Production of Hydroxypropyl Methylcellulose (HPMC) from α-Cellulose Derived from Cassava Stems

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Abstract. Cassava stems contain 56.82% α-cellulose, 21.72% lignin, 21.45% Acid Detergent Fiber (ADF), and a fiber length of 0.05-0.5 cm. One cellulose derivative product that is frequently utilized in the food and pharmaceutical industries is hydroxypropyl methylcellulose (HPMC). This study aims to produce HPMC from α-cellulose derived from cassava stems HPMC Batang Ubi Kayu (HPMC BUK) according to HPMC standard specifications (HPMC Komersil (HPMC KO)). In this study, extraction of α-cellulose from cassava stems was carried out using electromagnetic, pre-hydrolysis, delignification, and bleaching processes, then α-cellulose was treated with alkalization by adding 20 ml of NaOH with variations concentration 20% w/v, 25% w/v, and 30% w/v at room temperature with time variations of 60 minutes, 120 minutes, and 180 minutes. Then followed by a methylation reaction using 6.3 ml of dimethyl sulfate (DMS) and a propylation reaction using 6 ml of propylene oxide (PO) (for 5 g of α-cellulose) at a temperature of 58.11°C for 3 hours and continued with neutralization, filtering, and drying. The optimum conditions were obtained using 25% (w/v) NaOH with a reaction time of 60 minutes which resulted in HPMC specifications being yellowish-white, odorless, and tasteless, pH 7.7 and ash content 1.3%, water content 7.44%. The average particle size of HPMC BUK was 49.57 µm, with crystallinity of 12.5% with an oval shape and rough surface. The FTIR spectrum shows a relatively similar pattern to that of commercial HPMC. Based on the comparison with the reference, HPMC BUK showed relatively the same physicochemical characteristics.

Keywords: Cassava stem, α-cellulose extraction, alkalization, methylation, propylation.

1 Introduction

Lampung Province is the leading producer of cassava in Indonesia with a total production of 7,387.084 tons. However, only 10% of tall cassava stems can be replanted into

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seeds and the remaining 90% is waste [1]. Cassava stems contain 56.82% α-cellulose which can be utilized in various fields including the manufacture of semi-synthetic polymers [2]. Cellulose derivative products that can be produced include hydroxypropyl methylcellulose (HPMC), hydroxyethylcellulose (HEC), and carboxymethyl cellulose (CMC) [3]. HPMC is a potential semi-synthetic material that is widely used in the pharmaceutical, textile, food, formulation of cosmetic products and paper industries [4].

HPMC is produced by methylation and hydroxypropylation of alkali cellulose [5]. α-cellulose is reacted with NaOH to form alkali cellulose which is further reacted with methylation and hydroxypropylation reagents [6]. The cellulose structure is made ready for the addition of substituents by the alkali base, which also causes swelling. The ratio of caustic to cellulose can be changed to control the swelling's intensity [7,8]. The research on the synthesis of HPMC using betung bamboo as a raw material found that the optimum conditions for HPMC were 27.68% (w/v) NaOH and 1.26 ml dimethyl sulfate at 58.11°C which resulted in a molar substitution of 0.21 and a degree of substitution of 2.09 with the result that HPMC powder is yellowish, odorless and tasteless with pH of 7.02, Ash content 1.39%, methoxy group content 28.56%, hydroxypropyl group content 7.09%, average particle size of 98.595 μm, loss on drying 3.62%, and water content of 7.47%. The infrared spectrum and diffraction pattern are relatively similar to commercial HPMC [9]. Another study of synthesis HPMC from white jack been hulls using 23.11% NaOH, 81.8% PO, and 43,4% DMS produced characterization of HPMC have a water content of 9.04%, MS 0.15%, DS 1.18, WHC 2.20 g/g, OHC 2.09 g/g, lightness of 90.93% and yield of 114.78% and degree of crystallinity 64% with an FTIR spectrum which has the characteristics of the HPMC functional group [10].

