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Effect of Heat Moisture Treatment (HMT) Duration and Lactic Acid Concentration on the Characteristics of Purple Sweet Potato Flour (*Ipomoea batatas* L. Poiret)

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ABSTRACT

This study aims to determine the effect of heat moisture treatment (HMT) duration and lactic acid concentration on the characteristics of purple sweet potato flour (*Ipomoea batatas* L. Poiret). The method consisted of two stages, namely preliminary stage to produce control (unmodified) flour and main stage to produce modified flour. The method used was a randomized group design with a factorial pattern of 3 x 3 and 3 replications. The variables used were HMT duration (3, 5, and 7 hours) and lactic acid concentration (200, 400, and 600 ppm). The parameters observed in the main stage were water content, anthocyanin level, swelling power, color, solubility, and flour gelatinization profile or Rapid Visco Analysis (RVA). The results show that HMT duration affected the water content and solubility of the modified purple sweet potato flour. HMT duration of 7 hours and lactic acid concentration of 600 ppm resulted in flour anthocyanin level of 24.046 mg/kg. The gelatinization profile shows that the modified purple sweet potato flour experienced the initial temperature of gelatinization (pasting temperature) at 92.30ºC, peak viscosity at 1,343 cP, hot paste viscosity (hold viscosity) at 362 cP, cold paste viscosity (final viscosity) at 931 cP, breakdown (viscosity stability during heating) at 381 cP, and seatback (changes in viscosity during cooling) at -31 CP.

1. Introduction

Wheat flour is a natural substance formed as a result of wheat endosperm grinding. The type of wheat used will determine the chemical composition and rheological properties of the resulting wheat flour and its intended use in food products. Wheat for wheat flour production is categorized based on its protein content, namely hard red winter, soft red winter, hard red spring, hard white, soft white, and durum (Abdelaleema & Al-Azaba, 2021). However, wheat flour can cause gluten allergies and intolerance in certain people who consume it, due to the presence of specific amino acids that can cause allergies, namely gliadin, which is an amino acid that composes gluten (Marbun & Sinaga, 2018). According to Statistics Indonesia (2021), wheat grain imports by Indonesia in 2010 reached 10.29 million tons. About 90% of imported wheat grains are still widely used by the wheat flour industry, both on a small and large scale. Indonesia also apparently still imports wheat flour in finished form, both in fortified and non-fortified form. The total import of wheat flour during 2020 was 2,616 tons.

For this reason, several efforts have been made to produce flour from local natural resources as an alternative to wheat flour. These substitutes must be high in carbohydrates content, such as those from tubers, including sweet potatoes, wood tubers, and taro. Sweet potatoes can be divided into four types based on their color: white, yellow, red, and purple sweet potatoes. The nutritional compositions of each other are similar, but the varieties of purple sweet potato (*Ipomoea batatas* L. Poiret) are particularly richer in vitamin A, beta-carotene, vitamin E, and vitamin C, and are beneficial as antioxidants and preventing agents of cancer and various cardiovascular diseases. Purple sweet potato also contains dietary fiber that is beneficial for digestion, as its glycemic index is low to moderate. This is the added value of purple sweet potato as a functional food (Wisti, 2011). Purple sweet potato can be used as an alternative to wheat flour because its utilization in Indonesia is still very limited, even though it has a high anthocyanin level and is useful for supporting body health.

Anthocyanins, located in the water-soluble cell fluid, are a group of pigments that give purple sweet potatoes their reddish color. The anthocyanin components of purple sweet potato are mono or diacetyl derivatives of 3-(2-glucosyl) glucosyl-5-glucosyl peonidin and cyanidin (Rijal et al., 2019). Anthocyanins contained in purple sweet potatoes are quite high, reaching 519 mg per 100 gr of wet weight. These pigments function as antioxidants and free radical catchers, as well as playing a crucial role in preventing aging, cancer, degenerative diseases, liver function disorders, and hypertension (Santosa et al., 2015).

