



EFFECT OF BINDERS ON THE PERFORMANCE OF CHARCOAL BRIQUETTES PRODUCED FROM SELECTED BIOMASS

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ABSTRACT

Globally, renewable resources are widespread which has comparatively little pollution emission effect on the environment. This study was conducted to assess the potential impact of different binders in the production of charcoal briquette using mango leaves, black plum leaves and rice husk as biomass. The organic binder materials used are cow dung, ficus citrofolia (durumi) and okra (butt) while the inorganic binder used was clay. Thus, the mix ratio adopted in the study are 1:1 and 1:2 (biomass:binder). In addition, some of the parameters such as bulk density, moisture content in dry basis, compressive strength, ash content, volatile matter and calorific value were determined to identify the briquettes with highest integrity. The results show that briquettes produced from black plum leaves with clay as binder had the highest density of (1.587g lcm³ and 1.574g lcm³) and lowest moisture content of (0.56% and 0.57%) and highest compressive strength of (4.45N/mm² and 3.90N/mm²) from both mix ratios. Similarly, briquette produced from black plum leaves with okra as binder had the lowest ash content of 2.1% for both mix ratios. However, briquettes produced from black plum leaves with durumi and that of rice husk with durumi as binders yielded highest volatile matter of 36.5% and 37.2% respectively. It is noteworthy that the highest heating values of 33.81mj/kg and 28.43 mj/kg was observed in briquettes produced using mango leaves with clay as binder from a mix ratio of 1:1 and 1:2. Furthermore, the lowest heating values of 15.94mj/kg and 16.27mj/kg were observed from briquettes obtain from rice husk with cow dung as binder from both mix ratios. Therefore, it is evident that clay is a better binder for briquette production with significant combustion property, which is cost effective and readily available for both domestic and small-scale commercial purposes.

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1.0 Introduction

The demand for energy has been on the increase, mostly attributed to the population growth, rise in price of fossil fuel as well as the significant rise in the commercial and industrial activities witnessed across the globe (Sansaniwal *et al.*, 2017; Carter *et al.*, 2018; Gilvari *et al.*, 2018). Fossil fuels constitute about 80% of the global primary energy requirement (Sunday *et al.*, 2020). According to (Tursi, 2019), the increasing usage of fossil fuels for industrial and post-industrial development has attracted not only growth in wealth, but also higher levels of pollution and negative impact on public health. Recently, there has been resurgence of interest in the use of biomass as a source of energy in both developed and developing countries as an alternative to fossil fuel (GBS, 2019; Sanchez *et al.*, 2022). However, with the rapid rising in global energy needs by the teeming world population and rapid industrialization and urbanization as reported by Carter *et al.* (2018) and Gilvari *et al.* (2018), conversion of biomass to energy is considered as a promising alternative energy technology in the production of briquette for domestic and industrial use (Chaney *et al.*, 2012).

Biomass briquetting, a densification technology is one of the technologies used in improving the potential energy use of biomass primarily for household heating applications and power generation (Carter *et al.*, 2018). In biomass briquetting, plant drive raw materials are preferred as a densification material, while animal drive biomass is often used as a binding material. The predominant use of vegetable or plant biomass sources could be attributed to its widespread availability compared to animal derived biomass (Okey *et al.*, 2022). Biomass generally contain naturally occurring structural binders (lignin) that are released when biomass is densified at higher pressure (Oyelaran *et al.*, 2015), which improves the structural particle bonding in the briquettes. However, some biomass may not contain significant natural binder to densify into a solid shape. However, in such instances, additional binders may be required to achieve the desired hardness and durability. Briquette binders could be classified into organic, inorganic and compound binders. Zhang *et al.* (2018) noted that organic binders have high impact and water resistance properties with poor thermal stability. In addition, binders are mostly characterized with extensive availability, high heating value and low ignition temperature (Han *et al.*, 2014). The inorganic binders have strong adhesion with lower combustion efficiency due to limited calorific value and high ash content (Shu *et al.*, 2012). Consequently, compound binder comprises of the combination of two or more binders with the aim of taking the advantage of the multiple binding action offered by the different binders. Therefore, the aim of this paper was to investigate the effect of different binders in briquette production by carbonizing the biomass through pyrolysis. Also, the calorific value of produce briquettes will be evaluated.

