

High purity glucomannan after ultrasonic-assisted extraction and α -amylase liquefaction of porang (*Amorphophallus oncophyllus*) flour

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Abstract

Glucomannan extracted from the porang plant (*Amorphophallus oncophyllus*) is encapsulated by starch impurities. The main objectives of this study were to evaluate the effect of purifying glucomannan using thermostable α -amylase, ultrasonic-assisted extraction (UAE), and the combination of both treatments on glucomannan purity and the physicochemical properties of the porang flour, such as viscosity. This research was conducted through four main steps as follows: thermostable α -amylase production and preparation, liquefaction, extraction, and purification of glucomannan with ethanol, and the glucomannan properties assay. The liquefaction process was carried out at 70°C, at which α -amylase exhibited maximum activity. The combined treatment of UAE and α -amylase liquefaction successfully purified glucomannan from porang flour. This treatment significantly reduced starch and ash contents, increased glucomannan content to 89.69%, lowered viscosity to 160 cP, and enhanced solubility to 46.18%. This treatment improved the transparency and lightness of the flour. The pure glucomannan granules obtained by combining UAE and the enzyme treatment showed regular shaped and relatively smooth with more hydroxyl and carbonyl groups than the other treatments. These results provide an alternative method to obtain pure glucomannan by combining UAE and thermostable α -amylase liquefaction.

1. Introduction

Glucomannan is a water-soluble and non-ionic (neutral) polysaccharide dietary fiber mainly composed of β -1,4 linkages between D-mannose and D-glucose (Harmayani *et al.*, 2014). It is abundantly found in the roots and tubers of the perennial plant *Amorphophallus* sp. The molecular weight of glucomannan is approximately 1,000 kDa, which is considerably high. It is also known as the most viscous dietary fiber with a value of 30,000 cP, as it can absorb 50 times its weight in water (Doi, 1995; Liu and Xiao, 2004; Yaseen *et al.*, 2005). One of the locally cultivated porang species in Indonesia is *Amorphophallus oncophyllus*, which typically grows at the forest border (Wardhani *et al.*, 2019). Glucomannan has been widely employed as a stabilizer, thickener, texturizer, emulsifier, and bulking agent in food because of its distinctive properties (Chua *et al.*, 2010). In the body, whole glucomannan passes into the colon unchanged where it is fermented by colonic bacteria, as it cannot be hydrolyzed by salivary or pancreatic amylase. Consuming glucomannan has

been demonstrated to reduce body weight as well as glucose levels in adults (Keithley and Swanson, 2005; Keithley *et al.*, 2013). Unfortunately, glucomannan cannot be directly consumed due to impurities that encapsulate its tubers, such as starch, cellulose, and calcium oxalate (Ohashi *et al.*, 2000). The purity of glucomannan largely affects its physicochemical, bioactivity, and functional properties. Therefore, it is necessary to eliminate these impurities to achieve higher quality glucomannan. A top-grade glucomannan flour is required to contain at least 70% glucomannan (Ministry of Agriculture of the People's Republic of China *et al.*, 2002)

Several ways have been studied to achieve highly pure glucomannan, including dry, wet, and ultrasonic methods. The dry method involves separating the glucomannan after the tubers are washed, sliced, dried, and ground. Then, the glucomannan is purified by wind shifting, although the yield does not meet the standard. A study on konjac flour resulted in 50-70% glucomannan

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content using the dry method (Tatirat and Charoenrein, 2011). Purification by chemical extraction with various solvents, such as water, ethanol, or a benzene-ethanol solution removes undissolved contaminants. However, the final glucomannan product is only about 70% (Chen *et al.*, 2005). Recently, ultrasonic-assisted extraction (UAE) has been developed to purify glucomannan. A study on porang flour revealed that UAE resulted in 74%–83% glucomannan content (Wardhani *et al.*, 2020). An investigation of the effect of UAE on starch structure and characterization demonstrated that ultrasound processing, which is ultrasonic waves in a liquid medium, utilizes the cavitation effect to break down the cells (Chemat *et al.*, 2011; Zheng *et al.*, 2015; Chemat *et al.*, 2017). Polysaccharides can be extracted using ultrasonic waves from a dry form, based on immersing the material in solvents that facilitate the swelling and hydration processes that cause enlarged pores (Toma *et al.*, 2001; Vinatoru 2001). These pores, coupled with cavitation, cause damage to the cell wall, which triggers the release of analytes from the cell (Ebringerová and Hromádková, 2010).

