Effect of zeolite concentration and preheating temperature on sorghum [Sorghum bicolor (L.) Moench] juice clarification as liquid sugar manufacturing raw material

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Abstract. Sorghum juice can be used as raw material for producing liquid sugar. Impurity matters are one of the problems in producing liquid sugar that can affect the final product. The goal of clarification is to remove suspended and turbid particles and to allow subsequent concentration in a viable liquid sugar product using standard commercial evaporation technologies. This research aims to determine the optimum concentration of zeolite and the preheating temperature for removing impurities matters in the clarifying process. This study used a Randomized Block Design method with two factors, namely zeolite concentration factor with three levels (1.5%, 3%, 4.5%) and preheating temperature with three levels (60°C, 75°C, 90°C). The results show that the purification process with these two factors manages to clarify sorghum juice well. The best results of the purification process are obtained at 4.5% zeolite concentration and 90°C preheating temperature, with the results of remaining starch content of 0.754 ± 0.041%, protein content of 0.13 ± 0.007%, ash content of 1.198 ± 0.0028%, pH value 5 ± 0.1, turbidity of 9.14 ± 0.21 NTU, total dissolved solids 21.20 ± 0.4 Brix, density of 1.0708 ± 0.0026 gr / ml, brightness (L*) of 46.239 ± 1.16 , redness (a*) of -0.694 ± 0.22, and yellowness (b*) of 25.91 ± 0.48.

1. Introduction
Indonesia is a country with high sugar consumption, and according to Indonesia’s Industrial Ministry, sugar consumption level in 2017 reached 5.8 million tons. Whereas the number of sugar production in that year only reached 2.21 million tons, thus in order to fulfill the remaining demand, the sugar was obtained through import. Besides that, sugar demand in Indonesia has increased each year, so the alternative sugar beside cane sugar, which has become the main commodity, is needed in Indonesia.

Sorghum juice is one of the alternatives that can be utilized as the ingredient of liquid sugar manufacturing. Sorghum juice has a high level of sugar content, just like sugarcane juice. However, there is a difference where invert sugar levels, such as glucose and fructose in sorghum juice, are much higher than sugarcane juice [3]. The high level of invert sugar is the cause why sorghum juice utilization is limited as a sweetener. Liquid sugar must have high clarity level and directly visible impurities. Therefore, the goal of clarification is to remove suspended and turbid particles and to allow subsequent concentration in a viable liquid sugar product using standard commercial evaporation technologies.

The clarification process used in this research uses zeolite as adsorbent and preheating treatment. The clarification process commonly uses adsorbent as a water purifier. However, lately, it is used as a
purifier for liquid food. The purification of *Stevia rebaudiana* (Bert) Bertoni extract, which uses zeolite, can be purified up to three times [7], and purification using zeolite has better results rather than using bentonite and active carbon on decreasing mineral content [13]. The heating process in the juice has been commonly used for cane sugar production. The preheating process in sugarcane juice purification can decrease the dextran level (~10%) and starch level (~24%) and decreased lime that is using in the purification up to 4,6% [4]. However, pre-heating treatment and usage of adsorbent (zeolite) have never been used for clarifying sweet sorghum juice. Therefore, this research aims to determine the effectiveness of the preheating process and usage of zeolite as an adsorbent in clarifying sweet sorghum juice.

2. Materials and methods

2.1. Materials
Materials used in this research were sweet sorghum plants obtained from Indonesian Legumes and Tubers Crops Research Institute (ILETRI) Kendalpayak and Wajak in the District of Malang. The plants were harvested when the plants reached the age of 90 – 100 days. Materials used in the research, were HCl, alcohol 80%, arsenomolibdate reagent, Nelson A and B reagents, potassium sulfate, copper (II) sulfate, sulfuric acid, and HCL 0.1 N.

