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DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A LOW-COST PORTABLE MOULDER FOR BIOFUEL BRIQUETTE PRODUCTION

S. Namadi[1]*, A.O. Musa[2], U.M. Gana[2]

*[1]Department of Physics, Usmanu Danfodiyo University, Sokoto

[2]Department of Physics, Bayero University, Kano.

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Abstract: **The present study reports the design, construction, and performance evaluation of a low-cost portable briquette moulder capable of producing 10 briquettes at a time. Waste from neem tree branch residues were converted into biofuel briquettes using the native cassava starch as a binder. The physical, proximate, and elemental characteristics of the briquettes were determined according to American Society for Testing and Materials (ASTM) analytical methods and calculations. The results for the physical properties are: maximum density of 962.19 kg/m³, relaxed density of 448.16 kg/m³, relaxation ratio of 2.12, and density ratio of 0.47. Additionally, the briquettes exhibited 99.31% shatter resistance, 99.61% tumbling resistance, and a 93.15% water resistance index. The proximate properties were determined to be 5.01% moisture content, 46.66% volatile matter, 2.26% ash content, and 46.07% fixed carbon. The elemental composition of the briquettes included 50.57% carbon, 5.20% nitrogen, and 36.21% oxygen. The heating value of the briquettes was found to be 19.02 MJ/kg. The low-cost briquette moulder was effective and capable of producing high-quality briquettes that provide sufficient heat for household and small-scale industrial operations.**

Keywords: **Biomass, Briquette, Moulder, Physical and Combustion analysis.**

1. INTRODUCTION

Renewable energy resources are those that are naturally replenished. Nigeria is particularly fortunate to have access to renewable energy sources such as biomass, solar, wind, and hydroelectricity. Among these, biomass emerges as the most promising clean energy source due to its wide range of applications. Fuelwood, derived from biomass, is the least expensive, most abundant, and most accessible fuel source, not only in rural areas but also in some urban households (Osueke and Ezugwu, 2011). However, using raw biomass as fuel has several drawbacks, including poor ignition quality, excessive smoke release during combustion, lower calorific value, and high bulk volume, making handling, storage, transportation, and combustion inefficient. To improve biomass combustion efficiency and address related challenges, Araujo *et al*. (2016), advocate for a thermochemical process involving drying and mechanical densification, which converts raw biomass into compact, easily ignitable briquettes.

Briquetting process transforms biomass waste into dense, easily ignitable biofuel briquettes that burn efficiently, emitting fewer toxins compared to raw biomass and some fossil fuels (Araujo *et al.*, 2016). Ucar and Yumak, (2001) acknowledge briquetting as the most efficient method for compressing biomass into fuel. Utilizing low-cost or freely available materials such as newspaper, plant waste, or sawdust, briquette production offers a viable alternative energy source for both households and industries, often outperforming traditional options like charcoal, firewood, gas, coal, and electricity, as highlighted by Emerhi (2011). Moreover, depending on the materials used, briquettes tend to burn cleaner than charcoal and firewood. Additionally, converting waste biomass into briquettes helps combat deforestation, soil erosion, and desertification while transforming sawmilling waste into a valuable resource. This process also contributes to cleaner air by replacing firewood with environmentally friendly biofuel, promoting sustainability (Emerhi, 2011).