Studies about utilizing the combination of an enzyme and UAE to purify glucomannan are rare. Therefore, our study purified and characterized glucomannan using enzymatic liquefaction, UAE, and the combination of both methods. The presence of up to 10% starch in porang corms can lead to gelatinization, so the process may require a longer time. Chua *et al.* (2012) and Sugiyama *et al.* (2012) extracted glucomannan for 3 hrs at room temperature to avoid gelatinization. Interestingly, this condition can be overcome by using amyolytic enzymes. Hydrolysis using α -amylase has been applied to break starch down into smaller sugar units (Zheng *et al.*, 2015). Enzymatic hydrolysis using α -amylase results in 93% glucomannan content, but no information is available regarding its viscosity or transparency (Wardhani *et al.*, 2019). In this study, bacterial thermostable α -amylase was used to degrade starch during liquefaction. The α -amylase gen from thermophilic *Geobacillus* sp. DS3 isolated from the Sikidang Crater, Dieng Plateau, Indonesia (Witasari *et al.*, 2010; Widiana *et al.*, 2022) was subcloned into the pETSUMO plasmid, and transformed into *Escherichia coli* BL21(DE3) (Cahyono, 2020). Liquefaction requires high temperature; thus, the high temperature stability of the thermozyyme was beneficial. Moreover, thermozymes are more stable in storage, have a lower contamination risk, resist organic solvents, and increase catalytic activity (Sharma *et al.*, 2019). α -amylase only cleaves the α -1,4 glycosidic linkage of starch and leaves the β -1,4 glycoside of glucomannan.

This study aimed to overexpress the α -amylase gene,

determine its optimum temperature, and analyze its effectiveness during the glucomannan extraction and purification process. An enzymatic treatment using thermostable α -amylase, UAE, and the combination of both treatments was performed to evaluate the content, viscosity, solubility, and transparency of the glucomannan extracted from porang flour.

2. Materials and methods

2.1 Overexpression of thermostable α -amylase

A loop full of *E. coli* BL21(DE3) cells containing the pETSUMO-Amy recombinant plasmid was grown in 5 mL of LB liquid medium containing 50 μ L of kanamycin sulfate (50 μ g/ μ L) and incubated at 37°C and 75 rpm overnight. The 5 mL overnight culture was inoculated in 50 mL of LB containing 500 μ L of kanamycin sulfate and incubated for 2 hrs at 37°C and 75 rpm. After the OD₆₀₀ value reached 0.4–0.6 (mid-log), 50 μ L of 1 mM isopropyl β -D-1-thiogalactopyranoside (IPTG) was added to induce overexpression, and the culture was incubated at 37°C in a water bath shaker for 6 hrs.

2.2 Enzyme preparation and thermostable α -amylase assay

The culture was centrifuged at 3,046 \times g for 3 mins. The cell pellet was resuspended in 50 mL of lysis buffer, frozen in ice, and thawed at 42°C for 5 min. This step was performed in triplicate. The pellet was sonicated for 5 mins and centrifuged at 3,046 \times g for 3 mins. Approximately 5 mL of lysis buffer were added and heated at 70°C for 30 mins to inactivate any other enzymes. Approximately 10 mL of the crude enzyme extract was added to 490 μ L of acetate buffer pH 4.9 containing 500 μ L of soluble starch, 0.1% CaCl₂·2H₂O, and 0.02% MgSO₄·7H₂O, and the mixture was incubated for 3 hrs at 4, 30, 37, 50, 60, 70, 80 and 90°C. Enzyme activity was examined using the DNS (dinitro salicylic acid) method based on determining the reducing sugars with glucose as the standard. The free-reducing sugars were measured using a spectrophotometer at a wavelength of 540 nm. Enzyme activity was defined as the amount of enzyme needed to release the reducing sugars (1 μ mole) from the substrates.

