A STUDY OF ENERGY POTENTIALS OF COMBUSTIBLE ON-FARM AGRICULTURAL WASTE MATERIALS FOR PROCESSING OF AGRICULTURAL PRODUCE

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ABSTRACT

Biomass utilization allows for the management of on-farm agricultural waste, offering a sustainable solution for waste disposal and promoting energy production Biomass briquette of on farm agricultural waste materials is one of the proven efficient ways of energy generation. It involves collecting and compressing combustible waste materials into solid fuels of convenient shape that can be burnt like wood or charcoal. Investigation on the physical and proximate composition of both raw and briquettes samples of rice husk, sawdust, rice straws and maize cobs was conducted to determine the heating values from these on-farm agricultural waste materials. The result shows that the physical properties (bulk density) for both raw and briquettes samples were; 160.66kg/m^3 and 1,070.67kg/m^3 for rice husk, 211.67kg/m^3 and 1,408.85kg/m^3 sawdust, 76.72kg/m^3 and 633kg/m^{3}rice straw, and 171.32 and 560kg/m^3 for maize cobs respectively. The proximate composition of raw and briquette gives: moisture content of 9.42% and 6.59, 8.33% and 5.14%, 8.13% and 5.12%, 6.03% and 5.03%. Volatile matter: 64.02% and 14.67%, 76.2% and 10.92%, 66.67% and 57.18%, 68.64 and 69.77%. Ash content: 17.38% and 6.38%, 1.32% and 3.82%, 20.19% and 4.31%, 2.36 and 1.47%. Fixed carbon: 9.18% and 72.35%, 14.07% and 81.45%, 5.21% and 29.87%, 22.97% and 33.74% and calorific value: 13.75MJ/kg and 59.86MJ/kg, 16.90MJ/kg and 109.51MJ/kg, 13.12MJ/kg and 17.97MJ/kg and 17.32MJ/kg and 18.58MJ/kg for rice husk, sawdust, rice straws and maize cobs respectively. It was observed that the briquette samples produced has good combustion properties for domestic use, food processing and small-scale industrial cottage applications. due to its high calorific value with low ash content when compared with the raw biomass samples.

Keywords: Briquettes, Biomass, Rice husk, Waste materials, Charcoal

1 INTRODUCTION

Agricultural activities generate a significant amount of waste, including agricultural residues, wood sawdust, rice husk, rice straws, groundnut husk, maize stalks, maize cobs, beans, cow dung, etc. The byproducts are often considered as waste and are disposed of through inefficient and environmentally harmful practices, such as open burning or dumping in landfills. However, these agricultural wastes possess a high energy potential, which can be harnessed through effective energy recovery systems [1]. Biomass could be one of the renewable energy sources that can be transformed into energy directly or indirectly. Biomass takes the form of residual stalks, straw, leaves, roots, husk, nut or seed shells, waste wood and animal husbandry waste. Several reports have highlighted that developing countries produce large volumes of biomass annually as by-products from the agricultural, forestry and industrial activities. It is estimated that about 1 billion metric tonnes and 140 million metric tonnes of

biomass are produced annually from the forestry and agricultural sectors, respectively, in Sub-Sahara Africa [2]. Unfortunately, these biomasses are usually regarded as waste and hence are either burnt without heat recovery or left to rot in-situ, subsequently emitting greenhouse gasses (GHG) and leading to other environmental issues [1]. With the global campaign to combat climate change, countries are now looking for alternative sources of energy to minimize greenhouse gas (GHG) emissions. Aside from being carbon neutral, the use of biomass for energy reduces dependency on the consumption of fossil fuel, reduced environmental impacts, climate change and economic feasibility, reduce energy costs for farmers by generating on-site renewable energy, resulting in economic benefits through Providing added income to farmers without compromising the production of main food and even non-food crops. It has been reported that the utilization of the biomass residues in their natural form as fuel is quite challenging due to their low bulk density, low heat release and excessive smoke generation. These characteristics make it difficult to handle, store, transport and utilize biomass residues in their natural form. Briquetting technology has been identified as one of the methods for improving the thermal value of several biomasses. This development provides an environmental friendly approach to waste management by reducing the release of greenhouse gases and other pollutants associated with conventional disposal methods, offers an opportunity for farmers to generate clean and renewable energy on-site, reducing their reliance on traditional fossil fuels and mitigating the associated costs and to promotes sustainable agricultural practices by closing the loop of waste generation and energy consumption, creating a more circular and resource-efficient system. This study, therefore, focused on the investigation of thermal characteristics of on-farm agricultural wastes produced from four different biomass types sourced from Girei, Nigeria. Particularly, the physio-chemical properties (residual moisture content, ash content, fixed carbon, volatile matter, and calorific values) of both natural and briquettes produced from rice husk, wood sawdust, rice straw and maize cobs respectively.

