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Performance Analysis of Disc Mill Type FFC-15 Grinder for Making Charcoal Husk Flour

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ABSTRACT

This study is motivated by the great potential of rice husk as a waste material that has not yet been optimally utilized. The focus of this research is to evaluate the performance of the FFC-15 disc mill machine in producing flour from rice husk charcoal at three different moisture contents. The variations in the moisture content of rice husk charcoal studied were 10%, 15%, and 20%, with the goal of determining the optimal conditions in the production process of rice husk charcoal flour. The methodology used is experimental with repeated testing to produce data on machine capacity, electrical power consumption, flour yield, flour quality (moisture content, ash content, and mineral content), and the physical parameters of the charcoal. The results show that moisture content significantly affects the milling efficiency and quality of the flour produced, with optimal conditions achieved at a moisture content of 10%. Adjusting the moisture content before the milling process can enhance the operational efficiency of the machine and the quality of the final product. These findings are expected to provide benefits for follow-up by a group or industry that wants to optimize the utilization of rice husk charcoal.

1. INTRODUCTION

Rice husk charcoal is a byproduct generated from the abundant rice milling process and holds significant potential as a renewable energy source (Lim *et al*., 2012). However, the utilization of rice husk charcoal remains suboptimal. One approach to enhancing the added value of rice husk charcoal is by processing it into powder, in line with the biomass briquetting technology that has been developed (Grover & Mishra, 1996; Lisa *et al*., 2023). The utilization of rice husk waste for producing burnt husk and briquettes has been explored to improve energy efficiency and sustainability in local communities (Lisa *et al*., 2023). Rice husk charcoal powder offers various applications and benefits, contributing to agriculture, water and air purification, health and beauty products, as well as construction—similar to the uses of wood briquettes and charcoal in Malaysia (Kong, 1996). In the agricultural sector, rice husk charcoal powder is used to improve soil fertility, reducing the need for chemical fertilizers and supporting the growth of beneficial microorganisms (Glaser *et al*., 2002; Titin & Nurul, 2021). As a filtration medium, husk charcoal flour is effective in reducing pollution and improving the quality of drinking water and clean air, thanks to its high adsorption capacity (Mohan *et al*., 2014). In the beauty industry, husk charcoal flour is used in products such as face masks and scrubs to absorb dirt and oil from the skin (Inyang *et al*., 2016). Husk charcoal flour is also incorporated into the building material mixture to improve the thermal insulation and strength of the building material (Astika *et al*., 2023). The benefits of using rice husk charcoal powder include enhancing environmental health through the remediation of contaminated soil and water (Lehmann & Joseph, 2015), as well as serving as a component in bio-briquettes as an alternative energy source (Yuliah *et al*., 2017). Advancements in the design of rice husk carbonization equipment, such as the continuous-type rice hull carbonizer, have improved biochar production towards sustainable agriculture (Orge & Abon, 2012). In agriculture, the use of husk charcoal flour contributes to improved plant health, crop yields, and efficient use of water and nutrients (Wachira *et al*., 2024). Furthermore, husk charcoal flour supports agricultural sustainability by reducing the use of harmful chemicals (Wachira *et al*., 2024). Based on these functions and benefits, as outlined in the previous references, rice husk charcoal powder offers a solution that reduces operational costs and enhances output quality in both agricultural and industrial sectors, similar to the production and characterization of fuel briquettes made from coffee husks as an alternative energy source (Tesfaye *et al*., 2022). In addition, husk charcoal has various physical properties that can be analyzed to determine its quality and application in various fields, Some important physical parameters that need to be analyzed include density, water absorption, angle of repose, fineness modulus, and calorific value.

Different types of machines can be used to convert charcoal into powder, including hammer mills, disc mills, and ball mills. Hammer mills crush charcoal through the rapid impact of a rotating hammer, effective for achieving high fineness at output (Hafeez & Rana, 2023; Promdan *et al*., 2023). Disc mills, such as FFC Disc Mills, use a series of rotating discs or discs to grind charcoal, providing an advantage in terms of speed and efficiency. FFC Disc Mill was chosen in this study because of its advantages in terms of high milling speeds and the ability to adjust the output size by replacing different discs, making it ideal for studies that require consistency in charcoal flour particle size. Although according to several studies such as Sandra & Meiselo (2020), Lubis & Andasuryani (2023), Rangkuti *et al*. (2012), Ariwibowo (2016) the FFC 15 disc mill machine has been widely used to make various types of flour, but information about its performance in making charcoal husks is still limited. The information is related to the capacity of the machine, electrical power, flour yield, and the quality of the flour produced.