The study conducted by [11] on the production of carboxymethylcellulose (CMC) from cacao pod husk [11] utilized 15% (w/v) NaOH and 6.68 g DMS for every 5 g of α-cellulose at 55°C for 3 hours Degree of Substitution (DS) values 1.84; 3.73 g/g water holding capacity (WHC); 106.01 cps viscosity and 141.60% yield. Another research, focusing on hydroxypropylation of α-cellulose derived from betung bamboo employed 25% NaOH (w/v) and 10 ml of PO for every 1 g of α-cellulose at 70°C for 3 hours produced a yellowish, odorless, and tasteless hydroxypropylcellulose (HPC) powder at pH 7.49. The average particle size is 37.39 μm, the water content is 3.34% and the molar substitution is 3.32 [12]. Preparation of methylcellulose from sugarcane bagasse cellulose with 50% NaOH and 3 ml of DMS per gram of α-cellulose at 50°C for 3 hours produced a Degree of Substitution (DS) of 1.2 [5]. These studies demonstrate that the physicochemical properties of HPMC are influenced by the reaction circumstances and the source of α-cellulose utilized [13]. The goal of this study is to determine the ideal conditions for the synthesis of hydroxypropyl methylcellulose (HPMC) from cassava stem α-cellulose and the physical and chemical properties of HPMC.

2 Methodology

Materials. Cassava stem was collected from South Sungkai, North Lampung, Indonesia. The chemical used were HPMC KO (Shin Etsu), acetic acid (CH_3COOH) (Merck), sodium hydroxide (NaOH) (Merck) and hydroxygen peroxide (H_2O_2) (Merck) were used as alkali and bleaching agents, isopropyl alcohol (C_3H_8O) (Merck) as a solvent, dimethyl sulfate ($C_2H_6O_4S$), and propylene oxide (C_3H_6O) (Sigma-Aldrich) was used for methylation and hydroxypropilation reaction while ethanol (C_2H_5OH) (Merck) was used for product washing

Electromagnetic Induction. The electromagnet utilized in this study included 800 winding coils, wire that was 0.75 cm in diameter, socket height that was 7 cm, electric induction currents that were 10 Amperes, and magnetic induction that was 0.0178 Tesla.

Pre-hydrolysis Process. Cassava stems were crushed and sieved with range between 100 and 120 mesh then to dehydrate the moisture contents. A consistent mass was obtained by drying the cassava stem in an oven at 105°C. Cassava stem powder was pre-hydrolyzed by boiling it in 0.1 N CH_3COOH for 90 minutes at 105°C with a sample to solvent ratio of 1:20. [14]. After the sample was squeezed and filtered to get rid of the solvent, it was rinsed several times until the pH was neutral, and it was finally dried in an oven [15].

Delignification Process. The pre-hydrolyzed powder was heated under isolation conditions at 105°C with a ratio of sample to sodium hydroxide (NaOH) of 1:20 for 60 minutes [16]. During this procedure, a brown pulp is produced which is then filtered and neutralized by rinsing, the pulp is dried.

Bleaching Process. In this process the sample on the form of a delignified powder was heated with 2% hydrogen peroxide (H_2O_2) solution at 60°C for 120 minutes with a sample and solvent ratio of 1:15 [16]. After filtering the mixture, the residue was repeatedly cleaned with distilled water to bring it to pH neutrality. In addition, the pulp is dried for about 12-24 hours in an oven at 50°C [17]. The resulting dry pulp is known as α-cellulose.

Preparation of hydroxypropyl methylcellulose from α-cellulose cassava stems.
A beaker glass is filled with 5 g of α-cellulose powder, and it is then periodically agitated with 100 ml of isopropyl alcohol. The mixture is alkalized by adding increments of 20 ml of varied NaOH concentration (20% w/v; 25% w/v; and 30% w/v). The mixture is continually swirked at room temperature for an hour with a magnetic stirrer. Moreover, dimethyl sulfate (1.26 ml per g of α-cellulose powder) was progressively added to the methylation reaction after 6 ml of propylene oxide was supplied for the hydroxypropylation procedure. Beaker glass was heated for 3 hours at 58.11°C while being stirred and was carefully covered with aluminum foil. Following the completion of the reaction, the mixture is cooled to room temperature. The mixture is filtered

through a vacuum filter after being neutralized by adding 90% acetic acid into the solution to a pH 7. Then the sample was rinsed 3 times with 96% ethanol, dried for 6 hours in an oven at 50°C. The resulting precipitate was HPMC [9].

