

Physicochemical properties of heat moisture treated sweet potato starches of selected Indonesian varieties

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Abstract

The study was aimed to modify sweet potato starches (SPS) of Indonesian varieties to be suitable for starch noodle production. SPS were isolated from four varieties, namely Sுகು, Cangkuang, Jago and Papua Salosa. The native SPS were adjusted to moisture content of 25% and exposed to heat moisture treatment (HMT) at 110°C for 3, 4 and 5 h. The native and treated starches were characterized for swelling power, solubility, gel hardness, pasting properties and microstructure. The results indicated that HMT reduced the swelling power and solubility, even though the length of treatment did not affect both properties. Except in Papua Salosa, HMT increased gel hardness with the longer treatment time resulted in less increase. HMT increased pasting temperature, and longer treatment time led to higher increased value. HMT reduced peak viscosity, and the longer treatment resulted in the higher reduction. The final viscosity of treated starches was higher than the native ones, except for Papua Salosa. The highest final viscosity with a significant increment was shown by Sுகು (517.5 RVU) treated for 4 h. Longer HMT led to a slightly decrease in final viscosity. In general, HMT clearly shifted SPS from Type A to Type C of amylographic pattern, except for Papua Salosa. Photomicroscopy showed that the forms of SPS granules of all varieties were spheric. HMT did not modify the form and size of the starch granules. The greatest effect of HMT on the physicochemical changes was observed in SPS from Sுகು, followed by Jago and Cangkuang varieties. It could be concluded that heat moisture treated Sுகು starch for 3 h was recommended for noodle production.

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Introduction

Nowadays, food security in Indonesia is still a big problem mainly due to the productivity of main food crop that tends to level off, land use conversion and population growth. An alternative to overcome this problem is through food diversity development. The food material sources that need improvement are non-rice carbohydrate type. Through development of processing technique, the food materials will have higher added value and are able to fulfill food product criterias in terms of diversity, nutrition, quality, physical and economical availability (Suryana, 2001). Sweet potato is one of potential food commodities as a carbohydrate source that needs to be developed.

Sweet potato (*Ipomoea batatas* L.) is a carbohydrate source commodity after rice, maize and cassava. In Indonesia, sweet potato has important role for food and industrial material supplies. Sweet potato can be used to support food diversification program to fulfill calory need of the people (Rukmana, 1997; Lase *et al.*, 2013). As a productive crop containing

high carbohydrate, sweet potato is easily grown and produced at a shorter time in various field conditions with productivity ranging 20-40 ton/ha of fresh tubers (Zuraida and Supriyati, 2001). Several sweet potato varieties commonly grown in Indonesia are varying from white, yellow and violet tubers. They are spread out almost all the regions. Several varieties have been grown and developed by farmers such as Sுகು, Shiroyutaka, Cangkuang, Sawentar, Jago and Papua Salosa (Balitkabi, 2012).

In Indonesia, sweet potato is generally consumed by simple cooking, e.g. boiling, steaming, roasting or frying. For industrial purpose, sweet potato has to contain high total solid, particularly starch. In some Asian countries like China, Taiwan and Korea, sweet potato has been processed into important staple foods like starch noodle and cake (Collado and Corke, 1997; Zuraida and Supriyati, 2001). It needs appropriate technology to expand the utilization of Indonesian sweet potato for staple food like noodle.

In general, sweet potato starch (SPS) has inferior characteristics in relation to starch noodle production.

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SPS swells easily, does not gel firmly and shows Type A of pasting amylographic pattern (Tian *et al.*, 1991), while mungbean starch shows Type C which is suitable for starch noodle production. It is believed that starch noodle quality is closely related to high amylose content and limited swelling pattern (Kim and Wiesenborn, 1996; Collade *et al.*, 2001).