Factors that affect the performance of the FFC Disc Mill and the quality of the charcoal flour produced include the speed of rotation of the discs, the size and type of discs used, as well as the condition of the raw materials such as moisture content. Moisture content is an important variable that influences the physical behavior of materials during milling process, as demonstrated by Moon & Yoon (2018) in their study on balloon flower (*Platycodon grandiflorum*). They found that higher moisture levels increase the tendency of the material to clump, thereby reducing milling efficiency and altering the flow characteristics and final fineness of the milled product. This concept can be applied to the milling of rice husk charcoal powder, where high moisture content in the charcoal may also lead to clumping, subsequently lowering milling efficiency and affecting the fineness and consistency of the resulting charcoal powder.

This study aims to analyze the performance of the FFC15 disc mill type husk charcoal flour making machine and analyze the changes in the physical parameters of husk charcoal before and after milling. The analysis includes the size of the machine capacity, the measured electrical power, the yield of flour, the quality of flour (moisture, ash, and mineral content), the density of husk charcoal, the water absorption of husk charcoal, the angle of husk charcoal repose, the fineness modulus of husk charcoal, and the calorific value of husk charcoal without treatment.

2. METHODOLOGY

2.1. Research Design

This study uses an experimental quantitative approach to analyze the performance of the FFC15 disc mill type husk charcoal flour making machine with different moisture content variables. The engine performance test sample was repeated 5 times for each treatment of moisture content variables. The analysis carried out includes: the size of the machine capacity, the measured electrical power, the yield of flour, the quality of flour (moisture content, ash content, and mineral content), the density of husk charcoal, the water absorption of husk charcoal, the angle of husk charcoal repose, the fineness modulus of husk charcoal, and the calorific value of husk charcoal without treatment. The husk charcoal that is the material for the research is husk charcoal obtained from purchases at agricultural stores.

2.2. Research Procedure

The husk charcoal samples used in this study were processed to ensure the accuracy of the required moisture content. The drying process is carried out using an oven at a controlled temperature. If the moisture content of the sample was too low due to the drying process, water was added carefully to achieve the desired moisture content. Each sample was then tested with a Moisture Analyzer to confirm its moisture content. Through this process, the sample was divided into three groups that each had a moisture content of 10%, 15%, and 20%, according to the needs of the research.

2.3. Machine Capacity Measurement

Weigh 1 kg of husk charcoal for each moisture rate. Operate the FFC15 disc mill machine for each moisture content (10%, 15%, 20%) with 5 repetitions. The time required to grind the husk charcoal was recorded. The capacity of the machine (kg/h), was calculated from the weight of flour produced and the time required according to the following:

$$Machine\ Capacity\ =\ \frac{Flour\ Weight\ (kg)}{Time\ (minutes)} \times 60 \tag{1}$$

2.3.1. Electrical Power Measurement

The measurement of electrical power is carried out using a wattmeter that is connected directly to the machine during the milling process. The purpose of this measurement is to determine the electrical power used by the machine, which is measured in kilowatts (kW). These measurements provide insight into the relationship between the moisture content in the sample and its effect on the energy consumption of the machine. Higher power required at higher moisture content indicates an increase in machine workload (Grote & Hefazi, 2021).

2.3.2. Flour Yield Measurement

The flour yield was calculated by weighing the charcoal flour produced from each moisture content treatment.

$$Flour\ Yield\ =\ \left(\frac{(Weight\ of\ Flour\ Produced)}{(Initial\ Material\ Weight)}\right) \times 100\% \tag{2}$$

2.3.3. Flour Quality Measurement

The moisture content of the flour was measured using a vacuum oven, which was designed to reduce the possibility of oxidation and thermal degradation during the drying process. A sample of flour weighing 10 grams was placed in a vacuum oven that has been preheated to a temperature of 70°C. The drying process was extended for 24 hours to ensure that all the moisture in the sample has been removed. After the drying process, the sample was re-weighed, and the moisture content was calculated based on the weight difference before and after drying.

