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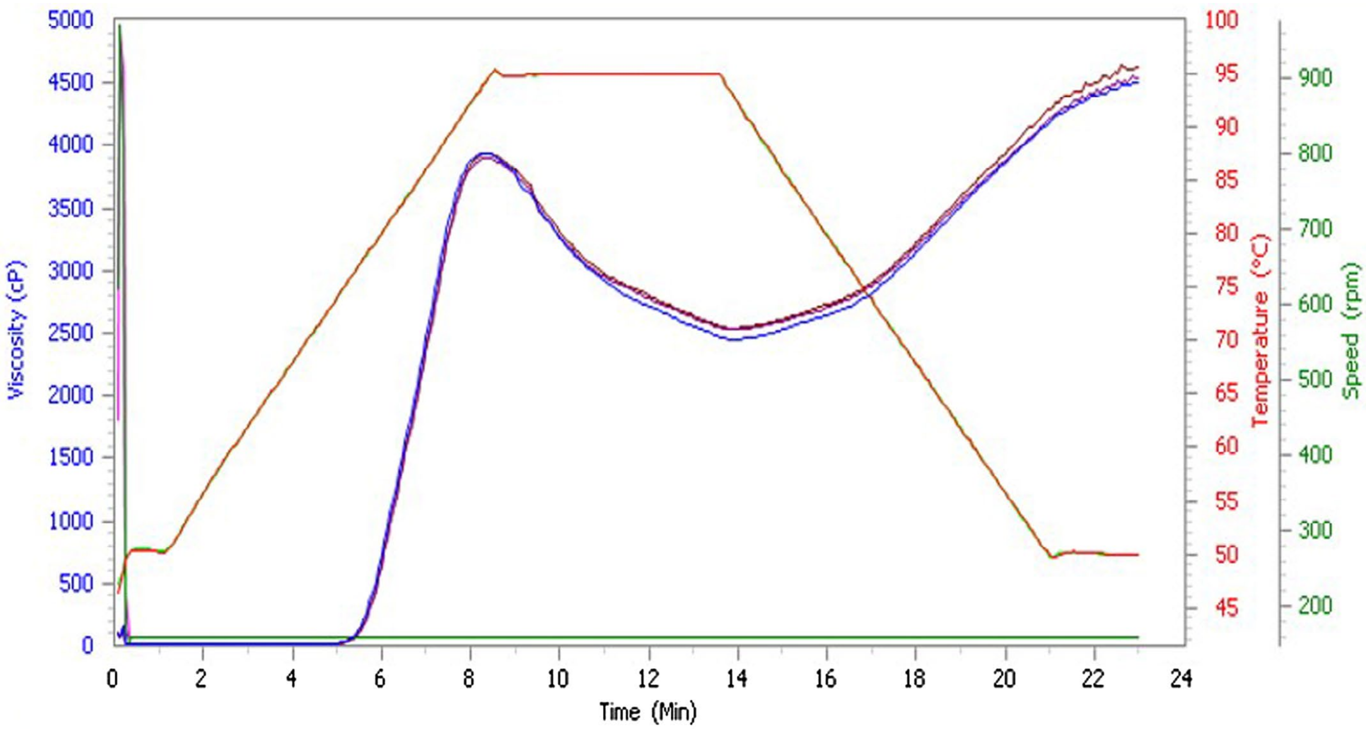

FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

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Physicochemical characteristics of starch from Indonesian Numbu and Genjah sorghum (*Sorghum bicolor* L. Moench)

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Abstract: Within this study, several physicochemical properties of starch from Indonesian Numbu and Genjah sorghum (*Sorghum bicolor* L. Moench) were investigated. This characterization is of importance to find the prospective applications of those starches. Based on the analyses of pasting, and gelatinization properties, starch from Numbu was suitable as an ingredient for dairy products, mayonnaise and salad dressings, while Genjah could be properly used as ingredient for noodles, soup and sauces. For both types of sorghum, the starch gelatinization temperatures were 75.97 and 77.30°C, respectively for Numbu and Genjah variety. It was higher compared to corn starch (i.e. 62–72°C). Herein, these starches conclusively require a longer cooking time and a larger thermal energy whenever used as ingredients for producing food products.