2.2. Methods
This research used Randomized Block Design as an experimental design. Factors used in this research were zeolite concentration with levels of 1.5%, 3%, and 4.5%, and also preheating temperature of 60°C, 75°C, and 90°C. The analytical testing in this research was a chemical analysis, such as starch, protein, and ash content, and also pH level, and physical analysis, such as turbidity, total dissolved solids, density, and color (L*, a*, and b*). The result were later analyzed using the ANOVA test using Minitab 16 application. The best experiment factors were determined using the Zeleny method [10].

2.3. Experimental design
Nine units of the experiment were determined from experimental design with three replications for each experiment, so the total of experiment design was twenty-seven units (see table 1). The research result is later analyzed using Minitab 16 software.

| Preheating temperature | Zeolite concentration |
|------------------------|-----------------------|
| 60°C                   | 60°C; 1.5%            | 60°C; 3%                   | 60°C; 4.5%               |
| 75°C                   | 75°C; 1.5%            | 75°C; 3%                   | 75°C; 4.5%               |
| 90°C                   | 90°C; 1.5%            | 90°C; 3%                   | 90°C; 4.5%               |

2.4. Research stages

2.4.1. Sorghum juice extraction. Harvested sorghum stalks are separated from its leaves then washed to remove impurities. Sorghum stalks are cut into two pieces, and they were pressed using a double cylindrical roll pressing machine. The extracted juice is filtered using three layers of filter cloths. Then, the extracted sorghum juice is stored inside the freezer to keep it cold.

2.4.2. Zeolite activation [2]. Zeolite is weighed up to 300 grams and put inside a beaker glass of 500 ml. Later, 500 ml HCL 25% is poured inside the glass for the activation process for 24 hours. After that, the zeolite is strained, and the pH is neutralized up until the pH is normalized to around 7 using distilled water. Zeolite is later put inside the oven with a temperature of 300°C for three hours in order to heat...
and evaporate the remaining water inside the zeolite. Before using the zeolite, it is heated with a temperature of 100°C for one hour.

2.4.3. Sorghum juice clarification. Sorghum juice is poured for 300 ml inside the pan and heated using stove with preheating temperature according to the factors used (60°C, 75°C, and 90°C) for five minutes. The juice moves into a beaker glass of 250 ml, and the zeolite is poured inside according to the factors used (1.5%, 3%, and 4.5%). The juice is later mixed and cooled up to one hour at room temperature. When it cools down, it is centrifuged with a speed of 3000 rpm for 10 minutes. Later, the juice is filtered using a paper filter and moved into another container, which is the Erlenmeyer flask.

3. Result and discussion

3.1. Chemical characteristics of raw sorghum juice
The physical and chemical properties in this research correspond to its literature source (shown in table 2). For the turbidity parameter, there is a slightly higher difference where sorghum juice used in this research has a turbidity level of 1340.44 ± 18.5 NTU, while in its source, literature has a turbidity level of 3943 NTU. According to [1], sorghum juice which is extracted immediately has a higher level of turbidity, and turbidity level above 1000 means that the juice is already very murky and turbid. Sorghum juice will be clarified first in order to remove its impurities. Sorghum juice used in the research corresponds with the criteria based on the source literature.

| Parameters               | Analysis Result | Literature Source |
|--------------------------|-----------------|-------------------|
| Turbidity (NTU)          | 1340.44 ± 18.50 | 3943[1]           |
| Total Dissolved Solids (Brix) | 15.77 ± 2.87       | 15.6[1]          |
| Brightness (L*)          | 33.90 ± 2.08    | 22.87[12]         |
| Redness (a*)             | -3.61 ± 0.59    | -0.28[12]         |
| Yellowness (b*)          | 9.31 ± 0.83     | 1.82[12]          |
| Density (gr/ml)          | 1.112 ± 0.013   | 1.03[11]          |
| pH level                 | 5.133 ± 0.057   | 5.07[12]          |
| Starch content (%)       | 10.076 ± 0.34   | 11.2[1]           |
| Protein level (%)        | 1.204 ± 0.113   | 1.50[1]           |
| Ash level (%)            | 1.763 ± 0.345   | 2.04[1]           |

