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# Effect of Microwave Exposure and Cooling Time on Physicochemical Characteristics of Modified Sorghum Starch *(Sorghum bicolor L. Moench)*

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**A B S T R A C T**

Sorghum *(Sorghum bicolor L. Moench)* is a type of cereal with high starch content. However, in general, natural *(native)* starch still has many weaknesses in its characteristics. One way to improve it is to modify the starch so that it has good characteristics and increases its functional value. Physical modification of starch is often used to improve the properties of natural *(native)* starch. The starch modification technique with microwave heating and cooling is one of the physical methods that can improve starch characteristics. The purpose of this study was to determine the effect of microwave exposure time and cooling time on the physicochemical characteristics of modified white sorghum starch. This research used completely randomized design (CRD) with 2 factors and 3 replications. First treatment is microwave exposure time (2 minutes, 3 minutes, 4 minutes) and second treatment is cooling time (12 hours, 24 hours, 36 hours). The data obtained were processed using *Analysis of Variance* (ANOVA) to determine the interaction and significant differences between each treatment. There are significant differences, further tests are carried out with the DMRT (Duncan Multiple Range Test) 5%. The results showed that the best treatment in the sample was modified sorghum starch treated with microwave exposure time of 4 minutes and cooling time of 12 hours which had physicochemical characteristics of moisture content of 8.27%, ash content of 0.78%, starch content of 69.13%, amylose 32.41%, amylopectin 36.70%, viscosity 4.97 mPas, swelling power 27.59 g/g, solubility 10.68%.

**Contribution to Sustainable Development Goals (SDGs):**

**SDG 2:** Zero Hunger
**SDG 9**: Industry, Innovation, and Infrastructure
**SDG 12:** Responsible Consumption and Production
**SDG 13:** Climate Action

## 1. INTRODUCTION

### *1.1. Research Background*

Sorghum (*Sorghum bicolor L. Moench)* is cereal crop that grows in sub-tropical areas such as Africa, northern Asia, and grows well in tropical countries such as Indonesia. The low level of popularity is factor influencing sorghum to be less favored and less appreciated as an alternative food commodity to replace the staple food. According to research by [1] local white sorghum variety Bioguma contains 66.38% starch, 23.16% amylose, and 33.82% amylopectin. As food ingredient, sorghum not only contains calories but also contains 6.98- 7.90% protein, 1.19-1.27% fat, and 1.79-1.90% crude fiber. Sorghum protein content has protein content that is almost equivalent to wheat flour and even higher than wheat flour [2], [3]. However, behind the high nutrition of sorghum does not rule out the weaknesses of sorghum itself, namely in [4] sorghum has several weaknesses in its characteristics, namely its rough, dry, sandy texture and crumb which is quickly hard.

Starch is complex carbohydrate composed of amylose and amylopectin, which are glucose polymers. In its application in the food industry, it is often used as texture shaper, thickener, foam stabilizer and flavor encapsule. Application, natural starch still has many weaknesses in its characteristic, this is explained in [5] that natural *(native)* starch still has tendency to low synergism, the value of swelling power and solubility is not good, experiencing retrogradation and syneresis which tends to be high, susceptible to heat and acid, the value of resistance to solubility and absorption when stirred mechanically makes its viscosity low. Natural *(native)* starch is also not resistant to very high temperatures, difficult to form gel uniformity, and not resistant to mechanical processing [6]. The weakness of the physicochemical properties of starch can be overcome by the process of starch modification, which is useful for improving the physicochemical characteristics of starch [7].