Subjects: Food Additives & Ingredients; Food Chemistry; Food Engineering

Keywords: sorghum; starch; gelatinization; pasting properties; amylose; amylopectin

1. Introduction

Sorghum is cultivated extensively in Asia and Africa since it is used in a wide range of applications—energy (bioethanol production), feeds and foods (processed and semi-processed foods) (Ali & Hasnain, 2014). Sorghum is usually resistant to drought, pests and diseases, owing a high production yield (can be up to 6 t/ha) with relatively inexpensive production costs (Indahsari & Wibowo, 2013;

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PUBLIC INTEREST STATEMENT

Processing sorghum as semi-processed foods, in forms of starch and flour is mostly done to improve the utilizations of sorghum, extend shelf life, ease or simplify the mixing, fortification and cooking. Considering Indonesia has a large annual consumption of carbohydrate, which is imposed mainly on the rice production; sorghum can be used as the alternative. This study was therefore, conducted to see the potentials of sorghum cultivated in Indonesia to fulfill the needs of starch in industrial process. From the overall analysis of pasting properties, starch from Numbu was suitable as an ingredient for dairy products, mayonnaise and salad dressings, while Genjah can be properly used for noodles, soup, and sauces. Further applications of these types sorghum flour should be studied in the future.

Suryaningsih, 2014; Tsuchihashi & Goto, 2004). In Indonesia, it is normally cultivated as monoculture or intercropping systems, distributed in the areas of Java, Sumatera, Nusa tenggara barat (NTB) and Nusa tenggara timur (NTT) (Suryaningsih, 2014).

In terms of processed foods, sorghum is normally used as an ingredient for bakery products and as functional ingredients (Awika & Rooney, 2004; Hugo, Rooney, & Taylor, 2003; Kulamarva, Sosle, & Raghavan, 2009; Serrem, de Kock, & Taylor, 2011). Processing sorghum as semi-processed foods, in forms of starch and flour is mostly done to improve the utilizations of sorghum, extend shelf life, ease or simplify the mixing, fortification and cooking process (Kulamarva et al., 2009; Youssef et al., 1990; Zhu, 2014). Considering Indonesia is having a large annual consumption of carbohydrate, which is imposed mainly on the rice production; sorghum can be used as the alternative (Tsuchihashi & Goto, 2008). On the other case, to fulfill the need of starch in industrial process, sorghum can be used as a complementary source/food ingredient as it has a high starch content, of 70% (Zhan et al., 2003).

In general, starch derived from different sources (grains, tubers, etc.) has different granule structures, sizes, molecular weight distributions, and ratios of amylose to amylopectin (Oladunmoye, Aworh, Maziya-Dixon, Erukainure, & Elemo, 2014). This consequently will influence the thermophysical, pasting and other physical characteristics (Castro, Dumas, Chiou, Fitzgerald, & Gilbert, 2006; Kulamarva et al., 2009). The properties of starch substantially determine the proper utilizations of starch, either for food, feed, or textile industries (Shewayrga, Sopade, Jordan, & Godwin, 2012; Zhou, Shi, Meng, & Liu, 2013). Hence, this research was aimed to characterize the starch extracted from Indonesia sorghum varieties. The characterizations were highlighted on the amylose and amylopectin contents, thermophysical and pasting properties.

2. Materials and methods

2.1. Materials

Sorghum variety of Numbuh and Genjah were obtained from Mt. Kidul, Yogyakarta, southern area of central Java, Indonesia. Other chemicals for the starch extraction and analysis purposes were analytical grade and purchased from Sigma-Aldrich (Germany).

2.2. Starch isolation

A method described by Pérez Sira and Lares Amaiz (2004) to isolate starch at laboratory scale was adopted with minor modifications. The polished sorghum grains (ca. 1 kg) were soaked in 0.25% (wt) NaOH for overnight. The grains were washed with water to neutralize the pH. The wetted grains were crushed for 2 min. The homogenate was screened through an 80 Mesh sieve for four times and followed by a single screening using 100 and 200 Mesh sieve. The filtrate was rested overnight. The resulted starch was washed with distilled water and eventually was dried overnight in a drying oven at 45°C.

