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Research Article

The Effect of Clay Soil Binding Agent Ratio and Compaction Pressure Level on the Physical Properties of Carbonized Rice Husk Briquettes

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Abstract

The outer covering of the rice grain, known as the rice husk, separates during the milling process. The rice husk is widely available and mostly considered a waste material that poses environmental and health risks if not properly managed. Despite not being the ideal feedstock due to its composition, however, rice husks can be effectively utilized as a renewable energy source by transforming them through a carbonized process and by compressed using a briquetting machine to create a stable, energy-dense product with enhanced properties, serving as a cost-effective and eco-friendly fuel source. Therefore, this study investigated the effect of clay soil binding agent ratio and compaction level on the physical properties of carbonized rice husk briquettes of the bulk density, moisture content, volatile matter, fixed carbon, and ash content at five levels of clay soil ratios: 0%, 5%, 10%, 15%, 20% and three levels of compaction level (6 mm, 12 mm, and 18 mm). The study implemented 5×3 factorial experiment in a completely randomized design with three replications and compared treatment means at a 95% level of significance. The result revealed that the bulk density ranged from 0.7795 to 1.3209 g/cm^3, the moisture content ranged from 4.0207 to 5.0447%, the volatile matter ranged from 13.413 to 24.479%, the carbon fixed ranged from 50.492 to 68.269%, and the ash content ranged from 13.774 to 20.208%. In general, varying clay soil binding agent ratio and compaction pressure can enhance carbonized rice husk briquetting efficiency, enhancing storage efficiency, reducing transportation costs, decreasing ash residue, ensuring structural integrity, shape retention, and enhancing energy value. Future studies should explore alternative binder materials and different agricultural crop residues for carbonized briquetting, as well as examine thermal properties to understand combustion efficiency, heat generation capabilities, and economic feasibility.

Keywords

Rice Husk, Clay Soil Binder, Compaction Pressure, Carbonized Rice Husk Briquetting, Physical Properties

1. Introduction

Rice husk is the most prolific agricultural residue in rice producing countries around the world. The rice husk is the outermost layer of the paddy grain that is separated from the rice grains during the milling process and the rice husk is widely available more than 150 million tons of husks were produced and often considered a rice milling waste product,

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cause of disposal problems [28, 46, 26, 25]. Improper handling of rice husk can lead to environmental pollution, health hazards, and air pollution from burning, water and soil contamination affecting ecosystems, agriculture, attraction of pests and disease vectors from accumulated waste [17]. The open combustion of rice husk releases harmful particles that can have a negative impact on the environment. Moreover, due to its high silica, lignin, ash content, and low nutrient value, rice husk is not ideal as feedstock [35]. However, rice husk can be utilized to produce value-added products such as briquettes, bioethanol, biogas, biochar, activated carbons, catalysts, geopolymers, cement, etc. [44].

Like most other biomass materials, rice husk is rich in organic components such as silica, cellulose, lignin, and hemicellulose [18, 25]. This organic rice husk and its various compositions can be positively utilized as a renewable energy source as well as suitable for generating heat, electricity, or biofuels, offering a sustainable and environmentally friendly alternative to fossil fuels [39, 5].

Fuel wood and farm residues are indeed the most common cooking fuels [32]. The collection of firewood can be a significant burden on families, especially women, and can lead to additional strain on local forest resources especially in areas where wood is scarce [42, 48]. In communities facing a scarcity of fuel wood, utilizing rice husks to produce heat for households and local food processing industries can be a viable alternative [9]. However, untreated rice husks present challenges due to their bulky, uneven, high moisture content, and low energy density characteristics, making them difficult to handle, store, transport, and utilize effectively. Through carbonization, rice husks are transformed into carbonized rice husk, a more stable and energy-dense material with improved properties such as a higher carbon content, making it a valuable fuel source for energy generation [23].

Thermochemical conversion of rice husk to produce heat energy can be achieved via direct combustion, gasification, and pyrolysis [19]. Gasification transforms carbonized rice husk into syngas for renewable energy, while biofuel production results in bio-oil, biochar, and syngas for diverse applications [26]. While gasification and biofuel technologies may require a higher initial investment compared to briquettes, they offer long-term advantages in terms of energy efficiency and sustainability [3].

Briquettes, compressed blocks of coal dust or other combustible biomass materials, are commonly used as a cost-effective and eco-friendly fuel source, contributing to sustainable energy solutions [16, 31]. The factors that can affect rice husk briquetting include the moisture content of the rice husk, the presence of impurities or contaminants, the type and quality of binder used, the compression pressure applied during briquetting, the temperature and duration of the carbonization process, the equipment used for briquetting, the skill and experience of the operators, and the market demand for the briquettes [35, 27, 13, 6].