The making of flour from purple sweet potato cannot be conducted carelessly because it can eliminate the anthocyanin contained in it. Thus, it is necessary to perform special treatment in the making so as not to damage the flour components. Anthocyanins contained in purple sweet potato, namely cyanidin and peonidin, are stable at pH 4, thus soaking purple sweet potato in lactic acid is one of the efforts to maintain the anthocyanin level so that it is not lost or damaged during the making process of purple sweet potato flour (Nuraini, 2016). Lactic acid soaking was carried out at concentrations of 200, 400, and 600 ppm for 20 minutes. In addition, another treatment to protect anthocyanins contained in purple sweet potato is the microencapsulation technique. This is a process in which small molecules or liquid droplets are wrapped or coated by polymeric materials to produce small particles known as microcapsules or microspheres (Baena-Aristizábal et al., 2019). The microencapsulation technique used in this study was immersion using a solution of 2% of maltodextrin + 1% of Arabic gum and 5% of maltodextrin + 5% of soy protein isolate for 10 minutes.

Various kinds of flour modification had been conducted, including heat moisture treatment (HMT), crosslink, acid hydrolysis, oxidation, dextrination, and acid conversion (Collado et al., 2001). Heat moisture treatment (HMT) is a type of flour modification by applying a certain amount of heat to flour in order to produce desired flour characteristics. Purple sweet potato is known to be easily damaged by heat (Putri et al., 2012). The flour modification process using the HMT method normally takes place in varied durations, namely 3, 5, and 7 hours.

Thus, this study aims to determine the effect of heat moisture treatment (HMT) duration and lactic acid concentration on the characteristics of purple sweet potato flour (*Ipomoea batatas* L. Poiret).

2. Methods

2.1 Tools and materials

The tools used were knives, cutting boards, trays, cabinet dryers, fomacs, vibratory screens, weighing bottles, ovens, exiccators, choppers, measuring flasks, spectrophotometers, centrifuge tubes, vortexes, water baths, petri dishes, and RVA. The materials used were purple sweet potato purchased from the Lembang market, lactic acid solution with concentrations of 200, 400, and 600 ppm, 2% of maltodextrin + 1% of Arabic gum, 5% of maltodextrin + 5% of isolate soy protein, distilled water, purple sweet potato flour, potassium chloride (KCl), concentrated hydrochloric acid (HCl), and sodium acetate ($CH_3COONa.3H_2O$).

2.2 Time and place

This study was conducted from November to December 2022 at the Food Technology Research Laboratory, Faculty of Engineering, Pasundan University, Jl. Dr. Setiabudhi No. 193, Bandung; Test Services Laboratory, TIP Building 2nd floor, Faculty of Agro-Industrial Technology (FTIP) Building Complex, Jl. Raya Bandung Sumedang Km. 21 Jatinangor, Sumedang; Appropriate Technology Laboratory, National Research and Innovation Agency (BRIN) of Subang Area, Jl. Ks. Tubun No. 5 Subang, West Java; and Advanced Characterization Laboratory, BRIN, Cisitu, Bandung.

2.3 Procedure

The procedure was conducted in two stages, namely preliminary stage and main stage. The preliminary stage aimed to produce control (unmodified) flour, namely purple sweet potato flour without treatment. Purple sweet potatoes (*Ipomoea batatas* L. Poiret) were peeled and cut with a thickness of ± 1 cm, then washed and drained. Next, the sweet potatoes were dried using a cabinet dryer at 70ºC for 6 hours. The dried sweet potatoes were ground using a fomac tool. After grinding, the resulting flour was sieved using an 80 mesh sieve. The refined purple sweet potato flour then underwent water content analysis using gravimetric method, swelling power analysis, solubility analysis, color analysis, anthocyanin level analysis using pH-differential Lambert Beer method, and Rapid Visco Analysis (RVA).

The main stage aimed to produce modified purple sweet potato flour. Purple sweet potatoes were peeled and cut with a thickness of ± 1 cm, then washed and drained. Then, the purple sweet potatoes were soaked in lactic acid with varied concentrations (200, 400, and 600 ppm) for 20 minutes. Next, the sweet potatoes were soaked in a second time in a mixture of solutions, namely 2% of maltodextrin + 1% Arabic gum and 5% of maltodextrin + 5% of soy protein isolate for 10 minutes. The soaked purple sweet potatoes were then dried using a cabinet dryer at 65ºC for 6 hours. The dried purple sweet potatoes were ground using a fomac tool. After grinding, the resulting flour was sieved using an 80 mesh sieve.