2.3. Starch characterizations

2.3.1. Proximate and starch content analysis

Proximate analyses were carried out based on the official methods of analysis of AOAC International (AOAC, 2006) Starch content was determined using Luff Schoorl method (Drogba Alexis & Gnopo Jean, 2012; Sahoré, Nemlin, & Kamenan, 2007).

2.3.2. Amylose content

The stock solution was made by putting 4.0 g amylose standard into 100 mL volumetric flask, added with 1.0 mL ethanol 95% v/v and 9.0 mL 1 N NaOH. This solution was heated at 95°C for 10 min. After heating, such amount of distilled water was added into the flask to reach 100 mL of solution. A standard curve was made by taking as much as 1.0, 2.0, 3.0, 4.0, and 5.0 mL of stock solution and added with (respectively) 0.2, 0.4, 0.6, 0.8, and 1.0 mL 1 N $C_2H_4O_2$. As much as 2 mL iod solution (containing 0.2 g I_2 and 2 g KI in 100 mL distilled water) was eventually added to the prepared standards. The standards were then rested for 20 min and measured using spectrophotometer at 625 nm. The amylose content of the isolated starch was prepared and measured with the same procedure sample as above with the sample weight of 100 mg.

2.3.3. Bulk density and whiteness measurement
Bulk density was determined using a method developed by Okezie and Bello (Okezie & Bello, 1988). A 10 mL graduated cylinder, previously tared, was gently filled with sample. The bottom of the cylinder was gently tapped on a laboratory bench several times until there was no further dimunition of the sample level after filling to the 10 mL mark. Bulk density was calculated as weight of sample per unit volume of sample (g/mL). Starch's whiteness was determined using KETT Digital Whiteness Meter Model C-100, PT. Damarus, Indonesia.

2.3.4. Pasting, morphological and thermophysical properties
Rapid Visco Analyzer (RVA) (TechMaster2, Perten Instruments, USA) was employed to measure the pasting properties of starch according to Singh, Kaur, Sandhu, Kaur, and Nishinari (2006). A temperature-time cycle (heating rate) was conducted as following: sample was heated at 30°C for 1 min, followed by heating to reach 95°C (~7.5 min) and this value was kept for 5 min. After that, sample was cooled down to 50°C within 7.5 min and kept for 2 min. Parameters, such as pasting temperature, peak viscosity, minimum viscosity, final viscosity, breakdown, and setback were recorded (Sang, Bean, Seib, Pedersen, & Shi, 2008).

Morphological properties were determined according to the method reported by Colussi et al. (2014). A scanning electron microscope (SEM) (Model JSM - 5310 LV, Deben, UK) was employed to view the morphologies of the samples. Starch was attached onto double-sided adhesive tape and coated with gold-palladium prior to analysis. There were ten samples analyzed for each sorghum flour.

For thermal properties measurement, starch (1.5 mg) was put on the aluminum pan, sealed hermetically and analyzed using differential scanning calorimeter (DSC) Model 60, Shimadzu Scientific Instruments (Singh, Inouchi, & Nishinari, 2006; Singh, Sodhi, & Singh, 2010).

2.4. Statistical analysis
Statistical package for social sciences (SPSS) 16.0 for Windows was used to analysis the data. Characteristics of Numbu and Genjah varieties were analyzed using independent sample *t-test* with the level of significance of 95%.

3. Results and discussion

3.1. Physicochemical characteristics of sorghum starch (Sorghum bicolor L. Moench) of Numbu and Genjah variety
In Table 1, the independent sample *t-test* of proximate analysis, starch content, amylose and amylopectin content, bulk density and whiteness between Numbu and Genja variety were tabulated. The moisture, protein, and fat contents of Numbu and Genjah were significantly different at 95% confidence level whereas the ash content of Numbu and Genjah were not. The ash contents measured in this study were lower than those from white and red sorghum starch reported by Olayinka, Olu-Owolabi, and Adebowale (2011). Protein contents of both varieties were quite high (3–4% db) with Numbu protein content was superior. Protein plays an important role in the swelling ability of starch granules. Proteins normally situated in the outer areas of starch granules and thus limit the swelling ability when the gelanitization process taking place (Charles et al., 2007). Moreover, the influence of macromolecule, such as fat will be on the amylograph profile of the starch. Higher content of fat that bonded with starch granules will result in a higher gelatinization peak temperature, which is believed to be an indicator of crystallite quality (Sang et al., 2008). Fat content of Numbu was higher compared to Genjah. Nevertheless, this value was still considered low (0.3–0.5% db).