Modification of starch by physical technique like heat moisture treatment (HMT) is considered to be safer than by chemical treatments. This method was able to modify functional properties of starches (Stute, 1992). HMT refers to starch treatment at high temperature, above gelatinization temperature (80-120°C) with limited moisture content (18-27%). In general, hydrothermal is known to affect an increase of gelatinization temperature and change in gelatinization range, X-rays diffraction pattern, swelling power and solubility with consequent functional changes. It has been studied that heat moisture treated SPS could modify Type A into Type C of amylographic pattern that usually belongs to bean starches only. Therefore, it leads to SPS to be suitable for starch noodle production (Collado and Corke, 1999; Tsakama *et al.*, 2011). This study was aimed to obtain HMT condition for SPS of four selected Indonesian varieties to result in improved starch characteristics for starch noodle production.

Materials and Methods

Materials

Four varieties of sweet potato namely Suku, Canguang, Jago and Papua Salosa were initially planted in the fields of Research Institute for Legumes and Tuber Crops, Malang, East Java. After growing for 4 months, fresh sweet potato tubers were harvested from the field and immediately transported into the laboratory for starch isolation process.

Starch extraction

Sweet potato starch was extracted by following the method of Collado and Corke (1997) with a slight modification. Sweet potato tubers were washed, peeled off, grated and extracted using distilled water in the ratio of water : sweet potato at 1:1, and filtered through 200 mesh to obtain filtrate 1. Cake resulted was added with distilled water at the water : cake ratio of 1:0.5, squeezed and filtered through the same mesh to obtain filtrate 2. Filtrate 1 and filtrate 2 were mixed, settled down for 6 h, and the water was replaced every 3 h. Water and sediment were separated, and the sediment obtained was to be wet starch which was then dried overnight using oven at 50°C. The dry starch was milled and sieved with 200 mesh and then kept in sealed containers for further

study.

Heat moisture treatment

The heat moisture treatment was carried out in accordance with the method of Collado *et al.* (2001) with a slight modification. Initially, the moisture content of the native starch was adjusted to 25% by adding distilled water, and kept at 5°C overnight. The sample was then heated in an oven at 110°C for varying time of 3, 4 and 5 h. After that, the samples were immediately cooled to avoid further gelatinization and dried in an oven drying 50°C overnight to reach moisture content <12%. The treated starch was cooled at ambient temperature and packed until further analysis.

Swelling power and solubility

Swelling power and solubility of the starches were measured based on the method of Tester and Morrison (1990). A sample (0.2 g) was put in a centrifuge tube and added with 10 ml of distilled water. The sample was equilibrated at 25°C for 5 min and then put in a waterbath at 95°C for 30 min. Then, it was cooled at 20°C for 1 min. After that, starch sample was centrifuged at 3,500 rpm for 15 min to separate gel and supernatant. The gel was weighed to determine swelling power.

$$\text{Swelling power} = \frac{(\text{Gel weight} + \text{container}) - (\text{Sample weight} + \text{container})}{\text{Sample weight}}$$

On the other hand, the supernatant was placed onto a petridish and dried at 100°C for 4 h to calculate dissolved starch. The dried supernatant was weighed to determine the starch solubility.

$$\text{Starch solubility} = \frac{\text{Dry weight of supernatant}}{\text{Sample weight}} \times 100\%$$

Gel hardness

The gel hardness of starches was measured according to Sanabria and Filho (2009). A starch suspension at 6% (w/v) was heated at 95°C for 15 min. The paste formed was poured into a 50 ml container and cooled at ambient temperature. Then, the sample was kept at 4°C for 24 h. The gel obtained was used for texture measurement by using Universal Testing Machine Zwick (Zwick ZO.5, Zwick GmbH & Co., Germany). Gel was tested with cylindrical plunger having diameter 10 mm at the speed head of 1.0 mm/s and the force (N) recorded was used to determine the gel hardness.

Pasting properties

Pasting properties was characterized using Rapid Visco Analyzer (RVA, Model 4D, New Port Scientific, Australia) following the method of

Shimelis *et al.* (2006). Three g of starch was analyzed based on standard profile 1, i.e. by mixing for 1 min, agitating and heating at 50°C, then heating up to 95°C for 3 min 42 sec at an increasing rate of 12°C/min and maintained at 95°C for 2.5 min. After that, the temperature was decreased to 50°C at the rate of 12°C/min and maintained at 50°C for 2 min. The process was ended after 13 min and the starch pasting curve was recorded.

