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Performance Test of Sieving Machine and Physical Characteristics of Corn Grits Production

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ABSTRACT

Corn grits can be used as a substitute for rice as a staple food. This is based on the nutritional content of corn grits and also rice is a food ingredient that is dense in energy in its processing. Sieving is an important operating unit in addition to size reduction and cleaning which is intended to obtain a certain particle size in the manufacture of corn grits. The use of a sieving machine in selecting the size of corn grits determines the quality of the product. The size of corn grits also determines the level of public preference. The purpose of this study was to analyze the performance of the sieving machine and the physical quality characteristics of the resulting corn grits. The treatment variables of the study included the machine rotation speed (A) of 240, 320, 520 RPM and the sieving duration (B) of 10, 15, 20 minutes. Data analysis used ANOVA and DMRT Test. The combination of treatments (machine rotation speed and sieving duration) gave a significant difference to the sieving capacity. The treatment of rotation speed of 520 RPM and sieving duration of 20 minutes gave the largest sieving capacity of 94.66 kg/hour, sieving yield of 90%; water content of 13%, angle of repose of 0,62 radian (35,54°), and size distribution (D) of 1.78 mm.

1. INTRODUCTION

In addition to rice and wheat, alternative food crops as sources of carbohydrates include corn (Adedokun *et al*., 2023). Local corn can be developed as an alternative food substitute for rice because it has good nutritional content (Djaina, 2017; Lalujan *et al*., 2017; Medho & Mohamad, 2024). The nutritional content of corn in the form of carbohydrates, protein, fiber, minerals and fat is influenced by meteorological conditions during the main growth period (Wu *et al*., 2024). By looking at its nutritional content, corn can be used as a staple food in addition to rice. Corn is a food source of carbohydrates that contains fiber and complex carbohydrate content when consumed as corn rice.

One of the products that can be developed in order to diversify food from corn is corn grits or corn rice. Corn grits are processed corn products with a coarser size than flour. Corn grits are smaller than corn kernels which can increase the surface area and affect its nutritional content (Sandhu *et al*., 2007). The particle size of corn grits resembles the particle size of rice. Corn grits have a high fiber content that can improve stool consistency, reduce blood pressure and disease (Abdulrahaman & Kolawole, 2006; Elleuch *et al*., 2011; Giacco *et al*., 2002). Corn grits can then be cooked directly into porridge (Hudji *et al*., 2019; Walalangi *et al*., 2020), or further processed into corn rice (Kumalasari *et al*., 2015; Sofiana *et al*., 2019) as well as instant products (Hudji *et al*., 2019; Sofiana, 2019; Mahmud *et al*., 2024). This food can prevent people diabetes mellitus, because it can reduce glucose and insulin responses (Wukirsari *et al*., 2022).

In the agroindustry, sieving plays an important role. The types of sieves used include rotation and vibration types. Sieving has a positive effect on the physical and chemical properties, standardization and classification of materials

(Sanchez-Suarez *et al*., 2022). The stages of making corn grits go through the grinding, sieving and cleaning processes. Sieving to separate grits based on particle size. The particle size of corn grits determines the quality of its physical quality. This study was conducted to determine the performance of the sieving machine and the physical quality of corn grits products that are in accordance with the provisions that are acceptable to the community. The research results can be used to increase food diversification based on corn product by utilizing locally available resources.

2. MATERIALS AND METHODS

The raw material for corn grits was dried corn grains with a water content of 12-15%. This study used HJ 21 Agritan corn variety. The water content of 12-15% corn is obtained by drying and measuring the water content. If the measurement resulted a higher water content, re-drying was carried out. Corn grains with water content of >15% can cause the grits product to be easily damaged during storage.

2.1. Research Design

This study used a Completely Randomized Design (CRD) with two factors, namely the sieving rotation speed (240, 380, and 520 RPM) and the sieving time (10, 15, and 20 min). The combination of treatments was repeated 3 times. The response variables included machine performance (sieving capacity and yield) and the physical quality characteristics of corn grits (size distribution, water content, water absorption, and repose angle).

2.2. Research Procedures

The research implementation included corn milling, grit sieving, measuring machine performance, and analysis of the physical quality of the corn grits produced. Corn milling was carried out with the same rotation speed (380 RPM) and milling time (0,67 min). The sieving process was carried out using a machine sketched in Figure 1 and Figure 2 at several variations of rotation speed and sieving time according to the experiment design. Machine performance included sieving capacity and the yield of corn grits. Physical quality measurements included water content, size distribution, repose angle, and water absorption.