The ash content in flour is measured to determine the total amount of minerals that do not burn after complete combustion. A 5-gram sample of flour was placed in a heat-resistant crucible and fired in a furnace at 525°C, in accordance with AOAC International (2019) standards. Burning is carried out to a constant weight, which usually takes about 4-6 hours. This process ensures that all organic matter has been oxidized, and what is left is non-volatile mineral components.

The mineral content in flour is measured using spectrometry techniques, specifically Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Prior to the analysis, the flour sample was processed through acid digestion, where the sample was mixed with a mixture of nitric acid and hydrochloric acid to convert all minerals into its solution form. This procedure follows guidelines published in the Handbook of Mineral Elements in Food by de la Guardia & Garrigues (2015). The solution was then analyzed with ICP-MS, which allows for the precise and sensitive detection and quantification of mineral elements.

2.3.4. Physical Parameters of Husk Charcoal

Density

The density measurement of husk charcoal was carried out using the water transfer method. The dried husk charcoal sample is measured in volume by adding it to a measuring cylinder (500 mL) filled with water, and the change in water volume indicates the volume of the sample. The mass of the sample is then accurately weighed. Density was calculated by dividing the mass by the measured volume according to the following formula:

$$Density = \frac{Mass}{Volume} \quad (3)$$

Measuring the density of husk charcoal before and after milling to determine the change in material density due to the milling process.

Water Absorption

Water absorption was calculated based on a standard procedure to determine the ability of a material to absorb water after being immersed for a certain period of time (Sandra & Meiselo, 2020). Water absorption was measured by soaking husk charcoal in water for 24 h, both before and after grinding. The filtration method was used to separate charcoal from water. The difference in mass before and after immersion was used to calculate water absorption. Water absorption was calculated by the formula:

$$Water\ Absorption\ Capacity = \frac{(Mass\ After\ Soaking - Initial\ Mass)}{Initial\ Mass} \times 100\% \quad (4)$$

The water absorption of husk charcoal was determined before and after milling to understand the influence of grinding on the ability of the charcoal to absorb water. This is similar to the research conducted by Kloss *et al*. (2012).

Angle of Repose

To measure the angle of husk charcoal repose, a method is used that refers to the standard procedure in granular material engineering. The measurement process begins by setting up a flat surface and a funnel on it. Husk charcoal is poured through a funnel to form a pile. Once no more material is added, the pile will reach a stable state and the angle between the top of the pile and the base is measured using a protractor. This method provides an accurate indication of the flow properties and ease of handling of materials (Higashitani *et al*., 2019). Measure the height and diameter of the base of the cone pile for husk charcoal before and after grinding. The angle of repose is calculated by the formula:

$$\tan(\theta) = \frac{Height}{Base\ Radius} \quad (5)$$

$$\theta = tan^{-1}\left(\frac{Height}{Base\ Radius}\right) \quad (6)$$

Measuring the angle of husk charcoal repose before and after milling to understand the changes in material flow properties after milling.

Fineness Modulus

The method used by Rangkuti *et al.* (2012) to measure fineness modulus (FM) focuses on sequential sieving techniques to determine the size distribution of husk charcoal particles. The process begins with the grinding of husk charcoal into smaller particles, followed by filtration through a series of cascading sieves from coarse to fine. The modulus fineness is measured by sifting the chaff charcoal that has been ground using a series of standard strainers. Weigh the amount of material held in each strainer. Calculate the fineness modulus of husk charcoal after milling to determine the particle size distribution produced by the FFC15 disc mill machine. The FM of husk charcoal was calculated based on the sequential sifting technique (Givi *et al*., 2010; Gómez *et al*., 2014) according to Eq. (7) which accumulates the weight of the particles held in each sieve to give an indication of the smoothness of the material.

$$FM = \frac{total\ weight\ of\ particles\ retained\ on\ each\ sieve}{total\ sample\ weight} \quad (7)$$

Calorie Value

The calorific value of husk charcoal is measured using a bomb calorimeter to determine the amount of energy released when burned. Determine the calorific value of untreated husk charcoal to evaluate the energy potential of husk charcoal as an alternative fuel before undergoing the milling process. In measuring the calorific value of husk charcoal, the use of a bomb calorimeter is a key methodology described in the book Biochar for Environmental Management: Science, Technology and Implementation by (Lehmann & Joseph, 2015). This method involves burning a sample of husk charcoal in a closed, high-pressure container, which allows for precise measurements of the energy released during the combustion process. A bomb calorimeter assesses the amount of energy released by absorbing the heat generated into a controlled environment, and then converts it into a calorific value that describes the energy potential of the sample. References from Lehmann & Joseph (2015) elaborate in depth on how biochar, including husk charcoal, can be characterized for its energy properties, making this a very useful resource for understanding and applying the correct measurement techniques in research or applications related to the use of husk charcoal as an alternative fuel.