2.3 Enzymatic liquefaction

Liquefaction was achieved according to the procedure described by Richardson *et al.* (2002) with some modifications. Four series of samples were used in this study: the UAE treatment only (U), the enzyme treatment only (E), the combined UAE and enzyme treatment (U+E), and no UAE or enzyme (C). Porang flour was thoroughly mixed with 400 mL of 0.1 M

NaOAc buffer (pH 4.9) containing 0.1% $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 0.02% $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.1% NaCl, and 0.1% K_2HPO_4 in a ratio of 2.5% (w/v) and sonicated for 15 min. Then, the thermostable α -amylase was added and heated for 3.6 hrs at 70°C under continuous stirring at 125 rpm. The suspension was filtered through filter paper and washed in a graded ethanol series of 48%, 70%, and 96% final concentrations. The suspension was centrifuged at $3,046 \times g$ for 3 mins, and the supernatant was aspirated. The ethanol flake residue was evaporated. The flakes were dried at 50°C , ground, and sifted through a 60-mesh sieve (Figure 1).

2.4 Glucomannan content

Glucomannan content was determined using the DNS colorimetric assay (Dave *et al.*, 1998). Glucomannan (0.2 g) was diluted in 50 mL of 0.1 M formic acid-sodium hydroxide buffer and magnetically stirred for 4 hrs at room temperature to obtain the glucomannan extract. The mixture was diluted with formic acid-sodium hydroxide buffer up to 100 mL in a volumetric flask, followed by centrifugation at $3,046 \times g$, for 15 mins at 25°C . Approximately 5 mL of the glucomannan extract and 2.5 mL of 3 M H_2SO_4 were added to a 25 mL volumetric flask and then hydrolyzed for 90 mins in a boiling water bath. After cooling, 2.5 mL of 6 M NaOH was added, and the mixture was brought up to 25 mL with deionized water to obtain the glucomannan hydrolysate. The glucomannan extract and hydrolysate were subjected to colorimetric reactions at a wavelength of 550 nm using deionized water as the blank.

Glucomannan content (db) was calculated according to Equation (1):

$$\text{GM content (\%)} = \frac{5000f(5T-5T_0)}{m(1-w)} \quad (1)$$

Where T_0 = glucose content of the glucomannan sample solution (mg), m = mass of the purified flour (200 mg), and w = water content of glucomannan.

2.5 Chemical composition

Glucomannan was analyzed for moisture, ash, starch, protein, and residual sugar contents. Moisture and ash were determined according to AOAC methods at 105°C , while ash content was determined at 500°C . Starch was

analyzed based on the method of Morel du Boil and Schaffler (1974). The Bradford method was used to analyze protein content. Residual sugars were determined using the DNS method, while the degree of polymerization (DP) was determined by the Nelson Somogyi method (Nelson, 1944).

2.6 Viscosity

The test was carried out by diluting 1% glucomannan with distilled water followed by agitation at 150 rpm until the glucomannan was entirely hydrated. The measurement was taken using a Brookfield Viscometer RVT 105202 at 25°C with spindle no. 2 at 0.5 rpm (Yanuriati *et al.*, 2017).

2.7 Solubility

The solubility of glucomannan was measured based on the method of Du *et al.* (2012). Glucomannan (0.1 g) was diluted with 24.9 g of deionized water and magnetically stirred for 1 hr. After centrifugation for 20 min at $3,046 \times g$, 10 g of the supernatant was dried to a constant weight at 105°C . Solubility (%) for Equation (2) was calculated as follows:

$$\text{Solubility (\%)} = \frac{m \times 2.5}{W} \quad (2)$$

where m is the weight of a soluble component in the 10 g upper solution and W is the total weight of glucomannan.

2.8 Transparency

The transparency of the sample solutions was determined according to Ye *et al.* (2014) using a UV-Vis spectrometer. Briefly, 1% (w/v) glucomannan solutions were prepared at 25°C , and transparency was determined at a wavelength of 550 nm with distilled water as the blank.

2.9 Morphology

The morphology of glucomannan was investigated by scanning electron microscopy (SEM) (Hitachi SU3500; Tokyo, Japan) at $1,000 \times$ and $5,000 \times$ magnification. A dried glucomannan sample was placed on a specimen holder and coated with a thin layer of gold.

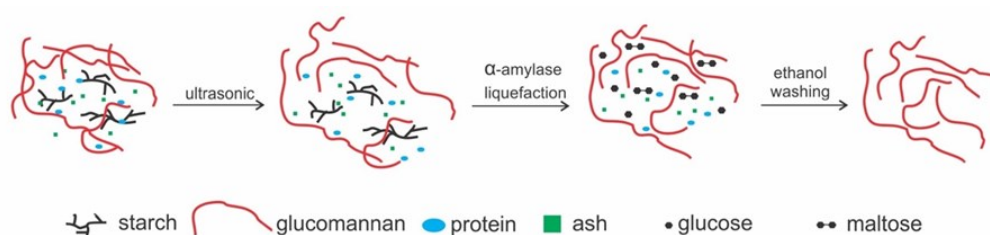


Figure 1. Glucomannan purification using the ultrasonic and α -amylase treatment.