2.1 Analysis

Characterization. Organoleptic test, pH, ash content, moisture content, infrared spectrum analysis, particle size analysis, degree of crystallinity, scanning electron microscope analysis and particle size were then used to characterize the HPMC products that had been produced. The results are in contrast to a commonly used commercial item that is HPMC 60SH (HPMC KO).

Organoleptic Test. Based on the 2015 United States Pharmacopeial Convention, an organoleptic test was performed on HPMC powder [19]. After the HPMC powder was put into white base, its appearance, color, smell, and taste were evaluated.

pH Determination. In this study, commercial and experimental HPMC samples were used for pH testing, which was done with a calibrated pH meter. Using a pH meter that was calibrated, a total of 1 g of the sample was dissolved in 100 ml of distilled water.

Moisture Content. A moisture content analyzer was used to measure the moisture content in this study. 2 g of HPMC powder was weighed on an aluminum plate, then the tool will show a measure of the moisture content of the HPMC powder.

Ash Content. The cup was heated to 600°C for 15 minutes in a furnace, then cooled in a desicator before being weighed to determine the amount of ash present. HPMC powder was weighed and heated for 6 hours at 600°C. The cup containing the HPMC weighed and allowed to cool in a desicator once ash has formed [9]. The residue can be calculating [19].

$$\text{Ash content} = \frac{W_1 - W_2}{W} \times 100 \quad (1)$$

Where, W is the sampple weight (g), W_1 is the sample weight + the weight of the cup after incineration (g), W_2 is the empty cup weight.

Analysis the functional group of HPMC. Perkin Elmer Spectrum Two spectrometerwere used to record the infrared spectrum of the HPMC samples. The transmission was measured at a wavelength range 4000-400 cm^{-1} after 3 mg of HPMC was applied to the reader.

Degree of Crystallinity. using Cu-Kα radiation at 2θ = 10-90° and an x-ray diffractogram operating in reflection mode (40 kV, 30 mA) were used to characterize HPMC [9]. The degree of crystallinity will be determined by calculating the graph based XRD analysis result using Origin Pro software. Degree of crystallinity can be calculated by the formula [20]:

$$C\ (\%) = \left(\frac{A_c}{A_c + A_a}\right) \times 100 \quad (2)$$

A_C is crystalline, A_a is amorf area and C is degree of crystallinity (%),

Analysis of scanning electrone microscope. The sample emits secondary electrons throuhout the SEM analysis process, and the detector detects these reflections. An electrical circuit then amplifies these reflections to produce a picture on the cathode rays. Then select certain parts and enlarge them to get a good and clear picture [21].

Anlysis of Particle Size. In order to stop particle aggregation, the sample is separated into medium-sized pieces. The particle size was then determined by inserting it into the (PSA Beckman Coulter LS 13 320) apparatus [16].

3 Results and Discussion

3.1 Organoleptic and Identification Test

The purpose of the characterization is to evaluate the results of the study HPMC cassava stems (HPMC BUK) compared to commercial HPMC (HPMC KO). The results of organoleptic and identification test showed the shape, color, smell, taste, pH, moisture content and ash content of each HPMC BUK synthesis result and HPMC KO which are shown in Fig. 1. and Table 1. HPMC has the characteristics of granular, white, odorless and tasteless. In addition, HPMC has a pH standard of 5.5-9.5; moisture content <5% and ash content ≤5% [22].

(a) (b)

Fig. 1. (a) HPMC KO, (b) HPMC BUK.

The color of HPMC KO is white, HPMC BUK is yellowish-white color as shown in Fig. 1. The color difference between HPMC BUK and HPMC KO is due to the presence of sodium hydroxide in HPMC BUK and the effect of the alkalization reaction temperature [11]. The higher concentration of sodium hydroxide used, the reaction

temperature and duration of reaction will produce a more yellowish HPMC [12]. The large difference sodium hydroxide concentration and reaction time in the alkalization reaction did not show a significant color change in the HPMC BUK color.

