Effect of Heat Moisture Treatment (HMT) on Physicochemical Characteristics of Sorghum Flour (*Sorghum Bicolor L. moench*)

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**Abstract.** The purpose of this research was to determine the effect of different heating temperature using HMT (Heat Moisture Treatment) on the physicochemical characteristics of the modified sorghum flour. Sorghum flour was modified by HMT at temperature (80°C, 90°C, 100°C and 110°C) for 4 hours with 27% of moisture content. This research used Completely Randomized Design (CRD) with one factor which are various of heating temperature of HMT (80°C, 90°C, 100°C and 110°C). The whiteness degree, moisture content, solubility, swelling power, water absorption capacity, setback viscosity, and gelatinization temperature were investigated. The results showed that increased the heating temperature of HMT lead to decreased whiteness, moisture, solubility, swelling power, setback viscosity, and water absorption. However, HMT could increase gelatinization temperature compared with unmodified flour.

1. Introduction

In Indonesia, many foods product were made from wheat, for example bread, noodle, cakes, etc. Indonesian wheat imports reached 7 million tons in 2012, and it was estimated that national wheat consumption rose 6% per year [1]. To overcome this problem, we need to explore local commodities for wheat substitution. Indonesia has rich of tubers, cereals and nuts, which are can be used as a substitute for wheat flour [36] [37]. One of the potential cereals is sorghum (*Sorghum bicolor L. Moench*).

Sorghum is a potential source of carbohydrate commodities and has high nutritional content compared with other cereals such as rice and corn. The chemical composition of sorghum is protein (10.4 g), fat (3.1 g), carbohydrate (70.7 g), crude fiber (2 g), and ash (1.6 g) per 100 gr [2]. Numbu variety is a superior sorghum variety, which has just been released by the Indonesian Cereals Plant Research Institute in 2001. Numbu variety has a potential yield reach 4-5 tons / ha and can be planted on paddy fields. In addition, the protein content of the Numbu variety was 9.12%, fat content (3.94%) and carbohydrates (84.58%) [3]. Processing sorghum into semi-finished processed products (flour) can extend shelf life and easily to use. The wheat substitution with sorghum flour will decreased import of wheat [4].

Utilization of sorghum flour for making foods products still have some problems. According to Wulandari [5], the native sorghum is not resistant on high temperatures lead to the granules expand quickly and break easily, so decrease the viscosity. To maximize the potential of sorghum flour, it needs the improvement of flour quality with modifying functional properties. Modification can be
done in several ways, one of which is physical modification using Heat Moisture Treatment (HMT). HMT is a physically starch modification method, which is carried out using heat treatment and adjust moisture content. The heating was carried out above the gelatinization temperature (80-120°C) with a limited moisture content (<35% w/w) for 15 minutes to 16 hours [6]. Therefore, the objective of this research was to investigate the effects of heating temperature on the physicochemical properties of sorghum flour.

2. Materials and Methods

2.1. Material

The main material was used in this study was the sorghum seeds with Numbu variety. It was obtained from PTPN XII Surabaya. Aquadest was used for solubility, swelling power, pasting profile and water absorption analysis.

2.2. Sorghum flour

Sorghum flour was obtained based on Suarni [7]. Sorghum seeds of the Numbu variety was soaked in water for 1 hour. It was drained and grounded using the grinding machine, then it was dried in a cabinet dryer with 60°C for 3 hours. It was sieved with 80 mesh sieves to obtain sorghum flour.

2.3. Heat Moisture Treatment (HMT)

HMT was performed with various of heating temperature (80°C, 90°C, 100°C, and 110°C). The moisture of sorghum flour was adjusted up to 27%. It was placed in a closed container and stored in a refrigerator with temperature 4-5°C for one night [8]. It was heated in an oven with various of temperature for 4 hours [9]. Then, it was grounded and sieved with 80 mesh.

2.4. Physicochemical properties

2.4.1. Whiteness degree. Whiteness degree of the modified sorghum flour was performed using chromameter. The flour was inserted in the machine and it was analyzed the value L*a*b*, L* indicated lightness, a* indicated red/green and b* indicated yellow/blue. The whiteness degree was calculated using formula below:

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\text{Whiteness degree} = 100 - [(100-L^*)^2 + a^2 + b^2]^{0.5}
\]

2.4.2. Moisture content. The moisture content was carried out using Thermogravimetry method. The 1-2 g of sample was dried in oven at 105°C until constant weight. The moisture was analysed by weight reduction before and after drying process.