2.10 Color

The color parameter L (lightness) of the glucomannan flour was evaluated using the Chroma Meter CR-400 (Konica Minolta, Tokyo, Japan).

2.11 Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (FTIR) spectra of the glucomannan powder were assessed using an FTIR spectrometer (Vertex 70v model, Bruker, Bremen, Germany). The spectral range was 4,000–400 cm^{-1} .

3. Results

3.1 Maximum activity of the recombinant thermostable α -amylase

The amylolytic activity of α -amylase toward soluble starch was measured at temperatures from 4 to 90°C. The enzyme actively hydrolyzed starch to 90°C (Figure 2). Activity increased gradually from 4 to 20°C and then remained stable at 60°C, although there was a slight increase at 50°C when 0.9–1.0 mg maltose was hydrolyzed. The highest activity occurred at 70°C during the 3-hr incubation. Activity decreased at 80 and 90°C. Therefore, this thermostable α -enzyme was used for the liquefaction process at 70°C.

3.2 Glucomannan content

Glucomannan content of the control (C) sample was 65.40% pure. The combination of UAE and the enzyme treatment significantly increased glucomannan content to 89.96%, making it the highest glucomannan content

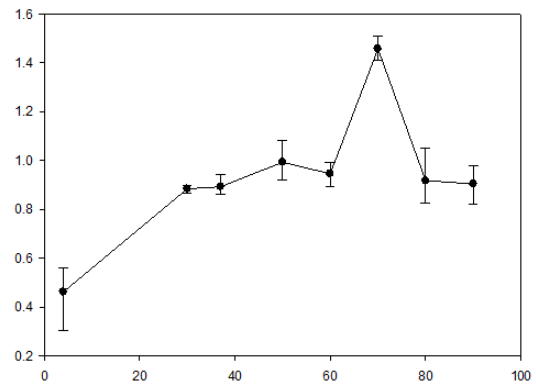


Figure 2. Thermostable α -amylase activity at different temperatures. Each assay was performed in four replicates; error bars indicate the standard deviation.

among the treatments. The enzyme treatment (E) reached 84.27% and UAE (U) reached 73.16% glucomannan content (Figure 3A).

3.3 Viscosity

The highest viscosity value was detected in the control sample (C), which was 1,200 cP. Viscosity decreased significantly after the other treatments. Viscosity in the UAE (U) was 400 cP, which was higher than the other treated sample values. The remaining samples (U+E and E) had the same 160 cP value (Figure 3b).

3.4 Solubility

The solubility (Figure 3c) of the treated samples was higher than the control (C) samples, which was 38.12%. The UAE (U) and enzyme (E) treatments individually increased solubility to 40.16% and 43.08%, respectively.

