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Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders

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ABSTRACT

The study was undertaken to assess the calorific value of briquettes produced from mixed sawdust of three tropical hardwood species (Afzelia africana, Terminalia superba, Melicia elcelsa) bonded with different binding agents (starch, cow dung and wood ash). Sawdust from each of the species was mixed with the binder in ratio of 70:30 for cow dung and wood ash and 70:15 of starch. The sawdust where mixed in a ratio 50:50 for each briquette combination produced. Combustion related properties namely percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquettes where determined. All processing variables assessed in this study were not significantly different except for percentage fixed carbon at five percent level of probability. The result shows that briquette produced from sample of Afzelia africana and Terminalia superba combination bonded with starch had the highest calorific value of 33116kcal/kg while briquette produced from sample of Afzelia Africana and Terminalia superba bonded with ash had the least calorific value of 23991kcal/kg. Since the aim of briquetting is to produce briquette that will serve as good source of fuel and support combustion, the best briquette was produced when sawdust was mixed with starch. Also the use of mixed wood residue from the selected species and other hardwood species for briquette production should be encouraged as this will provide an alternative to firewood for household cheap energy source.

Keywords : Briquette, *Afzelia africana, Terminalia superba, Melicia elcelsa*, combustion properties, calorific values binding agents.

INTRODUCTION

Traditionally, energy in the form of firewood, twigs and charcoal has been the major source of renewable energy for many developing countries. Although Africa accounts for 12% of the global population, it consumes only 4% of global energy [1]. The high and rapid demand for wood fuel consumption is considered as a major contributing factor to the fuel wood crisis in Nigeria [2]. The demand for fuel wood is expected to have risen to about 213.4 $x10^3$ metric tonnes, while the supply would have decreased to about 28.4 x10 metric tonnes by the year 2030. For this reason, a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria [3]. One of such energy source is wood waste or sawmill residue. Sawdust constitutes one of the most abundant waste or residue in wood industries. It was estimated that wood waste generated in the country in 1998 was 1.72million/m^3 out of which sawdust was 15% [4].

Briquettes made from materials that cost little or no money to obtain such as newspaper or partially decomposed plant waste or sawdust can be an alternate source of domestic and industrial energy to charcoal, firewood, gas, coal and electricity. Presently, the major source of energy to the rural community is fuelwood because other sources of energy (electricity, gas and kerosene) are either not available or grossly inadequate where available and they are beyond the reach of the masses. Fuel wood collection has grave consequence on forest conservation and sustainable forest resources management. Depending on materials used to make the briquettes, they may burn cleaner than charcoal and firewood. Briquettes production thereby turns waste materials into fuel source. This is therefore attractive because it is a sustainable process.

Briquettes made from charcoal and sawdust is a desirable fuel because it produces a hot, long-lasting and virtually smokeless fire. Briquettes are produced when charcoal and sawdust are combined with other materials and it is formed into uniform chunks. Successful briquette operations are found mostly in developed countries. An example is the industry based on carbonization of sawdust and bark in the southern USA. However, briquetting operations are not successful in developing countries like Nigeria and other African countries. This is mostly due to the high cost of production, lack of awareness on its sustainability, availability of market and poor packaging and distribution systems for the product. Despite these difficulties, opportunities of this type should be closely studied in the interest of the overall national fuel economy and biodiversity and environmental conservation.

The production of briquettes from sawdust exemplifies the potential of appropriate technology for wood waist utilization. It saves trees that can prevent soil erosion and desertification by providing an alternative to burning wood for domestic and industrial heating and cooking. Also, it substitutes sawmilling waste for a valuable resource. It improves health by providing a cleaner burning fuel and also provides a better alternative to firewood (40% more efficient, longer burning and better) as well as helping to protect the environment by reducing the number of trees cut for firewood. In addition, briquetting engenders many micro enterprise opportunities that include the production of the presses from locally available materials, using materials like agricultural waste and sawdust, briquette production enterprise, packaging and selling of the briquette. Briquettes can be produced with a density of 1.2 g/cm^3 from loose biomass of bulk density 0.1 to 0.2 g/cm^3 These can be burnt clean and therefore are eco-friendly arid also those advantages that are associated with the use of biomass are present in the briquettes [5].