After that, the purple sweet potato flour was modified using the HMT method. Before modification, the flour was sprayed using distilled water and stirred evenly, then analyzed until the water content reached 28%. Next, the flour was placed in a closed pan covered with aluminum foil and allowed to stand in the refrigerator for 24 hours for water content uniformity. After that, the flour was put into the oven at 65ºC with varied durations (3, 5, and 7 hours). Then, the flour was drained for 1 hour. After that, the flour was sieved using an 80 mesh sieve.

For the resulting modified purple sweet potato flour, the chemical parameters observed were water content and anthocyanin level; the physical parameters observed were swelling power, solubility, and color; and the physicochemical parameter observed was flour gelatinization profile or Rapid Visco Analysis (RVA).

This study used a randomized group design (RBD) with a factorial pattern of 3 x 3 and three replications. The variable of HMT duration included 3 variations, namely 3, 5, and 7 hours. The variable of lactic acid concentration included 3 variations, namely 200, 400, and 600 ppm.

3. Results and discussion

3.1 Chemical parameters

3.1.1 Water content

According to Winarno (2004), water content is the amount of water, in percent (%) unit, contained in food ingredients, and is often used as one of main parameters to determine the extent of food damage. The water content of the control (unmodified) purple sweet potato flour is 3.667%. The water content of the modified purple sweet potato flour is displayed in Table 1.

Table 1. Effect of HMT duration on the water content of the modified purple sweet potato flour.

Treatment	Water Content (%)
h1	3.83[a]
h2	3.33[b]
h3	3.00[b]

Description: Mean values followed with different letters indicate a significant difference at the 5% level based on Duncan's test. The mean value in this table uses % unit.

Table 1. shows that the longer duration of HMT resulted in a significant decrease in water content of the modified flour. This is thought to be because the longer the HMT temperature and lactic acid concentration, the lower the water content of the resulting modified flour because there was water evaporation due to heating during HMT. Therefore, the modified flour experienced a decrease in the value of water content compared to that of the control flour.

According to Meyer (2003), increasing temperature due to heating caused water molecules to enter the starch granules and got trapped in the arrangement of amylose and amylopectin molecules. HMT caused changes in the arrangement of starch granules so that the water molecules that enters the starch granules were able to be bound, thus the water drying process did not much occur. Similarly, according to Puung et al. (2012), when treated using HMT, starch granules that have swelled tend to have larger cavities, resulting in water becoming more volatile during drying.

According to Ariyantoro et al. (2016), the decrease in water content in modified koro sword flour was thought to be due to lactic acid being able to weaken hydrogen bonds. Weak hydrogen bonds caused a decrease in the starch's molecular weight, making its structure became loose and soft so that more water was able to evaporate during drying.

The breaking of water bonds from other components results in the material's texture becoming porous so that the water evaporation during drying becomes easier, thus the water content will decrease in the same drying duration (Harijono et al., 2008).

The freshness and durability of a food ingredient are often determined by the water content in it. High water content makes it easy for bacteria, molds, and yeasts to multiply, which will change the texture and characteristics of the food. The lower the water content, the slower the growth of microorganisms to multiply, so that the process of food damage/decay can be minimized (Winarno, 2004).

3.1.2 Anthocyanin level

Anthocyanins are anthocyanidin glycosides, which are polyhydroxyflavilium (2-arylbenzopyrilium) salts. The majority of anthocyanins come from 3,5,7-trihydroxyflavilium chloride and the sugar part is usually bound to a hydroxyl group on the third carbon atom (Apriliyanti, 2010). Anthocyanins are the basic formers of red, purple, and blue color pigments in plants, especially as coloring materials for flowers and fruits. Anthocyanins are heat sensitive, where their damage is directly proportional to the increase in temperature experienced (Markakis, 1982).