The usage of a briquette moulder or briquetting machine is necessary for briquette manufacture. Quite a number of briquetting devices have been invented and their performance assessed. These devices range in complexity from the simplest manual variants to the most complex ones that employ mechanical or electrical power. Kaliyan and Morey (2010), used a pilot scale roller press for manufacturing briquettes in the form of pellets from switch grass and corn starch. The compression pressure was maintained at 150 MPa and no binding agents were used during the preparation and mixing. Osarenmwinda and Ihenyen (2012), created a manually driven briquetting machine with 20 moulding dies. The equipment can produce 20 briquettes of 50mm height and 28mm diameter with a compaction pressure of 17kN/m^2. The briquetting machine was reported to be useful for small and medium-sized briquette manufacturers. A suitable briquetting machine with a 43 kg/hr production capacity was developed by Obi *et al.*, (2013) for producing biomass briquettes on a small scale. The machine successfully produced bio-briquettes from waste sawdust that could power a small-scale industrial cottage and provide the heat required for residential cooking in rural regions. They reported to have created a biofuel briquette with enough heating value and strength that would not collapse while being transported or stored. Davis and Davis (2013), made briquettes from Guinea corn residue by utilizing a hydraulically powered press using water hyacinth as the filler and phytoplankton scum as binder. A hydraulic pump was applied to move the piston at a speed of 30 millimeters per minute. During production, the pressure of 20 kPa was maintained for 45 seconds residence time. Ojaomo *et al.* (2015), developed a simple manually operated Briquetting machine for small-scale application using locally available materials. They reported that the simplicity and performance evaluation of the machine justify its efficiency, ease of operation and does not require the use of electricity or costly fuel. They concluded that the briquette made by the machine if used will go a long way in reducing greenhouse gas emission resulting from indiscriminate waste burning and poor waste management. Namadi and Abdullahi (2017), produced a briquette using residual sugarcane bagasse with the aid of a hand-press briquette moulder that produced five briquettes simultaneously. Ibitoye et al. (2023), developed a biomass densification machine for educational and research applications. The produced briquettes' characteristics indicate the machine's appropriateness for these purposes and support the development of sustainable energy solutions, particularly in developing countries. Similarly, Omoniyi and Ojo (2023), created an affordable, manually operated briquetting system capable of producing 176.40 kg of bio-briquettes per day using local metal scrap. These briquettes, made from Cardia millenii sawdust and cow dung binder, were found to be stable, durable, and water-resistant, making the system suitable for adoption as a biofuel source in rural communities.

Briquetting technology has a better chance of being successful, according to Hood (2010), if it is more reproducible, acceptable, affordable, locally accessible, easy to make, ecologically safe, and culturally appropriate. Some existing briquette production systems suffer from low productivity, substandard briquette quality and high expenses. Consequently, there is a critical need to develop a briquette moulder from affordable, locally sourced materials. Therefore, the aim of this research is to create an affordable briquette moulder capable of producing multiple briquettes simultaneously.

2. MATERIALS AND METHOD

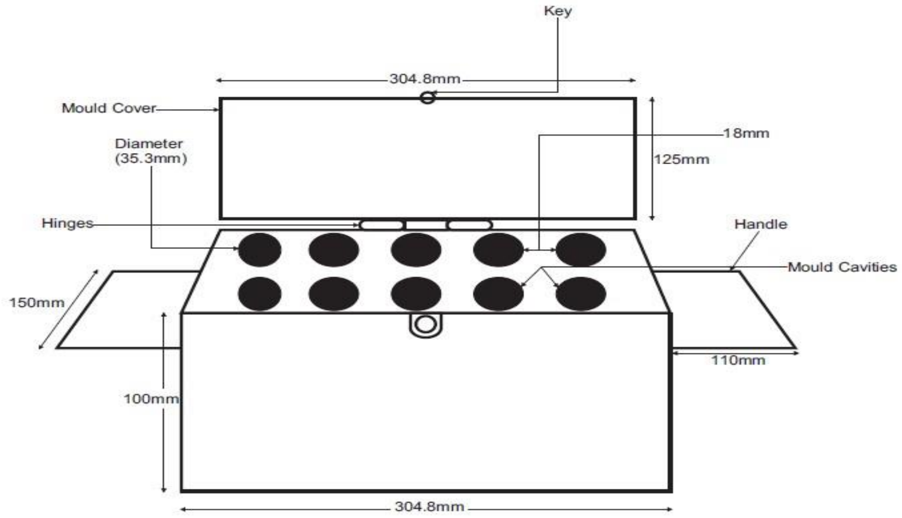
This section highlights the materials used in the study, moulder design and construction process as well as the procedures followed in carrying out experimental analysis.