2 MATERIALS AND METHODS

2.1 Materials

Four different biomass sample (rice husk, sawdust, rice straw and maize cobs) obtained from different parts of Girei, Adamawa State, Nigeria were used in the study. And heating stove, cooking pot, and metal container are the main equipment used in this study.

2.2 Experimental Methods

2.2.1 Samples preparation

The rice husk, sawdust, rice straw and maize cobs were sundried for a week to reduce the moisture content to approximately 12%, which is within the acceptable operating limit for briquetting and storage [3]. The collected sample were manually cleaned to remove external materials and cut into pieces to obtain required sizes for the experiment and then pass through sieves (Plate 1).

Plate 1. Samples preparation

2.2.2 Briquette production

The collected biomass samples were screened from stones and other impurities that might inhibit proper briquette formation. The charred biomass was ground and sieved through a 1.18 mm-sized screen to ensure uniform feed particle sizes, similar to that method reported by [3]. Hot water was boiled using the heating stove. The hot water was then mixed with the starch until a sticky gel was produced. Approximately

500 g of the sieved product of each charred rice husk, sawdust, rice straw, and maize cobs was then wetted with water to enhance uniform mixing with 250g of the binder starch in proper binder mix ratio of 100: 20. The mixture was manually handfed into a metal container pipe and compacted to obtain uniform briquettes sizes. The compacted briquettes were then dried in an oven at a temperature of 120°C for 12 h. Plates 2 shows starch used as binder and plate 3 show briquette production. The produced briquettes were placed in an open air for moisture removal and a solid mass was formed capable of being used as substitute for wood fuel (Plate 4). The formed briquettes were then subjected to physical and proximate analysis. Three replications of each test were carried out and the mean values were reported. The energy potential of each sample was determined under two different states; as raw and briquettes produced.

Plate 2. Starch (binder).

Plate 3. Briquettes production

Plate 4. Produced briquettes.

2.3 Physical properties and proximate composition characteristics of the biomass samples

The properties of the raw and compacted briquettes produced from the rice husk, wood sawdust, rice, straw, and maize cobs were assessed. The residual moisture content, volatile matter, ash content, fixed carbon and calorific value (specific heat of combustion) of the raw and briquettes produced from the various biomass were examined using methods similar to those methods reported by [3].

2.3.1 Bulk density

Bulk density of the biomass was determined according to the method described by [4] AOAC (2005). A 0.001m^3 graduated cylinder was filled with the sample and tapped 10 times against a table top until constant volume was achieved. The volume was taken and the weight was also recorded. The bulk density was determined which is express as kg/m^3.

2.3.2 Determination of Moisture Content of the samples

The percentage moisture content (mc) was determined by weighing 1.5g of the briquette sample placed in a crucible of known mass and placed in an oven set at 105°C ± 5°C for 3 hours. The crucible and its content were removed from the oven allowed to cool to room temperature and reweighed. This process was repeated until the weight after cooling became constant and this was recorded as the final weight. The sample's moisture content was determined using equation (1) [3, 5].

$$MC = \frac{w_1 - w_2}{w_1} \times 100 \quad (1)$$

Where MC= percentage moisture content, W_1= the initial weight of briquette sample and W_2= the final weight of briquette sample. The moisture content influences the overall durability, strength and calorific value of the briquettes.

