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EFFECT OF BLENDING RATIO ON THE PHYSICAL AND COMBUSTION CHARACTERISTICS OF BRIQUETTES PRODUCED FROM *Pterygota microcarpa* and *Brachystegia nigerica* SAWDUST

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Abstract:

This study investigates the physical, proximate, and heating properties of briquettes produced from sawdust of two Nigeria wood species, Oporoporo (Pterygota microcarpa) and Ekku (Brachystegia nigerica), at various blending ratios. The analysis revealed that Ekku, known for its higher density (0.86±0.06 g/cm³) compared to Oporoporo (0.61±0.04 g/cm³), contributes significantly to the compactness, extended burning time, and overall energy efficiency of the briquettes. The 100% Ekku briquettes exhibited the highest bulk density (0.86±0.06)g/cm³) and the most extended burning duration (50.67±0.58 minutes), confirming the role of dense biomass in improving combustion performance. Proximate analysis showed consistent moisture content across all samples, with 100 % Ekku maintaining stable values, while blends such as the 50:50 mixture displayed higher volatility, enhancing combustion vigor. The heating properties of the briquettes showed that the 100% Ekku and the 25:75 blend (Oporoporo: Ekku) had the highest calorific values of 18.98 MJ/kg and 18.99 MJ/kg, respectively, indicating their superior energy content. The ignition time varied significantly, with the 25:75 blend igniting fastest at 25.65 seconds, while the 75:25 blend took the longest at 37.58 seconds. The study confirms that blending ratios significantly impact the physical properties, energy content, and combustion characteristics of the briquettes, with Ekku contributing more favorably to the overall energy yield and combustion efficiency. These findings highlight the importance of optimizing the blending ratio for enhanced bioenergy production from biomass materials.

Key words: *Biomass, Briquette, Sustainable Energy, Sawdust, Renewable Resources, Calorific value*

INTRODUCTION

Energy is one of the most imperative needs of human life. Assessing a country's social and economic development often hinges on its energy consumption patterns (Halder *et al.* 2014). Conventionally, primary energy sources like natural gas, oil, and coal have dominated the global energy landscape (Yin 2011). However, persistent energy challenges have spurred researchers worldwide to explore alternative, environmentally friendly, and economically viable energy sources. An emerging solution in this quest is the utilization of biomass for briquette production, a practice aimed at providing cost-effective heating alternatives (Tornubari 2019). Biomass energy is one of the alternative sources of energy, which is particularly accessible in huge quantity worldwide in rural areas. Solid biomass waste accounted for 14% of the world's energy needs in 2020, placing it as the fourth most valuable energy resource globally after gas, oil, and coal (Swapan *et al.* 2020). The amount and makeup of feedstock determine the potential of biomass resources. In terms of the environment, there are several advantages to using biomass resources as an energy source. Biomass fuels consist a range of materials like firewood, forest waste, animal dung, and agricultural leftovers, commonly utilized in both rural and urban households for domestic purposes (IEA 2016). Agricultural residues, among these biomass sources, offer renewable and sustainable biofuels that hold potential to notably mitigate greenhouse gas (GHG) emissions if managed and utilized effectively (Maninder *et al.* 2012). However, inefficient utilization and improper disposal of agricultural residue and wood waste lead to environmental pollution, posing health risks and hazards to both humans and ecosystems. The primary materials utilized for producing these briquettes or pellets encompass not only wood and its byproducts (sawdust, wood chips, wood chops, and shavings) but also agricultural waste like straws, food industry leftovers, and dedicated fuel crops like myscanthus (Jiang 2016). Briquetting involves compressing loose and inefficient combustible organic materials of low density into solid fuel of higher density, shaped conveniently. This process enhances the physical, chemical, and combustion characteristics of the initial materials (Olaoye *et al.* 2017). Ekku wood sawdust is known for its high density and energy efficiency, and Oporoporo wood sawdust, with lower density and faster ignition properties, are commonly used in biomass briquette production for renewable energy applications. The heating properties of briquettes made from sawdust are essential for determining their efficiency as biofuels, especially for applications requiring sustainable energy. Sawdust from different wood species, such as Ekku and Oporoporo, exhibit varying heating characteristics that influence their performance during combustion. This study is therefore assessing the properties, process, physical and combustion properties of briquettes produced from sawdust of *Pterygota microcarpa* (Oporoporo) and *Brachystegia nigerica* (Ekku) at different blending ratio.