The anthocyanin level of the control purple sweet potato flour is 11.188 mg/kg. The anthocyanin level of the modified purple sweet potato flour with HMT duration of 7 hours and lactic acid concentration of 600 ppm is 24.046 mg/kg. The increase in anthocyanin level in the modified flour is thought to be due to the anthocyanin level contained in fresh purple sweet potatoes was trying to be maintained through lactic acid soaking. However, according to Prasetyo (2020), anthocyanin level in processed purple sweet potato flour was lower than that of in fresh one, indicating that processing is supposedly reduces the anthocyanin level in the resulting product. At high heating, the stability and durability of anthocyanin change and result in its damage. High temperature and prolonged heating also accelerate anthocyanin damage. In addition to temperature, anthocyanin's stability is also affected by light, enzymes, oxygenation, its inner structure, and its concentration.

3.2 Physical parameter

3.2.1 Color

The resulting colors of the control purple sweet potato flour are lightness (L*) of 68.483, redness (A*) of 7.163, and yellowness (B*) of 10.067. The colors of the modified purple sweet potato flour are displayed in Table 2, 3, and 4 below.

Table 2. Effect of HMT duration on the L* color of the modified purple sweet potato flour.

Treatment	Lightness (L*)
h1	65.71^{a}
h2	66.69^{a}
h3	66.15^{a}

Description: Mean values followed with same letters indicate a non-significant difference at the 5% level based on Duncan's test.

Table 2 shows that the longer duration of HMT resulted in a non-significant increase in the L* color (lightness) of the modified purple sweet potato flour. The L value is an attribute that indicates the brightness of the purple sweet potato flour. The L value has a range from 0–100. An L value close to 0 indicates the sample has low brightness (dark), while an L value close to 100 indicates the sample has high brightness (bright). In this study, HMT duration caused the decrease in brightness degree (L*) in a not significantly different manner. This is because the modification process used a low temperature so it did not cause a significant change in lightness.

Table 3. Effect of lactic acid concentration on the A* color of the modified purple sweet potato flour.

Treatment	Redness (A*)
l1	9.37^{a}
l2	9.85^{a}
l3	10.00^{a}

Description: Mean values followed with same letters indicate a non-significant difference at the 5% level based on Duncan's test.

The A* (positive) value represents the chromatic color of red-green mixtures with values from 0 to +80 for red and A* (negative) value from 0 to 80 for green. The B* (positive) value expresses the chromatic color of blue-yellow mixtures with values from 0 to +70 for yellow and B* (negative) values from 0 to -70 for blue.

The attractive purple color of purple sweet potato comes from anthocyanins, which exhibit antioxidant activity (Pokarny et al., 2001) and are soluble in water. Table 3 shows that the increasing concentration of lactic acid produced a non-significant increase in the A* color (redness) of the modified purple sweet potato flour. This is thought to be because the more lactic acid concentration used, the more flour color was able to be bound. This result is supported by a study on the modified breadfruit flour (Feny & Dimas, 2013), where the soaking duration and lactic acid concentration affected the increase in the degree of white color of breadfruit.

Table 4. Effect of lactic acid concentration on the B* color of the modified purple sweet potato flour.

Treatment	Yellowness (B*)
l1	6.76[a]
l2	6.28[a]
l3	5.79[a]

Description: Mean values followed with same letters indicate a non-significant difference at the 5% level based on Duncan's test.

Table 4 shows that the higher concentration of lactic acid resulted in a non-significant decrease in the B* color (yellowness) of the modified purple sweet potato flour. The higher the concentration of lactic acid used, the more yellowish red the color of the purple sweet potato flour resulted.

3.2.2 Swelling power

The swelling power value of the control purple sweet potato flour is 8.800 (gr/gr), while Table 5 presents the swelling power values for the modified flour.

Table 5. Effect of HMT duration on the swelling power of the modified purple sweet potato flour.

Treatment	Swelling Power
l1	8.26[a]
l2	8.24[a]
l3	7.97[a]

Description: Mean values followed with same letters indicate a non-significant difference at the 5% level based on Duncan's test. The mean value in this table uses gr/gr unit.

Table 5 shows that the longer duration of HMT resulted in a non-significant decrease in the swelling power of the modified purple sweet potato flour. HMT modification caused the granule molecules of the starch to be arranged more tightly, which in turns also decreased the starch's ability to swell. Therefore, the modified flour experienced a decrease in swelling power compared to that of the control flour.