2.1 Materials

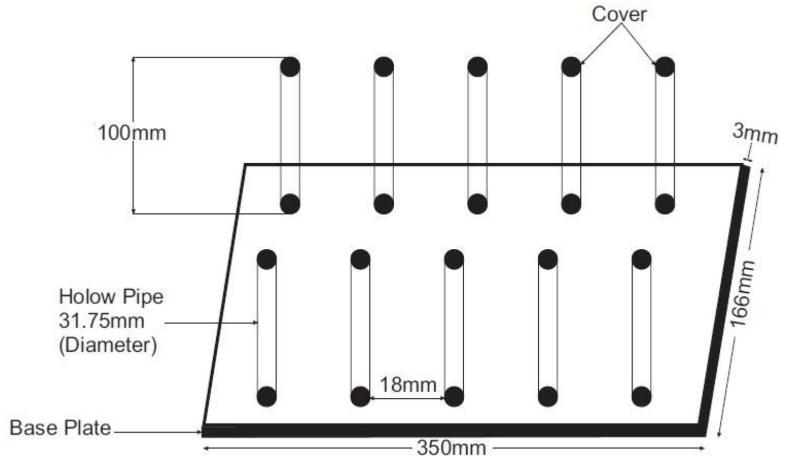
Materials used in the study includes feedstocks; which composed of Neem tree branch residues of thickness (67.21mm and below) obtained from trimming activities withing the Bayero University, Kano (Old Campus). Others are traditionally and locally made cassava starch and water. Hollow pipes of diameter (33.3mm and 31.75mm), Vices, oxyacetylene cylinder, Electric welding machine and electrodes, Steel flat bar, Hinges, Electric hand grinder, measuring tape are some of the materials used for moulder construction and assembling processes. Physical and Proximate analysis were performed with the aid of Electric muffle furnace, Electronic digital caliper, Digital weighing balance, Bomb calorimeter, Crucibles, Spatula, Metal tongs and so on.

2.2 Design and Construction Process

The briquette moulder was designed and constructed as shown in the figure 1 and plate 1 respectively. The moulder was made by using the materials as stated in 2.1 above in such a way that it can produced 10 briquettes at a time using 10 cavities each measuring 100mm height, 35.3mm diameter and placed 18mm apart in the mould box.



(a)



(b)

Figure 1: Schematics diagram of (a) Mould box (b) Base plate with both-end closed pipes attached

(a) **(b)** **(c)**

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(d) **(e)** **(f)**

(g) **(h)** **(i)**

Plate 1: Moulder Construction Processess; (a) Hollow pipe cutting process (b) Pipe-covers cutting process (c) Flat bar cutting process (d) Assembled base plate and Moulder (e) Painting Process (f) Upper view of the moulder (g) Front view of the briquette moulder (h) Produced briquette (i) Sun-drying process.

2.2.1 Considerations in design and fabrication of briquette moulder

The design of the briquette moulder takes into consideration several key factors to enhance its construction and performance. These factors encompass the moulder's size and weight, the anticipated load and stress it will bear, the cost and availability of materials, the selection and assembly process of materials, the time needed for safe discharge, and the maintenance requirements. For ease of operation, the size and weight of the moulder components were designed for easy handling and transport. The materials for constructing the moulder were sourced locally from a scrap market in Sokoto, Nigeria, including a steel flat bar from scrap truck body and iron pipes from a used school chair. These materials were chosen for their low cost, local availability, and ease of conversion. Their properties, such as strength, durability and weldability, were also considered, ensuring they could withstand the load and stress during compaction. The time required for each briquette batch, including weighing, binder preparation, mixing, loading, and easy ejection from the mold, was considered to enhance production capacity and performance. The moulder was coated with durable black oil paint, chosen for its longevity, resistance to wear, and smooth finish. Maintenance involves safekeeping and cleaning with water and tissue immediately after use.

2.2.2 Description of some Moulder Parts

Mould box: The Mould box of size 304.8mm x 125.0mm x 100.0mm was made using metal flat bar of thickness 3mm. It housed the moulding cavities made using hollow pipes ($1\frac{1}{4}$ inch) which are placed 18mm apart and serve as chamber for briquette production. A flat metal bar was hinged to the mould box for the soul purpose of covering the upper end of the cavities during compaction which will be opened during ejection of the briquettes.

Base plate: The moulder's base plate, sized at 350mm x 166mm, was crafted from 3mm flat bar. Ten closed pipes, each measuring 10mm in height and 31.75mm in diameter, were fixed onto the plate, positioned 18mm apart. These pipes are strategically aligned with the mould box cavities, providing essential support for compaction by exerting upward pressure that counteracts the compaction force. The extra 45.2mm in length on the base plate as compared to that of mould box was to provide an avenue for foot-press (on both sides) while moving-up the box handles during briquette ejection process.

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Handles: The moulder composed of two (2) handles which were made using 10mm metal rod. The rod was bend into 110mm length and 150mm width and welded on the mould box at the opposite sides. Its main function is to maneuver the up and down movement of the mould box during briquette production process.

Cover Plate: The cover plate was made using 3mm metal flat bar which was cut into lengths 304.8mm x 125.0mm and hinged with moulding box. It is used to cover biomass feedstock during compression.