Physical modification techniques can be one way to overcome the weakness of starch characteristics. One of the methods of starch modification that can be done is by heating techniques using microwaves and cooling. The working principle of microwaves is based on ionic conduction and dipole rotation. Ionic conduction and dipole rotation usually occur simultaneously in both converting microwave energy into thermal energy [8]. Microwave heating is different from the commonly used conduction and convection heating methods. The heat energy generated by microwaves will be conducted to the center of the material so that it has higher temperature than on the surface due to evaporation of water vapor and there is turntable that ensures uniformity of heat penetration in the material. Microwave modification can minimize the occurrence of damage and loss of nutrients in the material because the application is used in short and fast duration [9]. Cooling treatment was carried out as an effort to accelerate the retrogradation process in starch that has been gelatinized due to microwave heat. According to [10] the retrogradation process of starch will cause recrystallization and increase the formation of resistant starch type 3.

In the research of [11] found that microwave modification with 13% moisture content and 300 W power was able to reduce starch particle size, increase starch content, increase amylose content, increase amylopectin content, reduce the swelling power of palm starch and increase the solubility value of palm starch. The solubility of sorghum seed protein was significantly reduced in the research of [12] found that protein solubility decreased from 12.5% to 11.9% and 7.6% in the treatment of 350 W and 500 W microwaves for 15 seconds, respectively. Research by [13] showed that modification of corn starch by microwave-cooling method can affect the size of starch granules.

### *1.2. Literature Review*

Sorghum *(Sorghum bicolor L. Moench)* is one of the cereal plants that contains fairly high amylose on average 26.9%, food fiber content of 7%-9%, starch digestibility of 72%- 80% and protein digestibility of 69%-71% [4]. The weaknesses of natural sorghum starch include stickiness, not resistant to shear forces, temperature and tend to experience retrogradation and syneresis [14]. Based on [15] sorghum contains protein equivalent to wheat, which is 10.6 g and higher total sugar content than other types of cereals.

The working principle of microwave heating is that microwaves will heat molecules by the dual mechanisms of ionic conduction and dipole rotation. Ionic conduction and dipole rotation usually occur simultaneously in both converting microwave energy into thermal energy [8]. Microwave heat energy is conducted to the center of the material so that it has higher temperature than at the surface due to evaporation of water vapor. To prevent heating that is only concentrated in certain parts so as to create hot or cold spots, most microwaves are equipped with stirrers or turntables to ensure uniform heat penetration in the material [16].

Microwave-cooling modification is physical modification that utilizes microwaves (radiation) combined with cooling. The principle of this method is to heat starch with irradiation or microwaves so that the starch is gelatinized and retrograded, namely the splitting of the amylose fraction which has linear structure and long chains that allow strong intermolecular hydrogen bonds to occur during the cooling process which will form heat-stable resistant starch and its complex granule structure, while amylopectin has branched structure and tends to experience less retrogradation due to more complex chain structure to prevent the formation of strong intermolecular hydrogen bonds ([17]. The low temperature storage process of the resulting starch will accelerate the retrogradation of starch [18]. During starch gelatinization, the birefringence properties of starch granules are lost due to the addition of excess water and heating at certain time and temperature, so that the starch granules swell and cannot return to the condition of all (irreversible) [19]. Microwave-cooling research has been conducted by [13] and [11] which stated that the microwave-cooling method affects the size of starch granules, increases starch content, amylose content, decreases swelling power, and increases solubility value.

### *1.3. Research Objective*

The purpose of this study was to determine the effect of microwave exposure time and cooling time on the physical and chemical characteristics of modified white sorghum starch. In addition, this study was conducted to determine the best treatment of microwave exposure time and cooling treatment which produced modified sorghum starch with the best physicochemical characteristics.

## 2. MATERIALS AND METHOD

### 2.1 Material and Tools

The raw material used in this research is white sorghum flour which will be extracted into white sorghum starch. Chemicals used in the analysis include anhydrous glucose, Iod, pure amylose, Nelson reagent, Arsenomolybdat reagent, sodium hydroxide (NaOH), hydrochloric acid (HCl).