Photomicroscopy

Microscopic examination was carried out in accordance to the procedure of Chen (2003). Starch sample was put on the deck glass, observed under an optical microscope (Optika Microscopes, Italy) equipped with a 8.0 Mega pixels digital camera at 400 X magnification and the picture was taken.

Statistical analysis

Experimental design used in this study was Complete Randomized Design (CRD). All treatments were repeated in a triplicate. Statistical data analysis employed software Statistical Package for Social Science (SPSS) version 12 with One Way Anova and Univariate Analysis of Variance at significance level of 95% ($p < 0.05$). Means difference was using Duncan's Multiple Range Test (DMRT).

Results and Discussion

Swelling power, solubility and gel hardness

The SPS had swelling power values ranging from 16.98 to 20.64 g/g (db) as shown in Table 1. Different varieties exhibited significantly different swelling power. The lowest swelling power was shown by Sukeh variety and the highest one by Cangkuang. These results were obviously lower compared to that of reported by Collado and Corke (1997) who obtained the values between 30.9 to 35.3 g/g (db). Swelling power of the starch is affected by amylose and amylopectin present in the starch granule (Tester and Morrison, 1990). The starch granule will expand continuously when heated up in the water and the amylose is one factor affecting the swelling level. HMT affected significantly ($p < 0.05$) swelling power of the SPS. The lowest swelling power was resulted by Jago (11.64 g/g (db)) HMT for 5 h, but it was not significantly different from the same variety treated for 4 h (Table 1). Table 1 also shows that all native starches had higher swelling power compared to their respective HMT starches. These results were similar to that of studied by Collado and Corke (1999) with two varieties of SPS, and with the works of Hormdok and Noomhorm (2006) with rice starch. The different HMT time did not show significant differences in

Table 1. Swelling power, solubility, gel hardness of native and treated SPS

Varieties	Treatment	Swelling Power (g/g) db	Solubility (%) db	Gel Hardness (N)
Sukeh	Native	16.98±0.51 ^c	14.66±3.74 ^b	0.14±0.09 ^{bcd}
	HMT 3 h	12.95±0.32 ^{ab}	5.43±2.94 ^a	0.39±0.03 ⁱ
	HMT 4 h	12.76±0.31 ^{ab}	5.65±0.96 ^a	0.38±0.04 ⁱ
	HMT 5 h	12.41±0.71 ^{ab}	5.54±3.24 ^a	0.31±0.02 ^b
Cangkuang	Native	20.64±1.82 ^e	15.13±1.0 ^b	0.13±0.01 ^{bc}
	HMT 3 h	13.40±0.24 ^b	5.72±1.23 ^a	0.25±0.02 ^g
	HMT 4 h	13.05±0.27 ^{ab}	6.80±1.47 ^a	0.23±0.02 ^{efg}
	HMT 5 h	12.64±0.54 ^{ab}	6.50±2.28 ^a	0.22±0.02 ^{ef}
Jago	Native HMT	18.55±0.35 ^d	12.73±2.17 ^b	0.08±0.00 ^a
	3 h	12.67±0.79 ^{ab}	3.70±0.38 ^a	0.24±0.00 ^{fg}
	HMT 4 h	12.23±0.58 ^{ab}	3.76±1.33 ^a	0.20±0.01 ^e
	HMT 5 h	11.64±0.79 ^a	5.95±1.12 ^a	0.17±0.01 ^d
Papua Salosa	Native	19.86±1.13 ^{de}	12.76±0.82 ^b	0.13±0.01 ^{bc}
	HMT 3 h	13.68±0.68 ^b	5.16±2.28 ^a	0.16±0.01 ^{cd}
	HMT 4 h	12.56±0.12 ^{ab}	6.66±2.38 ^a	0.16±0.01 ^{cd}
	HMT 5 h	12.75±1.92 ^{ab}	7.65±1.32 ^a	0.11±0.02 ^{ab}

Mean ± standard deviation

Value in a column followed by the same superscript is not significantly different ($p > 0.05$)

the swelling power. During HMT, there was an increase of molecular bond interaction in the starch, but it caused a loss of double helix formation of the starch molecule, therefore limiting swelling power. Srichuwong *et al.* (2005) stated that the decrease of swelling power in the starch after HMT is due to the loss of starch granule integrity after the swelling attained. According to Adebawale *et al.* (2005), the low swelling power of starch due to HMT was related to the limited water penetration into the starch. This is due to the increase of crystallinity.

