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Original Article

Physical and combustion properties of composite briquette produced from wheat offal and carbonised hardwood sawdust

OPEN ACCESS

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ABSTRACT

With the growing population and the relative cost of conventional fuels, biomass resources, especially forest and agro-residues, can serve as an alternative and affordable energy source for the significant majority of the global population. Hence, this study investigated the physical and combustion properties of briquettes produced from a blend of carbonised sawdust and wheat offal at 20:80, 40:60, 60:40, 80:20, and 50:50 ratios (carbonised sawdust: wheat offal), using inorganic starch as a binder at 3%, 6%, and 9% inclusion levels. The study adopted a 3×5 factorial experiment in a completely randomised design and the briquettes produced were analysed based on their physical and combustion properties. The physical properties investigation revealed density ranged from 0.437 to 1.109 g/cm^3.and the moisture content ranged from 3.14 to 9.87%. Briquettes made from an 80:20 biomass mixing ratio have the lowest moisture content (3.14%) and the highest compressed and relaxed density 1.109 g/cm^3 and 0.601 g/cm$^{3, \text{ respectively)}}$. While the average volatile matter, ash content, fixed carbon, and heating values of the briquette ranged from 20.29 to 32.90%, 3.99 to 13.43%, 49.92 to 70.58%, and 28.158 to 31.029 MJ/kg, respectively. Briquettes made from a 20:80 biomass mixing ratio have the highest volatile matter content (32.90%), while those made from an 80:20 ratio have the highest fixed carbon content (70.58%) and heating value (31.092 MJ/kg). Findings of the study revealed that the briquette produced exhibited desirable properties, and that 80:20 biomass mixing and 6% binder inclusion produced briquettes with the most desirable characteristics and are thus recommended for producing quality composite briquettes from agricultural and forest-based residues.

KEYWORDS: *Affordable energy, Bioenergy, Biomass briquette, Carbonisation, Densification*

INTRODUCTION

Biomass resources derived from agricultural sources such as crop residues, perennial energy grasses, and forest-based residues are becoming increasingly important as alternative energy source globally, particularly in places with endemic energy crisis (Alemu *et al.,* 2024). These resources are often secondary or by-products, making their collection and utilisation both sustainable and beneficial in preventing concerns such as food-energy crises, land use problems, and environmental hazards associated with their accumulation (Casau *et al.,* 2022). Hence, the negative impacts of using agricultural and forest residue for bioenergy production might be considered minimal, if not non-existent, especially when compared to the unsustainable utilisation of wood for firewood and charcoal production (Saleem, 2022). Despite the growing adoption of liquefied petroleum gas (LPG) for cooking across the urban and some part of the rural areas, a significant majority of the population in most of the developing countries still rely on the traditional firewood and charcoal for cooking and heat (Sulaiman, & Abdul-Rahim, 2020). This continuous reliance accelerates further deforestation and environmental

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degradation, creating an urgent need for a more sustainable and affordable alternative. Therefore, the sustainable utilisation of agro and forest-based residues for energy presents a compelling solution to some of the energy crisis and the restoration of the environment.

Biomass materials can be converted into bioenergy through various techniques, among which briquetting technology is notably effective. This process involves compressing loose biomass materials under pressure to improve their density and combustion characteristics. Briquetting technology is the most practiced among other biomass converting technologies especially in the developing countries, due to its less complexity and how it essentially converts both primary and secondary biomass materials that are usually bulky, burns rapidly and gives out a lot of smoke to a smokeless, slow burning, high density energy material (Gilvari *et al.,* 2019). It has been reported that briquetting can increase the density of biomass materials to over 1000 kg/m^3, and to nearly ten times the volume of the original biomass (Wakchaure & Indra, 2009). Prior to the densification process, the biomass material undergoes pre-treatment, which depends on the desired type and quality of the briquette product. There are different per-treatment methods, thermochemical pre-treatment has been gaining much interest among researchers, it involves application of heat to cause structural decomposition of the biomass material in the absence of oxygen to produce carbon-rich residue through a process called carbonisation. Carbonisation has been demonstrated to improve the combustion properties of briquettes (Kipngetich *et al.,* 2023). In addition to carbonisation, other process/production variable significantly influence the briquette quality. The type of binder use (organic or inorganic), the percentage of binder, compaction pressure and temperature all have directly or indirectly significant impact on the briquette's end use quality (Casau *et al.,* 2022).