Table 1. Organoleptic and identification test result.

Characteristic	Standard	HPMC KO	HPMC BUK
Form	Powder	✓	✓
Color	White	✓	x
Odor	Odorless	✓	✓
Taste	Tasteless	✓	✓
pH	5.5-9.5	✓	✓
Moisture content	<5%	✓	x
Ash content	≤ 1,5%	✓	✓

In addition to the results of the pH test, from Table 1 reveals differences in the moisture content between the HPMC BUK obtained in this study and the standard HPMC. Testing the moisture content is crucial for determining the amount of substancecan evaporate during the sample drying process. Excessive moisture can promote bacterial growth and accelerate the decomposition time of materials thereby potentialy reduce the quality of ingredients [23]. The high value of moisture content affects the shelf life of HPMC [24]. Notably, HPMC BUK has greater moisture content than HPMC KO which is at a standard of less than or equal to 5%. This can be overcome by drying for a longer time at the end of HPMC drying process so that the appropriate moisture content value is obtained.

3.2 Analysis the functional group of HPMC

The purpose of infrared spectrum analysis is to verify that HPMC BUK contains functional groups. This is accomplished by examining the shift in the raw material's infrared spectrum before and after treatment, additionally comparing the infrared spectra of HPMC BUK and HPMC KO. On the FTIR graph, the y axis (%T) represent the percentage of transmittance which is the ratio of the infrared light that is not absorbed by the sample to the infrared light given the sample. Meanwhile, the x-axis represents the infrared absorption area expressed in wave numbers (cm^{-1}) [25]. The presence of hydroxyl groups α-cellulose has indicated at number of 3341.61 cm^{-1} which indicates the presence of hydroxyl groups from cellulose [26]. Furthermore, the peak at 2916.97 cm^{-1} was read, the absorption from the C-H stretching group was the cellulose framework which was usually read at 3000-2800 cm^{-1} [27]. The wave number of 1026.96 cm^{-1} on the raw material graph shows the C-O-C content, namely lignin in the raw material. Wavenumber 905.94 cm^{-1} as β-glycosidic linkages.

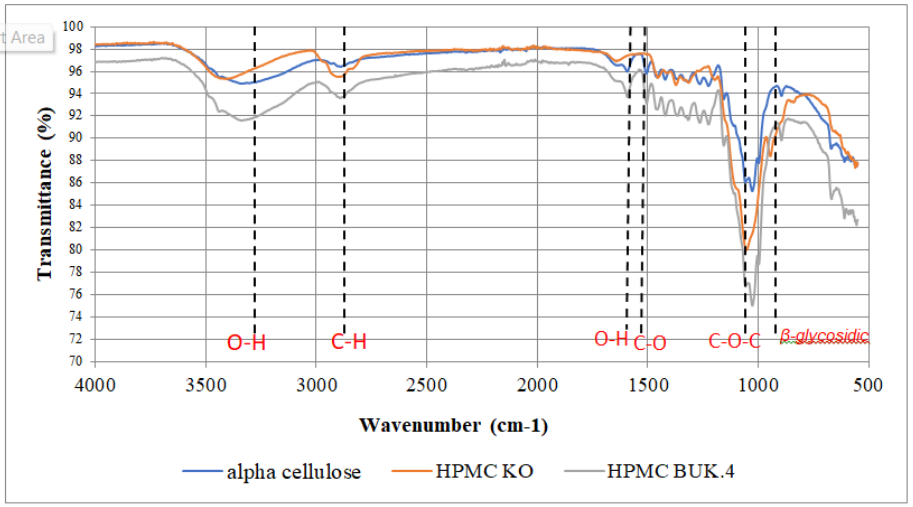

Fig. 2. Comparison IR spectrogram analysis of raw material, commercial HPMC and HPMC cassava stems experiment no. 4.

Table 2. IR Transmitance.