2.3.3 Determination of Volatile Matter of the samples

The percentage volatile matter (VM) was determined by placing 1.5g of the briquettes sample in a crucible and kept in a furnace for 8 minutes, at temperature of 550ºC ± 5°C and weighted after cooling. The percentage volatile matter of the sample was determined using equation (2) [3, 4].

$$VM = \frac{w_2 - w_3}{w_2} \times 100 \quad (2)$$

Where VM= percentage volatile matter, W_2 = the weight of the oven-dried sample (g); W_3 = the weight of the sample after 8 min in the furnace at 550°C (g).

2.3.4 Determination of Ash Content of the samples

1.5g of the samples are kept in a closed furnace and burnt completely. The weight of the residue was taken with an electronic balance. The percentage weight of residue gives the ash contained in the sample and its determined using equation (3).

$$AC = \frac{w_4}{w_2} \times 100 \quad 3$$

Where AC= Percentage ash content, W_4= the weight after complete burning, W_2 = the weight of the oven-dried sample (g); [3, 4] gave the percentage fixed carbon (PFC) as equation (4).

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

Where FC= percentage fixed carbon, MC= moisture content, VM=volatile matter, AC= ash content.

2.3.5 Determination of Calorific Value of the samples

The calorific value of the briquettes was determined using a bomb calorimeter. 1.5g of the briquettes sample was burnt completely in oxides of oxygen. The liberated heat was absorbed by the water and calorimeter. The heat lost by burning briquette was the heat gained by water and calorimeter. The calorific value (CV) of the fuel was calculated from the measured data using equation (5) and equation (6) where there is no available calorimeter, a prediction method was also used by [3, 6].

$$CV = \frac{BF(T_2 - T_1) - 2.3 \times H}{W} \quad 5$$

OR

$$CV = 0.1846(VM) + O.0352(FC) \quad 6$$

Where CV= calorific value, VM=volatile matter, FC=fixed carbon.

3 RESULTS AND DISCUSSIONS

The physico-chemical properties of raw biomass and the briquettes produced from biomass were limited to determination of the bulk density, the percentages moisture content, volatile matter, ash content, fixed carbon, and calorific value. Table 1 showed the results of the physical (bulk density) and proximate composition of raw and briquette on-farm agricultural waste material. The result shows bulk density of 160.66 and 1071.67kg/m^3 for raw and briquettes rice husk, 211.67 and 1408.85 kg/m^3 for raw and briquettes sawdust, 76.72 and 633.33 kg/m^3 for raw and briquettes rice straw, and 171.32 and 560.00 kg/m^3 for raw and briquettes maize cobs respectively. The bulk density of briquettes produced is higher than the raw materials.

Table 1. Physical and proximate composition of Raw and Briquette on-farm agricultural waste material

Sn	Samples	Bulk density (Kg/m^3)	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (MJ/kg)
1	Raw rice husk	160.66	9.42	64.02	17.38	9.18	13.75
2	**Briquette rice husk**	1,071.67	6.59	14.67	6.38	72.35	59.86
3	Raw sawdust	211.67	8.33	76.25	1.32	14.07	16.90
4	**Briquette sawdust**	1,408.85	5.14	10.92	3.82	81.45	109.51
5	Raw rice straws	76.72	8.62	66.67	20.19	5.21	13.12
6	**Briquette rice straws**	633.33	5.13	57.18	4.31	29.87	17.97
7	Maize cobs	171.32	6.03	68.64	2.36	22.97	17.32
8	**Briquette maize cobs**	560	5.03	69.77	1.47	33.74	18.58

In terms of the average moisture content, it shows 9.42 and 6.59%, 8.33 and 5.14%, 8.62 and 5.13%, and 6.03 and 5.03% for raw and briquette rice husk, sawdust, rice straw, and maize cobs respectively. The

average percentage moisture content for the briquettes produced is less than that of raw agro-waste materials. Briquettes produced from rice husk have the highest moisture content (6.59%), followed by sawdust (5.14%), rice straw (5.13%), and maize cob (5.03%) (Figure 1).