The use of composite raw materials in the production of briquette has been an ongoing investigation. This usually stemmed from the idea of quality improvement or simply innovation in briquetting technology. The approach leverages on the variations in the physical and chemical characteristics of different biomass materials to influence the properties and performance of the produced briquettes (Obi *et al.,* 2022). A number of studies have reported the production of composite briquettes from materials exhibiting both similar and varying characteristics, such as briquette made from the blends of crop residues and sawdust (Akogun *et al.,* 2022; Waheed *et al.,* 2013), mixture of sawdust from different tropical hardwood species (Tomen *et al.,* 2023), sawdust and municipal solid waste (Otieno *et al.,* 2022). These studies investigated the combustion physical such as moisture content, compressed and relaxed density, and, combustion properties like volatile matter content, ash content fixed carbon and heating values. Studying these properties will give an input as to the success and limitations of using the biomass materials for briquette production. One of fundamental aspects of sustainable exploration biomass resources is the selection of the materials, and to develop them in a comprehensive way and at appropriate measures. Therefore, this study explored the combustion properties of composite briquette produced from carbonised wheat offal and sawdust for alternative domestic energy utilisation.

MATERIALS AND METHOD

Biomass Material Preparation

The sawdust used for the study was sourced from the Baga Road Timber market and processing mill (11° 52' 11" N, 13° 7' 11" E) while the wheat offal was obtained from the Maiduguri Flour Mill area (11° 51' 40" N, 13° 08' 44" E), all located within Maiduguri, Borno State. After collection, the biomass materials were brought back to the Wood and Fibre Science Laboratory at the Department of Forestry and Wildlife, University of Maiduguri 11° 48' 35" N, 13°12' 22" E) where they were sorted out to remove any debris. The sawdust was then carbonised using a 200litre cylindrical oil drum with a chimney fixed at the top as described by Hassan *et al.* (2017). The residual char produced were pulverised to finer particles. Starch (inorganic) was used as binder and was prepared using hot water to form a thick liquid.

Briquette Production

The composite briquette was produced by blending the two biomass materials (carbonised sawdust: wheat offal) at a mixing ratio of 20:80, 40:60, 60:40, 80:20 and 50:50 by weight, respectively, until a uniform mixture is formed. For each batch of the briquette produced, the blended materials were mixed with binder at a varying level: 3%, 6% and 9% weight of the biomass materials. The biomass and binder mixture were then fed into a perforated cylindrical mould of 5cm diameter and 25cm height with two metal lids smaller than the mould circumference covering the both ends. The briquettes were produced using a metal framed press machine equipped with hydraulic jack, compression lasted for 5minutes at a pressure of 1.2x10^3 N/m^2. The produced briquettes were stored at room temperature for 3 days before undergoing further tests and analysis.

Physical and Combustion Properties determination

Moisture content, compressed and relaxed density, and relaxation ratio are the physical properties of the briquette samples determined.

The moisture content of biomass was determined by oven drying the sample at 100 ± 5°C and to a constant weight using the following formula, in accordance with ASTM D2444-16. (2016):

$$\text{MC}\ (\%) = \frac{W_o - W_i}{W_i} \times 100 \quad (1)$$

Where: M.C = Moisture Content %, W_o *= Initial Weight of the sample (g), and* W_i *= Oven dried Weight of the Sample (g)*

Compressed and Relaxed Density

Both compressed and relaxed density were determined using ASTM D2395-17. (2017). Compressed density was determined immediately after the briquette is produced, as the ratio of the sample weight to its volume while the relaxed density was determined when the air-dried samples reached a constant weight and dimension, equally evaluated as the ratio of final weight to the volume of the samples. The relaxation ratio which measures the relative expansion and shrinkage of the briquette after production was evaluated as the ratio of compressed to relaxed density, using the following formula:

$$\text{Rr} = \frac{\text{Compressed density}}{\text{Relaxed density}} \quad (2)$$

Combustion Properties

Volatile Matter Content

The percentage of volatile matter content was determined by heating 1g of dried sample at 600 °C in a furnace for 7 – 10min. thereafter removed from the furnace and allowed to cool in a desiccator for an hour. It was evaluated according to the ASTM standard ASTM D3175-18 (2018) using the following formula:

$$\text{Volatile Matter (\%)} = \frac{M_{OD} - M_S}{M_{OD}} \times 100 \quad (3)$$

Where M_{OD} *= weight of oven-dried sample (g), and* M_S *= weight of sample (g)*