Table 1 shows that the solubility of SPS from four varieties studied is not significantly ($p > 0.05$) different. The starch solubility in this study was closed to those of reported by Collado and Corke (1997) at 14 varieties of sweet potato, ranging from 10.7 to 14.6%. The lowest solubility was revealed by Jago treated for 3 h. However, this result was not significantly different with those of treated for 4 h and 5 h, but was significantly different from the native starch. In all varieties, the solubility of native starches was higher than the HMT starches. However, the solubility tended to increase with the longer HMT time. The increased solubility due to longer HMT was attributed to the weakness of molecular binding of starch intermolecules. Leach *et al.* (1959) stated that the lower swelling power is in line with the lower solubility. The binding strength of the starch granule is getting weak and extended. When the starch is heated up in the water, the crystalline structure of starch molecule is damaged and the water molecule will bind free hydroxyl group of the amylose and amylopectin through the hydrogen bond, therefore it leads to increase in starch solubility (Sanabri and Filho, 2008).

Theoretically, the increase of amylose solubility and the decrease of swelling power of the starch is consequent with the increase of gel hardness. It can be said that the important factors affecting gel hardness and gel rigidity of the starch are amylose content

Table 2. Viscoamiliograph parameter of native and heat moisture treated SPS of different varieties

Varieties	Treatment	Gelatinization Temperature (°C)	Peak Viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Setback (RVU)	Final Viscosity (RVU)
Sukuh	Native	75.75±0.48 ^a	553.36±15.71 ^a	317.94±7.10 ^{ef}	234.09±13.38 ^c	97.78±12.13 ^c	415.72±10.98 ^{cd}
	HMT 3 h	81.65±0.83 ^d	367.67±32.42 ^d	341.89±16.91 ^{gh}	9.11±2.34 ^a	173.95±5.42 ⁱ	515.83±22.30 ^g
	HMT 4 h	82.47±0.80 ^{de}	357.86±17.32 ^d	353.22±15.65 ^h	6.64±1.33 ^a	164.28±14.67 ^{hi}	517.50±28.45 ^g
Cangkuang	HMT 5 h	84.57±0.53 ^{gh}	309.69±8.13 ^c	303.81±9.62 ^{cde}	5.89±1.59 ^a	125.33±6.20 ^f	429.14±15.53 ^{de}
	Native	74.95±0.56 ^a	563.17±12.14 ^a	305.00±6.95 ^{cde}	258.17±7.56 ^f	74.83±5.64 ^b	379.83±12.59 ^b
	HMT 3 h	82.72±0.46 ^e	367.78±2.79 ^d	337.50±0.75 ^e	30.28±2.69 ^b	160.28±7.30 ^{gh}	497.78±6.92 ^{fg}
Jago	HMT 4 h	83.02±0.49 ^{ef}	353.20±30.11 ^d	336.36±6.90 ^e	30.50±2.10 ^b	153.92±5.86 ^{gh}	489.94±10.77 ^f
	HMT 5 h	84.58±0.46 ^{gh}	326.78±5.31 ^c	292.00±5.01 ^c	34.78±0.92 ^b	118.58±2.96 ^{ef}	410.58±6.93 ^{cd}
	Native	77.62±0.03 ^b	490.81±8.50 ^f	272.50±3.18 ^b	218.30±5.87 ^d	52.33±5.29 ^a	324.83±2.11 ^a
Papua Salosa	HMT 3 h	83.78±0.42 ^{fg}	353.00±0.38 ^d	341.58±3.08 ^{gh}	11.42±2.92 ^a	175.56±5.40 ⁱ	517.14±2.41 ^g
	HMT 4 h	85.42±0.49 ^{hi}	303.50±6.93 ^{bc}	296.80±6.76 ^{cd}	6.69±2.55 ^a	149.00±7.94 ^e	445.81±7.57 ^e
	HMT 5 h	85.72±0.77 ⁱ	283.64±5.29 ^b	277.30±5.36 ^b	6.33±1.06 ^a	122.95±4.03 ^{ef}	400.25±1.34 ^{bc}
Papua Salosa	Native	78.77±0.46 ^c	441.28±6.42 ^e	330.72±3.18 ^g	80.57±3.94 ^a	102.11±4.03 ^{cd}	432.83±4.46 ^{de}
	HMT 3 h	85.43±0.50 ^{hi}	315.86±9.04 ^c	309.47±9.10 ^{de}	6.39±1.71 ^a	111.72±8.26 ^{de}	421.19±16.65 ^{cd}
	HMT 4 h	87.27±0.03 ^j	301.14±4.18 ^{bc}	296.92±3.06 ^{cd}	4.22±1.17 ^a	89.94±0.88 ^b	386.86±3.89 ^b
	HMT 5 h	87.55±0.52 ^j	254.67±9.64 ^a	248.64±9.50 ^a	6.03±1.72 ^a	69.64±5.56 ^b	318.28±3.89 ^a