The tools used in this study Electrolux brand microwave (600W power, 220V, 50Hz, and 20L capacity), Samsung refrigerator (321L capacity and 100W power), waterbath, erlenmeyer, blender, baking sheet, cabinet dryer, 80 and 100 mesh sieves, analytical balance, stirrer, spatula, oven, desiccator, furnace, spatula, porcelain cup, weighing bottle, filter paper, volumetric flask, volumetric pipette, test tube, vortex, centrifuge, stopwatch, Spectrophotometer, Brookfield viscometer, SEM Hitachi SU3500.

**Table 1.** Treatment Combinations of modification

| Microwave exposure time | Cooling time | | |
|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ |
| $M_1$ | $M_1C_1$ | $M_1C_2$ | $M_1C_3$ |
| $M_2$ | $M_2C_1$ | $M_2C_2$ | $M_2C_3$ |
| $M_3$ | $M_3C_1$ | $M_3C_2$ | $M_3C_3$ |

Description:

M1C1 = Microwave exposure time 2 minutes: cooling time 12 hours
M2C1 = Microwave exposure time 3 minutes: cooling time 12 hours
M3C1 = Microwave exposure time 4 minutes: cooling time 12 hours
M2C1 = Microwave exposure time 2 minutes: cooling time 24 hours
M2C2 = Microwave exposure time 3 minutes: cooling time 24 hours
M3C2 = Microwave exposure time 4 minutes: cooling time 24 hours
M1C3 = Microwave exposure time 2 minutes: cooling time 36 hours
M2C3 = Microwave exposure time 3 minutes: cooling time 36 hours
M3C3 = Microwave exposure time 4 minutes: cooling time 36 hours

The data obtained were processed using *Analysis of Variance (ANOVA)* to determine the interaction and significant differences between each treatment. There are significant differences, further tests are carried out with the *DMRT (Duncan Multiple Range Test)* 5% using *IBM Statistics SPSS* 26 for *Windows* 11. Decision making in determining the best treatment combination of modified sorghum starch treatment microwave exposure time and cooling time using the *De Garmo* method effectiveness test.

**Extraction of White Sorghum Starch**

The starch extraction process was carried out based on the modified [37] method. The white sorghum flour was uniformed in size with an 80 mesh sieve, then weighed 75 grams. After that, 75 grams of white sorghum flour was mixed with 1000 ml of distilled water and stirred until homogeneous. Perform repeated washing with 1000 ml of distilled water until the water is clear and the starch precipitate is taken after 24 hours of standing. The white sorghum starch precipitate was then dried with cabinet dryer at 55$^o$C for 8 hours. The dried white sorghum starch was pulverized and sized with 100 mesh sieve.

**Modified Starch Microwave Exposure and Cooling Method**

The modification process with microwave exposure and cooling treatment was taken from the modified method [39]. Sorghum starch was weighed and adjusted to 30% (b/v) moisture content and then stirred until homogeneous. The starch suspension was then subjected to microwave treatment for (2, 3, 4) minutes with 600W power and 77% power output to form gelatinized starch paste. The starch paste was cooled for 30 minutes at room temperature. Then, the starch paste was stored at low temperature of 4$^o$C with cooling time for (12, 24, 36) hours in closed condition. Next, the starch paste was dried with cabinet dryer at 55$^o$C for 8 hours. The dried white sorghum starch was pulverized and sized with 100 mesh sieve.

### *2.2 Research Analysis*

*2.2.1. Raw Material Evaluation*

The raw material analyzed was white sorghum starch. The analysis included moisture content, ash content, and starch content, amylose, amylopectin, solubility, swelling power, viscosity.

*2.2.2. Physicochemical Analysis of Modified White Sorghum Starch*

Parameters analyzed included moisture content, ash content, and starch content, amylose, amylopectin, solubility, swelling power, viscosity.

