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PROXIMATE AND FUEL PROPERTIES OF AFRICAN LOCUST BEAN PULP AND CASSAVA STARCH FLOUR BINDERS FOR FUEL BRIQUETTE PRODUCTION

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ABSTRACT
The study investigates the proximate and combustion properties of affordable and locally available briquette binders, namely: African locust bean pulp and cassava starch (flour) using the American Society for Testing and Materials (ASTM) methods. The findings indicate varying levels of moisture content (4.55% to 6.89%), volatile matter (30.06% to 64.21%), ash content (0.93% to 23.36%), and fixed carbon (7.89% to 62.12%). Elemental composition of carbon, hydrogen, and oxygen range from 34.24% to 53.25%, 4.39% to 5.09%, and 32.96% to 33.19%, respectively. The calorific values obtained in the study are 16.85±0.48 MJ/kg for African locust bean pulp and 20.69±0.34 MJ/kg for cassava starch flour. Both binders exhibit properties conducive to producing high-quality briquettes capable of generating sufficient heat for household and small-scale industrial settings.

Keywords: African Locust bean pulp, Briquette, Cassava Starch flour, Proximate Analysis, Calorific value

INTRODUCTION
A binder is a liquid or dough-like substance that solidifies materials by means of chemical reactions or physical changes, thereby binding together fibers, filler powders, and other particles mixed with it, resulting in a cohesive and solid structure. Biomass binders are used to combine biomass particles into denser and more cohesive forms for various applications (Olugbade *et al.,* 2019). They are essential in biomass processing, particularly in industries such as bioenergy, agriculture, and bioproducts. Natural biomass binders include lignin, found in woody biomass and agricultural residues, and starch, derived from crops like corn, wheat, or potatoes. Biomass as a binder source has attracted both domestic and international interest due to its numerous advantages, such as abundant availability, low cost, and high heating value (Blesa *et al.,* 2003). It can be used to enhance particle adhesion, compressive strength, abrasion resistance, and energy content of densified biomass like briquettes, and at the same time reduce production costs and equipment wear (Muazu & Stegemann, 2017). A key feature of biomass for fuel is its proximate analysis, which evaluates the chemical properties of biomass by examining four specific components: moisture content, volatile matter, ash content, and fixed carbon (Dayana *et al.,* 2016). Proximate analysis derives its name from "approximate analysis," indicating that the results are not precise but approximate. This analysis is used to assess the quality of fuels and, in addition to measuring calorific value (Alakangas, 2016) and understand how biomass components change when heated under specific conditions (Grammelis *et al.,* 2016). Methods such as ASTM (2006), ASTM D3175-18 (2018), ASTM E1755-01 (2020) provided a detailed standard test procedure of proximate analysis for biomass materials. Moreover, the elemental analysis of biomass identifies the average chemical elements it contains, including carbon, hydrogen, oxygen, nitrogen, and sulfur (Soares *et al.,* 2019).

Biomass briquette is defined as block of combustible material used as fuel to start and maintain a fire. The briquetting process compresses loose biomass into a solid shape, making it usable as fuel similar to wood, coal, or charcoal (Ohagwu *et al.,* 2022; Ominiyi & Oja, 2023). This process requires a binding agent to hold the particles together, facilitating formation, transportation, storage and thermal conversion compared to loose biomass materials. High density and strength are essential to prevent briquettes from crumbling during handling and storage (Mohammed & Olugbade, 2015). Briquette's strength, thermal stability, combustion performance and cost depend on the briquette binder (Altun *et al.,* 2001).