The energy absorbed by starch granules during heating will unfold the double helix of amylopectin and facilitate the arrangement or formation of new intermolecular bonds. The longer the modification process, the more amylose undergoes restructuring. In addition, the decrease in swelling power is also caused by partial hydrolysis that occurred during the modification process. Partial hydrolysis produced starch fractions with low molecular weight so that the ability of the starch molecules to expand became restricted (Parwiyanti et al., 2015).

According to Yuniarchristi (2019), the decrease in swelling power can be caused by rearrangement of molecules in the granule, formation of amylose-lipid complexes, degradation of amylopectin molecules, increased interactions among amylose chains, and changes in interactions between amorphous matrix and crystallite matrix.

3.2.3 Solubility

The solubility value of the control purple sweet potato flour is 30%, while Table 6 and Table 7 present the solubility values of the modified flour.

Table 6. Effect of HMT duration on the solubility of the modified purple sweet potato flour.

Treatment	Solubility
H1	22.11[a]
h2	15.11[ab]
H3	10.74[b]

Description: Mean values followed with different letters indicate a significant difference at the 5% level based on Duncan's test. The mean value in this table uses % unit.

Table 6 shows that the longer duration of HMT resulted in a significant decrease in the solubility of the modified purple sweet potato flour. This is thought to be because the hydrogen bonds in the starch were broken or lost due to heating during HMT, which lasted for a relatively long duration. The loss of free hydroxyl groups reduced the solubility of starch and made it difficult for the starch to absorb water. As a result, the starch did not produce too much swelling (Sumarlin, 2011).

Table 7. Effect of lactic acid concentration on the solubility of the modified purple sweet potato flour.

Treatment	Solubility
l1	19.77[a]
l2	14.55[a]
l3	13.63[a]

Description: Mean values followed with same letters indicate a non-significant difference at the 5% level based on Duncan's test. The mean value in this table uses % unit.

Swelling power and solubility is a unity that has the same tendency and is directly proportional. Hydrolysis using lactic acid increased the solubility of the starch molecules in water because this process changed the molecular structure of the starch to be simpler and hydrophilic. In this process, the replacement of hydroxyl groups by more non-polar groups decreased the cohesive force among starch molecules, which led to an improvement in its flow properties. Besides, the addition of lactic acid also functioned to reduce the ambient pH so as to decrease the molecule size of the starch and made it easier for the starch molecules to dissolve in water (Erezka et al., 2018).

3.3 Physicochemical parameter

3.3.1 Gelatinization profile or Rapid Visco Analysis (RVA)

The gelatinization profile of the control sweet potato flour is presented in Table 8.

Table 8. Gelatinization profile of the control purple sweet potato flour.

Parameter Observed	Value

Pasting temperature (ºC)	18
Peak viscosity (cP)	2,917
Hold viscosity (cP)	2,379
Final viscosity (cP)	4,498
Breakdown (cP)	533
Seatback (cP)	2,119