MATERIAL AND METHODS

This research was conducted in the Federal University of Technology, Akure, Ondo State, Nigeria's Department of Forestry and Wood Technology, between latitudes 07º 16ˈ and 07º 18ˈN and longitudes 05º 09ˈ and 05º 11ˈE as shown in Fig. 1. Oporoporo (*Pterygota microcarpa*) and Ekku (*Brachystegia nigerica*) wood sawdust was collected from the Sawmill in Akure, Ondo State, Nigeria. The samples collected were sundried for five (5) days and screened. Foreign materials were initially removed from the raw samples of sawdust. The sawdust was screened using 2.36 mm sieve according to ASTM E 11-20 sieve sizes to obtain the required particles for the densification process. The sawdust samples which includes Oporoporo and Ekku wood species sawdust was varied in 3 different blending ratio (25:75, 75:25, 50:50) as shown in Table 1. The hydraulic press method was employed, utilizing a binder and a high-pressure briquetting technique. Sawdust samples were placed into the mold of the briquetting machine, with cassava starch serving as the binding agent. The raw materials were mixed in a 1:2 ratio, starch:sawdust. Each briquette was subjected to a pressure of 11.77 MPa, with a dwelling time of 10 minutes to ensure proper consolidation in the mold and prevent the compressed biomass from springing back. Timing was monitored using a stopwatch. Once formed, the briquettes were removed from the mold and dried in an oven at 105°C for 24hours to eliminate moisture and reach a constant weight. Afterward, the samples were stored in a desiccator. The produced briquettes are visible in Fig. 2.

Table 1

Blending ratio of different briquette samples of Oporoporo sawdust and Ekku sawdust with binding ratio of 1:2 cassava starch

Sample ID	Oporoporo (wt%)	Ekku (wt%)
C	25	75
D	50	50
E	75	25

* Samples A and B are pure Oporoporo Sawdust and pure Ekku Sawdust.

These samples were selected for further investigations such as physical and heating properties.

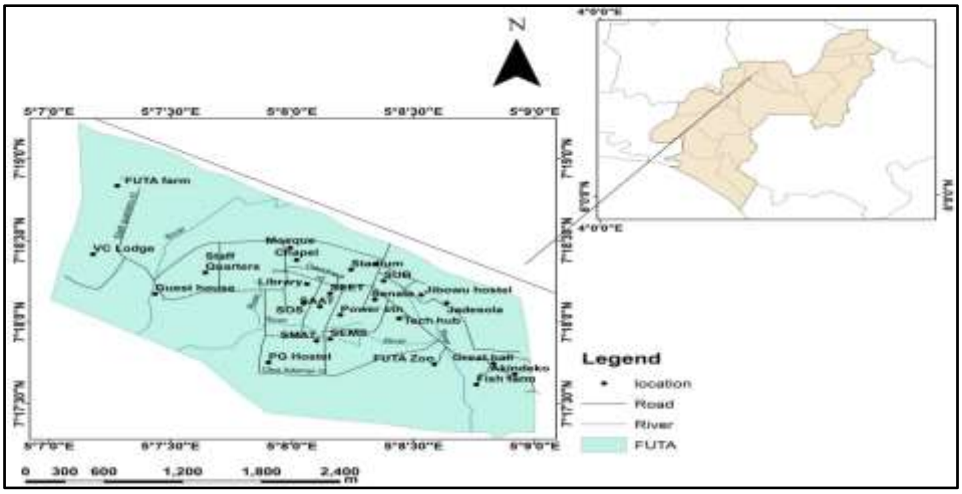

Fig. 1.
Map of Nigeria, showing Ondo State and FUTA the study area.