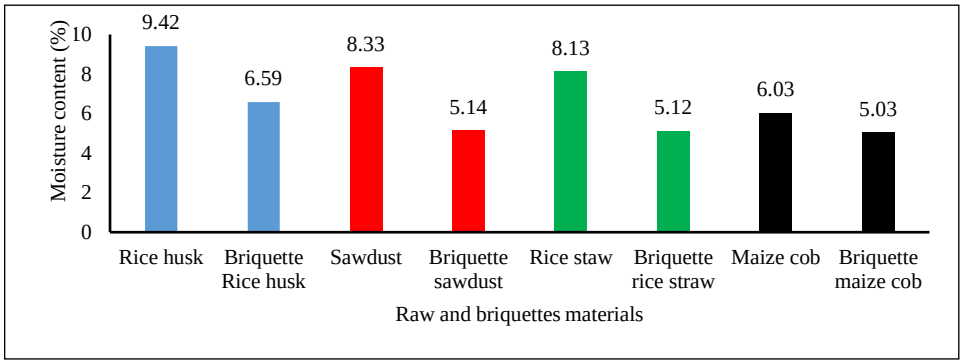

Figure 1. Moisture content (%) for raw and briquettes produced from rice husk, sawdust, rice straw and maize cobs

The differences in moisture content variations can be attributed to the variations in the feed particle size, moisture content, and surface area, as well as the binder content. The results of moisture contents of the various briquettes are in agreement with the standard residual moisture content of 5 - 10%, [3, 5]. The variations in the residual moisture contents observed affect the general performance of briquettes in terms of their calorific value, ash content, fixed carbon content and volatile matter content [3, 5]. Thus, briquettes with low moisture content are expected to ignite easily, yielding higher energy/calorific values [3, 4]. Therefore, it is expected that briquettes produced from maize cobs, with lowest moisture content, would ignite easily and yield higher calorific value, followed by those produced from rice straw, sawdust and rice husk. Moisture content of all briquette's materials increased with increase in binder concentration and decreased with increase in compaction pressure. These results are in agreement with [5, 7], who recommended 5 – 10% for moisture content. Figure 2 shows the volatile matter content of both the raw and the briquettes produced from rice husk, sawdust, rice straw and maize cob. The results indicate that the volatile matter content for both the raw and the briquettes produced from rice husk, sawdust, rice straw and maize cob are 64.02 and 14.67%, 72.65 and 10.92%, 66.67 and 57.18%, and 68.69 and 69.77% respectively. The differences in volatile matter can be attributed to the variations in the moisture contents and the quantity of combustible-incombustible materials present in the briquette. The results show that maize cobs briquettes produced has the highest volatile matter (69.77%) compared with those considered in the study. A high volatile matter content is an indication of the readiness of briquettes to ignite and burn easily with a rapid burning and high proportionate flame length but low heating values. This result is in agreement with those of [3, 8].

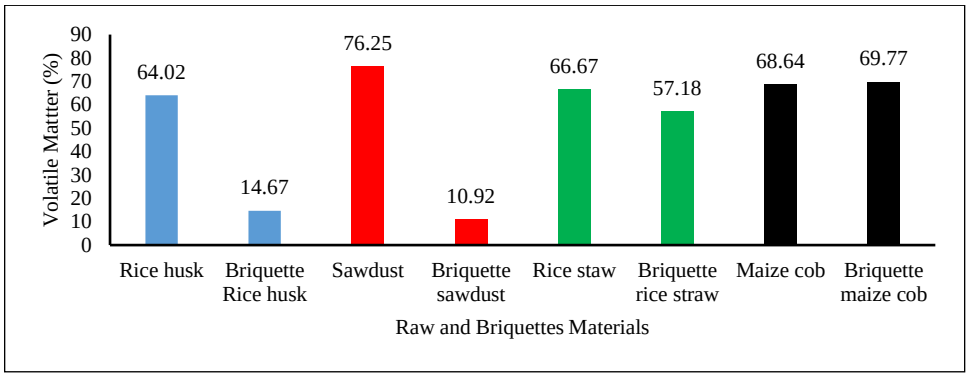

Figure 2. Volatile Matter (%) of raw and briquettes produced from rice husk, sawdust, rice straw and maize cobs