Key: The key was fastened at the top center of the upper face of the cover plate. Its primary purpose is to lock and unlock feedstock mixtures poured into the moulding cavities during compression and ejection respectively.

2.2.3 Calculation of some Parameters

1. Estimation of Area of the Cover Plate (A_C):

The plate is a quadrilateral that has its parallel sides equal to each other and all the four vertices are equal to 90°.

$$Area\ (A_c) = length \times width \quad (1)$$

$$Area\ (A_c) = 304.8mm \times 125mm = 38{,}100(mm)^2 \cong 0.0381m^2.$$

2. Volume estimation of the mould cavity (V_m)

Internal diameter of the mould cavity $= 35.3mm$

Radius $(r) = d/2 = 35.3mm/2 = 17.65mm$

Height of the mould cavity $= 100mm$

$$\text{Volume of the mould cavity } (V_m) = \pi r^2 \text{h} \quad (2)$$

$$(V_m) = 3.142(17.65mm)^2(100mm) = 97{,}880(mm)^3$$

$$(V_m) \cong 9.788X10^{-5}m^3$$

3. Pressure Estimation:

(a) On the Mould Box Surface (P_m)

Mass of the mould cover + Hings + Key $(M_{CHK}) = 0.71kg$

Mass of the mould box + Cavities+ Handle $(M_{BCH}) = 3.49kg$

Total mass of the mould frame = $M_{CHK} + M_{BCH} = 4.20kg$.

Average mass of the load (solid blocks) placed on the moulder= $63.61kg$.

The pressure applied on the mould box surface area

$$P_m = \frac{F}{A} \quad (3)$$

$$P_m = \frac{mg}{A} = \frac{63.61kg \times 9.81ms^{-2}}{0.0381m^2}$$

$$P_m = 16{,}421Pa \cong 16.42Kpa$$

(b) On the mixture inside the cavity (P_c);

Assuming the pressure is transmitted undiminished to each moulding cavity, the pressure applied on the residues due to masses placed can be determined using the relation;

$$P_c = \frac{Force}{Area}$$

$$\text{Area of a cylinder}= 2\pi r(r+h) \quad (4)$$

$$\text{Radius}= \frac{d}{2} = \frac{35.3mm}{2} = 17.65mm \cong 0.01765m$$

Average height covered during the compression= $50mm \cong 0.05m$.

Area of the cylinder= $2 \times 3.142 \times 0.01765m\ (0.01765m + 0.05m) = 7.503 \times 10^{-3}m^2$

The pressure on the mixture inside the moulding cavity can be calculated as;

$$P_c = \frac{Force}{Area} = \frac{mg}{Area} = \frac{63.61kg \times 9.81ms^{-2}}{7.503 \times 10^{-3}m^2} = \frac{624.0141}{7.503 \times 10^{-3}m^2} = 83{,}167Pa$$

$P_c \cong 83.167Kpa$

4. Determination of stress on the mould cavity.

Assuming the pressure (16,421 Nm^{-2}) is undiminished and transmitted to the moulding cavities at all level. The axial stress acting on the cylindrical cavity can be determine using the relation (Ominiyi & Ojo, 2023);

$$\sigma_\times = \frac{Pd}{4t} \qquad (5)$$

where; P = Internal pressure, d= diameter of the moulding cavity, t= thickness of the cylindrical cavity. Thus;

$$\sigma_\times = \frac{Pd}{4t} = \frac{16,421Pa \times 0.0353m}{4 \times 0.003m} = 48{,}305Nm^{-2}$$

The briquette moulder was constructed at a total cost of N 13,000, a lower price compared to that reported by Obi *et al.*, (2013). The moulder production performance was determined by producing briquettes of about 1,157.06g/hr which corresponds to 27.77kg/day.