2. Materials and Methods

2.1 Materials

Some of the materials used in this study include black plum leaves, mango leaves, rice husk, ficus citrofolia (durumi), cow dung, okra and clay. Similarly, some of the equipment used in the work include forced air-drying oven (VNB300, Mammert Germany), drying cabinet (FSM 140, Ohaus core USA), digital Analytical balance (PA214), Pioneer Ohaus USA), porcelain crucibles, muffle furnace (P-Select 2000368, select HORN Ohaus USA) and needle penetrator (A46-5290 Germany).

2.1.1 Collection of Biomass Materials

Black plum and mango leaves were collected in residential area along Polo ground while the rice husk was collected from a rice milling center in Bulumkutu area of the Metropolis (Figure 1). The ficus citrofolia (durumi) was collected from a residential area near the Federal high court in Maiduguri as well while cow dung sample was collected from cow herd at the Ramat Polytechnic Farm in Maiduguri. Similarly, the clay material used in the study was collected from an open deposit, along the polo ground in Maiduguri.

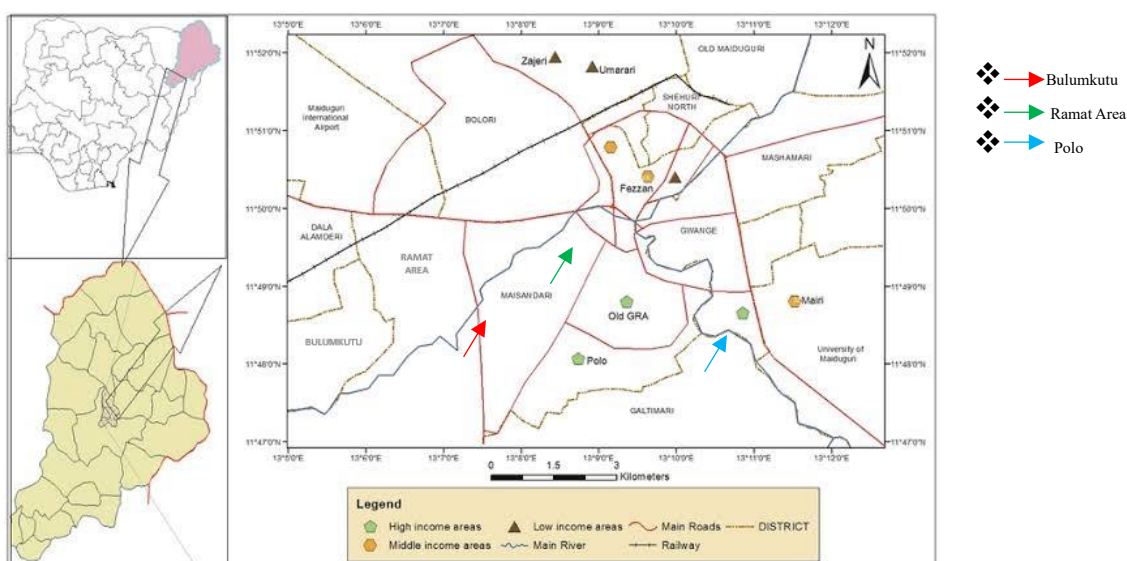


Figure 1: Map of Maiduguri (Source: Kelechi et al 2020)

2.2 Methods

2.2.1 Sample Preparation

The leaves fall (mango and black plum) and rice husk were screened from impurities and then sundried to reduce moisture content. Thereafter, it was carbonized in an open drum for 3 and 4hrs (Nattaporn *et al.*, 2013), respectively. The cooled carbonized biomass and the binders were grounded into pulverized form and sieved using 0.6mm sieve size to ensure steady grain size and ease of compression. The biomass material and the corresponding binders were respectively mixed using a ratio of 1:1 and 1:2 where 10g of each sample was adopted for all materials. 2

2.2.2 Production of Briquettes

The mixture of materials used for the production of the briquettes are presented in Table I.