Physical Properties

Bulk Density

The bulk density of the loose biomass was determined according to ASTM D7481-09 (2009) standard.

$$\text{Bulk density} = \frac{IMM\ (g)}{VC\ (cm3)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 1)}$$

where: IMM represents Initial Mass of Material, while VC represents Volume of Cylinder.

Relaxed Density and Maximum Density of Briquettes

Three briquettes were randomly selected from each production batch to evaluate their physical properties. The average maximum density of the briquettes was measured immediately after being ejected from the mold and was calculated as the ratio of the average mass to the briquette's volume. The mass was recorded using a digital weighing scale, while the volume was determined by measuring the dimensions of the cylindrical briquettes (radius and height). The volume was then computed using the formula for the volume of a cylinder ($\pi R^2 H$).

The relaxed density was measured after the briquettes were dried in an oven. It was calculated as the ratio of the briquette's mass after drying to its volume. Relaxed density, also known as spring back density, refers to the density of the briquette once it has stabilized. The density ratio was determined by dividing the relaxed density by the maximum density.

$$Density\ ratio = \frac{RD\ \ (g)}{MD\ (g)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 2)}$$

where: RD represents Relaxed Density, while MD represents Maximum Density

The maximum density refers to the compressed density of the briquettes right after they were ejected from the briquetting machine. The relaxation ratio was calculated as the ratio of the maximum density to the relaxed density.

$$Relaxation\ ratio = \frac{Maximun\ density\ (g)}{Relaxed\ density(g)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 3)}$$

Fig. 2.
The produced Briquette.

Proximate Analysis of Briquette

Moisture content

The percentage moisture content was measured following the ASTM D2444-16 standard method. A 3g sample from each briquette was weighed using a wash glass, then placed in an oven dryer for 24 hours at a temperature of 105 ± 3°C. This process was repeated until a constant weight was achieved. The moisture content was then calculated using the following equation:

$$\text{Mc (\%)} = \frac{Wo-Wd}{Wo} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 4)}$$

where: W_0 is the original weight of the sample and W_d is the final (dried) weight of the sample.

Volatile matter content

One gram of each pulverized briquette sample was weighed and placed in a crucible with a known mass. The sample was oven-dried until it reached a constant mass. Following the ASTM D3175-18 standard, the samples were heated in a furnace at 900°C for 7 minutes, then cooled and weighed. The volatile matter (Vm) was calculated as the percentage of mass lost during heating, using the equation shown below.

$$Vm\ (\%) = (B-C)/B \times 100\% \quad \text{(Equation 5)}$$

where: B is the weight of the oven-dried sample and C is the weight of the furnace-dried sample.

Ash content

The percentage ash content was measured according to the ASTM D3174-12 standard. A 1g sample of the briquette was placed in a porcelain crucible and transferred to a muffle furnace set at 550°C, where it was burned for about 4 hours until it turned to white ash. The crucible and its contents were first cooled in the furnace, then brought to room temperature in a desiccator before being weighed. The ash content was calculated using the formula provided in Eq. (6) below.

$$Ac\ (\%) = D/B \times 100\% \quad \text{(Equation 6)}$$

where: Ac is the percentage ash content, D is the weight of ash (furnace dried), and B is the weight of the oven-dried sample.

Fixed carbon

The percentage of fixed carbon or each sample of briquette was estimated using the relation in Eq. (7).

$$Fc\ (\%) = 100 - (Vm + Mc + Ac) \quad \text{(Equation 7)}$$

where: Fc represents the fixed carbon content of each briquette sample, Vm is the volatile matter, Mc is the moisture content, and Ac is the ash content, all measured for each briquette sample.

Heating Properties

Determination of ignition time of the briquette.