2.4. Data Analysis

The data obtained from the repeatability of the measurement was statistically analyzed. The analysis includes the calculation of averages, standard deviations, and analysis of variance (ANOVA) to determine the effect of moisture content on machine performance and flour quality. The results were analyzed to see the relationship between the moisture content of husk charcoal and the milling efficiency and quality of the flour produced.

3. RESULTS AND DISCUSSION

The following is data about the performance of the FFC15 disc mill machine in processing husk charcoal.

3.1. Machine Capacity

The capacity of the machine in producing husk charcoal flour decreases along with the increase in moisture content in the husk charcoal. At 10% moisture content, the average weight of flour produced is 0.86 kg, while at 20% moisture content only produces an average of 0.70 kg. This indicates that higher moisture content reduces milling effectiveness (Table 1). From Table 1, it is known that the engine capacity in kg/hour decreases along with the increase in moisture content in the husk. At 10% moisture content, the average engine capacity is 4.54 kg/hour, while at 20% moisture content it is only 2.27 kg/hour. This shows that the FFC15 disc mill machine works more efficiently at lower moisture content. The decrease in the capacity of the FFC15 Disc Mill machine with the increase in the moisture content in the husk charcoal can be explained through several physical and mechanical aspects of the material. The high moisture content in husk charcoal can cause several changes in the physical properties of the material, such as increased humidity which makes the charcoal particles stickier and denser. This results in a decrease in the free flow of material through the machine, thereby increasing resistance to grinding. In addition, husk charcoal with a high moisture content tends to clump, which challenges the milling process and reduces efficiency. This coagulation reduces the effectiveness of the contact between the husk charcoal and the grinding element, resulting in a decrease in the amount of material that can be treated at one time.

Research by Sandra & Meiselo (2020) also showed similar results, where the increase in moisture content in rice flour materials led to a decrease in the efficiency of the milling machine, because wetter materials tended to clump and inhibit the milling process. These findings are consistent with Rangkuti *et al.* (2012) who found that lower moisture content in raw materials results in more efficient milling performance on Disc Mill machines. This shows that maintaining a low moisture content in raw materials is essential to maximize the performance of milling machines.

Table 1. Data on time (min), flour weight (kg), and machine capacity (kg/h).

Replication	Moisture content treatment (%)								
	10			15			20		
	Time (min)	Weight (kg)	Capacity (kg/h)	Time (min)	Weight (kg)	Capacity (kg/h)	Time (min)	Weight (kg)	Capacity (kg/h)
N1	12	0.85	4.25	15	0.75	3.00	18	0.70	2.33
N2	11	0.87	4.75	16	0.74	2.78	19	0.69	2.18
N3	11	0.86	4.69	15	0.76	3.04	18	0.70	2.33
N4	12	0.85	4.25	15	0.75	3.00	19	0.69	2.18
N5	11	0.87	4.75	16	0.74	2.78	18	0.70	2.33
Average	11.4	0.86	4.54	15.4	0.75	2.92	18.4	0.70	2.27
SD			0.23			0.12			0.07

3.2. Electrical Power

Electrical power consumption increases along with the increase in the moisture content of husk charcoal. At 10% moisture content, the average power consumption is 1.46 kWh, while at 20% moisture content increases to an average of 2.24 kWh. This increase in power consumption is due to the additional workload of the machine for drying and grinding wetter husks (Table 2). Research by Lubis & Andasuryani (2023) on cane sugar particles shows that the higher moisture content in raw materials leads to increased electricity consumption as machines work harder to grind wetter materials. This shows the similarity in the behavior of the FFC-15 Disc Mill machine towards various types of raw materials with varying moisture content. This indicates that the grinding machine requires more energy to grind materials with high moisture content due to the greater friction and the additional energy requirement for partial evaporation of water during the milling process.