➤ Mango Leaves	(ML)
➤ Black Plum Leaves	BPL)
➤ Rice Rusk	(RH)
➤ Cow Dung	(CD)
➤ Durumi	(DM)
➤ Okra	(OK)
➤ Clay	(CL)

Table I: Materials for briquettes production

Biomass	Binder
ML	CD, DM, OK, CL
BPL	CD, DM, OK, CL
RH	CD, DM, OK, CL

The binders were made into non-thick gel considering the moisture content of each binder prior to mixing with biomass. The biomass and the corresponding binders were mixed as presented in Table I above. Each mixture was filled into a cylindrical mold and placed on a pressing hydraulic jack machine and compressed with a pressure of 10.13mpa. This has helped in regulating the constant pressure and prevention of oozing out of binders. A total of 24 (12 from each of the two mix ratios) cylindrical briquettes with a mean diameter of 2.88cm and height of 1.58cm were produced. The Produced briquettes were sundried for 6 days to ensure complete dryness of the briquettes for laboratory works.

2.2.3 Determination of Physical and Combustion Properties of produced Briquettes

Some of the physical and combustion properties of the produced briquettes determined include the density (D), compressive strength (CS), moisture content (MC) ash content (AC), volatile matter (VM) and calorific value (CV).

2.2.4 Determination of Density of produce Briquette

The equivalent mass (m) of each of the briquettes in grams (g) was divided by its subsequent volume (v) in cm:

$$d = m (g)/v (cm^3) \tag{1}$$

2.2.5 Determination of Moisture Content of produced Briquettes

2g of the grated sample of the briquettes produced was evenly spread on a clean and dried weighed container which was rapidly placed in an oven (UNB 300) preheated to 103°C without a lid. Thereafter, the briquettes sample was left to dry for 2hrs before the lid was replaced on the container and removed from the oven to prevent any form of, moisture that might arise from the lid cap. Thus, the briquettes sample was left to cool in drying cabinet (FSM 140) at less than 20 % humidity and then reweighed.

$$M \text{ (g/g)} = \left(\frac{m_3 - m_1}{m_2 - m_1} \right) \times 100 \quad (2)$$

Where, m_1 = weight of glass container (g), m_2 = weight sample and glass container before drying (g) and m_3 = weight of sample glass container after drying (g).

2.2.6 Compressive Strength of produced Briquettes

Briquette sample was inserted between two plates on a compressing machine subjected to compression. The ratio between the maximum breaking force and the cross-sectional area of the sample indicates the resistance to breaking by compression.

2.2.7 Determination of Ash Content of produced Briquettes

Approximately, 5g of a grated briquette sample was evenly spread on a weighed container (crucible) and placed on to a muffle furnace (P-select 200 368, select HORN) set at 570°C. The sample was kept at the above temperature until it appeared light grey, hence, crucible was removed and placed in a drying cabinet (FSM 140) which was left to cool and reweighed immediately.

$$AC \text{ (g/g)} = \left(\frac{m_c - m_a}{m_b - m_a} \right) \times 100 \quad (3)$$

Where, m_a = weight of porcelain crucible (g), m_b = weight of porcelain crucible and sample (g) and m_c = weight of porcelain crucible and ash (g).

2.2.8 Determination of Volatile Matter of the Briquettes produced

Grated briquette sample (5g) was evenly spread on a weighed crucible and placed to a muffle furnace (P-select 2000368, select HORN) set at 750°C and left for 7 min. (Lina *et al* 2015) Thereafter, the crucible was removed and placed in a drying cabinet (FSM 140) which was left to cool and weighed immediately.

$$VM \text{ (\%)} = \% \text{ loss in weight} - \% \text{ moisture content} \quad (4)$$

2.2.9 Determination of Calorific Value of Briquettes

The calorimeter was calibrated by combusting 1g of benzoic acid which has a known CV. About 1 g of a briquette sample was placed in a metal sample cup which was placed into a holding slot between two electrodes extending from the lid of a stainless-steel container. Thereafter, a thin metal wire fuse was attached to the electrodes which forms a loop into the coal sample and then placed into “bomb container”. Thus, the bomb containing the briquette sample was transferred to a water bath where an electrical current was used to spark the sample which ignites the bomb. The sample in turn heated the water bath, hence, the change in water – bath temperature was used to determine the calorific value of the sample.