Briquette making has the potential to meet the additional energy demands of urban and industrial sectors, thereby making a significant contribution to the economic advancement of developing countries. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage [6;7]. However, in order to make a significant impact as a fuel source, there is the need to improve and promote its production technology [5]. This is a densification process for improving the handling characteristics of raw materials and enhancing the volumetric calorific values of biomass. [8].

There is shortage of fuel wood in developing countries today. With successful production of briquettes from sawdust, fuel wood users especially rural dwellers can have an alternative to fuel wood as sources of energy at lower cost. There is over exploitation of wood for burning due to the high rise in population. This is one of the major drivers of deforestation, desertification and erosion. This has led to the depletion of over 75% of the total forest cover in many sub-Saharan countries and thus leading to environmental crises. With the increase in the rate of tree felling for furniture making and charcoal production as well as for firewood, the forest ecosystem has been greatly disturbed and altered thus leading to a high rate of deforestation and environmental pollution. However, inefficient wood conversion and low biomass recovery from the timber process in Nigerian forest industry have led to the prevalence of sawdust hills around sawmills, thereby constituting a visual blight to the local environment and a breeding ground for wood decaying organisms. But, these sawdust hills could be compacted into briquette for fuel energy supply [9]. Briquettes made from sawdust can reduce forest degradation and deforestation to mitigate these problems. One of the promising solutions to the problems unutilized agricultural residues and saw dust is the application of briquetting technology [8]. The technology may be defined as a densification process for improving the handling characteristics of raw materials and enhancing volumetric calorific value of the biomass [10].

It is obvious that most of the world's energy demand is not met by fossil fuel mainly coal, crude oil, and natural gas. Fossil fuel, which is non renewable, provides about 80% of man's energy sources now and this may start to depreciate in the next twenty to thirty years. This has been the major concern of the entire world. Since briquetting operation have not been successful in areas like Nigeria and other developing countries, the markets for briquette have not been explored in these areas and with materials locally available, production cost will be low and hence reduce dependence on and costs in purchase of kerosene and charcoal.

If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel, they must be characterized to determine parameters such as the moisture content, ash content, density, volatile matter, and heating value among others [10]. The objectives of this study are therefore to determine; the binding agent that can give the highest calorific value during burning, the species of wood that has the highest calorific value and to assess the percentage volatile matter, ash content and the fixed carbon of the briquettes.

MATERIALS AND METHODS

Study Area

Sawdust of three different hardwood wood species (*Afzelia Africana,* Terminalia *superba, and Melicia elcelsa)* of the tropical rainforest ecosystem were collected from various sawmill industries in Ibadan metropolis, Nigeria for the production of the briquettes. The briquettes were produced and analyzed at the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria.

Methods of briquette production

The three tropical hardwood species of rainforest ecosystem were paired and their sawdust were mixed together thoroughly in equal proportion to form three sets of material for briquette production (AB – *Afzelia Africana* + *Terminalia superb,* BC – *Afzelia africana* + *Melicia ecelsa and* AC – *Terminalia superba* + *Melicia elcelsa).* The sawdust were dried under the sun to a moisture content of about 12% . Different binding agents were added to the various mixtures and a hand press machine was used as moulder by the application of high pressure to form the briquettes. The briquettes were then oven dried at a temperature of 100^0c. Five replicates of the briquettes of the mixture of the wood species and different binding agents were produced. They were re-burnt in the ballistic bomb calorimeter to determine their physical and calorific values. Proximate analysis was carried out on the briquette samples to determine the percentage volatile matter content, % ash content, % content of fixed carbon and heating value of the samples. The procedures of ASTM E711-87 [11] were adopted.