Based on the varying material compositions, briquette binders are classified into three categories: organic, inorganic, and compound binders. Briquettes made with organic binders offer superior cold strength and high volatility than those made with inorganic and compound binders but tend to have poorer hot-strength and produce complex combustion byproducts (Zhang *et al.,* 2018). African locust bean pulp and cassava starch flour are recognized as organic binders. The African locust bean pulp is derived from the African locust bean tree (*Parkia biglobosa*), a perennial tree belonging to the Leguminosae family (Akande *et al.,* 2010). This tree is highly valued economically due to its diverse applications, with various parts being utilized (Arinola *et al.,* 2019). During the processing of African locust bean seeds, the pulp is usually discarded as waste to recover the seeds. However, repurposing this waste pulp is seen as a sustainable method to create value from waste, given its composition of 28.20 to 32.14% starch, 6.5 to 7.5% moisture content (Okegbejo-Samsons *et al.,* 2004), and 72.68% carbohydrates (Arinola *et al.,* 2019). These properties suggest that the pulp can be effectively used as a binder. Recently, its application as a binding agent for producing fuel briquettes was documented (Namadi *et al.,* 2023). Similarly, cassava (*Manihot esculenta*) is a staple root crop consumed worldwide, known for its high starch content, which is crucial in various industrial processes (Oyeyinka *et al.,* 2019). In Nigeria and other tropical regions, cassava roots are traditionally processed into fermented food products (Balogun *et al.,* 2012). The physicochemical properties of cassava flour include an average of 8.92% moisture content, 84.44% carbohydrates, and 2.25% ash (Oyeyinka *et al.,* 2019). For many years, cassava flour has been a key binding agent in the manufacture of briquette fuels. Zhao *et al.,* (2001) identified key characteristics for an ideal briquette binder to includes: strong bonding, pollution-free properties, no adverse impact on coal heat release and combustibility, non-interference with coal utilization, environmental acceptability, and economic feasibility.

Numerous biomass materials have been briquetted using different organic binders. This includes sawdust and coconut fiber bonded with starch and molasses as binders (Chin & Siddique, 2000); Neem wood residues bonded with gum arabic and starch as binders (Sotande *et al.,* 2010); sawdust from three hardwood species bonded with cow dung, wood ash, and starch as binders (Emerhi, 2011); empty fruit bunches of oil palm plant bonded with starch and asphalt as binders (Kenechukwu & Kevin, 2013); rice husk and corncobs bonded with starch binder (Muazu and Stegemann, 2015); sawdust bonded with Okra (Abelmoschus esculentus) as binder (Ohagwu *et al.,* 2022); and sawdust bonded with African locust bean (Parkia biglobosa) pulp and cassava starch as binders (Namadi *et al.,* 2023). Densifying biomass into fuel briquettes has been reported to improve energy density compared to the original materials (Chou *et al.,* 2009), enhance thermal conversion (Oke *et al.,* 2016), and result in convenient, uniformly sized briquettes that offer significant advantages in storage and transportation (Mohammed & Olugbade, 2015). Some frequently used briquette binders have been reported to have negative impacts due to their carcinogenic nature, high smoke emissions, and cost, highlighting the need to explore more locally available and alternative binders (Ohagwu *et al.,* 2022). Although, a number of studies discussed biomass briquetting with different binders, there is a notable gap in the information regarding the proximate and fuel characteristics of those binding agents. This work intends to examine the proximate and fuel properties of African locust bean (Parkia biglobosa) pulp and cassava starch (Manihot esculenta) flour binders for fuel briquettes production. This will in turn add value to the data available in the literature and enhance the production of high-quality briquette fuel.

MATERIALS AND METHODS

This section highlights the materials used and the method adopted in carrying out the proximate and fuel properties analysis for the briquette binders.

Materials

The feedstocks (briquette binder) used in the current study are cassava starch flour (Manihot esculenta) and African Locust bean (Parkia Biglobasa) Pulp. These materials were traditionally made and locally sourced from a market within Sokoto Metropolis at an affordable price. Other materials are: Electric muffle furnace (Nabertherm 30-3000℃, Model: LT 40/12/B180), Digital Analytical balance (Ohaus, Model: PX224/E), Electrothermal thermostatic drying oven (BZF-6021), Crucibles, Spatula, Desiccator and Metal tongs.