Figure 3 shows the ash contents for both the raw and the briquettes produced from rice husk, sawdust, rice straw and maize cob. The ash content for the briquettes produced ranged from the lowest (1.47%) of maize cobs to the highest (6.38%) of rice husk. The ash content of the briquettes produced were found to be within the acceptable ash limit (5 - 40%) for a solid biomass briquette as reported by [9]. Generally, high ash content of briquette means a high combustion remnant of such material fuel was high with a low heating value. Low ash content offers higher heating value for briquettes but high ash content results in dust emissions that lead to air pollution. High ash content also results in low calorific value while lo ash content results in higher calorific value. Hence, the produced briquettes from the rice husk, sawdust rice straw and maize cobs would perform well based on the ash contents. The ash content in maize cobs is relatively low both for raw and the briquettes produced, it's therefore, preferable to used maize cob for combustion.

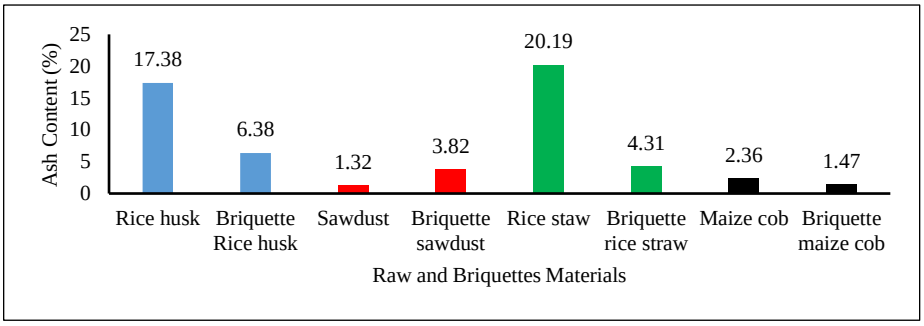

Figure 3. Ash content (%) of raw and briquettes produced from rice husk, sawdust, rice straw and maize cobs

Figure 4 shows the fixed carbon contents for the briquettes produced from rice husk, sawdust, rice straw and maize cobs. The results showed that briquettes produced from the sawdust exhibited highest fixed carbon content of 81.45%, followed by rice husk (72.35%), maize cobs (33.74%) and straw (29.87%). The variations in the result of fixed carbon contents was due to the variations in their moisture content. Increasing moisture content of briquettes often leads to decreasing fixed carbon content. Generally, a low percentage of fixed carbon is an indication of a low heating (calorific) value of the briquettes, and the higher the fixed carbon of the briquettes of fuels, the greater the calorific value. Therefore, biomass with high fixed carbon, such as sawdust (81.45%) and rice husk (72.35%) are preferred for pyrolysis. These results agreed with the result of [8] who reported the suitability of briquettes with fixed carbon as 70.5% for domestic applications.

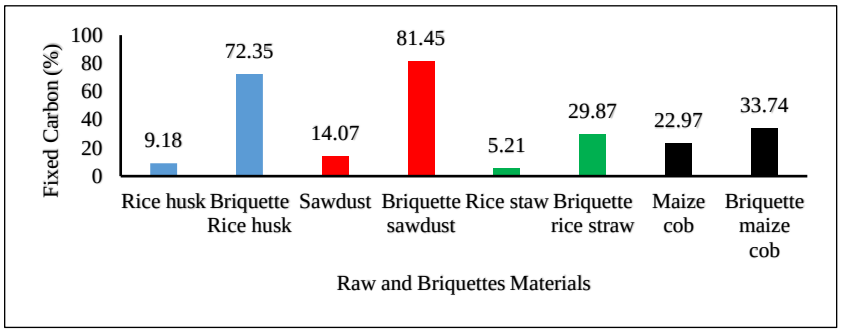

Figure 4. Fixed carbon (%) of raw and briquettes produced from rice husk, sawdust, rice straw and maize cobs

The calorific value determines the amount of heat energy present in a material. The calorific (heating) values for the briquettes produced from rice husk, sawdust, rice straw and maize cobs. Figure 5 showed that briquettes from sawdust has the highest calorific value of 109.51MJ/kg, followed by rice husk briquettes (59.86 MJ/kg), maize cob (18.58MJ/kg) and rice straw (17.97 MJ/kg).