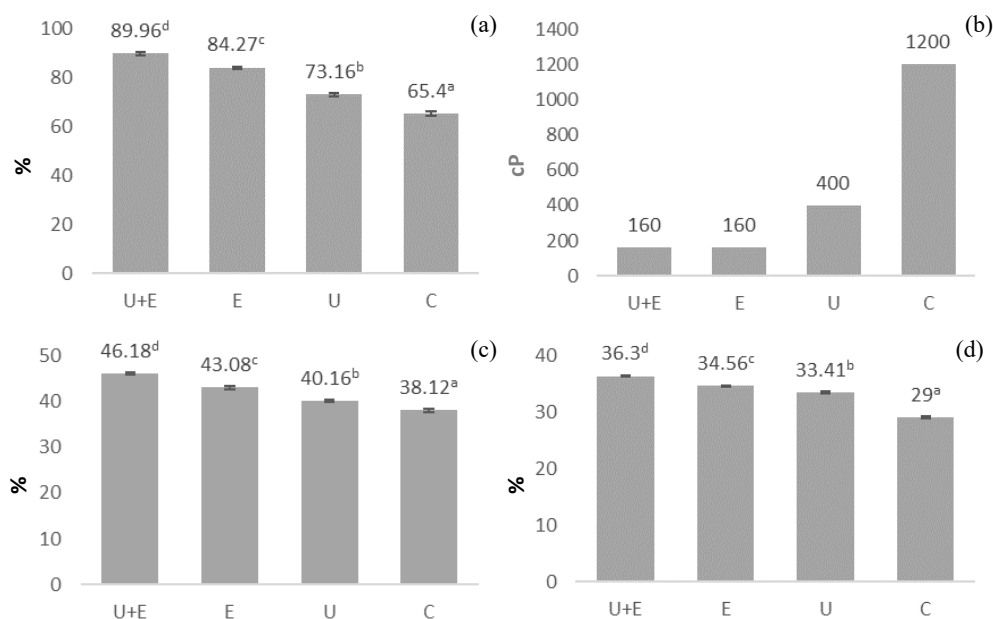


Figure 3. Glucomannan content (A), viscosity (B), solubility (C), and transparency (D) of the ultrasonic and enzyme treatment (U+E), the enzyme treatment (E), the ultrasonic treatment (U), and the control (C). Each assay was performed in triplicate; error bars indicate the standard deviation. Values with different superscripts are statistically significantly different ($P < 0.05$) between treatments.

The highest solubility was 46.18%, which was achieved after the UAE and enzyme combined (U+E) treatment.

3.5 Transparency

Impurities are present around the surface of the glucomannan granule. A glucomannan-water solution can form a thin film with translucent properties. The combination of UAE and the enzyme (U+E) treatment resulted in the most transparent glucomannan, which was 36.3%, followed by the enzyme (E) treatment (34.5%) and the UAE (U) treatment (33.4%) (Figure 3d). The control sample (C) only produced 29% transparency. A brownish color was observed, particularly in the control sample, indicating the presence of impurities within the glucomannan, such as starch, protein, and ash (Table 1). As a result, the solutions and gels prepared with the control sample were cloudy due to water-swollen particulate impurities. Therefore, the results showed that the control sample had the lowest transparency.

3.6 Chemical composition analysis

As shown in Table 1, the starch, reducing sugar, yield, ash, and protein contents of the samples were significantly different, while water content was not significantly different. The combination of UAE and the enzyme treatment resulted in the lowest starch content (0.93 ± 0.02) and consequently the highest reducing sugar level (2.15 ± 0.03). The enzyme and UAE treatments had higher starch content values, which were 1.13 ± 0.0 and 1.98 ± 0.02 , respectively. The treatments lowered the ash content from 3.05 ± 0.04 to 1.58 ± 0.03 after UAE, to 1.42 ± 0.03 after the enzyme treatment, and 1.34 ± 0.02 after a combination of both. The highest protein content was observed in the UAE-treated samples (0.66 ± 0.22). The enzyme and the combined treatments gave almost the same amounts of protein (enzyme 0.54 ± 0.01 , UAE and enzyme 0.55 ± 0.01). Among all samples, the combined UAE and enzyme treatment resulted in a $57.47\pm 2.47\%$ yield, which was the highest (Table 1).

3.7 Morphology

Morphological evaluations were conducted to investigate the effect of enzymatic hydrolysis on the

microstructure of the glucomannan granules. Figure 4 shows the surface of the control granules (A1 and A2), which are magnified 1000 and 5000 times, and the granule surface of the enzyme and UAE treatments magnified 1000 and 5000 times (B1 and B2). The surface of the control was rough and irregularly shaped and was covered by impurities (mainly starch). In contrast, the surface was less rough and the granules were more regularly shaped after the enzyme and UAE treatment (Figure 4).

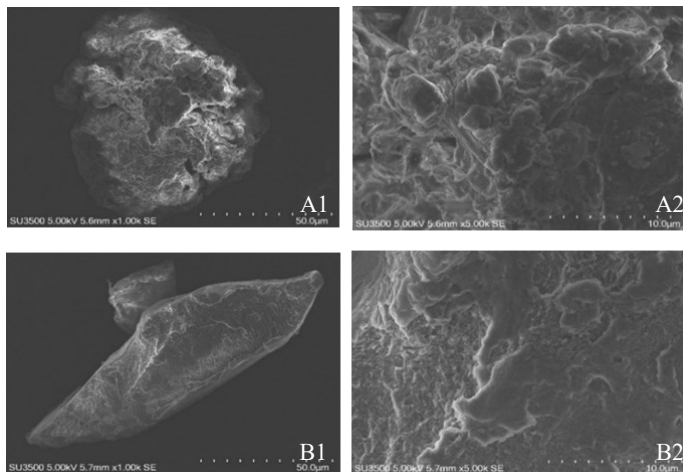


Figure 4. SEM images of the control at 1,000 \times magnification (A1), the control treatment at 5000 \times magnification (A2), the ultrasonic and enzyme treatment at 1000 \times magnification (B1) and the ultrasonic and enzyme treatment at 5000 \times magnification (B2).