Mean ± standard deviation

Value in a column followed by the same superscript is not significantly different ($p > 0.05$)

and water binding capacity. Table 1 shows the gel hardness of native starches ranging from 0.08 N to 0.14 N. The highest gel hardness was performed by Sukuh, and the lowest one was Jago. HMT increased gel hardness of the starches from Sukuh, Cangkuang and Jago, but not from Papua Salosa. It occurred because of the increase of crosslinking between amylose chains in the starch granules during HMT. This result was in accordance with Collado and Corke (1999) in SPS, with Purwani *et al.* (2006) in sago starch and with Horndok and Noomhorm (2007) in rice starch. The highest gel hardness was shown by SPS of Sukuh variety treated for 3 h, showing 0.39 N, and it is not significantly ($p > 0.05$) different from that of treated for 4 h (0.38 N) as seen in Table 1. In all varieties of sweet potato, the longer HMT process led to decrease in gel hardness. The longer time of HMT affected amylose binding in starch granules weakened. It happened due to the increase of starch solubility, therefore it will cause the decrease in gel hardness. The higher temperature and longer time of HMT are supposed to cause degradation of the starch granule structure. The loss of amylopectin crystallinity in the starch granule causes the decrease in the gel hardness. The high viscosity of starch gel is also due to high amylose content and the length of amylopectin chains (Mua and Jackson, 1997). Starch gel is a solid system in the liquid having continuous network in bound liquid phase. Free amylose molecule builds hydrogen bond, not only with amylose but also with amylopectin branches during starch expansion. It can be said that the starch granule is the site of this continuous solid network (Penfield and Campbell, 1990).

Pasting properties

Gelatinization properties and profile of mixed starch and water can be observed by Rapid Visco Analyzer (RVA). Every starch from various plants has different gelatinization property. The pasting parameters consisting of gelatinization temperature,

peak viscosity, through viscosity, breakdown, setback and final viscosity are presented in Table 2.