In rice husk briquetting, the type and quality of binder are crucial as adhesives, enhancing the quality, strength, and durability of the briquettes [38, 49]. Common binders used in rice husk briquetting include starch, clay, molasses, and vegetable oils [37]. Starch, a cost-effective and biodegradable binder, lacks water resistance, impacting durability [40]. Molasses enhance binding strength and calorific value but are sticky, posing handling challenges [24]. Vegetable oils provide enhanced energy content and binding properties but are typically more expensive than other binders [36].

A binder for rice husk briquetting should be low-cost, easily derived, and have minimal impact on the burning characteristics of the solid fuel while also being outside the human food chain. Clay soil, known for its cohesive properties, can effectively function as a natural binder in rice husk briquetting, enhancing the durability of the briquettes. This cost-effective and sustainable approach improves the quality of the briquettes, making them suitable for energy production and cooking fuel applications [36].

Compaction pressure, on the other hand, refers to the force applied during the briquetting process to compress the rice husk and binder mixture into dense and solid briquettes. The optimal compaction pressure ensures that the briquettes are well-formed, have high density, and are resistant to breaking or crumbling. Insufficient pressure may result in loose or weak briquettes, while excessive pressure can lead to over-compression and difficulty igniting the briquettes.

Therefore, this study investigates the effect of varying ratios of clay soil binding agents, set at 0%, 5%, 10%, 15%, and 20%, and compaction pressure levels of 6 mm, 12 mm, and 18 mm, on the physical characteristics of carbonized rice husk briquettes in terms of density, moisture content, volatile matter, carbon fixed, and ash content to assess the quality and performance of the briquettes.

2. Materials and Method

The research was conducted in the Agricultural Engineering Research Department workshop at the Fogera National Rice Research and Training Center (FNRRTC), Wereta, Ethiopia, for three years, from 2021 to 2023. FNRRTC is located at 11° 58’ N latitude, 37° 41’ E longitude, and at an elevation of 1810 m above sea level.

2.1. Description of Research Materials

The materials in this research are used to make carbonized rice husk briquette processes that convert carbonized rice husk into charcoal briquettes. The components of materials for the process of making carbonized rice husk briquette are a carbonizer, a miller, and a mold maker.

Carbonizer: It is frustum or pyramid-shaped and perforated with a 1 cm hole, and the lower portion, or base, is square with a 56 cm length and a 25 cm height, which is the result of cutting off the upper portion with a plane parallel to the base of the shape welded on the 10 cm height with a 56 cm square base. A 10-cm-diameter, 100-cm-long tube is inserted at the top and in the center to act as an air inlet. The tubes can be easily removed by slowly twisting them out, as shown in Figure 1a.

Hammer Miller: it is a hammer mill machine used to grind and crush carbonized materials or biochar into carbonized powder operated by an electric motor. The biochar can be lifted manually into the hammer mill for grinding. The hammer mill consists of a rotor and hammers, with the rotor typically made of heavy-duty steel. The screen or grates at the bottom determine the biochar powder and control the flow of crushed biochar. The feed hopper is the entry point, and the discharge chute directs the powder into a collection container as shown in Figure 1b.

Mold Maker: The mold maker of the briquette process consists of a hydraulic jack, frame, and piston. The hydraulic jack powers the apparatus, providing mechanical force to raise and compress the fermented mixture. The jack is attached to a plate holding the piston and a base frame made of low-carbon mild steel plates. Steel plates are useful in building briquetting equipment, including base plates, pressure plates, and cylinder head covers. The piston, a prism with a 3.5 cm square base and 10 cm height, is used to shape briquette charcoal as shown in Fig 1c and 1d. The piston is made up of 36 cubes secured within a container in the shape of charcoal briquettes. Each cylinder has a piston that transmits compressive pressure to the briquette materials inside the cylinders, acting as molds.

The laboratory research materials and instruments used for testing the carbonized rice husk briquette process included rice husk as the charcoal source, clay soil as the binding agent, a precision balance for weight measurements, a plastic bucket for mixing carbonized rice husk and clay soil powder for consolidation, a spade for mixing the carbonized rice husk with clay soil, a construction spoon for compaction and leveling during mold making, and an oven for drying the molds.

