greater vitamin C retention in formulations containing higher concentrations of CMC.

Another factor contributing to the improved vitamin C retention is the enhanced water-binding capacity of CMC. The strong interaction between the hydroxyl and carboxymethyl groups of CMC and water molecules reduces the amount of free water available for oxidative reactions. This protective environment helps maintain the stability of heat-sensitive compounds throughout processing. Moreover, the formation of a stable hydrocolloid matrix may reduce the leaching of water-soluble nutrients, including vitamin C, thereby preserving the nutritional quality of the final product.

The findings of this study are consistent with previous reports concerning the protective role of hydrocolloids in food systems. Ahmed et al. (2018) reported that CMC improved the stability of heat-sensitive nutrients by reducing oxygen permeability and enhancing the structural integrity of semi-solid food products. Likewise, Chen et al. (2023) demonstrated that cellulose-based hydrocolloids contributed to the preservation of bioactive compounds during thermal processing by limiting oxidative degradation. Rahman et al. (2021) also emphasized that the excellent water-binding capacity and film-forming properties of CMC help maintain the physicochemical stability of processed foods, thereby improving the retention of sensitive nutritional components. The agreement between the present findings and previous studies suggests that CMC synthesized from oil palm fronds performs similarly to commercial CMC in protecting labile nutrients during food processing.

From a nutritional and technological perspective, the improved retention of vitamin C represents an important advantage because vitamin C is a major natural antioxidant that contributes to the nutritional value and oxidative stability of chili sauce. The ability of oil palm frond-derived CMC to preserve vitamin C while simultaneously improving texture, viscosity, and product stability demonstrates its multifunctional role as a food hydrocolloid. Therefore, utilizing CMC derived from oil palm fronds not only enhances the physicochemical quality of chili sauce but also supports the development of functional and sustainable food ingredients derived from renewable agricultural biomass.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Viscosity of Chili Sauce

Table 6. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Viscosity of Chili Sauce

CMC Concentration (%)	Viscosity (cP) (Mean $\pm$ SD)
0.0	2334.33 $\pm$ 18.56 ^a
0.5	2920.67 $\pm$ 24.50 ^b
1.0	3568.67 $\pm$ 27.01 ^c
1.5	4275.00 $\pm$ 27.00 ^d
ANOVA (F-value)	3490.047
Significance (p-value)	< 0.001

Note: Values are presented as mean $\pm$ standard deviation (n = 3). Means followed by different superscript letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at p < 0.05.

Viscosity is one of the most critical quality attributes of chili sauce because it determines product consistency, pourability, emulsion stability, and consumer acceptance. As presented in Table 6, the addition of Carboxymethyl Cellulose (CMC) extracted from oil palm fronds significantly increased the viscosity of the chili sauce. The control treatment (0% CMC) exhibited the lowest viscosity value

(2334.33 $\pm$ 18.56 cP), whereas the highest viscosity (4275.00 $\pm$ 27.00 cP) was obtained with the addition of 1.5% CMC. The overall average viscosity of all treatments was 3274.67 $\pm$ 756.47 cP, indicating that viscosity increased progressively with increasing CMC concentration. The one-way Analysis of Variance (ANOVA) revealed that CMC concentration had a highly significant effect on the viscosity of chili sauce ($F = 3490.047$; $p < 0.001$). Duncan's Multiple Range Test (DMRT) further showed that each treatment belonged to a different homogeneous subset, indicating that all treatment means differed significantly ($p < 0.05$). These results confirm that increasing the concentration of oil palm frond-derived CMC consistently enhanced the viscosity of the chili sauce.

The increase in viscosity can be explained by the hydrocolloid behavior of Carboxymethyl Cellulose in aqueous food systems. CMC is a high-molecular-weight polysaccharide that readily hydrates upon contact with water, causing the polymer chains to expand and occupy a larger hydrodynamic volume. As hydration proceeds, the polymer chains become increasingly entangled, forming a continuous three-dimensional network capable of entrapping large amounts of water. This network substantially reduces the mobility of free water molecules and dispersed particles, thereby increasing internal friction within the food matrix and enhancing resistance to flow. Consequently, greater force is required for the sauce to flow, resulting in significantly higher viscosity values as CMC concentration increases.

In addition to polymer chain entanglement, the presence of hydroxyl and carboxymethyl functional groups enables extensive hydrogen bonding between CMC molecules and water. These interactions promote water immobilization and reduce the amount of free water available within the continuous phase. As the proportion of immobilized water increases, the distance between suspended particles decreases, creating a denser and more homogeneous matrix. This mechanism not only increases viscosity but also improves emulsion stability, prevents sedimentation, and minimizes serum separation during storage. Therefore, the rheological improvement observed in the present study reflects both the thickening effect and the stabilizing function of oil palm frond-derived CMC.