Percentage Ash Content

The Percentage Ash Content determined according to ASTM D3174-12. (2018) and was calculated using the equation below:

$$\text{Percentage Ash Content (\%)} = \frac{W_a}{W_{od}} \times 100 \quad (4)$$

Where W_a *= weight of ash (g), and* W_{od} *= weight of the oven-dried sample*

Fixed Carbon Content

This was calculated as the difference between the sum of percentage moisture content, volatile matter, and ash content based on ASTM Standards E711-87 (2004), as shown in the equation below;

$$\text{Fixed Carbon Content (\%)} = 100 - \text{MC (\%)} + \text{VMC(\%)} + \text{AC (\%)} \quad (5)$$

Heating Value

The heating value was evaluated using the Goutal formula as described in Sotannde *et al.* (2017).

$$H_v = 2.326(147.6C + 144V) \quad (6)$$

Where H_v *= Heating value in MJ.kg*$^{-1}$*, C = percentage fixed carbon, and V = Percentage volatile matter*

Experimental Design and Data Analysis

The experiment was designed in a 3x5x5 factorial experiment in a completely randomised design with binder inclusion at three level and biomass mixing ratio at five levels, replicated five times. The effects of biomass proportion and binder inclusion on the physical and combustion properties of the produced briquette were subjected to Analysis of Variance ($p \leq 0.05$) and Duncan Multiple Range Test (DMRT) as a follow up test. All the data was implemented using SPSS (statistical package for social science) version 16.

RESULT AND DISCUSSION

Physical Properties of the Briquette

Moisture content

The briquettes produced is 3.5 × 5 cm and weighted 50g (Plate 1). Biomass mixing ratio significantly influenced the moisture content of the briquette samples ($p<0.05$) (Table 1). Briquettes made from 50:50 mixing ratio have the highest moisture content (9.87%), followed by those produced from 60:40 (wheat offal: sawdust) mixing ratio (5.74%). Samples made from 80:20 biomass mixing ratio had the lowest moisture content (3.14%) as shown in Table 2. In terms of binder proportion, the briquette sample has almost 6% moisture content at 3% binder inclusion, which is the highest when compared to the moisture content at 6% and 9% binder proportion (4.43% and 5.18% respectively). This is in line with the observation that the higher the binder proportion, the lower the moisture absorption and retention by the briquette. This is because the binder improves compaction and reduces pore spaces that support moisture absorption within the briquettes (Zhang *et al*., 2018). Moisture content of the briquette produced from composite material is lower than the recommended 8–10% moisture level, indicating the desirability of the composite briquette and comparability to other research-proven biomass briquettes such as those made from cocoanut and Bambara nut (Sotannde *et* al., 2017), banana leaves (Bamisaye & Rapheal, 2021), sawdust, cornhusk, and cassava peels (Waheed *et al*., 2023).

Plate 1: Briquette produced from carbonised sawdust and wheat offal

Compressed, Relax Density and Relaxation Ratio

Briquettes made from 80:20 mixing ratio have higher compressed and relaxed densities, while those made from 20:80 mixing ratio have the lowest compressed and relaxed densities (0.911 g/cm^3 and 0.473 g/cm^3, respectively), but a higher relaxation ratio than 80:20 mixing ratio. The compressed density of the briquette showed an increasing trend with the increasing percentage binder inclusion, while relaxed density showed an inverse relation with the increasing binder proportion. In a similar way, the relaxation ratio showed an irregularly increasing trend as the percentage binder inclusion rose from 3% to 9% (Table 2). The density of the composite briquette is within the range of 0.473 g/cm^3 to 1.123 g/cm^3 and can be compared favourably with other studies (Falemara *et al*., 2018; Thliza *et al.,* 2020; Umeocho *et al.,* 2024). The effect of variation in biomass mixing ratio significantly affects the compressed and relaxed density, while percentage binder inclusion significantly influences the compressed density and relaxation ratio of the composite briquette (Table 2). The variation in the compressed and relaxed density of the composite briquette could be attributed to variations in factors such as particle size, moisture content, and the chemical composition of the biomass material (Bello and Onilude, 2020). The relaxation ratio values observed appeared to be lower compared to those reported by Akpenpuun *et al.* (2020). Briquettes with a lower relaxation ratio are usually more stable and less elastic compared to those with a high ratio (Awulu *et al*., 2015).