Source: [1, 12, 11]

3.2. Chemical properties of clarified sorghum juice
The lowest remaining starch level in the clarified juice is found in the juice treated with preheating temperature of 90°C and zeolite concentration of 4.5% (table 3). Treatment using different levels of preheating temperature and zeolite concentration gave a significant difference with the starch level after the juice was clarified, and there was an interaction between those treatments. Starch, which has a shape of granule, will swell because of the heat. It will break, and the hydrogen bond inside starch will break as well, letting water inside the starch, expanding the starch particle size, and it will be much easier to be separated. Besides that, inside the juice, there will be a natural occurrence of flocculation within its organic matters, such as protein coagulation. Those flocculants will float into the surface, and it can be separated easily as well. The higher the zeolite concentration used, the more impurities will be adsorbed thus purifying the juice. Zeolite can adsorb precipitated impurities, where the chemical bonds between soluble starch with the zeolite structure caused the starch adsorbed with zeolite.

Preheating temperature treatment of 90°C and zeolite concentration treatment of 4.5% has the lowest remaining protein content compared with other treatments. The occurrence caused by protein coagulation. Protein begins to coagulate when heated at 65°C, and there will be phase alteration into a solid phase, releasing its water content. Protein will be precipitated and surfaced. As for zeolite, it will
affect the clarification by adsorbing the protein into the outer surface of the zeolite. The outer surface of zeolite has a complex matrix that could adsorb and bind the protein into the outer matrix of zeolite. The binding ability of the zeolite matrix is caused by its properties of being hydrophobic and organophilic, thus making it able to bind organic matters.

Preheating treatment of 90°C and zeolite concentration treatment of 4.5% show that it has the lowest ash content average compared to other treatments. The coagulation effect of organic matters such as starch and protein, which have a bigger particle size, can bring up and even ensnare the much smaller minerals, trapping them into precipitation. Protein, in particular, has a bigger size in particle, which would be able to carry the mineral up to the surface and precipitate. Proteins in sorghum juice can work as natural flocculant formed during heating, carrying, and trapping smaller organic and inorganic matters to the surface or pulling it down with adsorbent [1]. Minerals are unable to be broken down because of the preheating process with temperature up to 100°C. However, it can be seeped out from foods due to cooking loss, flushing them out with water, with simple examples such as boiling vegetables in water.

On the other hand, zeolite can pull minerals or metals. Adsorption ability from zeolite comes from its ability of ions exchanging, which bind metal ions. Zeolite got cations from its interaction with matters scattered around it. Cations accommodate zeolite in order to equate a negative charge on the outer surface pores of the zeolite. Zeolite can adsorb metal ions rapidly, such as Fe, Mn, Zn, and Cu, by ion exchanging and hydroxide metal settling [6].

### Table 3. Starch, protein, and ash content, the pH level of clarified sorghum juice with preheating and zeolite adsorbent treatment.

| Pre-heating Temp. (°C) | Zeolite Conc. (%) | Starch Content (%) | Protein Content (%) | Ash Content (%) | pH     |
|-----------------------|------------------|-------------------|--------------------|----------------|--------|
| 60°C                  | 1.5%             | 4.597 ± 0.025     | 0.314 ± 0.023      | 1.587 ± 0.055 | 4.67 ± 0.058 |
| 60°C                  | 3%               | 3.568 ± 0.042     | 0.252 ± 0.010      | 1.558 ± 0.011 | 4.73 ± 0.058 |
| 60°C                  | 4.5%             | 2.464 ± 0.105     | 0.198 ± 0.025      | 1.520 ± 0.004 | 4.77 ± 0.058 |
| 75°C                  | 1.5%             | 3.471 ± 0.081     | 0.273 ± 0.003      | 1.319 ± 0.059 | 4.73 ± 0.058 |
| 75°C                  | 3%               | 2.340 ± 0.122     | 0.219 ± 0.006      | 1.289 ± 0.021 | 4.83 ± 0.116 |
| 75°C                  | 4.5%             | 1.644 ± 0.045     | 0.160 ± 0.012      | 1.249 ± 0.006 | 4.83 ± 0.058 |
| 90°C                  | 1.5%             | 2.541 ± 0.125     | 0.232 ± 0.003      | 1.234 ± 0.009 | 4.80 ± 0.100 |
| 90°C                  | 3%               | 1.590 ± 0.026     | 0.173 ± 0.003      | 1.211 ± 0.011 | 4.87 ± 0.058 |
| 90°C                  | 4.5%             | 0.754 ± 0.041     | 0.130 ± 0.007      | 1.198 ± 0.003 | 4.90 ± 0.100 |