2.2.10 Sample Identification

Table 2: Initials for biomass and their corresponding binders

S/N	SAMPLE	SAMPLE ID
1.	ML+CD	ML1
2.	ML+DM	ML2
3.	ML+OK	ML3
4.	ML+CL	ML4
5.	BP+CD	BP5
6.	BP+DM	BP6
7.	BP+OK	BP7
8.	BP+CM	BP8
9.	RH+CD	RH9
10.	RH+DM	RH10
11.	RH+OK	RH11
12.	RH+CL	RH12

Table 2 is used for sample labeling for easy identification and ensure correctness of work. Samples used in this study were based on the initials of biomass and their corresponding binders which was further simplified accordance with the sample ID as shown above.

3. Results and Discussion

The results of the physical and combustion analysis of black plump leaves, mango leaves, rice husk with durumi, cow dung, okra and clay paste as binders are presented in this section. The properties of the briquettes produced were limited to the determination of density, percentage moisture content, compressive strength, percentage ash content, percentage volatile matter and calorific value only. Figure 2 presents the density of the briquettes produced.

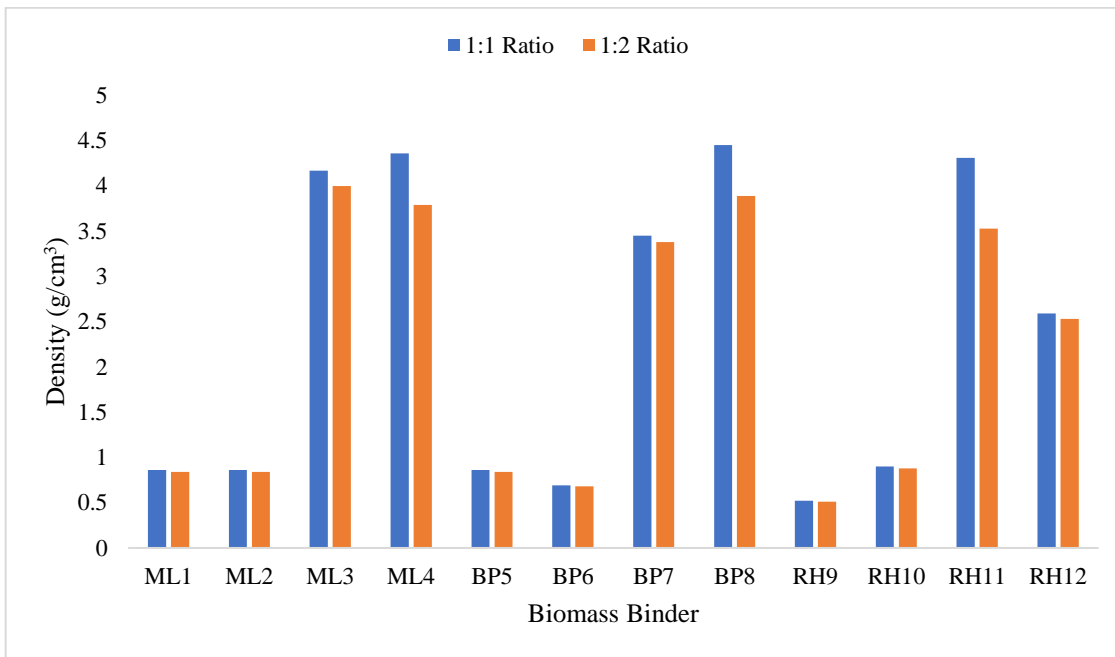


Figure 2: Density (g/cm³) of produced briquettes

The results show that the density of the briquettes varied from 1.002 g/cm³ – 1.587 g/cm³ for 1:1 mix ratio and 1.001 g/cm³ – 1.574 g/cm³ for 1:2 mix ratio. The lowest and highest densities were obtained from briquettes produced from ML+DM (ML2) and in BPL+ CL (BP8) respectively. The lowest density obtained in this study is greater than the highest obtained from a briquette of rice stalk and starch binder by Ige *et al.