Method

According to ASTM (2006); the proximate analysis of the briquette binders which involves the percentage composition in moisture content (%MC), volatile matter (%VM), ash content (%AC) and fixed carbon (%FC) were analyzed. The moisture content of the samples was determined by measuring a two-gram (2g) portion of each sample, placed in an empty, pre-weighed, and dried crucibles. The combined weight of the samples and crucibles was recorded. The crucibles with the samples were then placed in an electrothermal thermostatic drying box set to 105°C ±5°C for one hour. Using metal tongs, the crucibles were removed, allowed to cool in a desiccator and then reweighed. The dried samples left after assessing the moisture content were then placed in a muffle furnace at 300°C for 10 minutes in a partially closed crucible to determine the volatile matter content. The crucible and its contents were removed, briefly cooled in air, and then placed in a desiccator. The volatile matter content was determined following the ASTM D-3175-18 (2018) standard. After determining the volatile matter percentage, the remaining residues were reweighed, placed into a furnace, and heated at 600°C for 2 hours. After cooling in a desiccator, the crucible and its contents were reweighed and recorded. Three (3) replicates of each experiment were conducted and the average value was reported.

Plate 1: Crucibles containing 2g of the briquette binders

After the experiments, the aforementioned parameters (MC, VM, AC and FC) were calculated using the equations (1)-(3); (Ndecky *et al.,* 2022) and equation (4) (Elsisi *et al.,* 2023) respectively.

Percentage moisture content (%MC)

$$= \frac{M_0 - M_1}{M_0} \times 100 \quad (1)$$

Percentage Volatile Matter (%VM)

$$= \frac{M_1 - M_2}{M_1} \times 100 \quad (2)$$

Percentage Ash Content (%AC)

$$= \frac{M_3}{M_2} \times 100 \quad (3)$$

Percentage Fixed Carbon (%FC)

$$= 100 - (\%MC + \%AC + \%VM) \quad (4)$$

where; M_0: mass of the material before drying (g)

M_1: mass of the material after drying at105°C ±5°C (g)

M_2: mass of the sample after heating for 10 minutes at 300°C (g).

M_3: mass of the ash left after heating for 2hrs at 600°C (g).

Elemental Composition

Proximate analysis is notably valuable for determining essential elements such as Carbon (C), Hydrogen (H), and Oxygen (O) present in a given biomass material, as highlighted by Parikh *et al.,* (2007) and Ohagwu *et al.,* (2022). This elemental composition is known to influence the energy content and fuel characteristics of biomass (Obi and Okongwu, 2016). Parikh et al. (2007), developed a method to ascertain the elemental composition of biomass material based on proximate analysis results. They formulated these correlations by reducing errors and validating them against measured values of carbon, hydrogen, and oxygen percentages across a significant dataset, and they are expressed as follows:

$$C = 0.637(\%FC) + 0.455(\%VM) \quad (5)$$

$$H = 0.052(\%FC) + 0.062(\%VM) \quad (6)$$

$$O = 0.304(\%FC) + 0.476(\%VM) \quad (7)$$

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 a material for energy applications (Ayse & Serdar, 2017). Nhuchhen & Abdul Salam (2012), reported that experimental procedure for determination of higher heating values (HHV) of any fuel in the laboratory is time consuming and expensive at a point where the equipment required are not available. They asserted that derivation of various correlations help to ease such difficulties. Different formulae have been developed for estimating the calorific values (Channiwala & Parikh, 2002); Erol *et al.,* (2010) and (Ayse & Serdan, 2017). Hence, the calorific value of the binders was ascertained by correlation with the results of the proximate analysis with the help of equation (8) Nhuchhen & Abdul Salam (2012);

$$HHV = 19.2880 - 0.2135\left(\frac{VM}{FC}\right) + 0.0234\left(\frac{FC}{AC}\right) - 1.9584\left(\frac{AC}{VM}\right) \quad (8)$$

RESULTS AND DISCUSSION

This section provides the results obtained in the current study and their discussion. Figure 1 highlights the results of proximate analysis of the biomass binder materials.