2.4.3. Solubility. The solubility was done based on Fardiaz et al. [10]. The 2 g of sample was stirred with 100 ml of aquadest. The solution was filtered by filter paper. Filter paper and residue were dried in oven at 105°C. The solubility was calculated by weight of dried residue divided weight of sample.

2.4.4. Swelling power. Leach method was done in the analysis swelling power of the sample [11]. The 0.1 g of sample was dissolved with 10 ml of aquadest. The solution was heated at 60°C using waterbath for 30 minutes. The supernatant and paste were separated using centrifuge machine with 2.500 rpm for 15 minutes. Selling power was determined by the weight of paste divided the weight of sample.

2.4.5. Water absorption capacity. The water absorption capacity was conducted using Fardiaz et al. method [10]. The 3 g of sample was weighed and placed into filter paper which has been in the funnel. The warm water was poured into filter paper and the rest water was collected. The number of rest water and water in the filter paper was divided by weight of sample to determine the water absorption capacity of sample.
2.4.6. Pasting properties. Pasting properties was determined using Rapid Visco Analyzer (Brookfield). The 1 gr of sample was weighed and placed into canister tube with 10 ml aquadest. The solution was mixed and homogenized with spatula. The canister tube was put into the machine and analysed the pasting profile of sample.

2.5. Statistical analysis
Data were analyzed statistically using the SPSS software. Analysis of variance and DMRT tests with a significance of p < 0.05 were used to compare the differences of the treatments.

3. Results and Discussion

| Table 1. Physicochemical Characteristics of Modified Sorghum Flour with HMT |
|-----------------------------|----------------------|---------------------|-----------------|--------------------------|
| Sample   | Whiteness (% wb) | Moisture (%) | Solubility (%) | Swelling Power (g/g) | Water absorption (g/g) |
| Unmodified | 79,60 ± 0,37c | 9,95 ± 0,38a | 5,59 ± 0,25c | 3,34 ± 0,21c | 2,73 ± 0,04c |
| 80°C     | 76,77 ± 0,18d | 11,65± 0,46b | 3,80 ± 0,11b | 3,01 ± 0,22b | 2,42 ± 0,12b |
| 90°C     | 75,75 ± 0,35c | 11,55± 0,23b | 3,66 ± 0,06ab | 3,00 ± 0,02b | 2,18 ± 0,01a |
| 100°C    | 72,44 ± 0,27b | 11,35± 0,67b | 3,22 ± 0,62ab | 2,87 ± 0,13b | 2,17 ± 0,01b |
| 110°C    | 69,75 ± 0,18b | 10,91± 0,18b | 3,16 ± 0,21a  | 2,55 ± 0,10a  | 2,15 ± 0,17a |

Values represent the mean of triplicate measurements ± SD (Standard Deviation). Means within columns with different letters are significantly different (p < 0.05).

3.1. Whiteness degree
Whiteness degree is one of the important physical parameters to determine the colour quality of flour. Colour is one of the important attributes which is determined the acceptance of consumers. The effect of heating temperature on the whiteness degree can be seen in Table 1. The results suggest that the variation in heating temperature of HMT significantly affected the whiteness.

The whiteness of modified sorghum flour has a lower compared with untreated (control) sorghum flour. These has same result with Pinasthi in tapioca and corn starch [12]. The decrease in the whiteness of the modified sorghum flour was due to the heating process of HMT introduces the reducing sugars. Interaction between the protein with reducing sugar produce a brown color. According to Suriani in the arrowroot starch modification research, the heating process lead to non-enzymatic browning reaction (Maillard reaction) between the reducing sugars and the protein of the sorghum flour [13].

According to the Puslitbang Pascapanen, sorghum flour has a carbohydrate content of 73-83% and a protein content of 7-9% [14]. The modification process of HMT results in a maillard reaction. The higher heating temperature of the HMT cause the faster of maillard reaction. This was caused by more and more proteins being broken down into amino acids and reacting with reducing sugars which is result the maillard reaction. Sultanry and Kaseger stated that one of the factors which is influence browning reaction (maillard reaction) is temperature [15].