* (2018) of 0.590g/cm³. This is because high density is an indication of longer burning time, as such briquette produced from BPL+ CL (BP8) will tend to burn for a longer time compared to others. The result from Figure 3 indicates percentage moisture content of the produced briquettes which is between the minimum value of 0.56% from BPL+CL (BP8) of 1:1 mix ratio and maximum of 8.45% from RH+CD (RH9) of 1:2 mix ratio. The moisture content of briquettes produced in this study had lesser moisture content than the briquettes produced from sawdust, ficus exasperate and cassava peel using different binders which was 8.55% (cow dung) and 12.51% (starch) as reported by Ogunjobi *et al.* (2023). This result agrees with MC of 5-10% obtained by Pillari *et al.* (2013) for quality briquettes. With low moisture content, briquettes will easily ignite, facilitate heat transfer and higher calorific value is expected (Dawit, 2012).

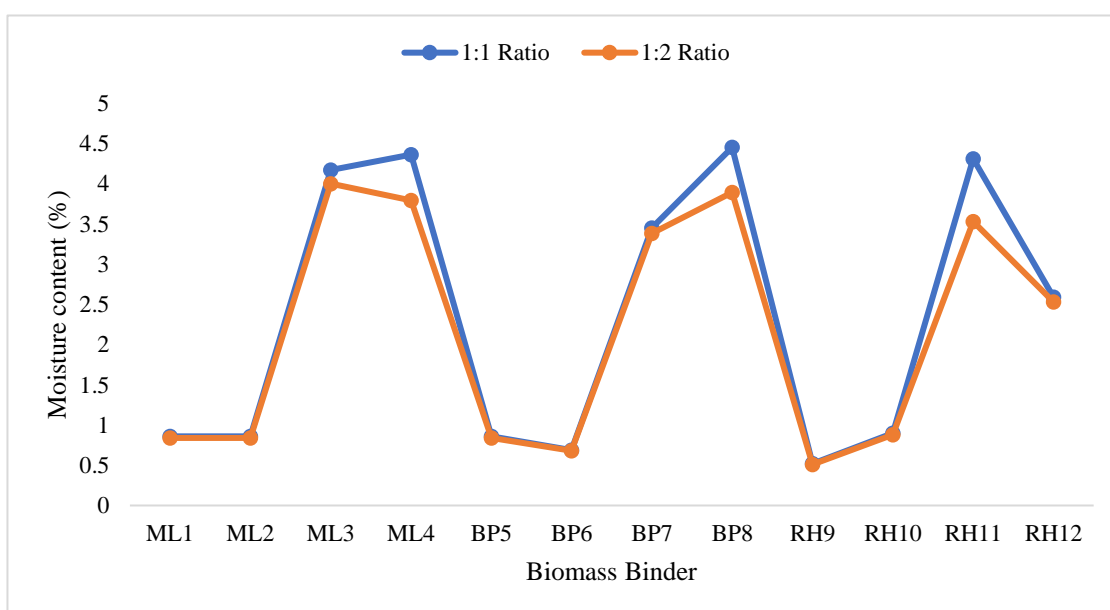


Figure 3: Moisture content (%) of produced briquettes

In this study, the compressive strength of the briquettes produced is shown in Figure 4. The results show that the compressive strength ranges between 0.51 – 4.450 N/mm² for briquettes produced from mix ratio of 1:2 and 1:1 respectively. The compressive strength achieved by the two mix ratios were found to be reasonable with the briquette of BPL+ CL (BP8) having the higher value of 4.45 N/mm² as compared to highest value of 10.94N/mm² from a briquette of charcoal fines and African elemirasin binder reported in a work by Barnard *et al.* (2021). The implication of this is that briquette from BPL+CL (BP8) will suffer less damage during packaging storage and transportation (Ige *et al.*, 2018). Above all, it is an indication of good quality briquettes because of the strong inter particle bonding (Onuegbu *et al.*, 2011).