Combustion Properties

Volatile Matter and Ash Content

The percentage volatile matter content and ash content of the composite briquette are significantly influenced by the biomass mixing ratio. However, the amount of binder inclusion does not have any marked effect on the volatile matter and ash content of the produced briquette (Table 3). The highest volatile matter was observed in the briquettes made from 20:80 mixing ratio (32.90%), while those made from 80:20 mixing ratio had the lowest (20.29%), (Table 4). The volatile matter content showed an unsteady increasing trend as the percentage binder inclusion increased from 3% to 9%, yet there was an inverse relationship between ash content and binder proportion, with the lowest value (8.44) was observed when the binder inclusion increased from 6% to 9%. The ash content observed in this study is lower than the 17–25% reported by Akpenpuun *et al.* (2020) for groundnut shell, rice husk, and sawdust briquettes. Briquettes with low ash contents tend to have a higher heating value. The volatile matter content obtained in this study is relatively low when compared to cocoanut husk, sawdust, and charcoal particles in Quaicoe *et al*. (2024), and sawdust and okra leaves (Ohagwu *et al.,* 2022). However, it was noted in Table 4 that the volatile matter content of composite briquettes increased with the addition of carbonised sawdust to the biomass mixing ratio. This supports one of the aims of using composite raw materials, which is to enhance the quality of the briquettes, as seen in this study, where one material complements the deficit of the other.

Table1: ANOVA on the variation in the percentage binder inclusion and biomass mixing ration on oven dry moisture content of the briquettes produced.

Sources of variation	Df	P-value			
		Compressed density	Relaxed density	Relaxation ratio	Moisture content
Biomass Ratio (BR)	4	0.004*	0.019*	0.606^{ns}	0.4035*
Binder Level (BL)	2	< 0.001*	0.370^{ns}	< 0.001*	0.720^{ns}
BR x BL	8	0.322^{ns}	0.517^{ns}	0.645^{ns}	0.247^{ns}
Error	30				
Total	44				

Df = degree of freedom; ns = not significant at α 0.05

Table 2: Effect of the biomass mixing ratio and percentage binder inclusion on the physical properties of the briquettes produced

Parameters	Compressed density (g/cm^3)	Relaxed density (g/cm^3)	Relaxation ratio	Moisture content (%)
	Biomass mixing ratio			
20:80	0.911±0.21^b	0.473±0.09^c	1.945±0.33^a	3.89±4.37^{b*}
40:60	0.926±0.11^b	0.515±0.05^{bc}	1.817±0.31^a	3.50±3.44^b
60:40	1.091±0.14^a	0.555±0.06^{ab}	1.987±0.32^a	5.74±8.75^{ab}
80:20	1.109±0.18^a	0.601±0.09^a	1.858±0.24^a	3.14±1.86^b
50:50	1.015±0.12^{ab}	0.533±0.08^{ab}	1.930±0.28^a	9.87±3.26^a
	Binder inclusion (%)			
3	0.904±0.13^c	0.550±0.10^a	1.674±0.24^b	5.97±7.42^a
6	1.123±0.15^a	0.544±0.07^a	2.074±0.22^a	4.53±3.61^a
9	1.004±0.17^b	0.513±0.08^a	1.975±0.26^a	5.18±4.50^a

* *Values with the same alphabet in the same column in each section are not significantly different from each other.*

Combustion Properties

Volatile Matter and Ash Content

The percentage volatile matter content and ash content of the composite briquette are significantly influenced by the biomass mixing ratio. However, the amount of binder inclusion does not have any marked effect on the volatile matter and ash content of the produced briquette (Table 3). The highest volatile matter was observed in the briquettes made from 20:80 mixing ratio (32.90%), while those made from 80:20 mixing ratio had the lowest (20.29%), (Table 4). The volatile matter content showed an unsteady increasing trend as the percentage binder inclusion increased from 3% to 9%, yet there was an inverse relationship between ash content and binder proportion, with the lowest value (8.44) was observed when the binder inclusion increased from 6% to 9%. The ash content observed in this study is lower than the 17–25% reported by Akpenpuun et al. (2020) for groundnut shell, rice husk, and sawdust briquettes. Briquettes with low ash contents tend to have a higher heating value. The volatile matter content obtained in this study is relatively low when compared to cocoanut husk, sawdust, and charcoal particles in Quaicoe et al. (2024), and sawdust and okra leaves (Ohagwu et al., 2022). However, it was noted in Table 4 that the volatile matter content of composite briquettes increased with the addition of carbonised sawdust to the biomass mixing ratio. This supports one of the aims of using composite raw materials, which is to enhance the quality of the briquettes, as seen in this study, where one material complements the deficit of the other.