Figure 1. *Components for Carbonized Rice Husk Briquetting Process, carbonizer (a), Hammer miller (b), mold maker (c), and mold maker with hydraulic jack (d).*

2.2. The Procedure of the Experiment

Figure 2. *Process of carbonized Rice Husk Briquetting: Carbonizing of rice husk (a), cooling and storing of biochar (b), biochar grinding (c), mixing of biochar powder with clay and water (d), molding of the mix using mold maker and hydraulic jack (e) and biochar charcoal briquettes (f).*

The experiments involved collecting rice husks from the FNRRTC rice milling processing workshop and undergoing a two-day sun-drying process to achieve the required average moisture level. The husks were then processed using carbonizer technology (Figure 2a) under controlled airflow levels, resulting in biochar that was cooled and stored (Figure 2b). The carbonizer was designed to burn rice husks with controlled airflow to produce biochar, while the miller grinds the biochar into a powder. The burned husks were milled using a carbonized rice husk hammer miller machine (Figure 2c) and the resulting powdered material was stored in a plastic container for a week. The binding substance was clay soil with a different proportion to rice husk, which was manually mixed properly (Figure 2d). The 2 kg milled carbonized rice husk and the adhesive (clay) mix depend on the ratio to the biochar and an equal 2 litter of water was added and thoroughly mixed for even consolidation and stirred evenly. The mold maker was used to create molds. The amount of mixed charcoal was put into a prism-shaped mold with a 3.5-mm square base and 100-mm height. It is then pressed at a compression level range of 6 mm–18 mm height using the hydraulic jack press with a model to produce charcoal briquettes (Figure 2e). Carbonized rice husk molds were crafted using a mold maker after a 24-hour fermentation period. The briquettes were made by lowering and lifting a hydraulic jack, combining biochar and clay binder, and allowing water to drain for three to five minutes. The briquettes were then set out on a try to dry in the sun (Figure 2f).

2.3. Experimental Design

This research study seeks to investigate the effect of clay soil binder agents and compaction pressure levels on the physical characteristics of carbonized rice husk briquettes. It involves three compaction pressure levels (6 mm, 12 mm, and 18 mm) and five clay soil binding ratio levels (0%, 5%, 10%, 15%, and 20%). A completely randomized design in factorial arrangements follows a 3 x 5 factorial setup with three replications, resulting in a total of 45 experimental units. The effects of these factors and their interactions on the physical properties of the briquettes; bulk density, moisture content, ash content, volatile matter, and fixed carbon were evaluated.

Figure 3. *Treatment setup: factors of clay soil ratio (a) and factors of compression level (b).*

2.4. Variables and Data Collection

The study focused on the characteristics and quality of the carbonized rice husk briquetting charcoal before combustion, particularly on physical properties such as bulk density, fixed carbon, ash content, volatile matter, and moisture content.

2.4.1. Independent Variables

Independent variables include the properties of rice husk, clay soil binding ratio, and compression level. The rice husk used for the experiment was collected from a local FNRRTC rice processing workshop. It was manually cleaned from other foreign matter and dried to lower the moisture content for better and more fully carbonizing. The paddy husk was converted to biochar using a carbonizer. The binding material suitable for the rice husk briquette used for this experiment was clay soil because of its easy availability. When combined with carbonized rice husk powder, it forms a cohesive mixture for compressed briquettes, providing structural integrity during burning. Various scientists have used different ratios of clay soil as a binding agent in their studies. For instance [10] used a ratio of 2.4-6.9%, [14] used 0% to 40%, [12] 10% were used. Therefore, in this study, a clay soil to carbonized rice husk ratio ranging from 0% to 20% to 100% to 80% was utilized (Figure 3a) to achieve optimal binding and energy content. This flexible approach enables customization to meet the specific needs of the briquettes, ensuring both efficiency and effectiveness in the production process.

Proper pressure is essential for effectively compressing the mixture of carbonized rice husk and binding material to create durable and long-lasting briquettes. The compaction level was controlled using a hydraulic jack to achieve the desired density and structural integrity of the briquettes, ensuring they maintain their shape and quality. The compression level of the hydraulic jack was adjusted using the prism-shaped piston (Figure 3b). Inadequate compaction can result in loosely packed, fragile briquettes, while excessive pressure can lead to over-compression and difficulties during combustion [13, 7]. Various studies have shown different compaction levels, such as [14] ranged from 25 mpa to 150 mpa, [13] ranged from 108 kpa to 397 kpa, [4] ranged from 402.4 kpa to 630.6 kpa, [2] ranged from 25 kpa to 65 kpa. However, this study adopted a compression range of 6 mm, 12 mm and 18 mm, consistent with other research findings.

2.4.2. Dependent Variables

The observed dependent variables of the charcoal briquettes are mainly the physical characteristics of carbonized rice husk briquettes, which are conducted and determined using the equation provided below.