## 3. RESULT AND DISCUSSION

*Raw Material Analysis*

Analysis of raw materials in this study was carried out white sorghum natural *(native)* starch. The results of raw material analysis can be seen in **Table 2.**

**Table 2.** Chemical Composition White Sorghum Starch

| Analysis | White Sorghum Starch | Literature |
|---|---|---|
| **Moisture content (db%)** | 9,08±0,040 | 9,19[a] |
| **Ash content (db%)** | 0,71±0,018 | 0,79[a] |
| **Starch (%)** | 71,79±0,111 | 66,39[a] |
| **Amylose (%)** | 23,64±0,035 | 23,16[a] |
| **Amylopectin (%)** | 48,15±0,096 | 33,82[a] |
| **Swelling power (g/g)** | 21,57±0,105 | 21,43[a] |
| **Solubility (%)** | 18,95±0,046 | 19,04[a] |
| **Viscosity (mPas)** | 6,07±0,020 | 28,83[b] |

Source of literature: a [1]; b [26]

Based on **Table 2.** it is known that white sorghum starch has moisture content of 9.08%, ash content of 0.71%, and starch of 71.79%, amylose of 23.64%, amylopectin of 47.91%, swelling power of 21.57 g/g, solubility of 18.95%, viscosity of 6.07 mPas. Based on the results of white sorghum starch research with the literature, most of the differences in results are not too significant.

The moisture content of white sorghum starch is known to be 9.08%, this is in accordance with research from [1] which shows the moisture content of white sorghum starch is 9.19%. The moisture content of the analyzed white sorghum starch is also in accordance with the standard that the maximum standard of flour or starch moisture content is 14% [20], this also shows that the temperature and drying time carried out at 55 $^o$C for 8 hours is appropriate.

The ash content of the analyzed white sorghum starch was slightly lower at 0.61% while according to the literature from [1] it was 0.71%. The difference according to [21], the value of ash content can be influenced by several factors, namely the method of ignition, type and variety of ingredients, temperature and time during drying.

The results of the white sorghum starch content analyzed were higher by 71.79% compared to the literature, which was

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66.39%. This is due to differences in the types of sorghum varieties used and the starch extraction process carried out. This is in [43] that the type of variety in sweet potatoes affects the level of starch content. According to [44] extraction carried out with a polar water solvent can increase the amount of starch produced because there is minimal starch degradation. According to [22] starch consists of two main components, namely amylose around 15-30% and amylopectin 70-80%. The difference in the proportion of amylose and amylopectin in starch will affect the physical, chemical and functional properties of starch.

Swelling power according to the literature from [1] the value is 21.57 g/g and the results are not much different from the results of the starch analysis which is 21.5 g/g. According to the literature from [23] swelling power occurs due to the formation of hydrogen bonds that bind water by starch molecules, however, hydrogen bonds and starch molecules will be broken after gelatinization and form hydrogen and water bonds, resulting in an increase in the swelling power value due to the amount of water absorbed in starch granules.

The solubility of the analyzed white sorghum starch was 18.95% while according to the literature [1] the value was 19.04%. According to [24], starch solubility will increase and is directly proportional to the higher pre-gelatinization temperature used. In addition, according to [25], amylose contained in the material will also affect the high and low value of solubility because amylose has straight chain of glucose that is easily soluble in water so that if the amylose content is higher, the soluble index value is also higher.

Viscosity is the ability of starch granules to swell. The results of the analysis showed that the viscosity of white sorghum starch was 6.07 mPas, which is lower than the literature [26] which is in fermented sorghum flour which is 28.83 mPas. The low viscosity value is thought to be because the heating temperature used in the analysis was too low, namely 50°C, which is not the starch gelatinization temperature. According to, [46] the gelatinization temperature of sorghum flour ranges from 75-90°C. The high and low viscosity of starch can also be caused by differences in the treatment of modification types, types of sorghum varieties and amylose and amylopectin levels.