3.8 The lightness of the glucomannan flour

Table 2 and Figure 5 show the lightness values of the glucomannan flour. The values are expressed from 0 (black) to 100 (white). The control sample produced a 72.17 ± 0.02 lightness value. The combination of ultrasound and the enzyme treatment (U+E) resulted in the highest value (75.23 ± 0.02). The enzyme and UAE treatments individually resulted in values of 73.68 ± 0.03

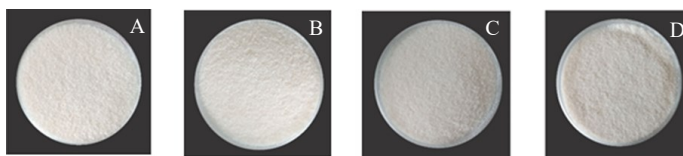


Figure 5. The lightness of the UAE and enzyme treatment (A), the enzyme treatment (B), the UAE treatment (C), and the control (D).

Table 1. Chemical composition of the glucomannan samples

Treatment Compositions (% db)	UAE and Enzyme	Enzyme	UAE	Control
Starch Content	0.93 ± 0.02^a	1.13 ± 0.03^b	1.98 ± 0.02^c	3.35 ± 0.1^d
Reducing Sugar	2.15 ± 0.03^d	1.86 ± 0.02^c	1.64 ± 0.02^b	1.58 ± 0.01^a
Yield	57.47 ± 2.47^c	53.98 ± 2.93^b	52.33 ± 2.69^b	49.84 ± 2.35^a
Ash	1.34 ± 0.02^a	1.42 ± 0.03^b	1.58 ± 0.03^c	3.05 ± 0.04^d
Protein	0.55 ± 0.01^b	0.54 ± 0.01^b	0.66 ± 0.02^c	0.52 ± 0.01^a
Water content	10.36 ± 0.10^a	10.19 ± 0.08^a	10.29 ± 0.08^a	10.30 ± 0.08^a

Values are presented as mean \pm SD of triplicates. Values with different superscript within the same column are statistically significantly different ($p<0.05$).

(43.08%). UAE had the least effective among the treatments. Viscosity is the hydrodynamic volume of a polymer which increases with the increase in molecular weight, chain rigidity, and electron charge density. Viscosity is higher in straight polymers than in branched polymers. The UAE treatment decreased the molecular weights of starch and polysaccharides, which affects viscosity (Iida *et al.*, 2008). The UAE treatment breaks down corn starch grains into smaller sizes by mechanical action and cavitation (Li *et al.*, 2017). This condition was improved by the presence of α -amylase, which degraded the straight polymer constructed of α -1,4 bonds. The solubility of glucomannan can be affected by molecular weight and surface morphology (Luo *et al.*, 2012), the presence of acetyl groups (Gao and Nishinari 2004; Chen *et al.*, 2011), and the strength of the hydrogen bonds (Pan *et al.*, 2013). Strong hydrogen bonding blocks the interactions between water and the OH groups of glucomannan and decreases solubility (Pan *et al.*, 2013). Solubility is low if there are few branch bonds (Capek, 2009). The solubility of glucomannan is affected by the presence of acetyl groups randomly located in the C-6 position of the sugar units every 9–19 sugar units and by the strength of the hydrogen bonds (Kohyama and Nishinari, 1997; Gao and Nishinari, 2004; Chen *et al.*, 2011; Pan *et al.*, 2013). Chen *et al.* (2008) reported that strong hydrogen bonds form between macromolecules of starch and konjac glucomannan, resulting in good miscibility between starch and konjac glucomannan in a blend. Increasing the glucomannan content is believed to increase the number of acetyl groups which enhances the solubility of glucomannan (Liu *et al.*, 2015).