3.2. Moisture content
The results of the analysis of moisture content of modified sorghum flour with variations in heating temperature of HMT are shown in Table.1. It can be seen that the moisture content at the various of temperature of HMT (80°C, 90°C, 100°C and 110°C) was not significantly different. However, it had significant difference in moisture content compared with control. In addition, it shows that the modified sorghum flour has a higher moisture content compared with control. Water evaporation occurs due to heating during HMT process. According to Siwi, the higher of temperature makes the starch granules more open. Thus, opening the granules also makes it easier for water to evaporate [16]. This is supported by the statement of Haryadi, swollen starch granules tend to have larger
cavities and will cause water to evaporate more easily during drying process [17]. Table 1 also shows the lowest moisture of modified sorghum flour was 110°C (10.918%), while the highest moisture content was 80°C (11.654%).

3.3. Solubility
The data of the solubility analysis from the modified sorghum flour on the temperature variation of HMT was presented in Table 1. Table 1 suggests that the solubility of sorghum flour at the kind of HMT temperature was significantly different from the solubility value of sorghum flour without treatment (control). The solubility of modified sorghum flour ranged from 3.164 to 3.804%. Solubility (solubility) is the release of dissociated molecules that come out of the granules during expand [12]. The results of this study indicated that the HMT treatment decreases the solubility of modified sorghum flour. Sumarlin stated that this phenomenon is caused by the breaking of hydrogen bonds in the granules starch during HMT treatments [18]. Decrement in the solubility value of modified sorghum flour was due to the higher heating temperature of HMT lead to the lower number of hydroxyl groups in the starch molecule, which is causing the lower ability of starch granules to absorb water. With the lower ability of starch granules to absorb water caused the lower the ability to expand starch. Flour with low water absorption ability had difficult to release starch molecular components, especially amylose, into the dispersing medium (water). Also, solubility was related to the easiness of water molecules to interact with other molecules in starch granules. It replaces hydrogen interactions between molecules. It leads to the granules will more easily absorb water and expand. The granule swelling will force amylose of starch molecules to come out [8].

3.4. Swelling power
The treatment with HMT reduced the swelling power of modified sorghum flour compared with the sorghum flour without treatment (control). The higher of HMT temperature caused the lower the swelling power in the modified sorghum flour. According to Indrastuti et al., swelling power was carried out when starch in excess water and starch suspension temperature rises above a certain range [19]. Molecular hydrogen bonds were disrupted, and water molecules will be bound to hydroxyl groups in amylose and amylopectin, then the granules get enlarged. In addition, it is due to the hydrogen bonds which is weaken the interaction the amylose and amylopectin molecules with increasing heating temperatures, so it is disrupting the compactness of starch granules.

Also, the decrease in swelling power is due to the damage of hydrogen bonds resulting in the loss of hydroxyl groups during HMT process, so that starch is difficult to absorb water. This is related to the ability of starch to hold water molecules. The lower the ability to hold water lead to the lower the starch expands. According to Damat and Haryadi, the expansion capacity shows how much starch granules can expand as indicated by weight gain due to the absorption of water by starch granules [20]. Water absorbed in each granule causes the starch granules to expand resulting in improvement the value of swelling power [21]. Leach et al., [11] said that the lower the strength of starch development will decrease the starch solubility.

3.5. Water absorption
The water absorption shows the ability of the flour to absorb water [22]. The results of the water absorption analysis of modified sorghum flour on the variation of HMT temperature be presented in Table 1. The results indicated that the temperature variation of the Heat Moisture Treatment (HMT) had significantly affects the water absorption of modified sorghum flour. The variation in heating temperature of HMT had significantly influences the decrement in the water absorption capacity of modified sorghum flour. It was concluded that the HMT can reduce the water absorption of modified sorghum flour. The water absorption capacity of modified sorghum flour decreased by the high heating temperature of HMT. The increment in heating temperature of HMT resulting in the lower number of hydroxyl groups in the starch molecule. This was causing the lower ability of starch granules to absorb more water [18].
3.6. Gelatinization temperature

Gelatinization temperature is a temperature range that causes starches to reach maximum swelling [23]. Gelatinization temperature was related with water imbibition and granule swelling [24]. The effect of various HMT temperature on the gelatinization temperature was shown in Table 2. It can be seen that untreated sorghum flour has 75.3°C in the temperature of gelatinization. Whereas, the temperature of gelatinization of modified sorghum flour ranged from 81.9°C-89.4°C. The lowest of gelatinization temperature was at a temperature of 100°C (81.9°C), while the highest gelatinization temperature was at the 80°C (89.4°C). The results of this study suggested that the HMT process can increase the gelatinization temperature of modified sorghum flour.