### ***3.1 Physicochemical Analysis of Modified White Sorghum Starch***

#### *3.1.1. Moisture Content*

Based on the analysis of variance in **Table 3.** it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on moisture content. Each treatment gave a significant effect on the moisture content of modified white sorghum starch. The treatment of microwave exposure time for 4 minutes and cooling time for 36 hours obtained the lowest water content value of 7.48% and in the treatment of microwave exposure time for 2 minutes and cooling time for 12 hours had the highest value of 8.63%. The results of water content due to the treatment of microwave exposure time and cooling time have value range of 7.48-8.63%, this is in accordance with standard that the maximum standard of flour or starch moisture content is 14% [20].

The decreasing water content is thought to be caused by overheating in microwave treatment, temperature treatment and starch drying time, and retrogradation. The longer microwave duration will push the water vapor in the material out so that the water vapor comes out of the starch pores. Another factor that causes low water content is the drying process with high enough temperature and time because in this study drying temperature of 55 °C for 8 hours was used. According to [25] the higher the temperature and time used in the drying process, the less water vapor content in the material because it has been bound by drying air. Microwave exposure treatment will make starch gelatinized and retrograded due to the length of cooling in low temperatures, decrease in temperature in starch causes the amylose fractions to close together and bind to each other. The shorter distance between amylose fractions causes the cavity where water is bound to be narrower and the bound water is pushed out of the gel system. The shorter distance between amylose fractions causes the starch gel to decrease in water content and harden.

This is reinforced by the literature of [28] that starch retrogradation causes decrease in the water content of the material. The distance between the chains of the amylose and amylopectin fractions that narrowed caused the pressure of bound water out of the starch matrix, so that free water and weakly bound water evaporated during heating. The higher amount of starch causes decrease in the moisture content of the material.

**Table 3.** Physicochemical Characteristics of Modified White Sorghum Starch

| Sampel | **Moisture content (db%)** | **Ash content (db%)** | **Starch content (%)** | **Amylose (%)** | **Amylopectin (%)** | **Swelling power (g/g)** | **Solubility (%)** | **Viscosity (mPas)** |
|---|---|---|---|---|---|---|---|---|
| M1C1 | 8.63 ± 0,034$^{g}$ | 0,72 ± 0,008$^{a}$ | 71.20 ± 0,085$^{i}$ | 24,26 ± 0,170$^{a}$ | 46,94 ± 0,242$^{i}$ | 24,01 ± 0,056$^{a}$ | 8,67 ± 0,037$^{a}$ | 5,36 ± 0,026$^{a}$ |
| M1C2 | 8.33 ± 0,025$^{e}$ | 0,72 ± 0,010$^{a}$ | 70.82 ± 0,015$^{h}$ | 24,88 ± 0,100$^{b}$ | 45,94 ± 0,115$^{h}$ | 24,29± 0,019$^{b}$ | 8,93 ± 0,056$^{b}$ | 5,43± 0,015$^{ab}$ |
| M1C3 | 7.97 ± 0,020$^{c}$ | 0,72 ± 0,021$^{a}$ | 70.67 ± 0,032$^{g}$ | 25,05 ± 0,046$^{c}$ | 45,61 ± 0,075$^{g}$ | 25,10 ± 0,085$^{c}$ | 9,34 ± 0,057$^{c}$ | 5,69 ± 0,020$^{b}$ |
| M2C1 | 8.45 ± 0,083$^{f}$ | 0,75 ± 0,009$^{a}$ | 70.41 ± 0,087$^{f}$ | 27,51 ± 0,165$^{d}$ | 42,90 ± 0,241$^{f}$ | 26,13 ± 0,009$^{d}$ | 9,68 ± 0,103$^{d}$ | 5,06 ± 0,021$^{c}$ |
| M2C2 | 8.08 ± 0,024$^{d}$ | 0,75 ± 0,010$^{a}$ | 70.12 ± 0,025$^{e}$ | 27,88 ± 0,012$^{e}$ | 42,24 ± 0,036$^{e}$ | 26,56 ± 0,075$^{e}$ | 10,17 ± 0,043$^{e}$ | 5,36 ± 0,044$^{d}$ |
| M2C3 | 7.84 ± 0,046$^{b}$ | 0,76± 0,016$^{a}$ | 69.91 ± 0,040$^{d}$ | 28,25 ± 0,093$^{f}$ | 41,67 ± 0,110$^{d}$ | 26,88 ± 0,104$^{f}$ | 10,33 ± 0,061$^{f}$ | 5,45 ± 0,030$^{d}$ |
| M3C1 | 8.27 ± 0,049$^{e}$ | 0,78 ± 0,004$^{a}$ | 69.11 ± 0,020$^{c}$ | 32,41 ± 0,234$^{g}$ | 36,70 ± 0,241$^{c}$ | 27,59 ± 0,046$^{g}$ | 10,68 ± 0,063$^{g}$ | 4,97 ± 0,010$^{f}$ |
| M3C2 | 7.78 ± 0,044$^{b}$ | 0,78 ± 0,003$^{a}$ | 68.57 ± 0,140$^{b}$ | 32,96 ± 0,040$^{h}$ | 35,61 ± 0,177$^{b}$ | 27,95 ± 0,047$^{h}$ | 10,91 ± 0,071$^{h}$ | 4,94 ± 0,015$^{f}$ |
| M3C3 | 7.48 ± 0,025$^{a}$ | 0,79 ± 0,001$^{a}$ | 67.96 ±0,050$^{a}$ | 33,70 ±0,061$^{i}$ | 34,26 ±0,087$^{a}$ | 24,01 ± 0,056$^{a}$ | 11,14 ±0,122$^{i}$ | 4,92 ± 0,015$^{g}$ |