2.3 Method

For ten days, at an average daily temperature of 39°C, the neem tree branch residues pulverized ≤ 20mm were sun-dried to reduce their moisture. Stones and other contaminants that can obstruct the correct briquette manufacturing and further examination were screened out using wire mesh. The dried residues were pulverized into small particles using hammer mills, after which they were sieved using laboratory test sieve. The particles that passed through 1.18 mm laboratory test sieve model were collected and kept in an airtight container for future use. To ensure homogeneity, the binder (Cassava starch) was prepared by dissolving 33.33g of cassava flour residues, or 30% by weight of biomass residues, in 50ml (50g mass equivalency) of pure water for a minute. Then, the mixture was poured into a pot with 250ml (250g mass equivalency) of water heated to 100°C, stirred, and gently cooked for approximately three minutes. The neem tree branch residues and the starch developed were combined at a binder-biomass ratio of one to three. A 50g binder-biomass mixture was uploaded into each moulder cavity to produce the briquettes. The combinations were sealed, compressed to a calculated pressure of 16.378 kPa, and held with a key for two minutes. By opening the mould cover through the key and gently pressing the moulder handles downward, the wet briquettes were removed. The briquettes were left to dry naturally in the sun for 10 days.

2.3.1 Determination of Physical Properties of the Briquettes

Maximum and Relaxed Densities

The maximum (compressed) and relaxed densities of the manufactured briquettes were established in accordance with the methods described by Olorunnisola, (2007). They were obtained by measuring the mass of each briquette with a digital weighing balance and its corresponding volume with the use of vernier calipers both immediately (maximum density) and after drying for sometime (relaxed density). The density and the volume of cylindrical briquettes was determined using the equations below:

$$\text{Density} = \frac{Mass\ (M)}{Volume\ (V)} \qquad (6)$$

$$V = \pi r^2 h \qquad (7)$$

where; r and h are the radius and height of the briquette respectively.

Shatter index

The shatter index is used to gauge how durable the briquettes are. It was obtained by adopting the procedure reported by Mandal *et al.*, (2019). The briquette was repeatedly dropped from a height of 1.5m onto a concrete floor. The percentage of the briquette retained after the drops served as the index's breakability. The percentage loss of material was calculated using the equation (Sengar *et al.*, 2012);

$$\text{Percentage of weight loss} = \frac{W_1 - W_2}{W_1} \times 100 \qquad (8)$$

% Shattered = 100 - % weight loss (9)

where; W_1, W_2 = weight of briquette before and after shattering in grams.

Water Resistance Test

Porosity of briquettes affects their ability to absorb water; a water absorption test is done to find out how much water is absorbed under particular circumstances. Resistance to water penetration test is important to determine briquette response during rainy seasons or while in contact with water or placed in a humid environment. It was ascertained by submerging the entire briquette in water at room temperature (27°C) for 30 seconds. The proportion of water absorbed by the briquettes was determined by recording the percentage increase in weight of the briquettes (Ikubanni *et al.*, 2020). The percentage water gained was calculated using the equation as reported by Ramani *et al.*, (2022).

$$\% \, Water \ gained \ by \ the \ briquettes = \frac{W_3 - W_4}{W_3} \times 100 \qquad (10)$$

where W_3 and W_4 are the weight of the briquette before and after water immersion. The percentage resistance to water penetration was calculated by extraction as shown below;

$$\% \, Resistance \ to \ water \ Penetration = 100 - (\%water \ gained) \qquad (11)$$

2.3.2. Proximate and Combustion Analysis of the Briquettes

Moisture Content

The sample's moisture content was evaluated using the ASTM (2006) technique. Two grams (2g) quantity of each material briquette was deposited in an empty, dried, crucible after been weighed empty. The sample's combined mass and the crucibles were measured. The crucibles and its contents were placed in an electrothermal thermostatic drying box set at a temperature of 110°C ±5°C for one hour. With the use of metal tongs, the contents were taken out, let to cool in a desiccator, and then reweighed. Thus;

$$\text{Percentage of moisture content (\%MC)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad (12)$$

where; W_1, W_2 are mass of briquette before and after drying respectively.

Volatile Matter

The dried samples that remained after evaluating the moisture content were then heated in a muffle furnace for 10 minutes at 300°C inside a relatively closed crucible to determine the volatile matter concentration. The crucible and its contents were then removed, momentarily cooled in air, and then put in the desiccator. The volatile matter was determined in accordance with ASTM D-3175-18 (2018);

$$\text{Percentage of Volatile Matter (\%VM)} = \frac{W_3 - W_4}{W_3} \times 100 \qquad (13)$$

where; W_3, W_4 are the original mass of the sample before heating and final mass of the sample after heating for 10 minutes at 300°C and cooling respectively.