As shown in Table 2, the gelatinization temperature of different varieties was significant ($p < 0.05$) difference, ranging from 74.95 to 87.77°C, and the highest value was Papua Salosa. Collado and Corke (1997) reported the gelatinization temperature of SPS between 78.3 to 84.1°C, similar to these varieties. HMT in SPS of all varieties resulted in a significantly ($p < 0.05$) increased gelatinization temperature, around 5-7°C. Longer HMT duration led to a little increased gelatinization temperature. HMT for 5 h in Papua Salosa starch showed the highest gelatinization temperature (87.55°C), and was not significantly ($p < 0.05$) different from that of treated for 4 h (87.27°C). HMT led to increased starch crystallinity because of the changes in starch granule structure. The strength of intramolecular bond in the starch due to HMT made the starch requiring greater heat to break down the structure and forming paste. There was a molecular interaction in the crystalline and amorphous regions to build a strong structure with hydrogen bond. Hence, there was a possibility of association between amylose molecules and or amylose molecule with a linear form of amylopectin branch and furthermore forming more compact structure. The high temperature is needed by starch granule to reach maximum expansion, and finally broken down. This condition describes that heat moisture treated starches has a higher stability against heating (Li *et al.*, 1995). These results were the same with those of reported by Collado and Corke (1999) and Singh *et al.* (2005) in SPS and with Pukkahuta *et al.* (2008) in mays starch.

Different varieties of sweet potato showed different peak viscosity of the starch extracted (Table 2). The peak viscosity indicates the starch capability to absorb water and its ease of starch granule being integrated. Peak viscosity of the starch from several varieties studied was ranging from 441.28 RVU to 563.17 RVU, which were higher than those of

investigated by Collado and Corke (1997) in 14 varieties of sweet potato, ranging from 329 RVU to 428 RVU, and by Collado and Corke (1999) in 2 sweet potato varieties, showing 321 RVU and 430 RVU. HMT decreased noticeably peak viscosity of the starch, becoming 254.67 RVU to 367.78 RVU. The peak viscosity was getting lower when the treatment time was extended. The decreased peak viscosity due to HMT was attributed to the decrease of water penetrated into the starch granules to dissolve their components, therefore the starch granules underwent limited swelling and finally leading to lower viscosity (Zobel, 1992). The decrease of penetrated water into starch granules was due to the increased compactness of starch molecule. The compactness was resulted by molecular interaction in the amorphous and chrySTALLIN regions (Hoover and Vasanthan, 1994). In addition, the decreased peak viscosity was also due to the solubility of amylose molecule during gelatinization process. It is not in the form of a long linear molecule, but mostly in the fragmented form (a group of molecules with hydrogen bond), therefore the peak viscosity of the starch tends to be low.

Table 2 shows that different varieties of sweet potato resulted in a different through and breakdown value. The results indicated that through viscosity of native starch varied from 272.50 RVU to 330.72 RVU and the breakdown varied from 80.57 RVU to 258.17 RVU. Zaidul *et al.* (2007) reported that trough and breakdown express the peak viscosity. Trough and breakdown in this study were higher than those of reported by Zaidul *et al.* (2007), who found trough value of 96.8 RVU and break down of 36.0 RVU. Except for Papua Salosa starch, HMT increased trough viscosity, and the longer treatment time tended to reduce the value. Breakdown values were decreased significantly by HMT and no difference due to treatment duration. The decrease in breakdown after HMT was associated with the swelling ability of the starch. HMT is reported to limit swelling in the starch granule, where the gel matrix structure and amylose were getting stronger. Therefore, it decreased breakdown value of the starch. Stute (1992) stated that HMT carried out with water addition of around 30% affected starch gelatinization profile; lowering peak viscosity and lowering breakdown. In addition, Whistler and BeMiller (1999) said that during breakdown, the starch swelling was further interfered and amylose granule was mostly dissolved.

Setback value is the returned starch viscosity during cooling from heating up of the starch suspension and it shows the tendency of the starch to retrogradation. The different varieties showed a significant ($p < 0.05$) difference in setback value. The

setback of native starches ranged from 52.33 RVU to 102.11 RVU (Table 2). The different setback in every sweet potato variety is caused by the different structure of amylopectin molecules of the starch (Singh *et al.*, 2008). The setback obtained in this study seems to be higher in comparison with that of reported by Wickramasinghe *et al.* (2009) in three varieties of sweet potato, ranging from 42 RVU to 59 RVU. HMT gave significant effect on the setback of the SPS of different varieties. Treated starches tended to result in a higher setback than respective native ones. However, the longer treatment time led to lower setback. The setback of treated starches ranged from 69.64 RVU to 175.56 RVU. HMT is presumed to cause the changes in structural arrangement of the starch molecules which involves the arrangement of hydroxyl groups, therefore the change of binding arrangement leads to starch molecule towards retrogradation. Hoover and Manuel (1996) also stated that HMT process leads to intermolecular and intramolecular hydrogen bond built in the starch granules. According to Adebowale *et al.* (2005), the setback value is used to determine the tendency of retrogradation and syneresis occurrences in the starch.