Note: Values accompanied by different notation indicate significant differences ($p \leq 0.05$)

#### *3.1.2. Ash Content*

Based on the results of the analysis of known variance analysis Table 3. it can be seen that there is no significant interaction ($p \geq 0.05$) between the treatment of microwave exposure time and cooling time on white sorghum starch on the modified ash content of white sorghum starch. The average value of the ash content of modified sorghum starch due to the treatment of microwave exposure time is around 0.72-0.78%. The results of the microwave exposure time treatment show that the higher the duration of microwave exposure time (4 minutes), the higher the ash content. This is in accordance with the statement of [29] which states that an increase in ash content can occur because the higher the heating temperature, the more air will be evaporated from the dried material, and provide an increase in the content of sugar, fat, minerals, resulting in an increase in ash content. [30] explained that microwave treatment can cause an increase in crude fiber and ash content but will reduce the value of fat and protein content. Meanwhile, according to [31] the amount of ash content depends on the type of material, method of drying, time and temperature used during drying, and the lower the non-mineral components contained in the material, the higher the percentage of ash relative to the material. Drying with high enough temperature in long enough period of time will also increase the ash content of starch, this is explained by [32] the longer the time and the higher the drying temperature, the higher the ash content value, which causes the water content to decrease. The drying process on the analyzed white sorghum starch used temperature of 55ºC for 8 hours.

It can also be seen that the cooling time treatment of white sorghum did not show significant differences in the results of ash content. This happened because the cooling time treatment did not affect the change in the value of ash content in modified sorghum starch. This happened allegedly because the cooling treatment only served to accelerate the retrogradation of starch. This is explained by [33] that retrogradation is the reformation of hydrogen bonds between amylose and amylopectin molecules in the cooling phase that occurs in gelatinized starch, causing rheological changes in starch paste.

*3.1.3. Starch*

Based on the analysis of variance in Table 3, it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on starch. Each treatment gave a significant effect on the starch content of modified white sorghum. The starch of white sorghum starch treated with microwave exposure time and cooling time ranged from 67.96- 71.20%. The lower the microwave exposure duration (2 minutes) and the shorter the cooling duration (12 hours) will produce the highest starch value, on the other hand, if the higher the microwave exposure time duration (4 minutes) and the greater the cooling time duration (36 hours), the starch value decreases.