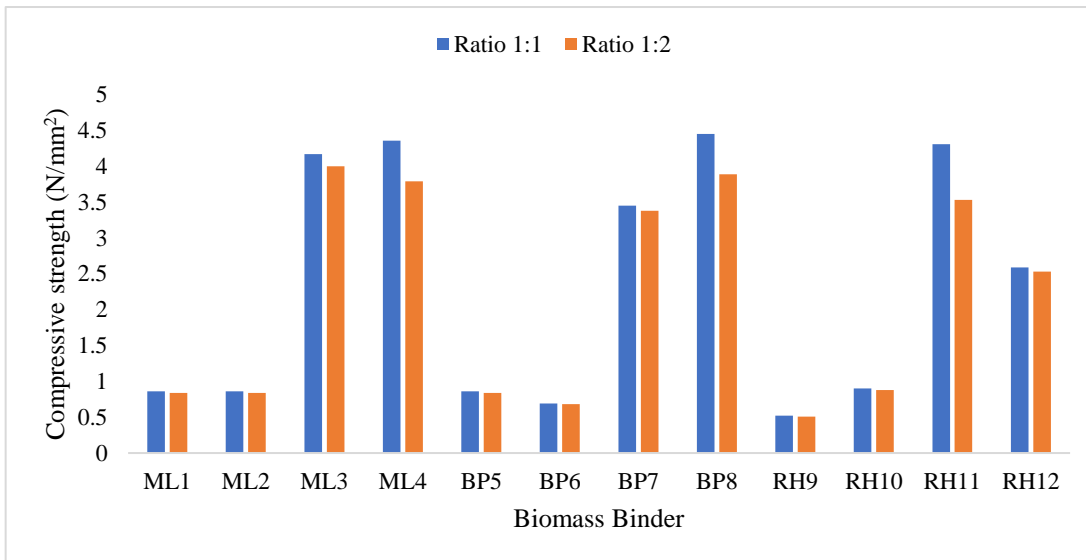


Figure 4: Compressive strength (N/mm²) of produced briquettes

Figure 5 shows the Ash Content of briquettes produced in this study which was lowest in BPL+ OK (BP7) at 2.1% and highest value was found in BPL+ DM (BP6) at 7.2% obtained from the mix ratios of 1:1. The result is lower when compared with that obtained by Ogunjobi *et al.* (2023) from a briquette of *ficus exasperata* and cassava peel with different binders. The low ash content as observed in this study is a reflection of high heating value (Figure 6) which is an indication that the briquette does not contain high mineral matters. However, low ash content is an indication of good quality briquette which offers higher heating value with less dust emissions (Obi *et al.*, 2013). Higher ash content in a fuel usually leads to air pollution and affects the combustion volume and efficiency of combustion (Ketimbo *et al.* 2014).