This is indicating that the increased resistance of the granules to heating [24]. The modified sorghum flour with HMT is resistant to heat, and requires a higher temperature to gelatinize. The increased temperature of gelatinization of the modified sorghum flour was occurred due to recrystallization or rearrangement of the starch granule component. HMT introduces interaction between the amyllose polymer chain and amylopectin in the granule structure which is causes an increase in the pulling force that connects between two polymer chains [25]. It is lead to form new bonds which are more complex between amyllose in the amorphous region and amylopectin in the crystalline portion resulting in the bonding stronger and denser [26]. The stronger and denser structures was needed higher temperature to break the bonds and absorb water. Furthermore, Wirakartakusumah stated that the media of heating affected the gelatinization process included the ratio of water or starch [27]. Increment in gelatinization temperature is desirable in making noodles, and vermicelli because it can increase cohesiveness and prevent damage strands of noodles and vermicelli. Also, it decreased leaching amyllose during the heating process so that it does not break easily [28] [29].

| Table 2. Pasting Properties of Modified Sorghum Flour |
|------------------------------------------|-----------------|-----------------|
| Sample        | Gelatinization Temp. (°C) | Setback viscosity (cP) |
| Unmodified    | 75.3              | 1310.0          |
| HMT 80°C      | 89.4              | 1745.0          |
| HMT 90°C      | 84.1              | 1810.0          |
| HMT 100°C     | 81.9              | 645.0           |
| HMT 110°C     | 87.5              | 480.0           |

3.7. Setback viscosity

Setback viscosity is reflecting the retrogradation ability of starch molecules in the cooling process [30]. Retrogradation is the formation of a microcrystalline network of amyllose-molecules which is bind together again [31]. From Table 2, we can get the setback viscosity value of sorghum flour without treatment (control) as 1310.0 cP. Whereas, the setback viscosity in modified sorghum flour ranges from 480.0-1810.0 cP. The lowest setback viscosity value of modified sorghum flour was found in the 110°C (480.0 cP), while the highest setback viscosity was obtained in the modified sorghum with 90°C (1810.0 cP). The higher temperature of HMT decreased setback viscosity of flour. The decrement in setback viscosity was also occurred with increasing duration of HMT in sago starch [8]. In addition, the same trend results at HMT of 110°C showed a sharp decrease in setback viscosity with the increase in heating from 4 hours to 8 hours in canna starch [32].

HMT treatment at 80°C and 90°C had higher setback viscosity than control. Setback viscosity of HMT at 80°C and 90°C were 1745.0 cP and 1810 cP, respectively. The increment in the setback viscosity is due to the rearrangement of the polymer chain. Utami [29] stated that during the HMT process, there increment in bonds interaction between the starch chains especially in the amyllose fraction thereby increasing the rigidity of the granules. This is related with results of Stute et al., hydrothermal modifications such as HMT can increase setback viscosity due to increased...
rigidity/tightness of granules [33]. According to Richana, this phenomenon was performed because less energy to break the intermolecular hydrogen bonds resulting amylose can join quickly when cooling process [34].

Retrogradation is the process of re-crystallization of starch which has undergone gelatinization when cooling process. A high setback viscosity value indicates that the starch has a tendency to retrograde. The higher the setback value indicates that the higher tendency to form the gel during cooling. Starch with a high setback viscosity tend to easily retrograde, so it is better to be used as raw material for vermicelli products [35].

4. Conclusion
It can be concluded that there is an effect of HMT heating temperature (80°C, 90°C, 100°C and 110°C) on the properties (whiteness, moisture, solubility, swelling power, water absorption, and pasting properties) of modified sorghum flour. Increasing the heating temperature of HMT will reduce the whiteness, moisture, solubility, swelling power, setback viscosity and water absorption capacity. In the pasting profile, modified sorghum flour could increase gelatinization temperature. The result of this research has potency to use in food application in further, especially in noodles, vermicelli and sauces industry.

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