Sample HPMC	Wavenumbers (cm^{-1})					
	3550-3200	3000-2840	1420-1330	1275-1200	1360-1000	1000-600
	O-H *stretching*	C-H *stretching*	C-H *stretching*	C-O *stretching*	C-O-C dan C-O *Stretch alcohol absorption*	*β-glycosidic linkages*
Raw material	3341,61	2916,97	-	1224,91	1026,96	905,94
KO	3406,11	2903,90	1372,66	1215,92	1052,63	945,03
BUK.1	3337,01	2892,05	1362,05	1225,12	1026,28	894,82
BUK.2	3337,01	2923,08	1360,50	1224,96	1026,65	894,81
BUK.3	3376,80	2931,05	1361,62	1224,88	1026,48	894,82
BUK.4	3353,91	2924,09	1380,58	1224,67	1026,57	894,85
BUK.5	3373,48	2932,04	1381,32	1224,62	1026,46	894,85
BUK.6	3374,85	2934,08	1358,56	1224,93	1026,02	894,60
BUK.7	3374,80	2918,50	1379,84	1224,89	1026,26	894,78
BUK.8	3377,50	2921,05	1381,78	1224,76	1026,26	894,86
BUK.9	3374,78	2925,08	1393,63	1258,85	1023,26	900,88

Experiment 4 (BUK 4) is considered to have the peak and transmittance values as well as wavenumbers that are closest to the commercial HPMC. HPMC BUK 4 has a peak at wavenumber 3353.91 cm^{-} which indicates the presence of O-H stretching groups with low intensity which proves the reaction of methylation and hydroxypropylation of α-cellulose where the hydroxyl group of anihydroglucose units is occupied by a methoxy dimethyl sulfate group and hydroxypropyl group from propylene oxide [5, 13]. Stretching C-H vibrations of the CH_3 and CH_2 methyl groups produce wavenumber 2924.09 cm^{-1} is the result of [12]. 1380.58 cm^{-1} as the C-H vibration of CH_3 was also found by [9] at wave number 1375 cm^{-1} as a sign of methylation reaction in α-cellulose which was not found in previous α-cellulose raw materials. The methylation reaction was also suggested by the absorption that appeared at wave number 1224.67 cm^{-} this suggest that C-O stretching from OCH_3 is present [5] discovered this absorption with a susceptibility of 1259-1000 cm^{-1}. The strongest peak intensity is seen at wave number 1026.57 cm^{-1} which is indicative the C-O-C bond found in cellulose ethers. The absorption at 894.85 cm^{-1} reveals the C-O-C in 1.4 β-glycosidic.

3.3 Degree of Crystallinity

A sample's degree of crystallinity is to be ascertained using XRD analysis. The presence of a crystalline form of HPMC powder produced sharp peaks while the amorphous form produced wide peaks [29]. The crystallinity is provided in Table 3. Based on computations performed using the FWMH obtained from the XRD test graphs of HPMC KO and HPMC BUK, the peak position value, and the area of the crystalline and amorphous fractions.

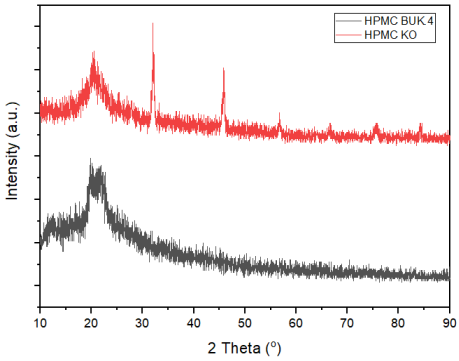

Fig. 3. A comparative graph showing the diffraction patterns of HPMC BUK and HPMC KO.

Table 3. Crystallinity.

Sample	Crystallinity (%)
Commercial HPMC (HPMC KO)	26,1%
Cassava Stems HPMC (HPMC BUK)	12,5%

HPMC KO has a higher crystallinity of 26.1% and HPMC BUK of 12.5%. At an angle of 2θ there are peaks around 20° on HPMC KO and HPMC BUK as well as several other peaks on HPMC KO which are stronger and clearer, thus showing a more semi crystalline character of HPMC KO [5,10]. HPMC KO and HPMC BUK diffraction pattern do not show significantly broad peaks because amorphous composition is very small [9,20]. According to [30] and [10] sodium hydroxide levels above 17.5% in the alkalization process can increase the degree of crystallinity caused by damage to amorphous areas of cellulose. In addition, the increase in crystallinity can also be caused by an increase crystalize due to co-crystallization from the crystalline region. Co-crystallization of the crystalline area is initially inhibited by the intercalation between the non-cellulose polysaccharides can assist c-crystallization of cellulose in larger crystallites by the joining of two or more crystals.