Table 3: ANOVA for the effect of binder inclusion and biomass mixing ratio on the combustion properties of the briquettes produced

Sources of variation	Df	P-value			
		Volatile matter	Ash content	Fixed carbon	Heating value
Biomass Ratio (BR)	4	< 0.001*	< 0.001*	< 0.001*	0.116^{ns}
Binder Level (BL)	2	0.112^{ns}	0.152^{ns}	0.992^{ns}	0.346^{ns}
BR x BL	8	0.333^{ns}	0.495^{ns}	0.071^{ns}	0.274^{ns}
Error	30				
Total	44				

*Df = degree of freedom; ns = not significant at α 0.05; * = significant at α 0.05*

Table 4: Effect of biomass mixing ratio and percentage binder inclusion on the combustion properties of the briquettes produced

Parameters	Volatile matter content (%)	Ash content (%)	Fixed carbon content (%)	Heating value (MJ/kg)
		Biomass mixing ratio		
20:80	32.90±4.02^{a}	13.29±2.29^{a}	49.92±7.25^{c}	28.158±21.24^{b}
40:60	32.53±2.84^{a}	13.43±6.35^{a}	50.54±6.78^{c}	28.246±23.31^{b}
60:40	27.71±1.20^{b}	09.53±4.06^{b}	57.03±12.58^{bc}	28.858±43.67^{ab}
80:20	20.29±8.27^{c}	5.99±2.44^{c}	70.58±11.41^{a}	31.029±13.19^{a}
50:50	24.48±6.10^{bc}	3.99±0.71^{c}	61.66±8.63^{b}	29.368±12.85^{ab}
		Binder inclusion (%)		
3	25.42±8.94^{a}	10.78±7.75^{a}	57.84±17.86^{a}	28.370±42.19^{a}
6	29.13±5.50^{a}	8.51±3.37^{a}	57.82±8.17^{a}	29.610±13.95^{a}
9	28.19±5.58^{a}	8.44±3.22^{a}	58.18±8.16^{a}	29.417±11.53^{a}

** Values with the same alphabet in the same column in each section are not significantly different from each other.*

Fixed Carbon and Heating Value

Briquettes produced from 80:20 mixing ratio have the highest fixed carbon content, while those made with 20:80 mixing ratio have the lowest (49.92%). Likewise, briquettes made with 80:20 mixing ratio also exhibit a higher heating value compared to the other mixing ratios (31.029 MJ/kg) (Table 4). In terms of percentage binder inclusion, the average fixed carbon content increased with higher binder inclusion. The fixed carbon content of briquettes, to a large extent, depends on the biomass material it is made from. The biomass mixing ratio significantly influences the carbon content of the composite briquette (Table 3). The fixed carbon obtained in this study ranges from 49.92% to 70.58%, thus comparable to rice husk (Inegbedion & Ikpoza, 2022) and higher than coffee husk, sawdust, and sugarcane bagasse (Lubwama *et al.,* 2020; Kebede *et al.,* 2022). The fixed carbon reported for this study is considered high, and suggesting that briquettes with high fixed carbons enhance the burning rate of the briquettes (Sotannde *et al.,* 2017). In the same vein, the average heating value of the composite briquettes increased as the percentage binder inclusion increased (Table 4). The average heating value from this study ranges from 28.158 MJ/kg to 31.029, which is higher than 11.98 to 15.55 MJ/kg for blend of corncob and rice husk (Sam Obu *et al*., 2022), (20.836 MJ/kg) rice husk, maize cobs, palm kernel shell, and sawdust (Sunnu *et al.,* 2021). Heating value is one of the combustion properties that determines the suitability of biomass material for energy production. The high heating value recorded in this study indicated the suitability of composite biomass materials for briquette production.

CONCLUSION AND RECOMMENDATIONS

The composite briquette produced exhibited the desirable combustion properties, making it a suitable alternative energy source for domestic and industrial utilisation. Based on the findings of this study, 80:20 biomass mixing and 6% binder inclusion level produced briquette with most desirable characteristics and are thus recommended for production of quality composite briquette from agro and forest-based residues. While the combustion properties of the briquettes are desirable, research should be focused on emission test to quantify the indoor air quality of the briquettes when burnt.

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Authors' Contributions

OAS designed the experiment and conducted data analysis. MU and SMI performed literature search and prepared the manuscript; OAS reviewed the drafted manuscript. SM conducted material collection and preparation, briquette production and data collection. All authors read and approved the final manuscript.

Ethical Statement

Not applicable

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