Ash Content

Following the percentage volatile matter determination, the leftover residues were further weighed, placed in a furnace, and heated for 2hrs at 600°C before being placed in a desiccator to cool. The crucible and its contents were reweighed and recorded. Ash content was calculated using the formula provided by Ndecky *et al.*, (2022).

$$\text{Percentage of Ash Content (\%AC)} = \frac{M_2}{M_1} \times 100 \qquad (14)$$

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where; M_1 is the initial mass of the dry sample before heating and M_2 is the final mass of the ash left after heating 2hrs at 600°C and cooling.

Fixed Carbon

The fixed carbon was determined as per the equation below as reported by Elsisi *et al.*, (2023).

Percentage Fixed Carbon (%FC) = $100-(\%MC + \%AC + \%VM)$ (15)

Elemental Composition

One among the importance features of proximate analysis is its application in determination of critical and common elements of Carbon (C), Hydrogen (H) and Oxygen (O) composed by a given fuel (Parikh *et al.*, 2007) and (Ohagwu *et al.*, (2022). This elemental composition has been reported to affect the energy content and fuel ratio of solid fuel (Obi and Okongwu, 2016). For energy materials, these elements can be estimated based on the results of proximate analysis using equations (13), (14) and (15) that were evaluated at an estimated 95% confidence level (Ohagwu *et al.*, 2022).

$$C = 0.637(\%FC) + 0.455(\%VM) \quad (16)$$

$$H = 0.052(\%FC) + 0.062(\%VM) \quad (17)$$

$$O = 0.304(\%FC) + 0.476(\%VM) \quad (18)$$

Above correlation were chosen based on the minimum error and validation recorded with respect to the measured value of %C, %H an %O over large number of data (Parikh *et al.*, 2007).

Calorific Value

The Calorific Value (CV) also known as High Heating Value (HHV) have been reported to serve as a key parameter in evaluating the fuel quality of material for energy applications (Ayse & Serdar, 2017). Nhuchhen & Abdul Salam (2012) reported that experimental procedure for determination of higher heating values (HHV) of any fuels in laboratory is time consuming and expensive at a point where the equipment's required are not available. They asserted that derivation of various correlations helps to ease such difficulties. Different formulae have been developed for estimating the calorific values (Channiwala & Parikh, 2002; Erol *et al.*, 2010; Ayse & Serdan, 2017). Hence, the calorific value of the briquettes was ascertained by correlation with the results of the proximate analysis with the help of equation (16) as reported by Nhuchhen & Abdul Salam (2012).

$$HHV = 19.2880 - 0.2135\left(\frac{VM}{FC}\right) + 0.0234\left(\frac{FC}{AC}\right) - 1.9584\left(\frac{AC}{VM}\right) \quad (19)$$

3. RESULTS AND DISCUSSION

This section highlights the results obtained in the currents study and their discussion.

Table 1: Physical Properties of the Briquettes

S/N	Parameter	Value	SI Unit(s)
1	Maximum Density, D_{max}	962.19	kgm^{-3}
2	Relaxed Density, D_{Rlx}	448.16	kgm^{-3}
3	Relaxation Ratio	2.15	---
4	Density Ratio	0.47	---
5	Percentage Shatter Resistance	99.31	%
6	Percentage Tumbling Resistance	99.62	%
7	Water Penetration Resistance	93.16	%

Table 1 gives the results of physical properties of the briquettes. Upon release from the briquette mould, the maximum density was ascertained to be 962.19 kgm^{-3}. This measurement falls within the range of values 0.92-1.02 gcm^{-3} reported by Zepeda-Cepeda *et al.*, (2021) for Pinus durangensis sawdust briquettes and 931.87 kgm^{-3} Namadi *et al.*, (2023) for sawdust bonded with cassava starch. This density exceeds the minimum requirement of ≥600 kgm^{-3} for effective transportation and storage of briquettes, as stated by Gilber *et al.*, (2009). The relaxed density of the neem tree residues in this study falls within the range reported by Sottande *et al.*, (2010) for neem wood residues briquettes using starch and gumarabic as binders and exceeds the maximum value reported by Oladeji & Enweremadu (2012) for corncobs briquettes. The higher density observed in this study suggests effective compaction during the briquette formation process, potentially resulting in high-quality briquettes.