Percentage volatile matter (PVM)

To determine the PVM, 2g of pulverized briquettes sample in a crucible were placed in the oven until a constant weight is obtained. The briquettes were now kept in the furnace at a temperature of 550^0c for 10 minutes and weighed after cooling and the PVM was determined with the formula:

$$PVM = \frac{B-C}{B} x100$$

Where B is the weight of oven dried sample and C is the weight of sample after 10min in the furnace at 550^0c

Percentage Ash content (PAC)

The PAC was also determined by heating 2g of the briquette sample in the furnace at a temperature of 550^0c for 4hrs and weighed after cooling. The PAC was determined:

$$PAC = \frac{D}{B} x100$$

Where D is the weight of ash and B is the weight of oven dried sample

Percentage fixed carbon (PFC)

The PFC was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) from 100

Heating value (Hv)

This was calculated using the formula: Hv = 2.326 (147.6c +144v)

Where c is the percentage fixed carbon and v is the percentage volatile matter (Bailey et al. 1982)

Data analysis

The experiment was laid out using the Randomized Complete Block Design (RCBD). While the binders formed the blocks (rows), the sawdust mixtures from pairing the wood species were in columns. The data were subjected to two-way analysis of variance at 0.05 probability level. Where significant differences were encountered, means were separated using the Fisher's LSD method. Descriptive statistic, that includes mean and standard error of estimates, was also carried out on the data. All the analyses were done with SPSS statistical software.

RESULTS

The physical and combustion properties of the briquettes examined in this study were limited to percentage volatile matter, percentage ash, percentage fixed carbon and the heating or calorific value. The results were therefore discussed according to the values obtained. Table 1 shows the results of the two-way analysis of variance for comparing the presence of significant difference in briquette properties according to the binders and the sawdust mixtures. The results show that there were significant differences ($p<0.05$) in the effects of binders on the briquettes' proximate properties except for percentage carbon where significant difference ($p>0.05$) was not observed. The ANOVA results also reveal that there were no significant differences ($p>0.05$) in the qualities of the briquettes produced from the different mixture of the sawdust from the wood species with reference to the four proximate values.

Table 1: ANOVA table for testing the significant differences in proximate composition of the briquettes according to the binders and tree species

	Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
% VM	Binders	1269.58	2	634.79	116.15	0.0002	6.94*
	Wood species	38.46	2	19.23	3.52	0.13	6.94ns
	Error	21.86	4	5.47			
	Total	1329.90	8				
% Ash	Rows	305.04	2	152.52	23.29	0.006	6.94*
	Columns	13.60	2	6.80	1.04	0.43	6.94ns
	Error	26.20	4	6.55			
	Total	344.84	8				
% Carbon	Rows	10.16542	2	5.082711	1.22	0.385506	6.94ns
	Columns	26.64602	2	13.32301	3.20	0.147872	6.94ns
	Error	16.64858	4	4.162144			
	Total	53.46002	8				
Heating Value	Rows	1.19E+08	2	59649751	3162.411	3.99E-07	6.94*
	Columns	160869.6	2	80434.78	4.264357	0.101931	6.94ns
	Error	75448.44	4	18862.11			
	Total	1.2E+08	8				