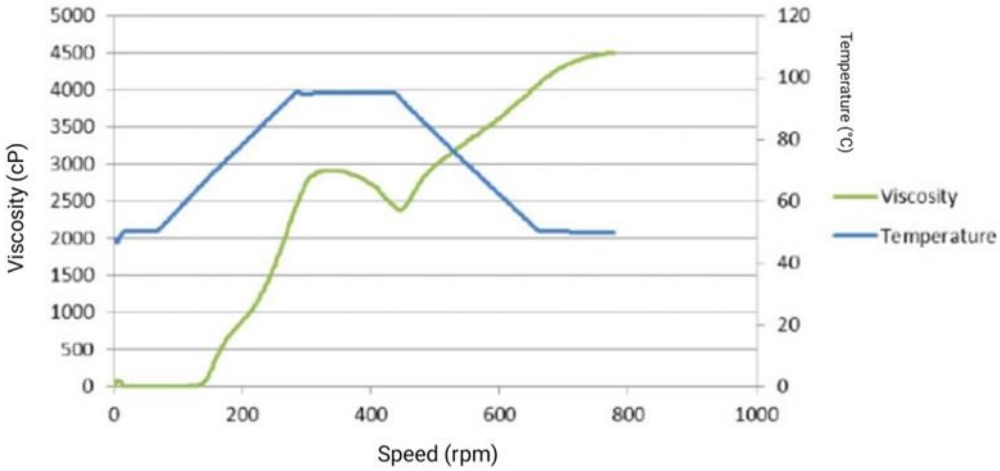

Figure 1. Amylograph curve of the control purple sweet potato flour

The results in Table 8 show that the control (unmodified) purple sweet potato flour experienced an initial gelatinization temperature (pasting temperature) at 18ºC, peak viscosity at 2,917 cP, hot paste viscosity (hold viscosity) at 2,379 cP, cold paste viscosity (final viscosity) at 4,498 cP, breakdown viscosity at 533 cP, and seatback at 2,119 cP. Figure 1 shows the amylograph curve of the control purple sweet potato flour. The temperature obtained in the RVA analysis of the control flour, namely 65°C, was then used for the modification temperature in the making of the modified sweet potato flour.

The gelatinization profile of the modified purple sweet potato with HMT duration of 7 hours and lactic acid concentration of 600 ppm is presented in Table 9.

Table 9. Gelatinization profile of the modified purple sweet potato flour with HMT duration of 7 hours and lactic acid concentration of 600 ppm.

Parameter Observed	Value
Pasting temperature (ºC)	92.30
Peak viscosity (cP)	1,343
Hold viscosity (cP)	362
Final viscosity (cP)	931
Breakdown (cP)	381
Seatback (cP)	-31

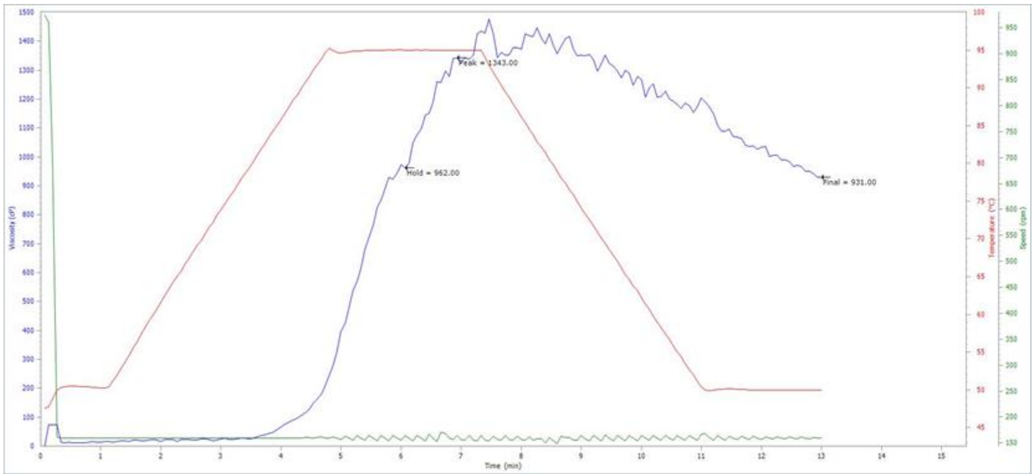

Figure 2. Amylograph curve of the modified purple sweet potato flour with HMT duration of 7 hours and lactic acid concentration of 600 ppm

The gelatinization profile in Table 9 show that the modified purple sweet potato flour experienced an initial gelatinization temperature (pasting temperature) at 92.30ºC, peak viscosity at 1,343 cP, hot paste viscosity (hold viscosity) at 362 cP, cold paste viscosity (final viscosity) at 931 cP, breakdown (viscosity stability during heating) at 381 cP, and seatback (changes in viscosity during cooling) at -31 cP. The peak viscosity value reflects the ability of starch granules to bind and maintain the swelling during heating (Nazhrah et al., 2014). The gelatinization profile in Table 9 also shows that the peak viscosity value of the modified purple sweet potato flour decreased compared to that of the control flour. This is thought to be because the starch granules have not been completely damaged so that it still takes time to gelatinize again.