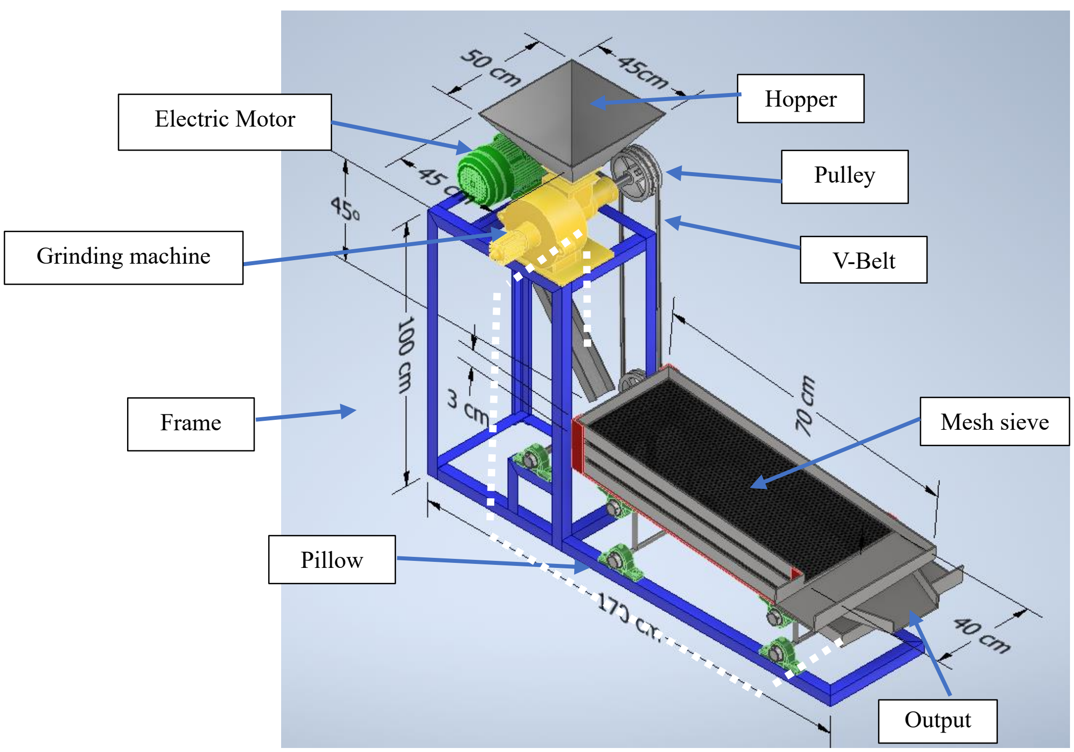

Figure 1. Sketch of corn grits sieving machine

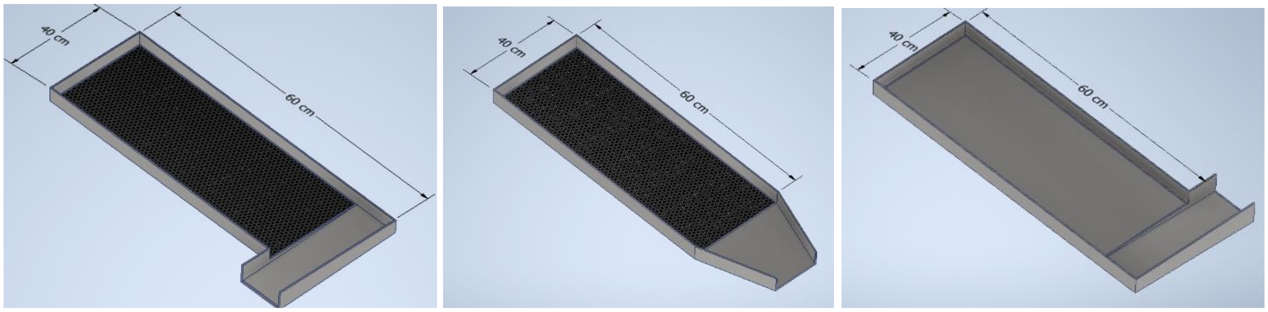

Figure 2. Screen equipped in the sieving machine: (a) Mesh 12, (b) Mesh 16, and (c) Mesh 30