Moisture Contents

The percentage moisture content was determined by weighing randomly selected three sample briquettes from each treatment placing them in a crucible of known mass and heated in an oven set at 105 ℃ ±5 ℃ for 1 hour using the formula.

$$PMC = \frac{W_1 - W_2}{W_2} \times 100 \tag{1}$$

Where: W_1: the initial weight of the briquette sample, W_2: the final weight of the briquette sample

Volatile Matter

The volatile matter (VM) was determined by randomly selecting three samples from each treatment by placing the briquette sample in a crucible and exposing it to a furnace at a temperature of 550 ℃ ±5 ℃ for 8 minutes, followed by weighing the sample after cooling, then estimated using formula.

$$VM = \frac{W_2 - W_3}{W_3} \times 100 \tag{2}$$

Where: W_2: represents the weight of the oven-dried sample (g), W_3: is the weight of the sample after 8 minutes in the furnace at 550 ℃ (g).

Ash Content

Three sample briquettes were randomly selected from each treatment and first measured the weight, then placed in a crucible of known mass and oven-dried until a constant mass was achieved. Subsequently, these samples were subjected to heating in a furnace at 555 ℃ for 4 hours and weighed after cooling, followed by weighing the sample percentage loss in mass of the sample using the following formula.

$$Ash\,content\,(\%) = \frac{D}{B} \times 100 \tag{3}$$

Where: D: the weight of the ash (Furnace-dried) in grams, B: the weight of the oven-dried sample in grams.

Fixed Carbon

The fixed carbon was also determined by the randomly selected three sample values from each treatment and computed using the following equation.

$$FC(\%) = 100 - (VM + MC + AC) \tag{4}$$

Bulk Density

The three samples of briquettes were randomly selected and the mass of the sample briquettes was determined by weighing them before and after drying, while the volume of the briquettes was obtained by measuring their length, width, and height. Hence, the bulk density of sample briquettes was determined through the equation.

$$bd = \frac{m}{v} \tag{5}$$

Where: bd: bulk density (g/cm^3), m: briquette mass (g) and v: the volume of briquetting (cm^3)

2.5. Statistical Data Analysis

Data were subjected to analysis of variance (ANOVA) using statistical procedures. The analysis was made using R software and Statistix-10 statistical software. When the effects of the treatments were found to be significant, the LSD test was performed to assess the difference between the treatments at a 5% level of significance.

3. Result and Discussion

The evaluation result revealed the effect and interaction effect of the clay soil binding ratio and compaction pressure level on the physical characteristics of carbonized rice husk briquettes, including bulk density, moisture content, volatile matter, fixed carbon, and ash content of the briquettes.

3.1. Bulk Density

Bulk density in carbonized rice husk briquetting refers to the mass of the briquettes per unit volume, indicating the tightness of compaction and influencing handling, transportation, and storage, with higher density denoting a denser, more solid structure and lower density suggesting a lighter, more porous composition [15, 8]. The ANOVA results indicated a significant interaction effect between clay soil binding agent ratio and compaction pressure levels on bulk density of carbonized rice husk at a 5% significance level. In Figure 4, at a compaction pressure of 6 mm, the bulk density remained consistent across varying binding ratios from 0% to 20%. However, at 12 mm compaction pressure, the bulk density increased with higher binding ratios. Similarly, at 18 mm compaction pressure, there was a notable rise in bulk density for all binding ratios. Increasing bulk density in briquettes offers benefits such as improved storage efficiency, reduced transportation costs, enhanced combustion efficiency, and decreased ash residue. Increasing both compaction pressure and clay soil binding ratio results in higher bulk density, aligning with findings from various studies [38, 49, 13, 5, 47].