Widjanarko *et al.* (2011) reported that carbonyl groups, such as the acetyl group, indicate the presence of β -1,4 linked glucose and mannose in glucomannan. α -amylase cleaved the α -1,4 linkage; therefore, the enzymatically treated samples (E and U+E) were dominated by β -1,4 linked compounds. The FTIR analysis confirmed that the enzymatic and combined treatments (E and U+E) had higher absorbance of carbonyl groups (C=O) than the UAE and controls, which were assigned to acetyl groups at $\sim 1,630\text{ cm}^{-1}$. Additionally, the U+E treatment revealed a wide O-H peak located at $\sim 3,438\text{ cm}^{-1}$, supporting the increase in hydroxyl groups, which led to higher solubility. The wide band in the polysaccharide spectrum observed at $3,000\text{--}3,700\text{ cm}^{-1}$ was attributed to O-H stretching vibrations of glucomannan (Figure 6). The main contribution was probably provided by the OH groups in the glucose and mannose residues (Zhang *et al.*, 2001). The peaks in the region $\sim 2,920\text{ cm}^{-1}$ originated from C-H stretching of carbohydrates, while the peak at $\sim 2,100\text{--}2,300\text{ cm}^{-1}$ was ascribed to adsorbed water or C=C (Nguyen *et al.*, 2011). The strong peak at $1,600\text{--}1,700$

cm^{-1} suggested the presence of carbonyl groups (C=O) (Liu *et al.*, 2015). The peak at $\sim 1,370\text{ to }1,440\text{ cm}^{-1}$ belonged to the angular deformation of C-H. The C-O ether bond was observed to be stretching at about $1115,37\text{ cm}^{-1}$, while the C-O alcohol bond was stretching at $\sim 1,060\text{ cm}^{-1}$ (Nguyen *et al.*, 2011; Wang *et al.*, 2015; Fan *et al.*, 2016).

The morphology of the U+E samples and the control were evaluated by SEM. The U+E treatment resulted in regularly shaped and less rough granules (Figure 4). Impurities in glucomannan are mainly found at the surface of the glucomannan granule (Zhao *et al.*, 2010). Ohashi *et al.* (2000) reported that glucomannan granules are encapsulated by impurities, including starch, cellulose, and nitrogen-containing material. A previous study on porang flour revealed that the surface became smoother after UAE (Wardhani *et al.*, 2020). Another study on potato-starch-based film reported that an ultrasonication treatment smoothed the film surface (Liu *et al.*, 2018).

Inorganic compounds are impurities that compromise the physical appearance of glucomannan flour. These inorganic compounds, including calcium oxalate and carotenoids, are represented by ash content. The lightness and transparency of the flour were appearance parameters of glucomannan flour. The U+E treatment resulted in the highest lightness ($75.23\pm 0.02\%$) and transparency (36.3%) values with only 1.34% db of ash content. The individual UAE and enzymatic treatments exhibited lower values for those parameters. We assumed that lower ash content was better for the color and transparency of the flour. High temperatures over a long period to a critical point can darken glucomannan and decrease transparency (Ohashi *et al.*, 2000). Wardhani *et al.* (2020) reported that UAE significantly reduces calcium oxalate in porang flour from 1.98% to 0.17%. Calcium oxalate is soluble in water and is removed by ethanol extraction. Natural carotenoids in tubers that are still present in porang flour can be released during the alcohol washing step because these pigments dissolve in ethanol (Wootton *et al.*, 1993). After extracting glucomannan from fresh porang tuber with ethanol, Nurlala *et al.* (2021) reported that moisture, lipid, protein, crude fiber, and calcium oxalate levels decreased significantly to 13.58%, 0.07%, 4.03%, 4.95%, and 0.56% respectively. The condition was improved by thermostable α -amylase, which hastened the liquefaction process.

5. Conclusion

The combined treatment of UAE and α -amylase liquefaction successfully purified glucomannan from

porang flour. This treatment significantly reduced starch to $0.93 \pm 0.02\%$ db and ash content to $1.34 \pm 0.02\%$ db. Consequently, the treatment increased glucomannan content to 89.69%, lowered its viscosity to 160 cP, and enhanced solubility to 46.18%. The treatment improved the transparency and lightness of the flour. The pure glucomannan granules obtained after the combined UAE and enzyme treatment were regularly shaped with a rather smooth surface and a higher frequency of hydroxyl and carbonyl groups than the other treatments. This study provides an alternative method to obtain purer glucomannan by combining UAE and thermostable α -amylase liquefaction.

Conflict of interest

The authors declare no competing financial interests or personal relationships that affected the work reported in this paper.

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