2.3. Data Collection

a. Sieving Capacity

Sieving capacity is the amount of ground corn entered into the sieving process per unit of time. The sieving capacity (*KK*) was calculated from the amount of corn grains (*BJ*) and sieving time (*t*) according to the following equation:

$$KK\ (\text{kg/h}) = \frac{BJ\ (\text{kg})}{t\ (\text{h})} \tag{1}$$

b. Sieving Yield

Yield is the percentage of grit product as compared to the weight of initial material. By this way, the percentage of weight loss during the grit processing can be calculated. Yield (R) was calculated from the weight of final product (*BI*) and the initial material (*B0*) according to the following formula:

$$R = \frac{BI}{B0} \times 100 \tag{2}$$

c. Size Distribution

Measurement of size distribution using a sieve mesh equipped on the sieving machine, namely 12, 16, and 30 mesh. As much as 1 kg corn grits were put into the sieving machine then sieved according to the treatment design. After completion, the grits retained on each sieve were collected and then calculated each percentage over the sieved samples. The diameter (*D*) of corn grits and the fineness (*FM*) and was calculated using the following equations.

$$d_g = \exp\left(\frac{\sum(w_i \ln d_i)}{\sum w_i}\right) \tag{3}$$

$$FM = \frac{\sum m_i \times f_i}{\sum m_i} \tag{4}$$

where, d_g is geometric mean diameter (mm), w_i is weight fraction or mass percentage of particles retained on sieve *i*, d_i is sieve hole size, *ln* is natural logarithm.

d. Repose Angle

The repose angle or stack angle was measured by dropping the material at a height of 30 cm with a material weight of 500 g. The stack angle (^{o}) and was calculated from stack height (*T*) and stack radius (*r*) as the following:

$$\text{Repose angle} = \arctan\ (T/r) \tag{5}$$

e. Water Content

Measurement of water content was begun by heating the empty cup in the oven at a temperature of 105°C for 15 min, cooling the cup in a desiccator for ±15 min, then weighing the empty cup (*a*). About 5 g fresh sample was put in the cup and was heated in the oven at 105°C for 6 h. After cooling in a desiccator for ±30 min, the dry stuff was weighed. The water content (MC) was calculated from the weight of dry sample (b) and fresh sample (c) as the following:

$$MC\ (\%\text{wb}) = \frac{(b-a)-(c-a)}{(b-a)} \times 100 \tag{6}$$

f. Water Absorption

Water absorption capacity was measured by weighing an empty test tube, 2 g of sample, and 20 ml of distilled water in the test tube. The material was placed in a water bath for 20 minutes at a temperature of 80°C. Absorbable water is the water absorption value of the material. The test tube containing water and grits is weighed to determine the final value. The following is the water absorption formula:

$$\text{Water Absorption} = \frac{(\text{weight after soaking} - \text{initial weight})}{\text{initial weight}} \tag{7}$$

2.4. Data Analysis

The results of the study will be presented in the form of tables and graphs. The research data will also be analyzed statistically using a two-way ANOVA (Analysis of Variance) test. This analysis aims to determine if the treatment results in significant differences in the performance of the sieving machine and the physical characteristics of grits. If the treatment results is significant, the analysis is continued with the Duncan Multiple Range Test (DMRT) at α = 0.05.

3. RESULTS AND DISCUSSION

3.1. Summary of ANOVA

Statistical data analysis was used to determine the significant differences in machine performance and physical quality characteristics of corn grits. Table 1 summarizes the results of the two-way ANOVA test for all observed variables. Interaction of engine speed and sieving duration is significant only for sieving machine capacity, and insignificant for the others. Engine speed is significant for all parameters, whereas sieving duration is significant for capacity, size distribution, and fineness modulus.

Table 1. Two-way ANOVA test results for machine performance and physical quality of corn grits

Observation Variables	RPM			Time			RPM×Time		
	F-count	*F*-table	*p*-value	*F*-count	*F*-table	*p*-value	*F*-count	*F*-table	*p*-value
Sieving capacity	2277.22	3.554	0.000*	105.093	3.554	0.000*	4.890	2.927	0.008*
Sieving yield	41.213	3.554	0.000*	12.929	3.554	0.000*	1.938	2.927	0.148 ns
Water content	1.582	3.554	0.233 ns	5.302	3.554	0.015*	0.204	2.927	0.933 ns
Size distribution	5.523	3.554	0.013*	0.049	3.554	0.952 ns	0.224	2.927	0.922 ns
Fineness modulus	3.509	3.554	0.052*	0.041	3.554	0.960 ns	0.356	2.927	0.837 ns
Stack angle	0.844	3.554	0.446 ns	12.847	3.554	0.000*	1.510	2.927	0.241 ns
Water absorption	0.075	3.554	0.928 ns	9.146	3.554	0.002*	0.850	2.927	0.512 ns