The results obtained in this study are consistent with previous investigations on the application of CMC in food systems. Ahmed et al. (2018) reported that increasing CMC concentration significantly enhanced the viscosity of sauce products by strengthening the internal hydrocolloid network and reducing water mobility. Similarly, Rahman et al. (2021) demonstrated that cellulose-derived CMC exhibited excellent rheological properties owing to its high molecular weight and strong water-binding capacity, making it an effective thickening and stabilizing agent for processed foods. Li et al. (2022) further reported that CMC improved viscosity and gel stability through polymer swelling and chain entanglement, resulting in greater structural integrity during storage. Moreover, Pratiwi et al. (2023) observed that higher CMC concentrations increased the apparent viscosity and consistency of semi-solid food products while maintaining homogeneous dispersion throughout storage. The close agreement between the present findings and previous studies confirms that CMC synthesized from oil palm fronds possesses functional properties comparable to those of commercial CMC and is suitable for food applications.

From a technological perspective, viscosity is one of the most important quality attributes of chili sauce because it directly influences product stability, appearance, handling characteristics, and consumer acceptance. A sauce with adequate viscosity exhibits improved coating ability, spreads uniformly over food surfaces, and is less susceptible to phase separation during storage. Furthermore, increased viscosity enhances the suspension of solid particles such as ground chili and tomato, thereby

maintaining product homogeneity and improving visual quality. The substantial increase in viscosity achieved through the addition of oil palm frond-derived CMC therefore demonstrates its effectiveness as a multifunctional hydrocolloid capable of improving both processing performance and final product quality.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Aroma Acceptance of Chili Sauce

Table 7. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Aroma Acceptance of Chili Sauce

CMC Concentration (%)	Aroma Score (Mean $\pm$ SD)
0.0	3.47 $\pm$ 0.51 ^a
0.5	4.23 $\pm$ 0.43 ^b
1.0	4.80 $\pm$ 0.41 ^c
1.5	4.13 $\pm$ 0.35 ^b
ANOVA (F-value)	49.280
Significance (p-value)	< 0.001

Note: Data are expressed as mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Aroma is one of the primary sensory attributes determining consumer acceptance of chili sauce because it directly influences the overall perception of product quality. As presented in Table 7, the addition of Carboxymethyl Cellulose (CMC) derived from oil palm fronds significantly affected the aroma acceptance scores of the chili sauce. The control treatment (0% CMC) exhibited the lowest aroma score (3.47 $\pm$ 0.51), whereas the highest score (4.80 $\pm$ 0.41) was obtained with the addition of 1.0% CMC. Increasing the CMC concentration to 1.5% resulted in a slight decrease in aroma acceptance (4.13 $\pm$ 0.35), although the product remained within the "liked" category. One-way Analysis of Variance (ANOVA) indicated that CMC concentration had a highly significant effect on aroma acceptance ($F = 49.280$; $p < 0.001$). Duncan's Multiple Range Test (DMRT) further revealed that the 1.0% CMC treatment formed a separate homogeneous subset, indicating that its aroma score was significantly higher than those of the other treatments ($p < 0.05$). Meanwhile, the 0.5% and 1.5% CMC treatments were classified within the same subset, suggesting that their aroma acceptance did not differ significantly.

The improvement in aroma acceptance observed at moderate CMC concentrations can be attributed to the hydrocolloid properties of CMC, which enhance water retention and reduce the loss of volatile aroma compounds during thermal processing. The formation of a stable gel network helps preserve the characteristic aroma of chili peppers, garlic, tomatoes, and spices, thereby improving the sensory quality of the final product. However, excessive CMC addition may produce an overly dense matrix that restricts the release of volatile compounds during consumption, resulting in a slight reduction in aroma intensity perceived by consumers. These findings are consistent with the study conducted by Handoyo & Suseno, (2021), who reported that CMC concentration significantly influenced the organoleptic characteristics, including aroma, of pumpkin coffee jam. Their study demonstrated that moderate CMC concentrations enhanced aroma acceptance by improving product

stability while maintaining the characteristic aroma of the raw materials. Similar findings were reported by Tumober et al., (2021), who observed that CMC acted as an effective stabilizer in probiotic ice cream, improving aroma acceptance through better retention of volatile flavor compounds during processing and storage. Overall, the results indicate that 1.0% oil palm frond-derived CMC provided the highest aroma acceptance score, suggesting that this concentration offers the optimum balance between aroma retention and volatile compound release. Koko et al. (2023) emphasized that hydrocolloids contribute to aroma stability by regulating the interaction between volatile compounds and the food matrix, thereby improving the overall sensory quality of processed foods. These findings support the present study, demonstrating that oil palm frond-derived CMC performs similarly to commercial hydrocolloids in preserving desirable aroma characteristics.