The final viscosity is one of the important factors in determining starch characteristic and it indicates the heat stability of the paste in the usage (Shimelis *et al.*, 2006). The results revealed that the different varieties significantly ($p < 0.05$) affected final viscosity (Table 2). The final viscosity of native starches resulted in this study varied from 324.83 RVU to 432.83 RVU. These results seem relatively higher compared to those of reported by Collado and Corke (1997) in 14 varieties of sweet potato, ranging from 208 RVU to 284 RVU, and by Wickramasinghe *et al.* (2009) in 3 varieties, between 139 RVU to 189 RVU. In exception for Papua Salosa, HMT significantly ($p < 0.05$) increased final viscosity of the SPS. The longer HMT duration led to a little decrease in final viscosity. The highest final viscosity (517.50 RVU) was found in the starch of Sukuh variety after HMT for 4 h. It is not significantly ($p > 0.05$) different from Jago variety of HMT for 3 h (517.14 RVU) and Sukuh variety of HMT for 3 h (515.83 RVU).

It is presumed that swelling power relates to final viscosity of gelatinization. The longer HMT time leads to decrease in swelling power, therefore the limited swelling of starch granule increases pasta stability during heating. The grown crystallinity in the starch granules due to HMT led to limitation of starch swelling and the disruption of starch granules. In addition, HMT caused the starches were dissolved, forming continuous starch gel matrix, thereby increasing final viscosity in the gelatinization. The

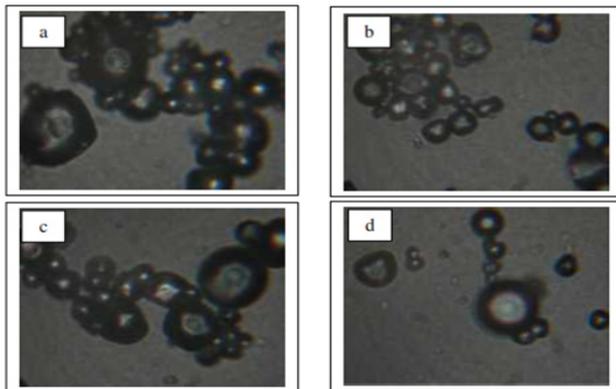


Figure 1. Micrograph of starch granules from Suku variety, a. Native starch, b. HMT 3 h, c. HMT 4 h, d. HMT 5 h

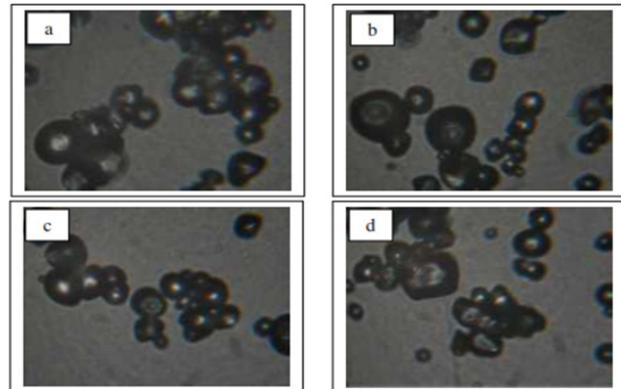


Figure 4. Micrograph of starch granules from Papua Salosa variety, a. Native starch, b. HMT 3 h, c. HMT 4 h, d. HMT 5 h