Note: values followed by the different notation (letter) shows significantly different

Table 3 shows a preheating temperature of 90°C and zeolite concentration of 4.5% shows the highest pH level. However, preheating temperature treatment shows an insignificant effect. The heating process only changes sorghum juice’s pH level momentarily, lowering its level due to heating or increasing its temperature also increases the molecule’s vibration, which enables water to ionize and create more hydrogen ions. Zeolite adsorption treatment also does not have a significant effect on pH level because zeolite does not affect the acidity of the sorghum juice or any liquid. Zeolite itself tends to be a material that does not change much of the acidity level. Lime is usually used to increase the pH level because it can significantly increase the pH level up to 7 or more. The pH level of sorghum juice tends to be acidic because of natural fermentation inside the juice. Sorghum syrup produced by Nimbkar Agriculture Research Institute (NARI) in Phaltan, India, has protein and ash content higher than clarified sorghum juice produced in this research [15]. It shows sorghum juice produced in this research can be used for raw material of liquid syrup or sugar syrup. Unfortunately, we did not find the quality standard of sorghum juice for sorghum syrup or sorghum liquid sugar manufacturing. However, the ash content of clarified sweet juice (1.198 %) is lower than the standard ash content of sulfured sugar syrup (6%) and un-sulfured sugar syrup (4.5%) [16].
3.3. Physical properties of clarified sorghum juice

Different preheating temperature and zeolite concentration treatment give significant effect to sorghum juice’s turbidity level, and there is an interaction between them. Starches inside the juice swell because of heating, increasing its size, and carrying smaller particles for precipitation. Proteins also coagulate because of heating, changing its phase into solid-state, which also able to carry smaller particles as well for precipitation. All of these occurrences facilitate the separation between the solids and liquid during heating treatment [8]. Zeolite's ability to adsorb increased as the concentration increased [7]. Very little information has been published on the clarification of sweet sorghum juice. Sorghum juice quality standards for sorghum syrup raw materials have not been found. Because the manufacture of raw sugar from sugarcane is an established industry, typical values for raw and clarified sugarcane juice are provided as a reference [17]. The better the clarification, the more transparent was the clarified juice, and, concomitantly, the lower was the clarified juice turbidity measured in NTU value.

Preheating treatment has a significant effect on the total dissolved solids (°Brix) level of sorghum juice (see table 4). It is caused by the fact that water in the juice evaporates, while the sugar or other organic matters do not. Since the water is getting hot, it will also increase the kinetic energy of the water, which makes water molecules evaporate, changing its phase into a gas state. This occurrence corresponds with [14], where the increase of heating temperature and also the heating time causes the increase of Brix level from fluids with high sugar level, such as mango juice heated at 40°C has higher Brix rather than 30°C in the same amount of time whereas zeolite was also able to increase the Brix level of the juice by absorbing the water inside the juice. Zeolite has a porous structure which enables water to enter the zeolite. Besides these, the sugar level of the juice, which affects total dissolved solids level does not give significant effect because the sugar content might increase due to heating, which causes the formation of invert sugar.