Note: * = significant; ns = not significant

3.2. Sieving Capacity

The capacity of the machine in carrying out material screening is one measure of machine performance. Figure 1 shows the effect of treatment on the value of the screening machine capacity. The results of the analysis of variance (ANOVA) concluded that there was a significant interaction between machine speed and the duration of the screening process with an F-count value of 4.248, greater than the F-table of 2.927. Table 2 shows that the screening capacity increases with the rotational speed of the machine, the duration of the screening. The largest sieve capacity value was found in the 520 RPM treatment with a time of 20 min, which was 94.66 kg/h, while the lowest sieve capacity value occurred in the 240 RPM treatment with a time of 10 min, which was 55.32 kg/h. This in accordance to (Utami, 2018) stating the faster the RPM used, the higher the value of the grinding and sieving capacity. The high motor rotation speed has an effect on the sieve vibration speed, thereby increasing the capacity of the screening process.

Table 2. Effect of treatment combination on the sifter machine capacity (kg/h)

Engine speed (RPM)	Time (min)		
	10	15	20
240	55.32±0.85 a	60.21±0.97 b	64.72±1.17 c
380	71.40±0.85 d	76.14±0.53 e	78.35±1.03 f
520	90.21±1.91 g	92.45±0.76 h	94.66±0.11 i

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

Table 3. Effect of treatment combination on the sieving yield (kg/h)

RPM	Time (min)			Average
	10	15	20	
240	76.90±4.27	76.34±3.07	79.74±1.47	77.66±3.15 A
380	74.89±0.36	80.65±2.66	84.33±0.94	79.96±4.36 A
520	84.87±1.85	87.71±2.58	89.77±1.88	87.45±2.82 B
Average	78.88±5.13 a	81.56±5.52 a	84.61±4.53 b	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

Table 4. Effect of treatment combination on the water content (%wb) of corn grits produced

RPM	Water Content (%wb)			Average
	10	15	20	
240	10.43±0.01	11.14±0.01	12.46±0.01	11.35±0.011 A
380	10.65±0.01	11.04±0.02	12.29±0.01	11.33±0.014 A
520	11.98±0.01	11.77±0.01	12.72±0.01	12.16±0.010 A
Average	11.02±0.78 a	11.32±1.05 a	12.49±0.59 b	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

3.3. Sieving Yield

The sieving yield is the percentage of grit results to the initial material. The sieving yield is one of performance parameters of the sieving machine. The yield value reflects the efficiency of the sieving machine. High yield indicates that the machine is working efficiently, producing high grit products and means little material loss. Figure 2 presents the effect of treatment on the sieving yield value.

The results of the ANOVA test (Table 1) concluded that there was no significant interaction between the machine speed and the duration of the sieving process with an F-count value of 0.909, greater than the F-table of 2.927. The single factor of the sieving duration also did not produce a significantly different effect, only the single factor of the machine rotation speed produced a significant effect on the sieving yield. From Table 3 it can be seen that the largest sieving yield value (90%) occurred in the 520 RPM sample with a time of 20 minutes, and the lowest yield value (75%) occurred in the sample with a 380 RPM treatment with a time of 10 minutes. The sieving process is greatly influenced by the rotational speed of the machine when the material is fed through the hopper. Mulyawan *et al*. (2018) stated that the rotational speed and time used on the machine will affect the grinding results. The highest yield value occurs in samples with the highest machine speed and longest time treatment. Candra *et al*. (2015) explained that the RPM used and the length of time for the sieving process will affect the results of the machine's performance, the higher the RPM used, the higher the sieving yield value of the machine. The high and low yield values are influenced by the corn grits that are still left in the machine, as well as the amount of corn that does not meet the grits criteria because the size is too small (corn flour).

3.4. Water Content

Water content is one of the parameters used to determine the physical quality characteristics of corn grits. Table 4 shows the effect of treatment on the water content of corn grits produced. It can be observed that during the milling process from corn to corn grits, the treatment results in different values of water content in corn grits. The highest water content value occurred in the 520 RPM treatment sample with a time of 20 minutes, which was 13%, and the lowest water content value occurred in the 240 RPM treatment sample with a time of 10 minutes, which was 10%. This explains that the water content value in corn grits is influenced by the rotation speed of the machine. The higher the RPM speed, the faster the corn grits are produced and the water content will not decrease much. Conversely, at a low RPM speed, the corn grits will take longer to be sieved so that the water content in the corn grits will decrease (Kharisma *et al*., 2014).