Effect of Carboxymethyl Cellulose (CMC) Concentration on the Taste Acceptance of Chili Sauce

Table 8. Effect of Oil Palm Frond-Derived Carboxymethyl Cellulose (CMC) on the Taste Acceptance of Chili Sauce

CMC Concentration (%)	Taste Score (Mean ± SD)
0.0	3.37 ± 0.49 ^a
0.5	4.23 ± 0.43 ^b
1.0	4.90 ± 0.31 ^c
1.5	4.13 ± 0.35 ^b
ANOVA (F-value)	74.181
Significance (p-value)	< 0.001

Note: Data are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate statistically significant differences among treatments based on Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

Taste is the most important sensory attribute affecting consumer preference for chili sauce because it reflects the balance of sweetness, saltiness, sourness, and pungency. As shown in Table 8, increasing the concentration of oil palm frond-derived CMC significantly influenced the taste acceptance of chili sauce. The control treatment produced the lowest mean taste score (3.37 ± 0.49), whereas the highest score (4.90 ± 0.31) was recorded for the treatment containing 1.0% CMC. Increasing the CMC concentration to 1.5% caused a slight reduction in taste acceptance (4.13 ± 0.35), although the product remained acceptable to consumers. The ANOVA results demonstrated that CMC concentration significantly affected taste acceptance ($F = 74.181$; $p < 0.001$). Duncan's Multiple Range Test indicated that the 1.0% CMC treatment differed significantly from all other treatments, while the 0.5% and 1.5% CMC treatments belonged to the same homogeneous subset, indicating no significant difference between these two concentrations.

The improvement in taste acceptance at moderate CMC concentrations is associated with the ability of CMC to improve the homogeneity and consistency of the chili sauce. As a hydrocolloid, CMC promotes a uniform distribution of dissolved flavor compounds throughout the food matrix, allowing sweet, salty, sour, and spicy components to be perceived more evenly during consumption. In addition, the increased viscosity produced by CMC prolongs the residence time of the sauce in the oral cavity,

enabling flavor compounds to interact more effectively with taste receptors. This mechanism creates a more balanced and pleasant flavor profile, thereby increasing consumer preference.

The decline in taste acceptance observed at the highest CMC concentration (1.5%) is likely related to excessive thickening of the product. A highly viscous matrix may restrict the diffusion of dissolved flavor compounds toward the taste buds and simultaneously reduce the release of volatile compounds that contribute to flavor perception. Consequently, although the product becomes physically more stable, the intensity of sweetness, sourness, saltiness, and pungency perceived by consumers may be slightly reduced. This finding demonstrates that sensory quality depends not only on the chemical composition of the product but also on the rheological characteristics of the food matrix, which influence flavor release during consumption.

The results obtained in the present study are consistent with previous findings concerning the influence of CMC on sensory quality. Handoyo and Suseno (2021) reported that moderate CMC concentrations significantly improved the taste acceptance of pumpkin coffee jam by enhancing product consistency without masking the characteristic flavor of the raw materials. Similarly, Tumober et al. (2021) observed that intermediate CMC concentrations produced the highest hedonic scores in probiotic ice cream because they improved flavor stability while maintaining efficient flavor release. Furthermore, Koko et al. (2023) emphasized that hydrocolloids influence flavor perception by modifying the interaction between flavor compounds and the food matrix, highlighting the importance of optimizing hydrocolloid concentration to achieve maximum consumer acceptance. These findings support the present study, demonstrating that oil palm frond-derived CMC exhibits functional properties comparable to commercial hydrocolloids in improving sensory quality.

From a technological and commercial perspective, consumer acceptance is one of the most important considerations in the development of chili sauce products. Although higher CMC concentrations substantially improved viscosity, texture, and physicochemical stability, excessive thickening may reduce flavor perception and slightly decrease consumer preference. Therefore, the addition of 1.0% oil palm frond-derived CMC represents the optimum formulation because it provides the highest taste acceptance while maintaining desirable physicochemical characteristics. This result demonstrates that oil palm frond-derived CMC can serve not only as an effective thickening and stabilizing agent but also as a functional food ingredient capable of improving the overall sensory quality of chili sauce.

CONCLUSION

This study demonstrated that Carboxymethyl Cellulose (CMC) synthesized from oil palm fronds significantly improved the physicochemical and sensory characteristics of chili sauce. Increasing the concentration of CMC enhanced crude fiber content, texture, viscosity, vitamin C retention, and pH, while reducing moisture content, indicating that oil palm frond-derived CMC functions effectively as a thickening, stabilizing, and water-binding agent. In terms of sensory quality, the addition of CMC significantly influenced aroma and taste acceptance, with the formulation containing 1.0% CMC receiving the highest hedonic scores, whereas 1.5% CMC produced the greatest improvements in physicochemical properties but slightly reduced sensory acceptance because of excessive thickening. These findings indicate that 1.0% CMC represents the optimum formulation, providing the best balance between physicochemical stability and consumer preference. The findings of this study

provide scientific evidence that Carboxymethyl Cellulose derived from oil palm fronds possesses functional properties comparable to commercial food-grade hydrocolloids and can be utilized as a sustainable alternative thickening agent in chili sauce. The utilization of oil palm frond biomass also contributes to agricultural waste valorization, promotes renewable food ingredients, and supports sustainable food processing practices within the palm oil industry.

Future studies are recommended to evaluate the storage stability, syneresis, microbiological quality, and shelf life of chili sauce containing oil palm frond-derived CMC under different storage conditions. In addition, further investigation into the rheological behavior and consumer acceptance using a broader sensory panel would provide valuable information for large-scale industrial application.

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