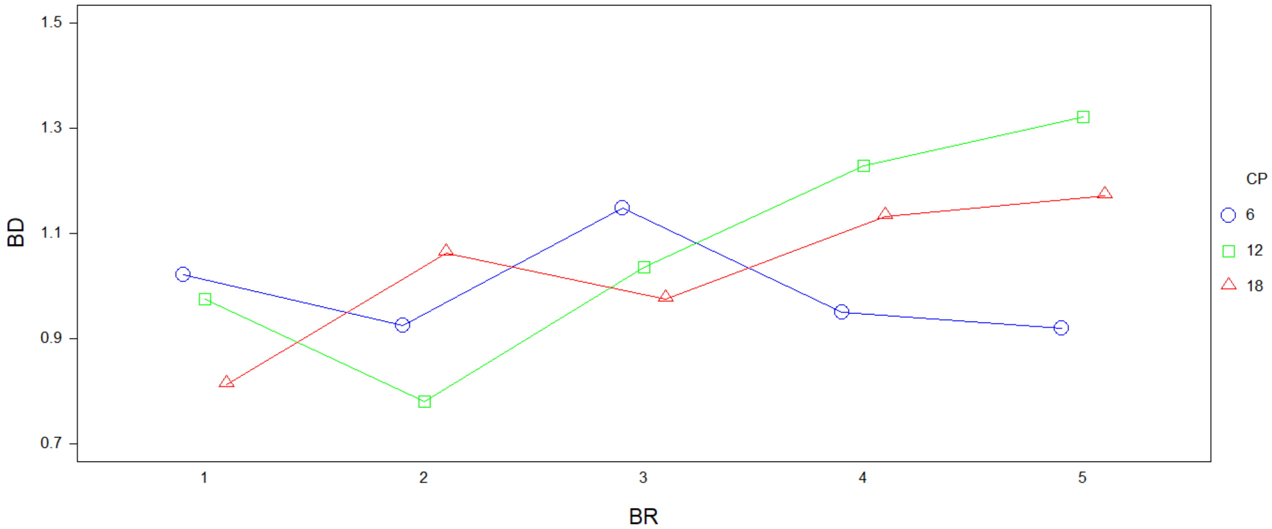

Figure 4. *Interaction Mean of Bulk Density, BD Binding Ratio, Cp Compaction Pressure.*

3.2. Moisture Contents

Moisture content is a measure of the amount of water present in a material, usually expressed as a percentage of the material's weight, and greatly affects the burning characteristics of briquetting [22]. The ANOVA analysis revealed a significant interaction effect at a 5% significance level between the clay soil binding agent ratio (BD) and compaction pressure levels (CP) on the moisture content of carbonized rice husk. As illustrated in Figure 5, the highest moisture content was observed at a 10% clay binding ratio and 12 mm compaction pressure level. Conversely, high moisture content was noted at a 15% clay binding ratio and 6 mm compaction pressure level, while the lowest moisture content was seen at a 5% clay binding ratio and 6 mm compaction pressure level. At a 6 mm compaction pressure, moisture content initially decreased from 0% to 5% clay soil binding, increased from 5% to 15%, and then decreased from 15% to 20%. Conversely, at a 12-mm compaction pressure, moisture content increased from 0% to 10% clay soil binding and then decreased from 10% to 20%. With an 18 mm compaction pressure, moisture content peaked at 5% clay soil binding and decreased with higher ratios up to 20%. The minimum moisture contents occurred at the minimum clay binding ratio due to its high void space, whereas at the maximum clay soil binding ratio and maximum compaction level, the moisture content was minimum, even making it difficult to burn [4]. In this study, the average moisture content was found to be 4.46%, which is considered minimal and suitable for storage and combustion purposes [22]. Whereas low moisture content in carbonized rice husk briquettes enhances burning efficiency, ignition rate, reduces smoke, and increases the heating value. Similar results were reported by [13, 12, 29].

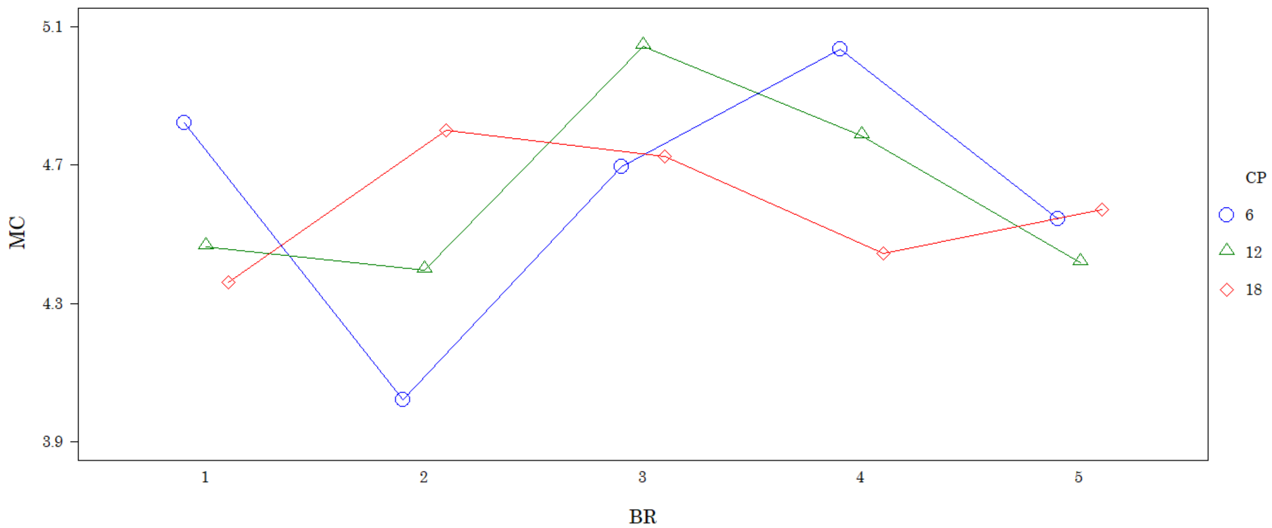

Figure 5. *Interaction Mean of Moisture content, BD Binding Ratio, Cp Compaction Pressure.*