Table 2. Electrical power usage

Moisture Content (%)	n-1 (kWh)	n-2 (kWh)	n-3 (kWh)	n-4 (kWh)	n-5 (kWh)	Average (kWh)	Standard Deviation
10%	1.5	1.4	1.5	1.4	1.5	1.46	0.049
15%	1.8	1.9	1.8	1.9	1.8	1.84	0.049
20%	2.2	2.3	2.2	2.3	2.2	2.24	0.049

3.3. Flour Rendement

The yield of flour also decreases with an increase in moisture content. The highest yield was obtained at 10% moisture content with an average of 86%, and the lowest at 20% moisture content with an average of 70% (Table 3). Research by Boonanuntanasarn *et al*. (2014) on the use of activated charcoal as a feed supplement also shows that lower moisture content in raw materials results in more efficient products in larger quantities. This indicates that lower moisture content tends to result in more end products in a variety of milling applications. Research by Rangkuti *et al*. (2012) also supports these findings by showing that materials with low moisture content produce more flour because the milling process is more efficient and less material is lost during the process.

Table 3. Flour yield (%)

Moisture Content (%)	n-1 (%)	n-2 (%)	n-3 (%)	n-4 (%)	n-5 (%)	Average (%)	Standard Deviation (%)
10%	85	87	87	85	87	86	0.98
15%	75	74	74	75	74	75	0.49
20%	70	69	69	70	70	70	0.49

3.4. Flour Quality

The moisture content of the flour increases in tandem with the moisture content of the husk charcoal. In husk charcoal with 10% moisture content, the flour produced has a moisture content of 7%, while at 20% moisture content, flour has a moisture content of 10% (Table 4). The mineral content (Calcium, Potassium, Magnesium, Phosphorus) in husk charcoal flour increases along with the increase in husk moisture content. A moisture content of 10% produces flour with 0.60% calcium, 1.20% potassium, 0.30% magnesium, and 0.10% phosphorus. At 20% moisture content, the content of these minerals increases to 0.70%, 1.30%, 0.40%, and 0.15%, respectively (Table 4).

Table 4. Flour quality (moisture content, ash content, mineral content)

Power Water (%)	Rate Averages Water (%)	Average Ash Content (%)	Calcium (%)	Potassium (%)	Magnesium (%)	Phosphates (%)
10	7	15	0.60	1.20	0.30	0.10
15	9	16	0.65	1.25	0.35	0.12
20	10	18	0.70	1.30	0.40	0.15

The ash content and mineral content in the husk charcoal flour are expressed based on a dry weight basis. This is done to avoid distortions in the measurements that can be caused by variations in moisture content in the sample. Measuring ash and mineral levels on a dry weight base provides a more consistent and accurate comparison, as moisture content that can vary greatly no longer affects the final measurement.

3.5. Physical Parameters of Husk Charcoal

Measurement of the physical parameters of husk charcoal before and after grinding provides important insight into the changes that occur in husk charcoal after processing using the FFC-15 disc mill machine. Overall, milling increased the density and water absorption, which indicates an increase in the density and ability of the husk charcoal to absorb water. Table 5 shows the results of measuring the physical parameters of husk charcoal for density, water absorption, angle of repose, fineness modulus, and calorific value.

Table 5. Data table of measurement of physical parameters of husk charcoal

Parameters	Moisture Content (%)	Flattening Before Grinding	Rattan After Milling	Standard Deviation
Density (g/cm³)	10%	0.352	0.402	0.004
	15%	0.332	0.372	0.003
	20%	0.302	0.352	0.004
Water absorption (%)	10%	55.2	60.2	0.4
	15%	50.2	55.2	0.5
	20%	45.2	50.2	0.5
Angle of repose (°)	10%	35.2	38.2	0.5
	15%	33.2	36.2	0.4
	20%	31.2	34.2	0.4
Fineness modulus	10%	-	2.48	0.02
	15%	-	2.28	0.03
	20%	-	2.08	0.02
Calorie value (kcal/kg)	10%	3510	-	-
	15%	3410	-	-
	20%	3310	-	-

Table 5 shows that the density of husk charcoal tends to increase after milling. The average density before milling ranges from 0.302 g/cm³ (20% moisture content) to 0.352 g/cm³ (10% moisture content), while the average density after milling ranges from 0.352 g/cm³ (20% moisture content) to 0.402 g/cm³ (10% moisture content).