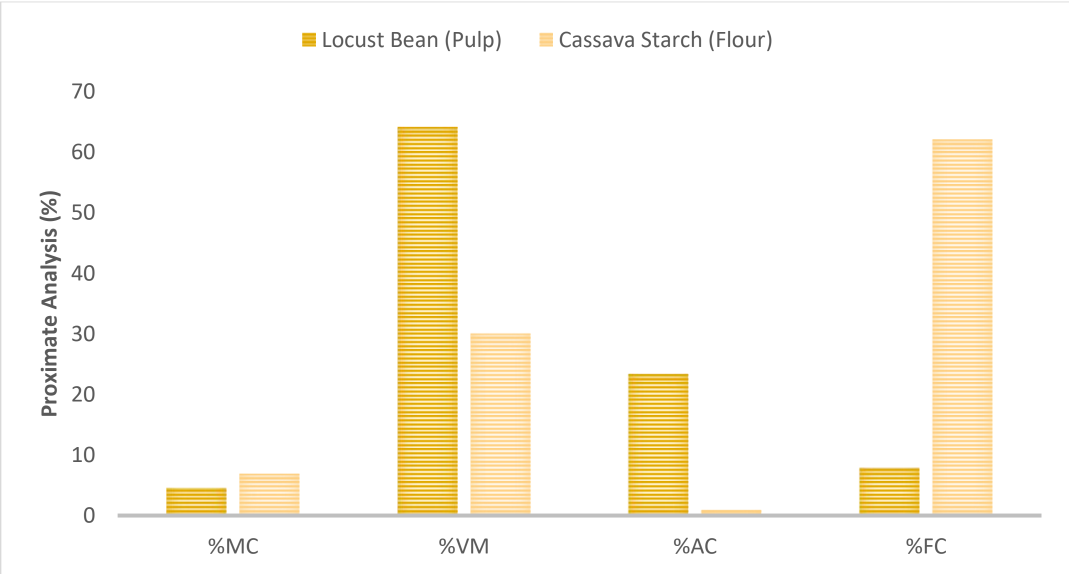

Figure 1: Proximate analysis of the binders

By heating known weights of cassava flour and African locust bean pulp at 105°C ± 5°C in an electric furnace, their moisture content ranged from 4.55% to 6.89%. Cassava flour had the highest moisture content, while the pulp had the lowest, indicating that the pulp dried more effectively than the cassava flour. Similar moisture content ranges of 5.42-7.63% were reported for sewage sludge and biomass samples (Jiang *et al.,* 2014). The moisture content values obtained in this study fall within the recommended limit of ≤14% for high-quality fuel (Ngusale & Kiplagat, 2014). Higher moisture content in the binder material can negatively impact fuel quality in terms of handling, transportation, combustion, and calorific value.

The volatile matter represents the combustible gases in biomass, excluding water, that are evaporated when heated above 300°C in the absence of air. This influences the properties of the resulting biofuels. In this study, cassava flour and African locust bean pulp recorded volatile matter contents of 30.06% and 64.21%, respectively. These values fall within the typical range for biomass samples 25.38% to 87.89% as demonstrated by Ndecky *et al.,* (2022). Other studies reported volatile matter values of 68.70% to 70.77% for mango leaves and sawdust briquettes (Ciubota-Rosie *et al.,* 2008), 40.62% for coffee pulp briquettes (Kebede *et al.,* 2022), and 72.33% to 77.44% for mixed sawdust briquettes from tropical hardwood species (Emerhi, 2011). Lower volatile matter is preferred for briquette binders to produce high-quality briquette fuel, as it leads to easier ignition and smoother burning (Maninder *et al.,* 2012). Hence, briquettes made with cassava starch binder may ignite and burn more efficiently compared to those made from African locust bean pulp.