The decrease in the value of starch might be likely caused by the excessive duration of microwave exposure time on white sorghum starch so that an overheating process occurs which causes starch degradation. Research by [34] explained that the use of excessive power in microwaves can cause excessive local heat which results in starch carbonization and chain cleavage in starch molecules so that the amylose chain will be cut off excessively due to the higher microwave power used. According to [47] excessive heating treatment will increase the amount of degraded starch, causing damage to the physical and chemical structure of the starch. According to [35], starch degradation also occurs in starch modification techniques with autoclave heating, namely the process of breaking glycosidic bonds in the starch fraction in the linear bond α-1,4 amylose and branching bond α- 1,6 amylopectin. The value of starch content produced by microwave exposure time treatment and cooling of white sorghum starch is still relatively higher, namely 67.957%.

*3.1.4. Amylose*

Based on the analysis of variance Table 3. it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on amylose content. Each treatment gave a significant effect on the amylose content of modified white sorghum starch. amylose content of modified white sorghum starch treated with microwave exposure time and cooling time ranged from 24.26-33.70%.

The higher the microwave exposure time duration (4 minutes) and the higher the cooling duration (36 hours), the higher the amylose content. The increase in amylose is thought to occur due to starch molecules experiencing vibrations by microwaves so that they are degraded during the cooking process with microwave exposure. During the modification process of white sorghum starch with microwave exposure time treatment and cooling time, three stages occur, namely gelatinization, glycosidic bond breaking and starch retrogradation. According to [35], heating starch above the gelatinization temperature can cause the breakage of hydrogen bonds from the double helix structure of amylopectin molecules, melting of crystalline regions and release of amylose from starch granules. Meanwhile, according to [36], the increase in amylose is caused by the breakage of the α-1,6 glycosidic bond chain which is unstable compared to the α-1,4 glycosidic bond which will form branched amylopectin chain which will change its structure to amylose which has straight chain. The treatment of microwave exposure time and cooling time can cause retrogradation of the amylose fraction where the starch has been gelatinized and then stored at low temperature of 4ºC which accelerates the retrogradation of starch. According to [10] the starch retrogradation process will cause recrystallization and increase the formation of resistant starch type 3.

*3.1.5. Amylopectin*

Based on the analysis of variance Table 3. it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on amylopectin content. Each treatment had a significant effect on the amylopectin content of modified white


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sorghum starch. The amylopectin content of modified white sorghum starch treated with microwave exposure time and cooling time ranged from 34.26-46.94%. The higher the microwave exposure duration (4 minutes) and the longer the cooling time (36 hours), the lower the amylopectin content value.

The decrease in amylopectin value might be likely caused by the long heating time at high temperatures and the occurrence of retrogradation. [45] stated that increasing the heating temperature will cause changes in the amylopectin molecule, namely the breaking of the α-1,6 glycoside bond, thereby breaking the branching of the amylopectin chain, and producing a polymer with a straight chain in the form of an amylose molecule. This is in line with the statement from According to [38] there is an interaction between amylose-amylose, amylopectin-amylose, and amylose-amylose which are glycoside bonds that are broken due to heat interactions, changing complex starch molecules into simple sugars. Then with cooling treatment, retrogradation can be faster. Retrogradation occurs more easily in the amylose chain than in amylopectin because amylose is a smaller and unbranched molecule. Retrogradation occurs due to the formation of an amylose network with amylose or amylopectin when the temperature decreases [48].

*3.1.6. Solubility*

Based on the analysis of variance Table 3, it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on the solubility value. Each treatment gave a significant effect on the solubility of modified white sorghum starch. The solubility of modified white sorghum starch treated with microwave exposure time and cooling time ranged from 8.67-11.14%.