Table 4. Turbidity, total dissolved solids, and density of sorghum juice clarified using preheating and zeolite treatment.

| Preheating Temp. (°C) | Zeolite Conc. (%) | Turbidity (NTU) | Total Dissolved Solids Levels (Brix) | Density Level (gr/ml) | Brightness (L*) | Redness (a*) | Yellowness (b*) |
|-----------------------|------------------|----------------|--------------------------------------|----------------------|----------------|-------------|---------------|
| 60°C                  | 1.5%             | 30.29 ± 0.93 a | 17.93 ± 0.21 1.102 ± 0.002 38.75 ± 1.49 -0.23 ± 0.12 | 17.42 ± 0.95       |                |             |               |
| 60°C                  | 3%               | 20.84 ± 0.42 d | 18.23 ± 0.29 1.091 ± 0.005 40.22 ± 0.91 -0.33 ± 0.37 | 17.78 ± 0.45       |                |             |               |
| 60°C                  | 4.5%             | 15.07 ± 0.46 f | 18.40 ± 0.30 1.086 ± 0.006 42.51 ± 1.48 -0.49 ± 0.08 | 18.49 ± 0.45       |                |             |               |
| 75°C                  | 1.5%             | 26.45 ± 1.06 b | 19.50 ± 0.40 1.093 ± 0.004 40.30 ± 1.11 -0.37 ± 0.03 | 23.44 ± 0.13       |                |             |               |
| 75°C                  | 3%               | 16.90 ± 0.40 e | 19.73 ± 0.35 1.083 ± 0.001 44.47 ± 1.44 -0.49 ± 0.18 | 23.96 ± 0.25       |                |             |               |
| 75°C                  | 4.5%             | 12.33 ± 1.11 g | 19.87 ± 0.40 1.075 ± 0.005 45.28 ± 0.66 -0.60 ± 0.23 | 24.79 ± 0.59       |                |             |               |
| 90°C                  | 1.5%             | 22.62 ± 0.40 c | 20.97 ± 0.21 1.090 ± 0.003 41.52 ± 1.33 -0.46 ± 0.07 | 24.48 ± 0.72       |                |             |               |
| 90°C                  | 3%               | 11.60 ± 0.43 g | 21.03 ± 0.25 1.080 ± 0.003 45.40 ± 1.43 -0.58 ± 0.16 | 25.08 ± 0.75       |                |             |               |
| 90°C                  | 4.5%             | 9.14 ± 0.21 h  | 21.20 ± 0.40 1.071 ± 0.002 46.24 ± 1.16 -0.69 ± 0.22 | 25.91 ± 0.48       |                |             |               |

Note: values followed by the different notation (letter) shows significantly different

Density decrease due to the clarification process using preheating with different temperatures gives significant effect except for temperature points of 75°C and 90°C, which has not too different value levels. The density of impurities in the juice, such as starch with a density of 1.5 gr/cm³ [9] and protein of 1.22-1.43 gr/cm³ [5]. While water has a density of 0.997 gr/cm³ [9], the clarification process can reduce the impurities which able to decrease density level, while the decrease of water can also reduce it as well. The increase of zeolite concentration also has a significant effect on density decrease because of its ability to adsorb the impurities.

The increase of lightness level along with an increase of preheating temperature and zeolite concentration has a significant effect but does not give a higher difference in value between the temperature of 75°C and 90°C. It happens because during preheating, a chemical reaction in the juice is
accelerated, as well as coagulation ability and sedimentation from colloids and non-sugar components increase. Besides this, the protein emulsifies fat and wax in the juice, which can be coagulated and sedimented with lime during the clarification process. Heating can make solids compounds coagulated and increase the movement of particle collision levels. Particles become enlarged because small particles stick together after each collision and float on the surface of the liquid. The effect of zeolites can adsorbs impurities. Impurities in the juice will be clotted due to the preheating process so that zeolites can pull them and can separate easily.