Consequently, the ash content results shown in Figure 1 indicates that cassava starch flour has the lowest ash content at 0.9294%, while the African locust bean pulp has the highest at 23.3587%. Studies show that higher ash content in biomass materials lead to more combustion remnants, which in turn reduces the heating efficiency (Sottande *et al.,* 2010). The ash content values obtained in this study are lower than those reported for some other binders used in briquette production, such as 33.16% for cattle dung (Kumar & Patel, 2014) and 31.27% for sewage sludge (Jiang *et al.,* 2014). Lower ash content recorded by cassava flour has been attributed to the washing process it undergoes during its production unlike the African locust bean pulp flour. Washing biomass before combustion reduces ash content and related issues, improving fuel quality and heating value, as demonstrated by Deng *et al.* (2013), Liu *et al*. (2015) and Ianez-Rodríguez *et al.* (2020).

In the current study, the fixed carbon content was found to be 7.86% for locust bean pulp and 62.18% for cassava flour. These values fall within the reported range of 2.73-69.39% for solid bio-briquettes (Ndecky *et al.*, 2022) and are close to the range of 9.2-50.0% (Ajimotokan *et al.*, 2019). The higher fixed carbon content in cassava flour suggests that it may produce bio-briquettes with a higher heating value. Hence, this study's findings align with the results of Ajimotokan *et al.*, (2019), who also found that higher fixed carbon content correlates with increased heating value in biomass fuel.

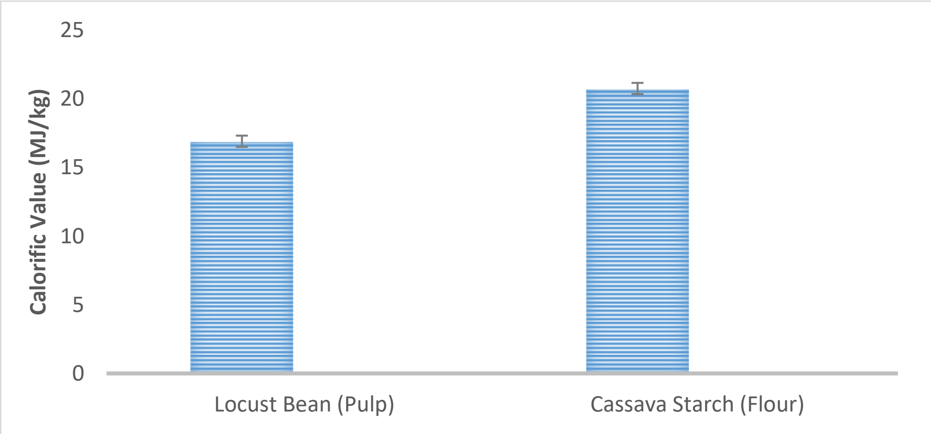

Figure 2: Calorific Value of the briquette binders

The calorific values of briquette binders in the current study, as depicted in Figure 2, range from 16.84±0.48 MJ/kg to 20.69±0.34 MJ/kg. These values compare favorably and exceed the ranges reported for other binders: 16.20 MJ/kg for sewage sludge (Jiang *et al.*, 2014), 15.59 MJ/kg for cattle dung (Kumar and Patel, 2014), 10.21MJ/kg for sludge from the paper industry waste (Sugimin Yoh *et al*, 2020), 13.38 MJ/kg and 10.61 MJ/kg for cassava peels and stalks, respectively (Suwannakhat, 2006). The highest value recorded in this study surpasses the range of 17.56-20.47 MJ/kg reported for briquettes made from a mixture of agricultural residues and starch (Elsisi *et al.*, 2023). Moreover, the calorific values obtained for the briquette binders in this study exceed the acceptable value of 16,500 kJ/kg set by the European briquette standard EN-14961-4 (Ohagwu, *et al.*, 2022). Creating a fuel briquette using a high-calorific value binder can enhance the overall heating value of the resulting biofuel.