Table 1. Physicochemical properties of sorghum starch (*Sorghum bicolor* L. Moench) of Numbu and Genjah variety

Physicochemical properties		Variety	
		Numbu	Genjah
1. Proximate analysis	Water content(% db)	7.44 ± 0.15^a	6.78 ± 0.06^b
	Ash content(% db)	0.28 ± 0.00^a	0.43 ± 0.00^a
	Protein content(% db)	4.21 ± 0.13^a	3.06 ± 0.06^b
	Fat content(% db)	0.47 ± 0.01^a	0.32 ± 0.01^b
	Carbohydrate content(% db)	87.60	89.41
2. Starch content (%)		79.49 ± 0.37^a	85.01 ± 0.62^b
3. Amylose and amylopectin content	Amylose (%)	22.48^a	18.62^b
	Amylopectin (%)	77.52	81.38
4. Bulk density (g/mL)		0.76 ± 0.00^a	0.79 ± 0.00^b
5. Whiteness (%)		83.41 ± 0.55^a	66.10 ± 0.60^b

Notes: Numbers followed by different letters as superscripts in similar row are significantly different with level of significance of 95% ($n = 3$).

Starch content of Numbu and Genjah were significantly different, of approximately 80 and 85% db, respectively. Herein, the purity of isolated starch was considerably low. The plausible explanation can be due to higher protein contents of those varieties (3–4% db). The amylose content of Numbu (22.48%) was higher than Genjah (18.62%). Generally, amylose content varies and dependent on the sources of starch, climate and soil conditions during cultivation (Singh et al., 2006; Zhu, 2014). Cited as an example, the amylose content of white and red sorghum starch were 27.1 and 24.80%, respectively, and these values are higher compared to those in this study (Boudries et al., 2009). These types of sorghum (e.g. white and red) were cultivated in Sahara, Algeria with annual temperature ranging from 8 to 45°C, whereas for Numbu and Genjah were cultivated in Mt. Kidul, Yogyakarta which having temperature between 22 and 28°C.

The result of bulk density analysis can also be seen in Table 1. Independent sample *t-test* showed that the bulk density of Numbu and Genjah were significantly different. Ganorkar and Kulkarni (Ganorkar & Kulkarni, 2013) reported a smaller bulk density of sorghum starch with variety CSH 9, which was approximately 0.58 g/mL. For the whiteness property, variety of Numbu (83.41%) had higher whiteness as compared to Genjah (66.10%). Starch from variety of Genjah had pinkish color. During the isolation, there was not any attempt to whiten the isolated Genjah starch. Compared to the whiteness of white and red sorghum starch which were 81.39 and 77.17%, respectively (calculated according to Stensby whiteness from L, a and b Hunter Color Coordinates), the whiteness of starch variety of Numbu was still higher (Boudries et al., 2009). There are several possibilities to increase the whiteness of sorghum starch during the isolation, such as soaking either with a mixture of 5.25% NaOCl solution and 10.70% KOH or in a mixture of SO_2 and 0.5% lactic acid (Pérez Sira & Lares Amaiz, 2004; Wang, Chung, Seib, & Kim, 2000).

3.2. Pasting properties

RVA-viscograms of Numbu and Genjah starch were recorded, where for each variety was analyzed thrice (3 lines were overlayed within one figure). The information from these viscograms was tabulated in Table 2. The higher fat and amylose content of Numbu led to a lower peak viscosity (see also Tables 1 and 2). Amylose can hamper the swelling of starch granules by forming a complex with fat, resulting in a lower peak viscosity at higher pasting temperature (Sang et al., 2008). Genjah variety is a pigmented sorghum grain, where it normally has a higher peak viscosity (Boudries et al., 2009). The results corresponded to this literature where Genjah variety had higher peak viscosity (4959 cP) than Numbu (3927.67 cP). Other factor that could be contributive for a higher peak viscosity is the amylopectin content. According to Ratnayake, Hoover, and Warkentin (2002), amylopectin is a