The relaxation ratio of 2.15 recorded in the current study was found to exist between 1.82-2.86 recorded for briquette made up of corncobs of 4.70mm particle size (Oladeji & Enweremadu, 2012). Closer values of 2.66-2.80 were observed for sawdust briquettes bound with African locust bean pulp and cassava starch as binders (Namadi *et al.*, 2023). Reportedly, a smaller relaxation ratio indicates greater stability for briquettes (Sing *et al.*, 2021); whereas higher value indicates poorer stability. Thus, the relaxation seen in this study suggests a more stable and superior briquette suitable for transportation, storage, and packaging. Also, the density ratio as shown in table 1 are compared well and found to exist within the range 0.35-0.55 reported as maximum and minimum values for 4.70mm particle size corncobs briquettes, but higher than 0.37 recorded for sawdust briquette bonded with hot prepared locust bean pulp (Namadi *et al.*, 2023).

The material briquette under investigation demonstrated a remarkable development in shatter resistance, recording 99.31%. Reports show that this value is greater than 86.40% for rice straw briquettes bound with cassava starch and closely matches value 99.2% for briquettes created using a combination of sugarcane bagasse, banana peels, coconut shells, and cow dung (Elsisi *et al.*, 2023). Similar results of 99.77% was reported for sawdust briquettes bonded with cassava starch (Namadi *et al.*, 2023). Findings from this study indicates that the briquettes demonstrate high resistance to shocks during storage and transportation. According to ASABE Standard S269.4 as reported by Mohd-Faizal *et al.*, (2022), a shatter resistance of >90% indicates good durability, between 80-90% suggests medium durability, and <80% suggests poor durability. The water resistance index of the briquettes in this study is higher than values reported for briquettes made from agricultural residues (Elsisi *et al.*, 2023). This high value suggests low porosity of the briquettes when exposed to water, potentially improving storage ability even in humid conditions and enhancing burning efficiency.

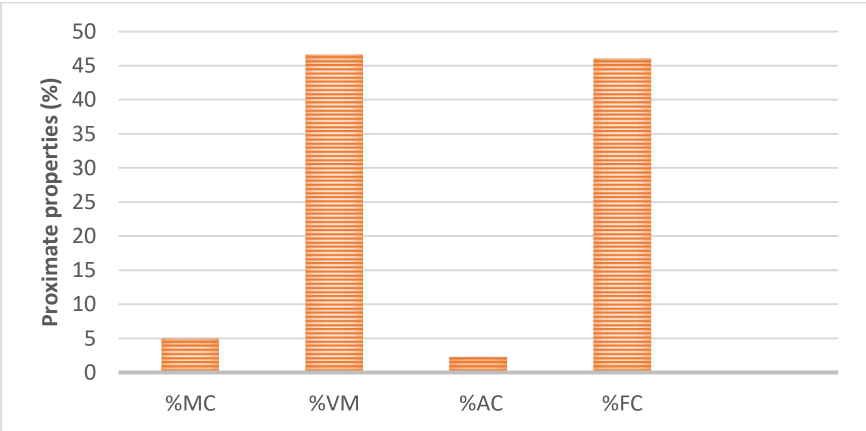

Figure 2: Proximate Analysis of the material briquette.

Figure 2 presents the results of proximate analysis (%MC, %VM, %AC and %FC) of the material briquette. The moisture content (%MC) observed in this study is lower than the range reported for sawdust briquettes bonded with okra (Abelmoschus Esculentus) at varying binder concentrations (Ohagwu *et al.*, 2022), but exist within the range reported for charcoal and sawdust agglomerates briquettes (Ajimotokan *et al.*, 2019. The lower moisture content found in this study is within the ideal value of less than 14% for briquettes (Ngusale, 2014).

The value obtained for %VM in this study is lower than the 68.09% reported for neem wood residues of Ghana origin (Quartey, 2022), but higher than the range 26.4-34.9% reported for agro-waste briquettes (Falemara *et al.*, 2018). High volatile matter in fuel enhances good flame release and ignition ease, indicating good performance (Ajimotokan *et al.*, 2019). The high value also suggests high combustibility with low ash content, similar to the 43-49% range found in previous research (Adegoke *et al.*, 2010).

Moreover, the %AC in this study corresponds well with the values 1.59-2.10% obtained for sawdust bonded with Okro (Ohagwu *et al.*, 2022) and falls within the recommended ≤ 2% by the European standard (EN-14774) for a good quality woody biomass briquette. The lower %AC reported was due to the fact that the feedstock under investigation belongs to

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the woody biomass. Higher values were reported for other categories; Pelumi *et al.,* (2019); Akpenpuum *et al.,* (2020) and Elsisi *et al.,* (2023). Higher %AC is undesirable as it significantly reduces the fuel's energy yield (James *et al.,* 2012) and downgrade the efficiency of heating chambers during combustion (Mitchual *et al.,* 2014). Therefore, low ash content realized in the current study is preferred for higher energy yield and combustion efficiency.