Ignition time was measured according to the ASTM E1321-13 (2013) standard test method for determining material ignition and flame spread properties. Each briquette was ignited by positioning a Bunsen burner on a platform 4 cm directly below the briquette, which was suspended on a tripod stand. The Bunsen burner, adjusted to produce a blue flame, ensured that the entire bottom surface of the briquette ignited simultaneously. Once the briquette was properly ignited, the ignition time was recorded using a stopwatch.

$$\text{Ignition Time} = t_1 - t_0 \quad \text{(Equation 8)}$$

where: t_1 is the briquette ignited time (sec) and t_0 is the burner lighted time (sec).

Burning Time

Burning time was measured by monitoring the mass changes using a mechanical balance and tracking the time with a stopwatch. Burning time, also referred to as combustion time, is the duration required for the complete combustion of the biomass.

Determination of combustion rate of the briquettes.

With known amount of total burnt briquette and burning time, average combustion rate was calculated using the following Eq 9.

$$CR = \frac{Total\ mass\ of\ burnt\ briquette\ (g)}{Burning\ time\ (min)} \quad \text{(Equation 9)}$$

$$\text{Total Mass of Burnt Briquette (g)} = IBM - RBM \quad \text{(Equation 10)}$$

where: IBM represents Initial Briquette Mass, and RBM represents Remaining Briquette Mass.

Determination of the Calorific value of the Briquette

The Calorific value also known as the heating value was evaluated as described by Duranay and Nazlicayci, (2019). 0.5g of each dried sample were used for this analysis using a bomb calorimeter (e2K combustion calorimeter) according to ASTM D5865-O4.

Statistical Data Analysis

The data obtained were analyzed using Analysis of Variance (ANOVA) and descriptive statistics with a statistical package for social science (SPSS). The data were subjected to the Duncan Multiple Range test to determine the significant difference between various treatments at a 0.05 significant level. Graphical representation was carried out using Microsoft Excel.

RESULTS AND DISCUSSION

Physical Properties of the Briquette

The bulk density of briquettes made from different blending ratios from sawdust of Oporoporo and Ekku provides insight into the compactness and energy content of the material. It was observed from this study that Ekku sawdust, known for its high density of 0.86±0.06 g/cm^3 (in the compact state) contributes positively to the compactness and extended burning duration of briquettes. This finding is supported by Bello *et al.,* (2020), who emphasized that higher-density briquettes result in slower flame propagation and prolonged combustion time, whereas Oporoporo which has a lower density of 0.61±0.04 g/cm^3 briquettes as shown in Table 2 tend to ignite faster but burn out more quickly. Furthermore, as noted by Antwi-Boasiako *et al.,* (2016), Ekku wood is a high-density species, and an increased proportion of Ekku sawdust in the briquette mixture enhances the density and overall performance of the briquettes. Recent studies by Zhang *et al.,* (2022) and Olufemi *et al.,* (2021) further confirm these observations, demonstrating that high-density biomass materials improve combustion performance by ensuring a more controlled release of energy, leading to extended burn times and better thermal efficiency. The 100% Ekku briquettes demonstrated the highest maximum density of 2.10±0.15 g/cm^3 at a moisture content over 50%eflecting a highly compact structure when fully compressed. In contrast, the 100% Oporoporo briquettes showed a lower maximum density of 1.62±0.13 g/cm^3 at a moisture content over 50%, indicating a less compact form under maximum compression. These findings align with recent studies by Zhang *et al.,* (2022) and Olufemi *et al.,* (2021), which highlight the influence of biomass density on briquette compactness and energy efficiency.