3.5. Size Distribution

Corn grits are a processed product from the utilization of corn kernels that have a smaller grain size due to the milling process. The ground corn particles were then sieved using 12, 16, and 30 mesh sieves with sieve hole sizes of 1.70, 1.18, and 0.60 mm, respectively. Figure 3 shows the distribution of corn grit particle size based on the mass fraction retained on the sieve used, namely mesh 12, mesh 16, and mesh 30. Corn grit particles are dominated by particles with a size of >1.70 mm with an average mass fraction of 62.53%, followed by particles measuring 1.18 – 1.70 mm with an average mass fraction of 33.97% and the least particle size of 0.60 – 1.18 mm with an average mass fraction of 3.50%. Based on the particle size distribution, the geometric mean diameter and fineness modulus (FM) value of corn grit were then calculated with the results as given in Tables 5 and 6.

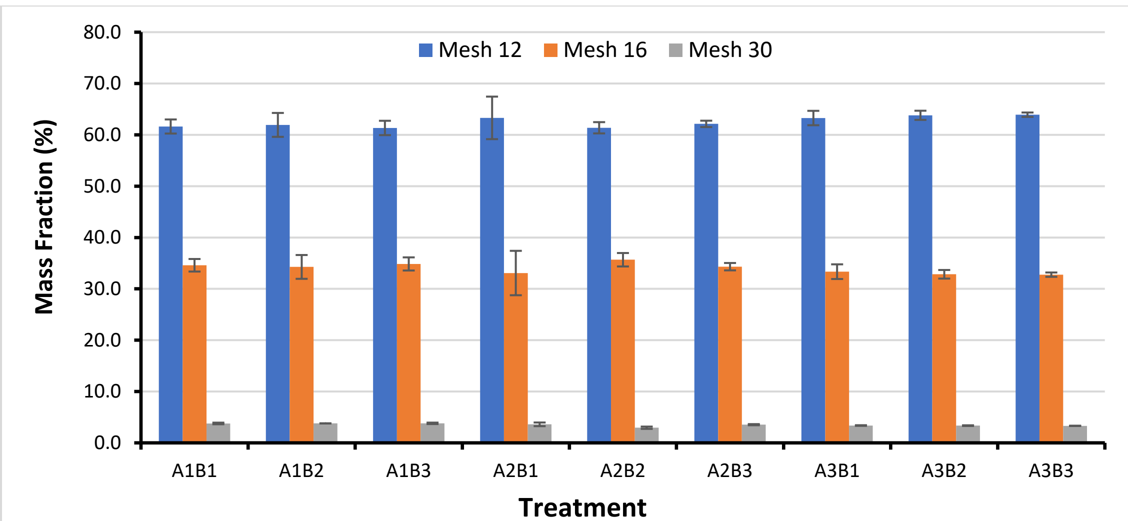

Figure 3. Average particle size distribution of corn grits

Table 5. Effect of treatment combination on the geometric mean diameter d_g (mm) of corn grits produced

RPM	Geometric Mean Diameter (mm)			Average
	10	15	20	
240	1.440±0.009	1.442±0.012	1.439±0.008	1.440±0.009 A
380	1.451±0.021	1.447±0.004	1.445±0.002	1.448±0.011 AB
520	1.453±0.007	1.456±0.005	1.457±0.002	1.455±0.005 B
Average	1.448±0.013 a	1.448±0.009 a	1.447±0.009 a	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

Table 6. Effect of treatment combination on the fineness modulus (FM) of corn grits produced

RPM	Fineness Modulus			Average
	10	15	20	
240	2.578±0.015	2.581±0.023	2.575±0.015	2.579±0.016 A
380	2.597±0.040	2.584±0.009	2.586±0.005	2.589±0.021 AB
520	2.599±0.014	2.605±0.010	2.606±0.004	2.603±0.009 B
Average	2.592±0.024 a	2.590±0.017 a	2.589±0.0159 a	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

Based on the tables, it can be observed that during the corn grits sieving process, the size distribution of the grits increased significantly with engine speed. The sifting time did not influence significantly on the size distribution. The increase occurred in the sample with the highest d_g value occurring in the 520 RPM treatment with average value of 1.455±0.005 mm, while the lowest sample occurred in the 240 RPM treatment with average value of 1.440±0.009 mm. In the FM value, the sample with the highest value occurred in the 520 RPM treatment with average FM value of 2.603±0.009 and the lowest occurred in the 240 RPM sample, namely 2.579±0.016. The size distribution value in each sample has almost the same value. The greater the RPM value and time used, the more perfect the milling and sieving process so that the size of the corn grits particles produced is smaller (Suprobo & Rahmi, 2015). In this study, the opposite results were possible because the use of a sieve that was only up to mesh 30. This causes many particles with smaller particle sizes to be accommodated in the pan and not included in the particle size analysis.