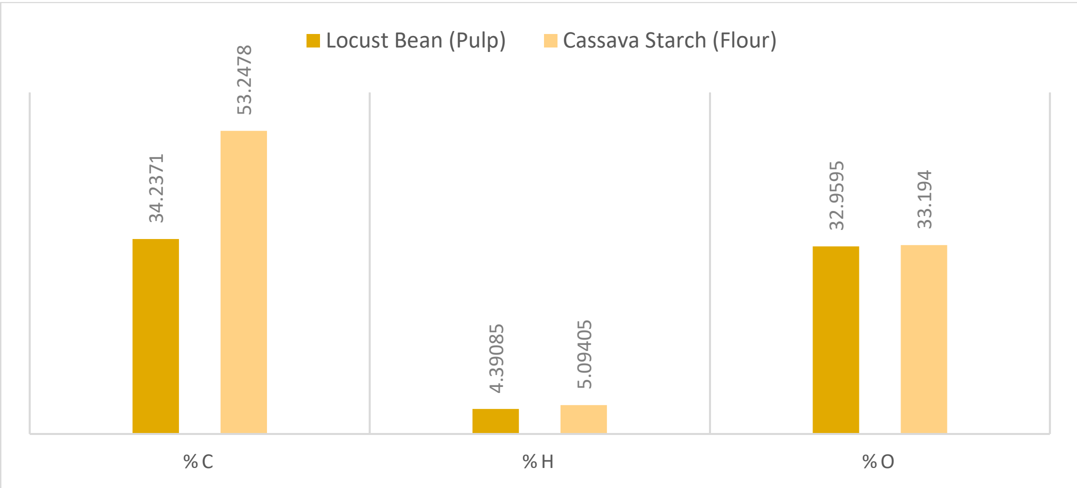

Figure 3: Elemental Composition of the material binders.

The elemental composition in biofuel have been reported to influence its combustibility and greenhouse gas emissions, thereby affecting the environment and living organisms. As depicted in Figure 3, the main elemental composition of Carbon (C), Hydrogen (H), and Oxygen (O) obtained for the briquette binders in this study ranged from 34.24-53.25%, 4.39-5.09%, and 32.96-33.19%, respectively. The lowest values for each element were found in African locust bean pulp. These results are consistent with the ranges reported by Parikh *et al.* (2007), Ajimotokan *et al.* (2019), and Jiang *et al.* (2014). Furthermore, the results of this study showed that carbon content was higher than hydrogen and oxygen content across all the binders. This implies that the binders have favorable characteristics, leading to the production of high-quality briquette fuel. These findings align with those of Obi & Okongwu *et al.* (2016), who found that an increase in carbon content enhances the heating value of fuel. Similarly, Mckebdry (2002) noted that a higher proportion of oxygen and hydrogen relative to carbon lowers the energy value of fuel, as carbon-oxygen and carbon-hydrogen bonds contain less energy compared to carbon-carbon bonds.

CONCLUSION

The study investigated the proximate and fuel properties of African locust bean pulp and cassava starch flour. Findings revealed varying levels of moisture, volatile matter, ash content, and fixed carbon. Calorific values obtained are 16.85±0.48 MJ/kg for African locust bean pulp and 20.69 ±0.34MJ/kg for cassava starch flour respectively. The higher heating value demonstrated by the two briquettes binders indicates their suitability for producing high-quality briquettes fuel capable of generating sufficient heat for household and some industrial applications to serves as an alternative to fossil fuels by reducing the emission of greenhouse gasses into the atmosphere. Using the binders in fuel briquette making can significantly enhance the heating efficiency of the final biofuel product and convert what was regarded as waste to value in the form of energy.

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