The higher the duration of microwave exposure time (4 minutes) and the longer the cooling time (36 hours), the higher the solubility value. The increase in solubility value is thought to be caused by the long duration of cooking and high amylose content. This is in line with [24]. The increase in starch solubility is caused by an increase in temperature and as result the hydrogen bonds are broken so that the resulting glycosidic chain is broken from the starch fraction that is split. This condition produces starch that is more soluble because it has smaller molecular size. Weaker hydrogen bonds will make it easier for water to enter the starch granules. According to [40] modified starch will have higher solubility value because the formation of hydrogen bonds between starch and water molecules tends to be greater due to the easier entry of water molecules into the granules. In the end, starch will become soluble due to the retention of water in the granule through hydrogen bonds.

The treatment of microwave exposure time and cooling time can cause gelatinized starch to be retrograded which will cause recrystallization and restructuring of starch bonds, so that amylopectin molecules will get shorter and more amylose bonds. According to [25], amylose contained in food ingredients will affect the value of high solubility.

*3.1.7. Swelling Power*

Based on the analysis of variance in Table 3, it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on swelling power. Each treatment gave a significant effect on the swelling power of modified white sorghum starch. The swelling power of modified white sorghum starch treated with microwave exposure time and cooling time ranged from 24.01-28.6 g/g.

The higher the duration of microwave exposure treatment (4 minutes) and the duration of cooling time (36 hours) on white sorghum starch, the higher the expansion value. The increase in starch swelling power value is thought to be due to the absorption of water by starch granules due to heating and high amylose content. According to [23] swelling power is related to the formation of hydrogen bonds so that there is binding of water by starch molecules. Hydrogen bonds between starch molecules will be broken after gelatinization, and hydrogen bonds with water are formed instead. This results in the maximum development of starch granules in the gelatinization process. In the end, there is an increase in swelling power because the starch granules swell and more water is absorbed into the starch granules.

The high content of amylose is also one of the factors that increase the value of swelling power, this is in line with [41] the high and low swelling power can be influenced by the amylose content contained in the starch. Starch with high amylose content will produce high swelling power as well. This is in accordance with the opinion of [42] which states that when heating occurs, water absorption will be easier and development is also greater in polysaccharide molecules that have high amylose content compared to polysaccharide molecules with low amylose content. This is because in the amorphous region (formed by mostly amylose), amylose forms fewer hydrogen bonds and the pathway is composed of more soluble polymers.

*3.1.7. Viscosity*

Based on the analysis of variance Table 3, it can be seen that there is a significant interaction ($p \leq 0.05$) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on viscosity. Each treatment gave a significant effect on the viscosity value of modified white sorghum starch. The viscosity value of sorghum starch with microwave exposure time and cooling time treatment ranged from 4.92-5.36 mPas. The lower the wave exposure time duration and the higher the cooling time duration, the higher the viscosity value. The results of viscosity values are thought to be influenced by the high value of starch expansion. This is in accordance with [43] who stated that the viscosity of starch granules is directly proportional to swelling power of the starch

It is known that the viscosity value of white sorghum starch from the treatment of microwave exposure time and cooling time is higher in value, which is between 4.92-5.36 mPas, while the viscosity of corn starch solution with the treatment of various acid concentrations and the length of HMT time tends to be lower, which is around 1-2 mPas. This is explained in [13] that sorghum starch and corn starch have different structures, sorghum starch has shorter chains and fewer branches than corn starch chains so that these structural differences can cause differences in viscosity values and in addition, viscosity values.

## 4. CONCLUSION

There is a significant interaction (p≤0.05) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on moisture content, starch, amylose, amylopectin, swelling power, solubility, and, viscosity. But there was no significant interaction (p≥0.05) between the treatment of microwave exposure time and cooling time on modified white sorghum starch on ash content.

The best treatment is known to be in the treatment of microwave exposure time of 4 minutes and cooling time of 12 hours with moisture content of 8.27%, ash content of 0.78%, starch content of 69.13%, amylose 32.41%, amylopectin 36.70%, viscosity 4.97 mPas, swelling power 27.59 g/g, solubility 10.68%.

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