The %FC entails the proportion of fuel's char available for combustion after the volatile component evaporates. It gives an idea for the fuel's heating value and acts as the main generator of heat during combustion (Akowuah *et al.*, 2012). The obtained values of %FC falls within the range of values 2.73-69.39% and 9.2-50.0% reported by Ndeccky *et al.*, (2022) and Ajimotokan *et al.*, (2019) respectively for solid briquettes.

Table 2: Elemental Composition of the Material Briquette

Element	**%C**	**%H**	**%O**
%Composition	50.57487	5.196144	36.2133

Table 2 presents the result of elemental composition of the material briquette in the current study. The values reported are compared well and found to exists within the range of value reported by Parikh *et al.*, (2007) & Ajimotokan *et al.*, (2019). Closer range of values were reported (Jittabut, 2015); Adekunle *et al.*, (2015) and Ohagwu *et al.*, (2022). Hence, the % composition of the elements recorded in the study are found to be significant and can enhance fuel's combustibility.

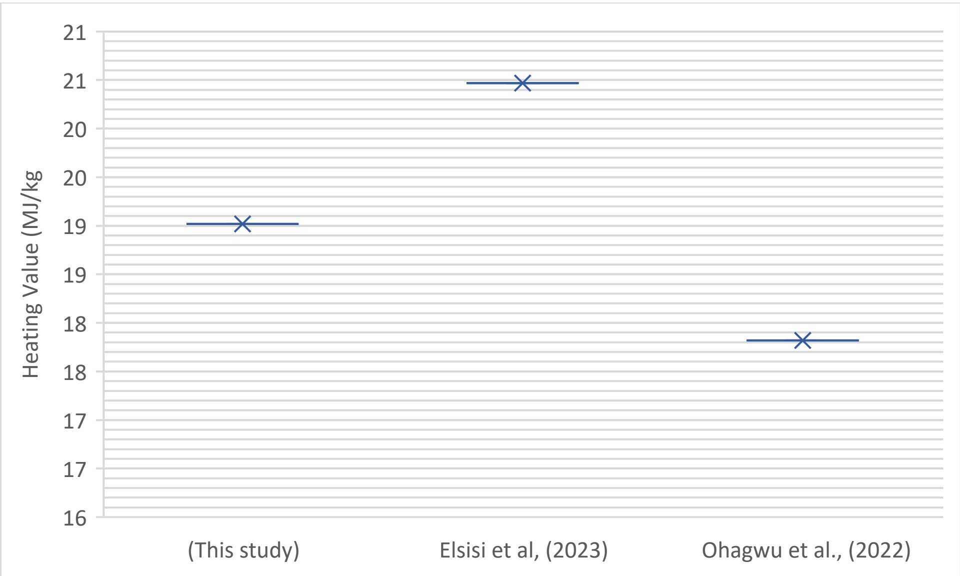

Figure 3: Calorific Value of the Material Briquette

Through correlation with proximate analysis findings and the empirical formulations reported by Parikh *et al., (*2007), the calorific value obtained in this study stands at 19.02 MJ/kg as shown in figure 3. This value was found to be higher than the utmost value 17.82 MJ/kg (Ohagwu *et al.*, 2022) and closer to the highest value 20.47 MJ/kg recorded for mixtures of agricultural residues (Elsisi *et al.*, 2023). The heating value realized in the current study is greater than the ≥16,500 kJ/kg acceptable value for European Briquette Standard; EN 14961-1. The high value obtained has been attributed to the higher percentage of fixed carbon recorded which has been tagged as the major generator of heat during combustion.

4. CONCLUSION

A high-quality briquette fuel suitable for household and small-scale industrial heat application was produced using a designed, constructed and low-cost portable briquette moulder capable of producing 10 briquettes simultaneously. The resulting briquette fuel exhibited superior performance, with excellent shatter, tumbling, and water resistance indices, low moisture and ash contents, significant fixed carbon, and a calorific value (or heating value) of 19.02 MJ/kg. Elemental analysis revealed significant carbon, hydrogen, and oxygen contents, which will go a long way to facilitate complete combustion of the biofuel.

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