3.4 Analysis of Scanning Electrone Microscope

Fig.4 displays the results of the scanning electron microscope (SEM) for cassava stem HPMC and commercial HPMC which shows that HPMC KO and HPMC BUK have same shape, namely oval, but differences in surface morphology were found between HPMC KO and HPMC BUK.

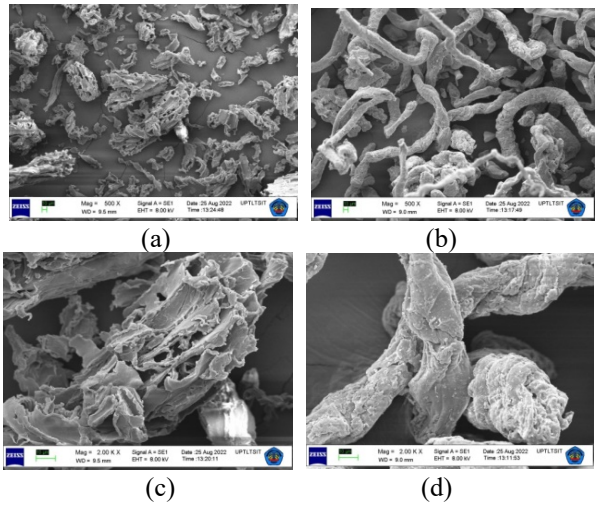

Fig. 4. (a) SEM analysis of HPMC BUK M=500x, (b) SEM analysis of HPMC KO M=500x, (c) SEM analysis of HPMC BUK M=2000x, (d) SEM analysis of HPMC KO M=2000x.

Since the etherification reaction occurred, HPMC BUK's surface is rougher than HPMC KO's. The etherification process causes residual deposits of propylene oxide or dimethyl sulfate to accumulate on the α-cellulose surface, giving it a rough texture. It can be reduced by optimizing the final washing process at HPMC. Furthermore, the yellowish-white hue of HPMC KO indicates that lignin residues from the α-cellulose manufacturing process can potentially produce roughness on the HPMC surface. This can be avoided by extending the delignification period or by going through the delignification procedure more than once [29]. Thus, the final HPMC's quality is likewise influenced by the quality of the α-cellulose .

3.5 Analysis of Particle Size

The particle size distribution and average size of HPMC BUK were ascertained via PSA analysis, and these results were subsequently compared with commercial HPMC as a baseline. The results of PSA analysis of cassava stems showed the average particle sized of HPMC BUK ia 49.57 µm and HPMC KO is 125.7 µ. The resulting HPMC BUK is at a standard vulnerable to HPMC particle size, namely 20-200 µm [9,31]. So that the HPMC produced from α-cellulose cassava stems has a particle size that is closest to the standard.

4 Conclusion

Based on this research, hydroxypropyl methylcellulose (HPMC) can be successfully synthesized using alkalization, etherification, methylation and hydroxypropylation methods employing α-cellulose derived from cassava stems. The optimal conditions for producing HPMC BUK powder were determined to be a 25% sodium hydroxide

concentration and a 60-minutes reaction time during the alkalization process. These conditions yielded HPMC with s organoleptic properties chacarcterized by a yellowish-white appearance, along with being odorless and tasteless. Chemical and physical properties test revealed that HPMC BUK exhibited apH of 7.7 and an ash content of 1.3%, witha mostuire content of 7.44%. Additionally, the average particle size of HPMC BUK was measured at 49.57 μm, falling within the standard range of 20-200 μm. The morphology of HPMC BUK revealed an oval shape with a rough surface, and its crystallinity was found to be 12.5%. Overall, HPMC BUK met the standard set for is commercial HPMC. However, it was found that the color of the final HPMC was affected by changes in the reaction time and sodium hydroxide concentration.

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