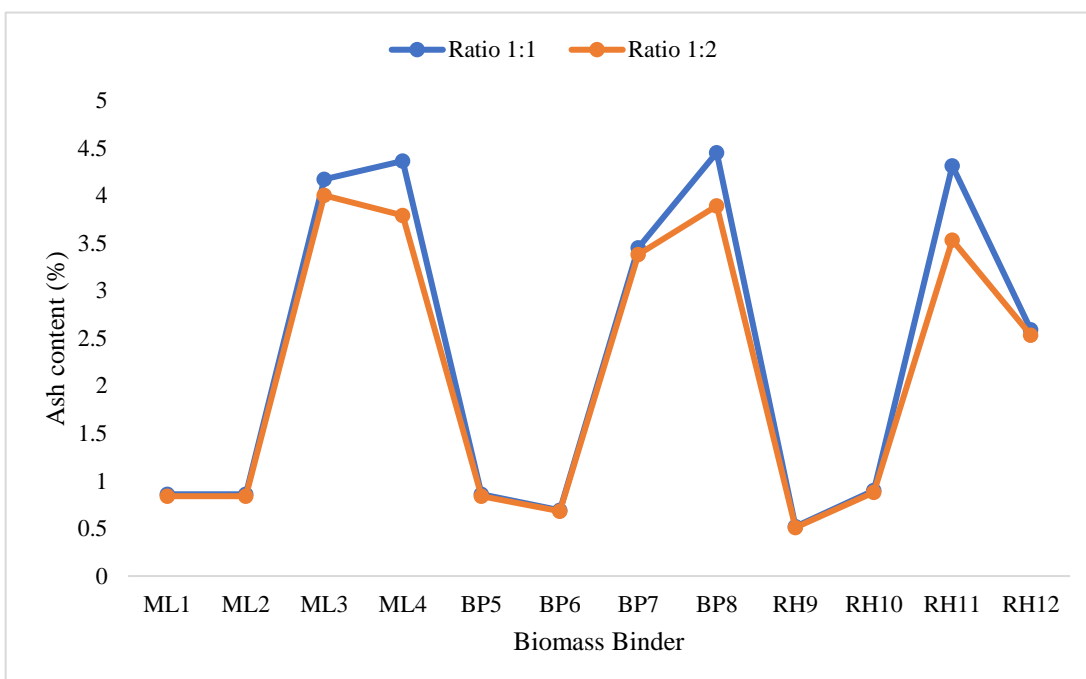


Figure 5: Ash content (%) of produced briquettes

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Figure 6 revealed the range of values for the volatile matter of the briquettes produced. were 20.6% (lowest) obtained from a briquette of BP+CL at 1:1 mix ratio and 37.2% (highest) obtained from briquette of RH+DM (RH10) at 1:2 mix ratio respectively. The lowest VM in this study was lower than the lowest of 24.4% obtained from a briquette of groundnut shall, corn cub with wood residue binder and the highest was slightly higher than the highest of 34.9% as shown by (Babajide *et al.* 2018). Conversely, Egbewole *et al.* (2009) and Sotannde *et al.* (2010) reported a lower volatile matter for briquettes made from wood sawdust (13.89% - 19.33%) and neem wood residues of (10% - 13%) respectively. However, the amount of volatile matter strongly influences the thermal decomposition and combustion behavior of solid fuel (Ogunjobi *et al.*, 2023). Similarly, lower volatile matter is an indication that the briquettes might not be easy to ignite, but once ignited it will burn smoothly as observed by Babajide *et al.* (2018). High volatile matter results in high combustibility at low ash content (Marinder *et al.*, 2012) that would be highly spontaneous in combustion utilization

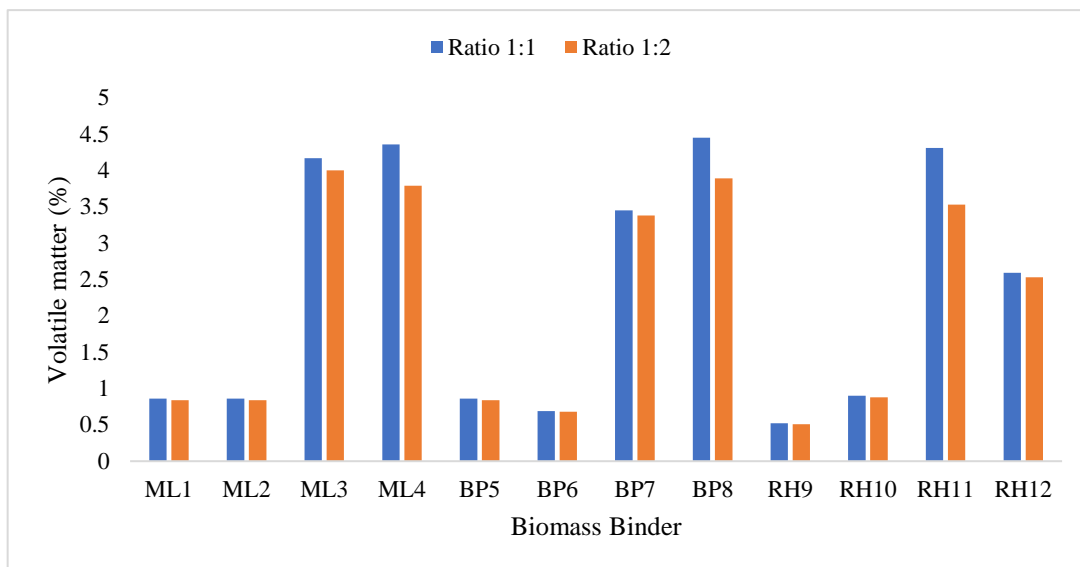


Figure 6: Volatile matter (%) of produced briquettes.