The redness of the juice is affected by the preheating process. It is because the most abundant pigment in sorghum stems is chlorophyll. The greenish color in the sorghum juice is due to the presence of chlorophyll A and chlorophyll B pigments. The process of chlorophyll degradation itself occurs significantly at 100°C. It is due to zeolite is expected to absorb chlorophyll pigments. The tendency of the color of the juice itself is more towards green than to red compared to sugarcane juice, especially if after being given a clarification process either by heating or added with lime.

The clarification process with preheating treatment shows a significant increase in the yellowish level, where there is a significant effect. It is due to the change in color of sorghum juice from greenish to yellowish color due to chlorophyll degradation. Chlorophyll degrades when the liquid atmosphere becomes acidic due to the loss of magnesium ions, which is then substituted by protons in the acids in the juice. Chlorophyll will turn into a new compound, named pheophytin. Chlorophyll degradation causes discoloration of the juice to become more yellowish, tends to turn yellow-brown, and increases the yellowish level (b*). Chlorophyll degradation due to the heating process has a significant effect starting in heating with temperatures around 70°C, even though the temperature below also allows for degradation even with a smaller amount. The effect of zeolite on yellowish discoloration itself is not significant and is expected to have the same effect as the effect of zeolite in influencing the redness of the sorghum juice.

### 3.4. The best treatments of sorghum stalk juice clarification

The selection of the best treatment in the clarification of sorghum juice with the preheating process and zeolite done by the Multiple Attribute method [10]. This method considers that each parameter is considered to have the same importance. The selection of parameters based on factors of importance and the best expectation value, where the selection is shown in table 5.

| Parameter         | Expectancy |
|-------------------|------------|
| Turbidity         | Lowest     |
| Total Dissolved Solids | Highest   |
| Density           | Lowest     |
| Lightness (L*)    | Highest    |
| Redness (a*)      | Lowest     |
| Yellowness (b*)   | Highest    |
| pH Level          | Highest    |
| Starch Level      | Lowest     |
| Protein Level     | Lowest     |
| Ash Level         | Lowest     |
Table 6. Physical and chemical characteristics of sorghum juice clarified by the best preheating temperature treatment and zeolite concentration.

| Parameter                  | Expectancy         |
|---------------------------|--------------------|
| Turbidity (NTU)           | 9.14 ± 0.210       |
| Total Dissolved Solids (°Brix) | 21.20 ± 0.400     |
| Density (gr/ml)           | 1.07 ± 0.003       |
| Lightness (L*)            | 46.239 ± 1.160     |
| Redness (a*)              | -0.694 ± 0.220     |
| Yellowness (b*)           | 25.91 ± 0.480      |
| pH Level                  | 5.00 ± 0.100       |
| Starch Level (%)          | 0.75 ± 0.041       |
| Protein Level (%)         | 0.13 ± 0.007       |
| Ash Level (%)             | 1.20 ± 0.003       |

Based on Table 5, the best juice clarification obtained in this study is clarification with a preheating temperature of 90°C and a zeolite concentration of 4.5%. The results of the clarification can be seen in Table 6.

4. Conclusion

The present findings confirm that the interaction does occur between the preheating temperature treatment and zeolite concentration on the parameters of turbidity and starch content. The treatment of preheating temperature and the treatment of zeolite concentration gives a significant effect on the parameters of turbidity, total dissolved solids, density, color, protein content, and ash content. The best treatment obtained on sorghum juice clarified with a preheating temperature of 90°C and a zeolite concentration of 4.5%, which can reduce turbidity, starch, protein, and ash content to 9.14 NTU, 0.754%, 0.130, and 1.198% respectively. On this basis, we conclude that this method can be used in clarifying sorghum juice, especially for reducing starch, protein, and ash content to enhance the clarity (turbidity) of sorghum juice. Future research should consider the potential use of any other color-removal adsorbents.