Table 2. Gelatinization profiles of Numbu and Genjah starch

	Numbu	Genjah
Peak viscosity (cP)	3927.67	4959.00
Trough viscosity (cP)	2506.33	1849.33
Breakdown viscosity (cP)	1421.33	3109.67
Final viscosity (cP)	4551.33	4220.00
Setback viscosity (cP)	2045.00	2370.67
Peak time (menit)	8.31	7.29
Gelatinization temp. (°C)	76.22	75.32

component that is responsible for granules swelling. Hence, the starch with higher amylopectin content will consequently have a higher peak viscosity. Protein content also plays an important role in influencing the ability of starch granule to swell. Protein that surrounds starch granules tends to restrict granules to swell and thus, lowering the peak viscosity (Charles et al., 2007). Additionally, according to Beta and Corke, the peak viscosity and its corresponding time of sorghum starch are remarkably influenced by genotype and environmental conditions (Beta & Corke, 2001). Corresponding to peak viscosity, Genjah starch had a shorter peak time which means a shorter cooking time of starch paste. This starch characteristic is suitable for a fill-viscosity aid in soups and sauces. Fill-viscosity aid generally provides sufficient viscosity at the beginning of cooking process.

From Table 2, breakdown viscosity of Genjah was higher compared to Numbu. An increase in breakdown viscosity values showed that the starch was less resistant to heating and stirring (Lee, Baek, Cha, Park, & Lim, 2002). Herein, Numbu variety was conclusively more stable to both cooking and stirring. Taking this characteristic into account, starch from Numbu variety can be used as ingredient in dairy products since the processes for dairy products manufacturing often involve high temperatures and intensive stirring operations. Moreover, it (e.g. starch from Numbu) might be also used as a thickener and stabilizer in mayonnaise and salad dressing preparations (Ali & Hasnain, 2014; Ratnayake et al., 2002; Zhu, 2014).

According to Goodfellow and Wilson (Goodfellow & Wilson, 1990), the proportion of amylose and amylopectin structure has an important role in the speed and degree of retrogradation. Other important parameters affecting retrogradation has been reviewed elsewhere (Zavareze & Dias, 2011). From setback viscosity, the information that could be evaluated is the tendency of retrogradation. Therefore, having a higher setback viscosity (see Table 2), starch of Genjah was likely having higher tendency to undergo retrogradation. This gives a suitability of Genjah starch's application in noodles since typical starch yields in a higher cohesiveness, hardness, lower stickiness and cooking loss. Genjah variety also had a higher peak viscosity. It is, therefore, contributive for a higher elongation property in noodles as well. Genjah starch tends to experience retrogradation because it had higher setback viscosity. This higher setback viscosity contributes to the higher cohesiveness and hardness of the paste after cooling (Crosbie, 1991) . Hereby, Genjah starch is possible to be used as ingredient for making noodles. By having higher cohesiveness and hardness, the noodles will have a lower cooking loss during the production. In addition to this, a higher peak viscosity for Genjah starch will also contribute to the higher percentage of elongation which is needed for noodle production (Beta & Corke, 2001). The same results have been reported elsewhere (Sandhu, Kaur, & Mukesh, 2010), where potato starch noodles were superior to rice starch noodles as they exhibited a higher peak viscosity and setback viscosity, thus, contributing positively to firmness, gel hardness, and chewiness.

3.3. Starch granules: Shape and size

The granule shapes of Numbu and Genjah are depicted in Figure 1. Sorghum starch granules from two varieties tend to be rounded and polygonal with some granules had rough surfaces. The size of Numbu starch granule varied from 3.8 to 38.7 μm, whereas for Genjah was ranging from 4.3 to