Figure 7 shows the calorific value of the produced briquettes which determines the amount of heat energy present in a material. It was observed that the calorific values obtained from this study was between 15.94 MJ/kg from briquettes of RH + CD at mix ratio of 1:2 and 33.81 MJ/kg from a briquette of ML + CL at mix ratio of 1:1. The lowest heating value obtained from this study is slightly lower than the lowest of 19.4 MJ/kg and highest obtained heating value is higher than the highest of 24.9 MJ/kg obtained by Ajimotokan *et al.* (2019). Similarly, the highest calorific value obtained in this study is higher than the highest of 32.79 MJ/kg and 24.60 MJ/kg as reported by Ogunjobi *et al.* (2023 and Gilbert *et al.* (2021), respectively. The lowest and highest calorific values were obtained from briquettes produced from organic binders. All briquettes produced have a significantly high heating value which offers good combustion properties that could be acceptable for domestic use and small - scale commercial purposes.

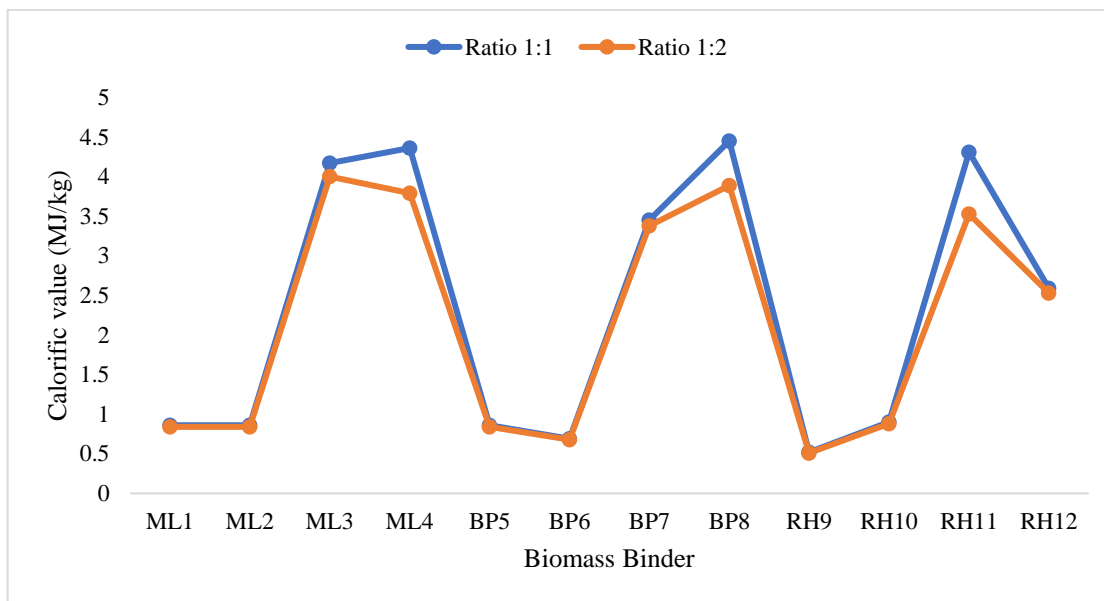


Figure 7: Calorific value (MJ/kg) of produced briquettes

4. Conclusion

The global rise in population growth has resulted in increasing energy (fossil fuel) demand which has impacted negatively on greenhouse gas emission and human health. To address this challenge, biomass briquetting technology has been introduced as an important part of global bioenergy supply both in developing and developed economies. This paper studied the effect of different binders in biomass briquetting which resulted in improved physical and combustion properties of the produced briquettes. The study revealed that briquettes produced from inorganic binders yielded better physical properties resulting in highest density and lowest moisture content. It also resulted in highest compressive strength. However, mix ratio (biomass: binder) does not reveal a significant impact on the quality of the produced briquettes. The heating value of the different binders used clearly appreciate their influence on the produced briquettes with highest heating value obtained using inorganic binder (clay). It is clear that all briquettes produced have a good heating value which is higher than the minimum value set by the Wood Pellet Association of Canada (calorific value $\geq 16.00\text{MJ/kg}$). Furthermore, decrease in moisture content has clear impact on increase in density.

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