3.6. Stack Angle

The stack angle or repose angle is the maximum angle between the surface of the stack of granular material (such as sand, flour, sugar, grains) and the horizontal plane, where the material can stack without collapsing. The corn milling process produces grits products with different repose angles depending on the treatment. Repose angle can be an indicator of the material's ability to flow (flowability) and is useful in the packaging, transportation, mixing, and drying processes. The greater the repose angle value, the more difficult it is for the material to flow or move. The results of the repose angle measurements of each sample with different treatments are presented in Table 7. It can be seen that the repose angle in each treatment has almost the same value. The ANOVA test concluded that the single factor of engine speed and its interaction did not produce a significant difference in the repose angle of the grits produced. However, the sifting time produced a significant difference. The largest repose angle value occurred in the grits produced sifting time of 15 to 20 min, namely 0.33 rad (or 18.91°). Meanwhile, the lowest repose angle value occurred in the sample with a sifting time of 10 min, namely 0.27 rad (or 15.47°). The longer the sifting time, the lower the water content in the corn grits, so that it can affect the repose angle value of the corn grits (Rahmana *et al*., 2016). To a certain extent, the repose angle value is directly proportional to the water content value of a material, the higher the water content, the easier it is to form a pile when dropped.

Table 7. Effect of treatment combination on the repose angle (rad) of corn grits produced

RPM	Repose angle (rad)			Average
	10	15	20	
240	0.25±0.02	0.34±0.02	0.33±0.01	0.31±0.05 A
380	0.31±0.03	0.32±0.04	0.34±0.03	0.32±0.03 A
520	0.26±0.04	0.33±0.04	0.33±0.02	0.31±0.05 A
Average	0.27±0.04 a	0.33±0.03 b	0.33±0.02 b	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

Table 8. Effect of treatment combination on the water absorption (%) of corn grits produced

RPM	Time (min)			Average
	10	15	20	
240	1.01±0.17	1.12±0.05	1.49±0.33	1.31±0.43 A
380	1.08±0.10	1.32±0.68	1.55±0.08	1.32±0.40 A
520	1.23±0.27	1.28±0.01	1.58±0.14	1.36±0.22 A
Average	1.11±0.19 a	1.24±0.35 a	1.54±0.23 b	

Note: Mean values followed by different lowercases are significantly different based on DMRT at α = 5%.

3.7. Water Absorption

The ability of a material to absorb water is also one of the important physical quality reference parameters. Corn grits are generally processed into corn rice through a cooking process so that they can be consumed. The requirement for gelatinization during cooking is the presence of sufficient water. Table 8 shows the effect of the treatment of machine rotation speed and sieving time on the water absorption value of the corn grits produced.

The ANOVA test concluded that the single factor of sieving engine speed and its interaction did not produce a significant difference in the water absorption ability of the grits produced. The sifting time, however, resulted in significant effect on water absorption characteristic of the corn grits. The highest water absorption value (1.54±0.23) occurred in sample from the 20 min sieving time, while the lowest water absorption (1.11±0.19) occurred in the sample 10 min sieving time. The water absorption value is also influenced by the chemical content of grits. The amylose content in the material will increase the ability of starch granules to absorb water and cause the rice to expand to be larger (Aryunis & Tafzi, 2017). The higher the water absorption value, the greater the possibility of gelatinization during the cooking process.

4. CONCLUSION

The results of the sieving machine performance test on the sieving capacity observation variable had the lowest value of 55.32 kg/hour and the highest value of 94.26 kg/hour. The yield observation variable has the lowest value of 5.88% and the highest value of 8.23%. The test results of the physical quality characteristics of corn grits for the water content variable had the highest value of 13%. The stack angle variable has the highest value of 0.33 rad (18.91°). In the size distribution variable, the highest value for diameter is 1.455±0.005 mm and fineness modulus is 2.603±0.009, resulted from treatment engine speed of 520 RPM. The observation variable for water absorption has the highest value of 1.54±0.23 %, resulted from a sample from 20 min sieving time. In general, the higher the RPM used, the higher the value of the physical quality characteristics of corn grits.

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