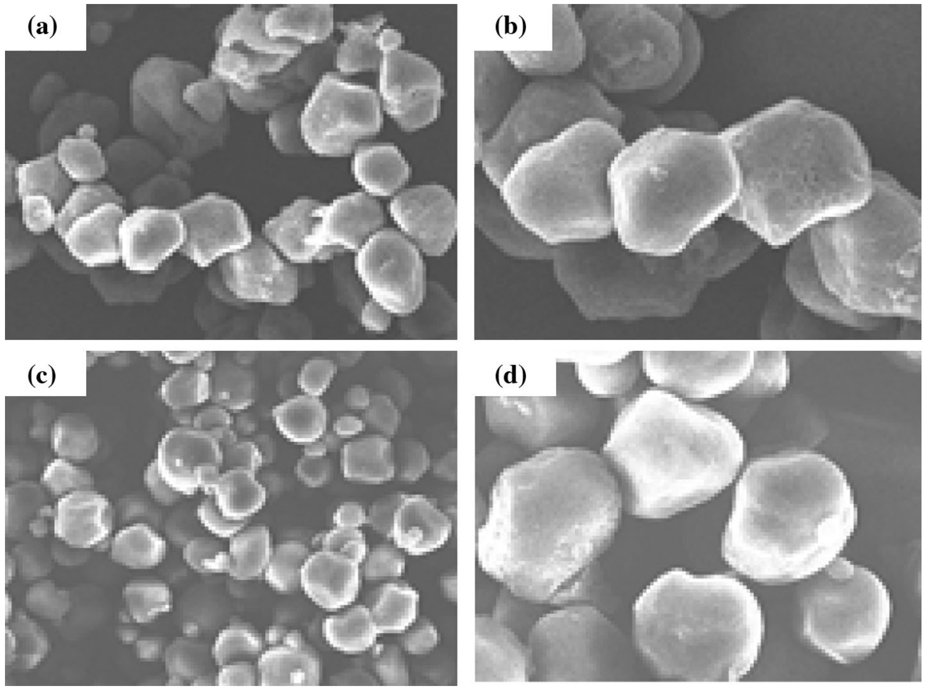

Figure 1. Shapes and sizes of Numbu (A and B) and Genjah (C and D) starch granules: (a) and (c) magnification = 1000X, (b) and (d) magnification = 2000X.

Table 3. Gelatinization characteristics of Numbu and Genjah starch

Variety	Peak/T_P (°C)	Onset/T_O (°C)	Conclusion/T_C (°C)	Heat/Δ*H* (J/g)
Numbu	75.97	65.03	63.57	−101.11
Genjah	77.30	40.41	75.00	−98.52

25.0 µm. Compared to the previous study, the sizes of sorghum starch granules have been reported in a range of 5 to 25 µm (Sang et al., 2008).

3.4. Gelatinization characteristics

The gelatinization transition temperature (T_O (onset), T_P (peak) and T_C (conclusion)) and the enthalpy Δ*H* of Numbu and Genjah starch are presented in Table 3. The peak temperature (T_p) of Genjah (77.30°C) was higher than Numbu. Herein, Genjah starch had a higher proportion of long chains in amylopectin, thus, required higher temperature to dissociate the granules (Karim et al., 2007). Moreover, it indicates the stability of starch crystals which consequently related to its applications (Moorthy, 2002). Gelatinization temperatures of sorghum grown in South Africa were in a range of 67 to 73°C, whereas in India between 71 and 81°C (Taylor, Schober, & Bean, 2006). Compared to corn starch, sorghum starch gelatinization temperature is higher, thus, requires a longer cooking time and a larger thermal energy.

4. Conclusions

Genjah variety had a larger swelling capability than Numbu considering its peak viscosity. Evaluation on breakdown viscosity, Numbu was conclusively more stable to heating and stirring process. From the overall analysis of pasting properties, starch from Numbu was suitable as an ingredient for dairy products, mayonnaise and salad dressings, while Genjah can be properly used for noodles, soup, and sauces. Further applications of these two types of sorghum flour should be studied in the future. The shapes of starch granules for both varieties were rounded and polygonal. The granule size of Numbu varied from 3.8 to 38.7 µm whereas for Genjah was in a range of 4.3 to 25.0 µm. Based on the DSC analysis, Genjah starch had a higher proportion of long chains in amylopectin, thus, required higher temperature to dissociate the granules. Such further study is needed to see other physical properties of these starches as well as their functional properties.

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Competing interest
The authors declare no competing interest.

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