Table 2

Densities for each briquette samples in varying Blending proportion

Blending Ratio	Bulk Density(g/cm^3)	Maximum Density(g/cm^3)	Relaxed Density(g/cm^3)	Density Ratio	Relaxation Ratio
(100% Oporoporo)	0.61^{d}	1.62^{d}	0.63^{bc}	0.39^{a}	2.57^{b}
(100% Ekku)	0.86^{a}	2.10^{a}	0.75^{a}	0.36^{ab}	2.81^{b}
(25:75)	0.73^{b}	1.80b^{c}	0.66^{b}	0.37^{a}	2.74^{b}
(50:50)	0.69^{bc}	1.75^{c}	0.67^{b}	0.38^{a}	2.62^{b}
(75:25)	0.67^{bc}	1.87^{b}	0.58^{c}	0.31^{b}	3.19^{a}

Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference.

Proximate Analysis of Briquette

The consistency in moisture content is crucial because it directly affects combustion efficiency and the stability of the briquettes (Sengar *et al.* 2012). Fig. 3 revealed that 100% Oporoporo and 100% Ekku both exhibit a moisture content of 2.33±0.00 % having no variability indicating consistent moisture levels across samples indicating that there is no statistically significant P>0.05. These results suggest that both pure materials have relatively low and stable moisture content, with 100% Ekku being particularly consistent. As the proportion of Ekku sawdust-based briquette increases in the blend, the fixed carbon content tends to decrease, which is consistent with findings that wood types with lower density and higher volatile matter, like Ekku, generally have lower fixed carbon levels (Demirbas 2004). However, the exception in the 75:25 blend with the percentage fixed carbon of 81.00±2.67 % may be due to synergistic interactions between the different wood types, which could alter the expected fixed carbon content through non-linear effects during the briquetting process (Olorunnisola 2007). Briquettes made from 100% Ekku (12.00±2.65 %) or a 50:50 (13.33±3.79 %) blend of Ekku and other wood types tend to exhibit higher volatility, resulting in a more vigorous combustion process due to the increased release of volatile compounds during burning as this corroborate with the findings of Demirbaş (2004). Therefore, optimizing the blending ratio is crucial for achieving desired combustion characteristics, making 100 % Ekku and the 50:50 blend potentially ideal for applications requiring high energy output.

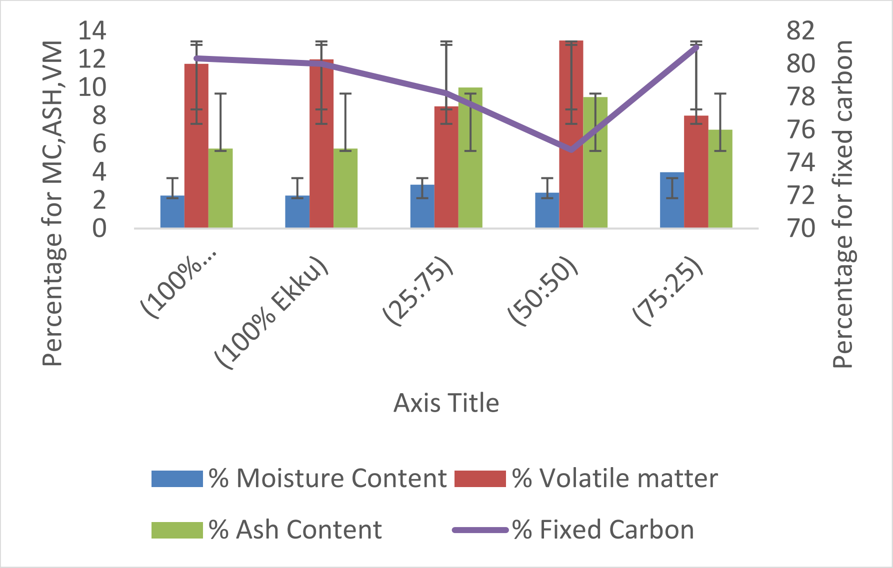

Fig. 3.
The Proximate Analysis of the Briquette.