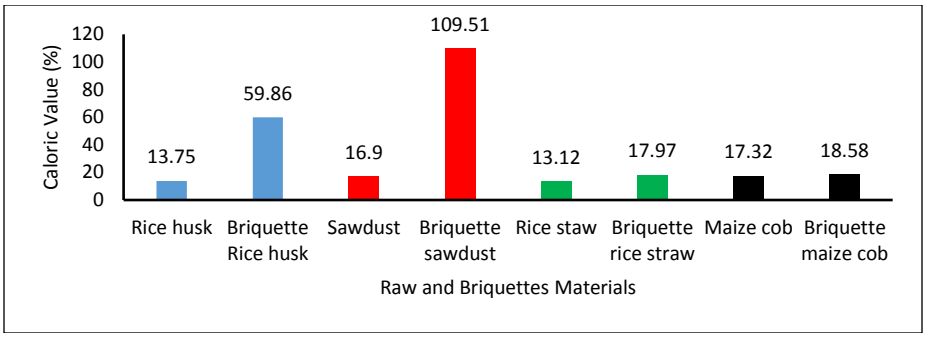

Figure 5. Caloric value (%) of raw and briquettes produced from rice husk, sawdust, rice straw and maize cobs

The briquette samples produced from rice husk, sawdust, rice straw and maize cobs has good combustion properties good enough for domestic use and small-scale industrial cottage applications. It is observed that a higher heating value is a great indication of a good and efficient briquettes. This implies that briquette performance in terms of caloric (heating) value is higher when produced from sawdust than those obtained from rice husk, rice straw and maize cobs. This result is in consonant with those reported by [10, 11]. While Table 2 shows the analysis of variance on the results.

Table 2: Analysis of variance (ANOVA) of the raw sample and briquettes biomass

Source of variation	df	SS	MS	F	p-value	F crit
Rows	23	969115.6	42135.46	1.14531	0.309854	1.623598
Columns	5	5113457	1022691	27.79842	2.29E-18	2.293205
Error	115	4230798	36789.55			
Total	143	10313371				

4 CONCLUSIONS

Agricultural waste, particularly rice husk, rice straw, sawdust, and maize cobs, holds significant potential as a renewable energy source. Briquetting these materials enhances their physical and combustion properties, making them suitable for various biomass energy applications. An assessment focused on estimating the thermal values of various biomass (rice husk, sawdust, rice straws and maize cobs) for both raw and briquettes were carried out to ascertain its suitability for domestic use and small-scale industrial cottage application. Briquettes of sizes ranging between 30 to 50 mm were produced using cassava starch as binder. The briquettes produced from rice husk containing the highest moisture (6.59%) followed by sawdust (5.14%), rice straw (5.12), and maize cobs (5.03%). The volatile matter content was 69.77%, 57.18%, 14.97%, and 10.92% for maize cobs, rice straw, rice husk, and sawdust respectively. The ash content for the briquettes ranged from 1.47% to 6.38% with rice husk having the highest ash content (6.38%), followed by rice straw (4.31%), sawdust (3.82%), and maize cobs (1.47%). The fixed carbon content of briquettes sawdust produced has the highest fixed carbon content of 81.45%, followed by rice husk (72.35%), maize cobs (33.74%), and rice straw (29.87%). For the calorific values, the briquettes from sawdust yielded the highest value of 109.51MJ/kg followed by Rice husk (59.86MJ/kg), maize cobs (18.58MJ/kg), and rice straw (17.97MJ/kg). This implies that briquette sample produced from sawdust has higher calorific value good combustion property good, enough for domestic use and small-scale industrial cottage applications than those obtained from rice husk, rice straw and maize cobs.

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