3.3. Volatile Matter

Volatile matter consists of organic carbon, hydrogen, and oxygen present in the biomass that compounds evaporate when heated, crucial for ignition, combustion, and affecting burning behavior, efficiency, and calorific value of briquettes [43, 36]. High volatile matter content in briquettes ease of ignition, rapid burning and proportionate increase in flame length but low heating values [21]. At a 5% significance level, the ANOVA analysis showed a significant interaction effect between the clay soil binding agent ratio and compaction pressure levels on the volatile matter of carbonized rice husk. Figure 6 illustrated that higher volatile matter content was observed at all compaction pressures with the initial clay binding ratio. As the clay soil binding ratio increased from 0% to 20%, the volatile matter content decreased, while an increase in compaction pressure from 6 mm to 18 mm resulted in a similar increase in the volatile matter content [12, 30]. Notably, at a compaction pressure of 12 mm and a clay soil binding ratio of 10%, the volatile matter content remained relatively high. Therefore, the findings suggest optimizing both factors to achieve strength, stability, improve density, and compaction of briquettes. The mean volatile matter content was found to be 17.855%. This result is supported by [13, 29, 11].

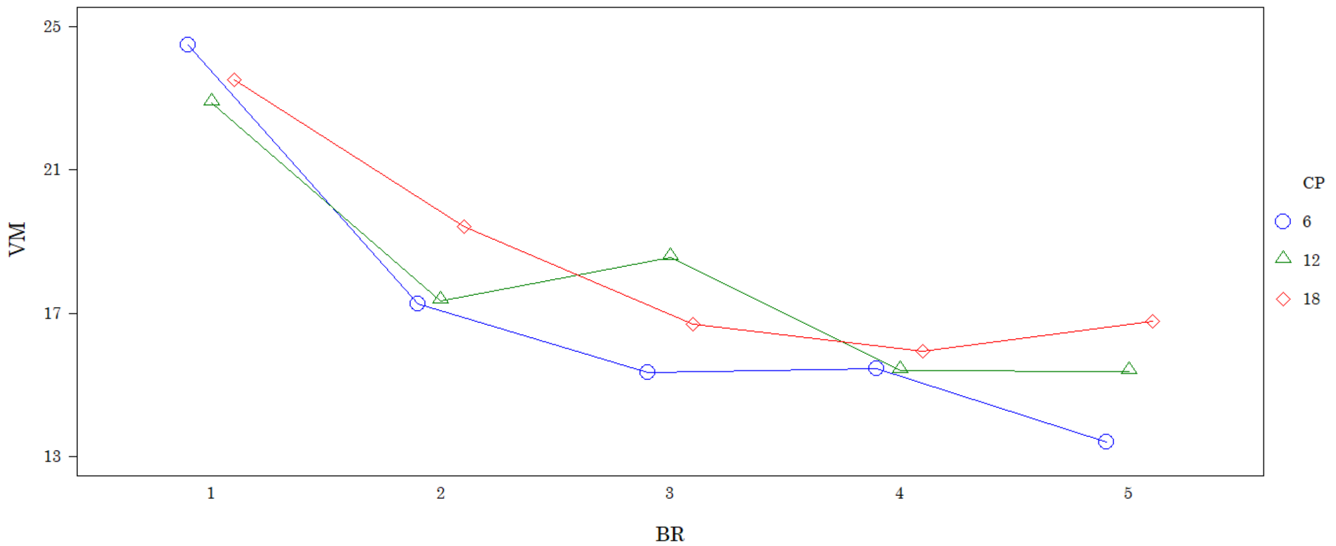

Figure 6. *Interaction Mean of Volatile Matter (VM), BD Binding Ratio, Cp Compaction Pressure.*