The increase in the density of husk charcoal after grinding, from 0.352 g/cm³ at 20% moisture content to 0.402 g/cm³ at 10% moisture content, indicates that the grinding process compacts the charcoal particles. This happens because the lower moisture content allows the particles to be more compact, improving milling efficiency and producing a higher density product. This higher density is important for facilitating the handling, storage and transportation of charcoal flour, as well as improving performance in combustion applications and use as a filter media, providing added value to the sustainability and economic viability of the product. The water absorption of husk charcoal tends to increase after grinding. The average water absorption before milling ranges from 45.2% (20% moisture content) to 55.2% (10% moisture content), while the average water absorption after milling ranges from 50.2% (20% moisture content) to 60.2% (10% moisture content). The water absorption of husk charcoal tends to increase after grinding because the grinding process enlarges the surface area of the charcoal particles, thereby increasing the ability of the particles to absorb water. Milling also opens the pores in the charcoal particles, increasing their porosity. This increase in water absorption is important for charcoal flour because it makes it more effective as a filter medium in water and air purification applications, as well as as a feedstock for organic fertilizers that can absorb and release nutrients more efficiently.

The angle of repose tends to increase after grinding. This is because the milling process produces smaller, irregular particles, which increases friction between particles and makes the material pile more stable at larger angles. This property is important for charcoal flour because it indicates that the material has a more controlled flow and better stability when stored or processed, which reduces the risk of spillage and improves efficiency in handling and storage. The average angle of repose before grinding ranges from 31.2° (20% moisture content) to 35.2° (10% moisture content), while the average angle of repose after milling ranges from 34.2° (20% moisture content) to 38.2° (10% moisture content).

The fineness modulus tends to decrease after milling because the milling process produces finer and more uniform particles. The fineness modulus indicates the fineness level of husk charcoal flour after grinding, while the average fineness modulus ranges from 2.08 (20% moisture content) to 2.48 (10% moisture content). This property is important for charcoal flour because finer particles improve reactivity and efficiency in a variety of applications, such as solid fuels, filtration media, and feedstocks for industrial products. Finer charcoal flour is also easier to mix and distribute evenly in product formulation, improving the quality and consistency of the final product. The calorie value of husk charcoal provides information about the energy potential contained in husk charcoal. The calorific value of rice husk charcoal provides information on the energy potential contained in the charcoal. The average calorific value ranged from 3310 kcal/kg (20% moisture content) to 3510 kcal/kg (10% moisture content) which is comparable to the combustion characteristics of rice husk and coconut shell briquettes (Sebastine *et al*., 2023).

The results of ANOVA analysis (Table 6) showed that the moisture content treatment had a real effect ($p < 0.05$) on the variables of Flour Moisture Content, Ash Content, Calcium, Potassium, Magnesium, Phosphorus, Density, Water Absorption, Angle of Repose, and Fineness Modulus. The treatment of moisture content had no real effect ($p > 0.05$) on the other variables in this study, because all the variables tested showed significant differences. The results of ANOVA analysis of the physical parameters of husk charcoal showed that the difference in moisture content significantly affected the density both before and after milling. The low moisture content results in a higher density after grinding, indicating better charcoal density. The moisture content also affects the water absorption. Charcoal with low moisture content has higher water absorption after grinding, showing increased porosity. The difference in moisture content affects the angle of repose, with higher moisture content resulting in a smaller larger angle of repose, which indicates a decrease in cohesiveness and a potential increase in the ease of handling husk charcoal. The moisture content has an effect on the fineness modulus and calorific value, with a lower moisture content resulting in finer flour and a higher calorific value, which corresponds to more efficient energy requirements.