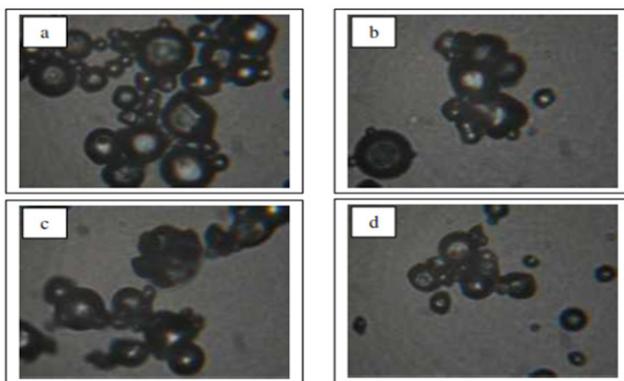


Figure 2. Micrograph of starch granules from Cangkang variety, a. Native starch, b. HMT 3 h, c. HMT 4 h, d. HMT 5 h

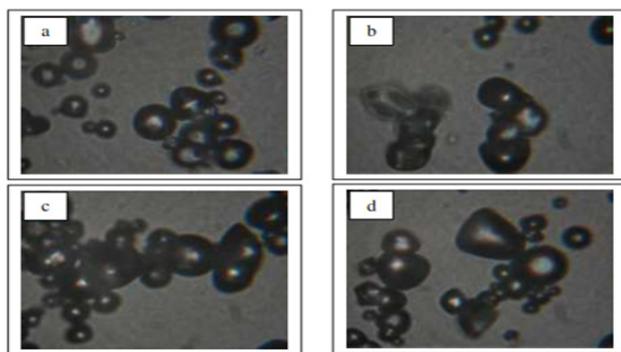


Figure 3. Micrograph of starch granules from Jago variety, a. Native starch, b. HMT 3 h, c. HMT 4 h, d. HMT 5 h

viscosity change of the starch during heating, followed by cooling in every starch has different characteristic (Srichuwong *et al.*, 2005). Shimelis *et al.* (2006) added that final viscosity of starch gelatinization shows the starch capability to form a paste or gel after cooling and the increased starch paste stability is related to the decrease of breakdown value. The increase of final viscosity of starch gelatinization obtained in this study was similar to that of reported by Pukkahutta *et al.* (2008) in mays starch and with that of investigated by Collado and Corke (1999) in SPS.

Low gelatinization temperature, the peak viscosity showing high starch swelling, high

breakdown, low setback and low final viscosity can be categorized as a type A of amylograph. Meanwhile, the high gelatinization temperature, low peak viscosity indicating limited starch granule swelling, low breakdown value, high setback and final viscosity in this study, indicated that heat moisture treated SPS of all varieties are categorized as type C of amylograph. Classification of starch viscosity pattern is important means to determine starch category for final products. The limitation of starch swelling plays a role in determining amount of starch needed for food products, especially in starch noodle (Shimelis *et al.*, 2006). HMT process, most likely, could improve the utilization of SPS to support food diversity (Collado and Corke, 1997).

Photomicroscopy of starch granule

The forms and shapes of sweet potato starch granules, whether native and treated starches can be observed by a light microscope as shown in Figure 1 to Figure 4 from all varieties. There was no marked difference in the starch granules from the native and the starch after HMT. It shows that the HMT did not modify the form of starch granules, because HMT caused limited gelatinization only, therefore the birefringence in the starch still existed. The starch granules of all sweet potato varieties appeared spheric and in heterogeneous size. The results were similar to those of reported by Chen (2003) and Singh *et al.* (2005). This indicated that there was no chemical reaction, because HMT is physical treatment (Tsakama *et al.*, 2011).

Conclusions

HMT led to decrease in swelling power and solubility, and increase in the gel hardness of the SPS. In the amylographic profile, HMT increased gelatinization temperature, lowered peak viscosity, decreased breakdown, and increased setback and

final viscosity. It indicated that HMT shifted SPS from type A to type C of amylograph pattern. The microscopic starch granule forms were not affected by HMT. The significant modified starch due to HMT was shown by Sukuh starch treated for 4 h, showed the highest final viscosity at 517.50 RVU with high gel hardness of 0.38 N.

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