3.4. Fixed Carbon

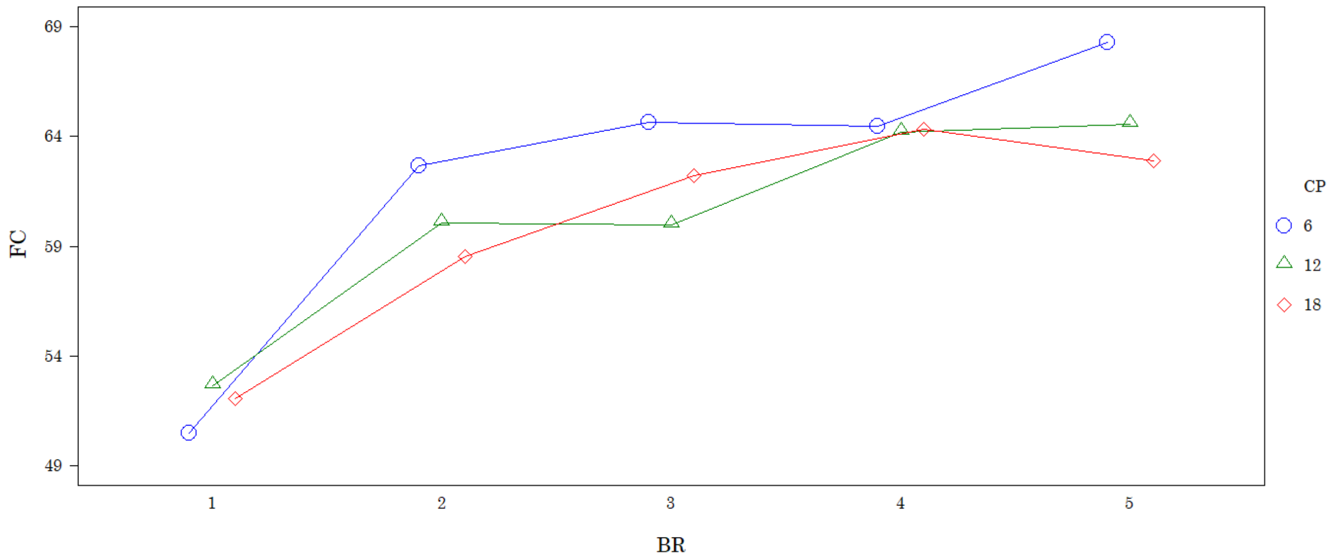

Figure 7. *Interaction Mean of Fixed Carbon (FC), BD Binding Ratio, Cp Compaction Pressure.*

The fixed carbon content in carbonized rice husk briquetting is an essential factor to consider as it directly affects the calorific value and burning efficiency of the briquettes [29, 1]. At a 5% significance level, the ANOVA analysis revealed a significant interaction effect between the clay soil binding agent ratio and compaction pressure levels on the fixed carbon content of carbonized rice husk briquetting. As shown in Figure 7, increasing the clay soil binding ratio from 0% to 20% led to a corresponding rise in the fixed carbon content of the briquettes. Conversely, lower compaction pressure at the 6 mm level was associated with higher fixed carbon content, whereas higher compaction pressure at the 18 mm level resulted in decreased fixed carbon content. From the research findings, it was observed that as the compaction pressure decreased and the binding ratio of clay soil increased, the fixed carbon value increased. This increase indicates higher energy content and improved combustion properties, making the briquettes more efficient as a fuel source [33]. The result is equivalent to [41, 34, 20].

3.5. Ash Content

Ash content is the percentage of inorganic material remaining after burning a sample, indicating the mineral matter present in carbonized rice husk briquettes [5, 45]. The ANOVA analysis at a 5% significance level revealed a significant interplay between the clay soil binding agent ratio and compaction pressure levels in relation to the ash content of carbonized rice husk. In Figure 8, it is illustrated that as the clay soil binding ratio increases from 0% to 20% and the compaction pressure varies from 6 mm to 18 mm, there is a decrease in the ash content of the briquettes. Interestingly, within the compaction pressure span of 6 mm to 18 mm, the ash content is low at 6 mm and 18 mm compaction pressure levels, but it is high at the 12 mm compaction pressure level. Increasing the clay binding ratio and reducing the compaction pressure in carbonized rice husk briquetting may lead to lower ash content. Higher ash content can negatively affect combustion properties, ultimately lowering energy efficiency and increasing emissions [11]. In this research finding, the presence of silicon dioxide (SiO2) in both the rice husks and clay binder ash contributes to the maximum ash content and the mean value of 16.74% [11]. Therefore, optimizing the clay soil binder ratio and compaction pressure level can achieve the desired final briquetting product, including controlling the ash content. The research result similar to [29, 20].