5. References

[1] Andrzejewski B, Eggleston G and Powell R 2013 Pilot plant clarification of sorghum juice and evaporation of raw and clarified juice Ind. Crops Prod. 49 648 – 58
[2] Ahmadi K and Mushollaeni W 2007 Chemical activation of natural zeolite for purification of fish oil from the by-product of fishmeal processing Jurnal Teknologi Pertanian 8 71-9
[3] Direktorat Jenderal Perkebunan 1996 Sorgum manis komoditi harapan di propinsi kawasan timur Indonesia Symp. Risalah Simposium Prospek Tanaman Sorgum untuk Pengembangan Agroindustri 17–18 January 1995 Jakarta Proc. Edisi Khusus Balai Penelitian Tanaman Kacangkacangan dan Umbi-umbian 4 pp 6-12.
[4] Eggleston G, Monge A and Ogier B E 2001 Sugarcane Factory Performance of Cold, Intermediate, and Hot Lime Clarification Process (New Orleans: USDA-ARS-Southern Regional Research Center & Cora Texas Manufacturing Co)
[5] Fischer H, Polikarpov I and Craievich A F 2004 Average protein density is a molecular-weight-dependent function Protein Sci. 13 2825 – 8
[6] Kimura M and Itokawa Y 1990 Cooking losses of minerals in foods and its nutritional significance J. Nutr Sci Vitaminol 36 S25 – S33
[7] Moraes E P and Machado N R C F 2001 Clarification of Stevia rebaudiana (Bert.) Bertoni extract
by adsorption in modified zeolites Acta Sci. 23 1375 – 80
[8] Potter N N 2013 Food Science Fourth Edition (New York: Springer)
[9] Whistler R L, James N B and Paschall E F 1984 Starch: Chemistry and Technology (London: Academic Press)
[10] Zeleny M 1992 Multiple Criteria Decision Making (New York: Mc Graw Hill Book Company)
[11] Holou R A and Stevens G 2012 Juice, sugar, and bagasse response of sweet sorghum (Sorghum bicolor (L.) Moench cv. M81E) to N fertilization and soil type Glob. Change Biol. Bioenergy 4 302-10
[12] Willis O, Mouti M, Sila D, Mwasaru M, Thiongo G, Murage H and Oijio N 2013 Physico-chemical properties and antioxidant potential of syrup prepared from ‘Madhura’ sweet sorghum (Sorghum bicolor L. Moench) cultivar grown at different locations in Kenya Sugar Tech. 1 1007
[13] Arifiandini Y, Wijana S and Hidayat A 2012 Pengaruh penambahan adsorben pada pengolahan gula semut siwalan dengan metode reprocessing dari gula cetak siwalan Industria: Jurnal Teknologi dan Manajemen Agroindustri 1 57-65
[14] Gundurao A, Ramaswamy H, and Ahmed J 2011 Effect of soluble solids concentration and temperature on thermo-physical and rheological properties of mango puree Int. J. Food Prop. 14 1018-36
[15] Ratnavathi C V and Chavan U D 2016 Sorghum Syrup and other by-products In Sorghum Biochemistry: An Industrial Perspective (Oxford: Academic Press) pp 253-310
[16] USDA 1957 United States Standards for Grades of Sugarcane Syrup (Washington D.C.: Fruit and Vegetable Division, AMS U.S. Department of Agriculture)
[17] Andrzejewski B, Eggleston G, Lingle S, Powell R 2013 Development of a sweet sorghum juice clarification method in the manufacture of industrial feedstocks for value-added fermentation products Ind. Crops Prod. 44 77 – 87

Acknowledgment
This research supported by the Center for Agricultural Biotechnology and Genetic Resources (BB BIOGEN), Bogor, Indonesia, for providing sweet sorghum plants. We thank our colleagues Prof. Endang Gati Lestari from BB Biogen and Dr. Amin Nur from Center for Cereal Crops Research, who provided the expertise that greatly assisted this research.