Combustion Properties of Briquette

The combustion properties of briquettes made from two wood sawdust shows notable variations across different blending ratios as shown in Table 3 revealed that there was significant difference across the blending ratio ($P < 0.05$). The ignition time, which measures how quickly the briquettes ignite, varies from 25.65 seconds in the 25:75 blend (25% Oporoporo, 75% Ekku) to 37.58 seconds in the 75:25 blend. The 75:25 blend had the longest ignition time (37.58 seconds), potentially due to a higher proportion of Oporoporo, and exhibited moderate burning time and combustion rates. Studies highlight that more volatile materials, such as Oporoporo, tend to ignite faster and burn out quickly, while denser materials like Ekku contribute to sustained combustion (Afonso *et al.* 2021; Wang *et al.* 2020). This variation in combustion behavior aligns with findings that biomass blending affects combustion properties such as calorific value, ignition time, and efficiency, often influenced by factors like density, moisture, and volatile matter content (Chen *et al.* 2019; Buravchuk *et al.* 2018). The 100% Oporoporo has the lowest calorific value, with a mean value of 14.69 MJ/kg, indicating it provides less energy during combustion while the 100% Ekku shows the highest energy value, with a mean value of 18.98 MJ/kg, suggesting that Ekku burns more efficiently and produces more heat compared to Oporoporo. This difference highlights high combustion efficiency of Ekku over Oporoporo, due to its denser structure and higher lignin content, which is consistent with findings from previous studies (Kuti 2015; Sotannde *et al.* 2010). The 25:75 blend, where Ekku dominates, also exhibited a high calorific value (18.99 MJ/kg), almost identical to pure Ekku, emphasizing Ekku's contribution to the energy content in blends. This finding aligns with the studies of Aina *et al.,* (2009) and Emerhi, (2011), which observed that blending ratios significantly affect the energy properties of composite fuels. The fact that the blending ratio contributes considerably to the variation in calorific values suggests that optimizing the ratio of high-energy species, like Ekku, can maximize the energy yield of briquettes, making the blending process a critical factor in bioenergy production.

Table 3

Heating properties of Briquette made from Oporoporo and Ekku sawdust with different blending ratio

Blending Ratio	Ignited Time (sec)	Burning Time (min)	Combustion Rate	Calorific value (MJ/kg)
(100% Oporoporo)	32.31 ± 6.90^{ab}	42.00 ± 1.73^{b}	0.45±0.02a	14.69 ± 1.21^{b}
(100% Ekku)	28.39 ± 4.34^{b}	50.67 ± 0.58^{a}	0.34±0.02b	18.98 ± 1.38^{a}
(25:75)	25.65 ± 4.09^{b}	41.67 ± 2.31^{b}	0.43±0.02a	18.99 ± 1.00^{a}
(50:50)	29.39 ± 1.57^{b}	54.67 ± 4.73^{a}	0.34±0.03b	17.92 ± 1.47^{a}
(75:25)	37.58 ± 1.86^{a}	49.67 ± 7.09^{a}	0.37±0.05b	14.80 ± 0.98^{b}

Values are means±SD, Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference.

CONCLUSION

The significant impact of the physical properties and the combustion characteristics of briquettes from wood sawdust in different blending ratios on environmental sustainability was revealed in this study. The results demonstrate that higher bulk density, as seen with Ekku sawdust briquettes, contributes to improved combustion efficiency, extended burn times, and better energy storage. Ekku, being denser and more lignin-rich, contributes positively to higher density, slower combustion rates, and extended burn times, as evidenced by its superior calorific value of 18.98 MJ/kg and bulk density of 0.86±0.06g/cm³. At the same time, Oporoporo's lower density results in faster ignition but quicker burnout, with a lower calorific value of 14.69 J/kg. The 25:75 blend (25% Oporoporo, 75% Ekku) demonstrates optimal performance, retaining much of Ekku's energy potential while maintaining compactness and good combustion characteristics. These findings emphasize the importance of selecting high-density species offer good specific consume and a slight density increases briquette density, optimizing blending ratios to maximize briquette performance, making Ekku-dominant blends more suitable for energy-efficient applications.

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