Hot paste viscosity (hold viscosity) is the viscosity maintained at 95ºC. Starch granules will become brittle, break, form polymers and aggregates, and experience a decrease in viscosity during the heating process, followed by higher temperatures after reaching peak viscosity. The decrease in hold viscosity value is due to the shift in the crystallization type of starch, which led to an increase in the stability of starch granules. The gelatinization profile in Table 9 show that the hold viscosity value of the modified purple sweet potato flour decreased compared to that of the control purple sweet potato flour. This is thought to be due to the formation of starch granules that produced more double helix amylopectin bonds, especially in amorphous regions. The formation of these bonds plays a role in changing the crystallinity properties of starch into a more stable form (Hastuti, 2017).

According to Budijanto and Yuliyanti (2012), cold paste viscosity (final viscosity) value is a parameter that shows the ability of the paste to form a viscous gelatine or gel after heating and stirring, and shows the resistance of the paste to shear forces that occur during stirring. According to Zayarese et al (2011), the gelatinization profile in Table 9 shows that the final viscosity value of the modified purple sweet potato flour decreased compared to that of the control flour. This is thought to be due to the rearrangement between amylose and amylopectin molecules, which led to the formation of more bonds between amylose and amylopectin molecules in the starch.

According to Singh et al. (2011), breakdown shows the stability of starch granules during the heating and stirring process so that a high breakdown value is not expected in the starch tested because it will cause uneven viscosity and can cause the starch paste to be very sticky during stirring. The gelatinization profile in Table 9 shows that the breakdown value of the modified sweet potato flour decreased compared to that of the control flour. According to Faridah et al. (2014), breakdown value indicates the stability of viscosity during heating, where the lower the breakdown value indicates that the paste formed is more stable to heat.

Another gelatinization profile presented here is seatback, which was obtained from the difference between the final viscosity and the hold viscosity values. According to Batey (2007), seatback is a process that occurs in the cooling stage characterized by a rise in viscosity caused by retrogradation of starch molecules, especially amylose. Retrogradation is the formation of a microcrystalline network of amylose molecules that bind back to each other or with the amylopectin branching outside the granule after cooling.

The gelatinization profile in Table 9 shows that the seatback value of the modified purple sweet potato flour decreased compared to that of the control flour. This is thought to be due to the use of higher temperatures, which caused damage in the integrity of the starch granules. After the granule destruction was complete, the reverse viscosity of the starch would be decreased. The decreased reverse viscosity indicates that the starch granules experienced low retrogradation (Pangesti, 2014). The minus result here is thought to be caused by the unstable crystallization process due to the use of unsuitable temperature. The temperature that should be used in the making of the modified purple sweet potato flour is 65ºC.

4. Conclusions

Based on the results of this study, the following conclusions are drawn. The preliminary stage, namely the making of control (unmodified) purple sweet potato flour, produced a water content of 3.667%, L* (lightness) color of 68.483, A* (redness) color of 7.163, B* (yellowness) color of 10.067, swelling power of 8.800 (gr/gr), and solubility of 30%.

The main stage to produce the modified purple sweet potato flour with HMT duration of 7 hours and lactic acid concentration of 600 ppm resulted in an anthocyanin level of 24.046 mg/kg. The gelatinization profile reveal that the modified purple sweet potato flour experienced an initial gelatinization temperature (pasting temperature) at 92.30ºC, peak viscosity at 1,343 cP, hot paste viscosity (hold viscosity) at 362 cP, cold paste viscosity (final viscosity) at 931 cP, breakdown (viscosity stability during heating) at 381 cP, and seatback (changes in viscosity during cooling) at -31 cP.

Suggestions that can be proposed for future studies is to use fresh purple sweet potatoes for the making of flour, and do not peel the potatoes and leave the potatoes exposed to air for too long because it can cause browning, which will greatly affect the color of the flour produced. Thoroughness of work during the study must also be observed. The most appropriate temperature of HMT for the making of purple sweet potato flour is 65°C. In addition, future studies also need to analyze the morphological characteristics of the modified purple sweet potato flour to characterize the surface morphology of starch granules in the resulting modified flour.

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