The overall analysis showed that the difference in moisture content had a significant impact on all the variables tested, including the physical parameters. With the increase in moisture content, there is a decrease in engine capacity and flour yield, as well as an increase in power consumption. Significantly, all physical parameters (the density, water

Table 6. Summary of LSD test results

No.	Variable		Moisture Content 10%	Moisture Content 15%	Moisture Content 20%	Significance Notes
1	Machine Capacity (kg/h)		4.54a	2.92b	2.27c	$p < 0.05$
2	Power Consumption (kWh)		1.46a	1.84b	2.24c	$p < 0.05$
3	Flour Yield (%)		86a	75b	70c	$p < 0.05$
4	Flour Quality					
	Moisture Content (%)		7a	9b	10c	$p < 0.05$
	Ash Content (%)		15a	16b	18c	$p < 0.05$
	Mineral Content	Calcium (%)	0.60a	0.65b	0.70c	$p < 0.05$
		Potassium (%)	1.20a	1.25b	1.30c	$p < 0.05$
		Magnesium (%)	0.30a	0.35b	0.40c	$p < 0.05$
		Phosphorus (%)	0.10a	0.12b	0.15c	$p < 0.05$
5	Physical Parameters					
	Density (g/cm³)		0.402a	0.372b	0.352c	$p < 0.05$
	Water Absorption (%)		60.2a	55.2b	50.2c	$p < 0.05$
	Angle of Repose (°)		38.2a	36.2b	34.2c	$p < 0.05$
	Fineness Modulus		2.48a	2.28b	2.08c	$p < 0.05$

Note: Different letters in the same row indicate a significant difference between moisture content at $\alpha = 0.05$ according to the LSD test absorption, angle of repose, and fineness modulus) are also affected. The density and absorption of water increased with the decrease in moisture content, indicating higher density and lower porosity, which could affect the effectiveness of husk charcoal as a filter material or building material. A lower angle of repose at a higher moisture content indicates a change in material handling, which can be important in industrial and agricultural applications.

The results of the study show that the performance of the FFC15 disc mill machine in processing husk charcoal is greatly influenced by its moisture content. The machine is more effective and efficient in grinding husk charcoal with lower moisture content, producing more flour with less power consumption and better flour quality. Therefore, regulating the moisture content of husk charcoal before the milling process is highly recommended to get optimal results, with reference to several previous studies such as those conducted by Raczkiewicz *et al*. (2024), Akam (2023), Misra *et al*. (2009). The concept of sustainability from similar research will also be the focus of researchers in the future, with reference to several studies such as those shown by Sunnu *et al*. (2021) on how agricultural waste can be processed into charcoal briquettes, which offer a more environmentally friendly alternative to traditional fuels. It supports the concept of sustainability by utilizing waste as a valuable resource, Phonphuak & Thiansem (2011) on the effects of charcoal on the physical and mechanical properties of burnt test briquettes, Kumar *et al*. (2021) discuss the performance of briquettes of various materials and look for ways to improve production efficiency as well as the final quality of products, which are essential for sustainable industrial practices, Akolgo *et al*. (2021) used water boiling and user acceptance tests to evaluate the feasibility of briquettes as an alternative fuel, demonstrating efforts to reduce dependence on wood as an energy source, and Suryaningsih *et al*. (2017) analyzed the combustion quality of briquettes from various agricultural wastes as an alternative fuel source. This reflects a commitment to the discovery of sustainable alternative energy solutions that utilize agricultural waste, which can reduce the environmental impact of burning fossil fuels.

Further stages of this study will combine research conducted by Boonanuntanasarn *et al*. (2014) regarding the analysis of husk charcoal flour for water quality neutralization, with water quality monitoring technology such as those produced by Kusumah *et al*. (2020; 2022). It will even be associated with the results of research based on embedded systems and AI as carried out by Siskandar *et al*. (2022; 2023).

4. CONCLUSION

This study comprehensively evaluated the performance of the FFC-15 disc mill machine in grinding husk charcoal and revealed a significant influence of moisture content on milling efficiency and the quality of the flour produced. From the results of ANOVA and BNT analysis, there are significant differences in milling capacity, energy consumption, and flour quality between different variations in moisture content, with the optimal condition being achieved at 10% moisture content. This shows that the lower moisture content not only improves the efficiency of the mill but also produces higher quality flour. In addition, milling has an impact on increasing density and water absorption, as well as changes in the angle of repose which signals a change in the physical properties of husk charcoal that can affect its application in industry. This study suggests the importance of moisture content control before the milling process to ensure optimal machine performance and produce high-quality products. These results not only contribute to the academic literature but also provide practical recommendations for related industries in improving the production process and quality of husk charcoal-based products. These implications confirm the importance of further research to optimize drying and milling techniques, leading to more sustainable industrial practices.

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