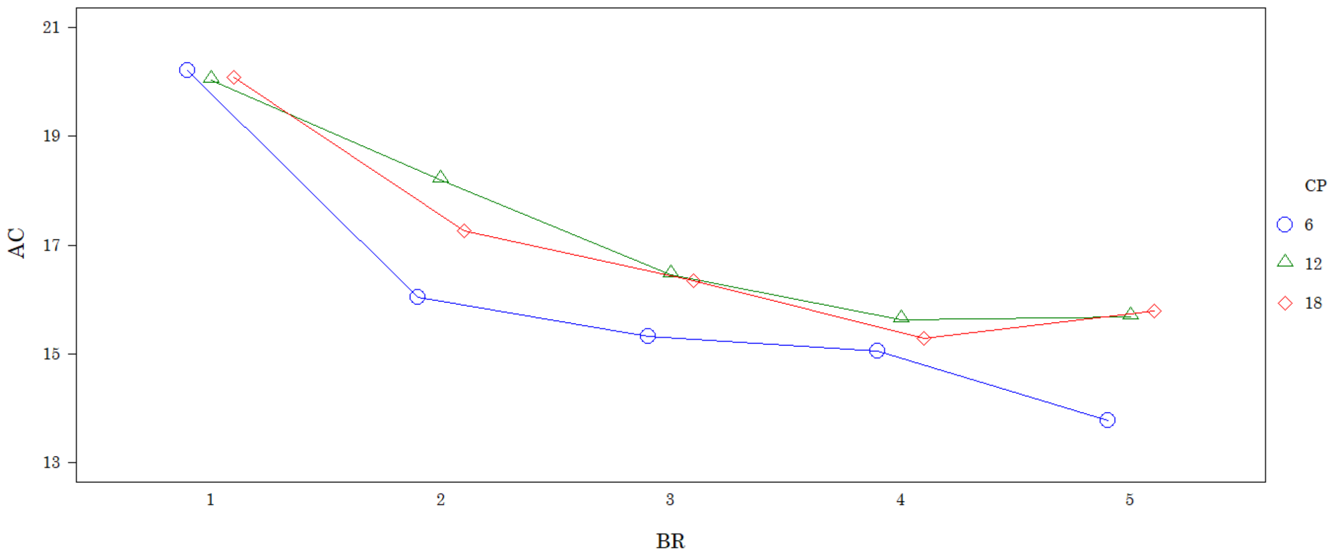

Figure 8. *Interaction Mean of ash content (AC), BD Binding Ratio, Cp Compaction Pressure.*

4. Conclusion

In this study, the objective was to examine the effect of varying ratios of clay soil binding agents and levels of compaction pressure, as well as their interactions, on the physical characteristics of carbonized rice husk briquettes. The research explored parameters such as bulk density, moisture content, volatile matter, fixed carbon, and ash content using a factorial design with three compaction pressure levels (6 mm, 12 mm, and 18 mm) and five clay soil binding agent ratio levels (0%, 5%, 10%, 15%, and 20%), conducted in triplicates.

The bulk density of carbonized rice husk briquettes is significantly affected by the combination of clay soil binding agent ratio and compaction pressure levels. The lowest bulk density was recorded at 779.5 g/cm ^{3} with a 5% clay soil ratio and 12 mm compaction pressure, while the highest bulk density of 1320.9 g/cm ^{3} was achieved with a 20% clay soil ratio and 12 mm compaction pressure.

The moisture content of carbonized rice husk briquettes varied significantly based on the interaction of clay soil binding agent ratio levels and compaction pressure levels. The lowest moisture content of 4.0207% was observed with a 5% clay soil ratio and 6 mm compaction pressure, while the highest moisture content of 4.0447% was seen with a 10% clay soil ratio and 12 mm compaction pressure.

The volatile matter content was highest at the lowest clay soil binding agent ratio and lowest at higher levels of clay soil binding agent ratio. The treatment combination with the minimum volatile matter had a clay soil binding agent ratio of 20% and a compaction pressure level of 6 mm, scoring 13.413%. Conversely, the treatment combination with the maximum volatile matter had a clay soil binding agent ratio of 0% and a compaction pressure level of 6 mm, scoring 24.479%.

The lowest fixed carbon percentage of 50.492% was observed with a 0% clay soil ratio and 6 mm compaction pressure, while the highest fixed carbon percentage of 68.269% was recorded with a 20% clay soil ratio and 6 mm compaction pressure.

The ash contents were highest at the initial clay binding agent ratio levels and lowest at the 20% clay soil binding agent ratio across all compaction pressure levels. The lowest ash content of 13.774% was observed with a 20% clay soil ratio and 6 mm compaction pressure, while the highest ash content of 20.208% was seen with a 0% clay soil ratio and 6 mm compaction pressure.

In general, the combination of clay soil binding agent ratio and compaction pressure levels significantly influenced the physical characteristics of carbonized rice husk briquettes. Higher clay soil binding ratios led to increased bulk density and fixed carbon percentage, while lower ratios resulted in higher moisture content, volatile matter, and ash content. As a recommendation, future studies should delve into exploring the effect of alternative binder materials beyond clay soil and consider utilizing various agricultural crop residues as a source of biochar in carbonized briquetting. Furthermore, conducting research focusing on examining the thermal properties of carbonized briquetting is recommended to understand how different binder materials and agricultural crop residues influence combustion efficiency, heat generation capabilities, and the economic feasibility of the briquettes.

Abbreviations

AC	Ash Content
ANOVA	Analysis of Variance
BD	Binding Ratio
CP	Compaction Pressure
FC	Fixed Carbon
LSD	Least Significance Difference
MC	Moisture Content
VM	Volatile Matter

Author Contributions

Mersha Alebachew Fetene: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Dessye Belay Tikuneh: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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