** Significant (p<0.05 or F-calculated > F-critical) ns – not significant (p>0.05 or F-calculated < F-critical*

The summary of the effects of binders on briquette qualities is presented in table 2. The mean percentage volatile matter of 75.17±8.40 was obtained for the briquettes in general but it was observed that the briquettes produced with cassava starch as binder has the highest percentage volatile matter of 89.47±0.22. Its mean value is significantly higher ($p<0.05$) than those from the other two binders. This is followed by briquettes produced with cow dung with a value of 75.67±2.83%, which is also significantly higher than the ones produced with wood ash as shown by the LSD results of mean separation. The least percentage volatile matter was recorded for those produced with wood ash (60.39±1.41%). For the ash content of the briquette, a general average of 19.99±4.12% was obtained. However, briquettes produced with wood ash as binder had the highest value of ash (28.13±0.37) which is significantly higher than those produced with cassava starch and cow dung. The % ash content when starch was used followed with 16.94±2.55% and the least was obtained with the use of cow dung (14.89±0.05%). Even though there were no significant differences in the amount of carbon produced by the briquette for all the binders, the highest was obtained with the use of wood ash (11.46±1.68%), followed by those from cow dung binder (11.14±2.08) and the least from cassava starch (9.06±0.23%). The heating values produced from the sawdust of the three species using these binders ranged between 24,160.67±136.63KCal/Kg and 33,078.67±133.52Kcal/Kg, with a general mean of 26,605 ±2574.44 Kcal/Kg. In addition, the LSD results show a significant difference in the means. From this table, the highest heating value was produced by briquettes with cassava starch as binder while the least was produced with the use of wood ash.

Table 2: Mean proximate analyses of the briquettes according to the binders

	Proximate composition			
Binders	% Volatile matter	% Ash	% Carbon	Heating values
Ash	60.39 ± 1.41a	28.13 ± 0.37a	11.46 ± 1.68ns	24,160.67 ± 136.63a
Cow dung	75.67 ± 2.83b	14.89 ± 0.05b	11.14 ± 2.08ns	28,578.33 ± 53.77b
Starch	89.47 ± 0.22 c	16.94 ± 2.55c	9.06 ± 0.23ns	33,078.67 ± 133.52c
Mean	75.17 ± 8.40	19.99 ± 4.12	10.55 ± 0.75	26,605 ± 2574.44

There is significant difference in means with the same letter along the column.

The results of the proximate analyses of the briquettes from mixed saw dust of the hardwood species is presented in table 3. For volatile matter, a mean value of 75.18 ±1.46 was obtained for all the briquettes but the highest value (77.44±7.82%) was obtained from the combination of the saw dust of *Terminalia superb* and *Melicia elcelsa* (AC). This is followed by those from the mixture of *Afzelia africana* and *Terminalia superb*a (AB) with 75.67±8.55% and the least volatile matter (72.44±9.00%) in the mixture of *Afzelia africana* and *Melicia elcelsa* (BC). The difference in these values, though there was no significant difference ($p>0.05$) are however shown in figure 1. On percentage wood ash, the values ranged between 19.07±4.80 and 21.72±3.88%. the highest value being for the mixture of *Terminalia* and *Melicia* also. This is followed by the mixture of *Afzelia* and *Melicia* and the least in the mixture of *Afzelia a*nd *Terminalia* (figure 2). The highest carbon content (12.99±1.76%) was observed in the mixture of *Afzelia* and *Melicia* while the least (9.27±0.61) is from the mixture of *Terminalia* and *Melicia* species. Figure 3 shows the variation in percentage carbon of the briquettes according to sawdust mixture. The heating values of the briquettes produced from the sawdust of the tree species are 28,794±2557.94, 28,528.33±2634.28 and 28,495.33±2532Kcal/kg for a mixture of *Afzelia* and *Melicia*, *Afzelia* and *Terminalia* and *Terminalia* and *Melicia* respectively. This relationship is also depicted with figure 4.

Table 3: Mean of proximate properties of the briquettes produced from the tropical wood species

Wood sawdust mixture	Proximate composition			
	% Volatile matter	% Ash	% Carbon	Heating values
AB	75.67 ± 8.55	19.07 ± 4.80	9.40 ± 0.99	28,528.33 ± 2634.28
BC	72.44 ± 9.00	19.17 ± 4.13	12.99 ± 1.76	28,794.00 ± 2557.94
AC	77.44 ± 7.82	21.72 ± 3.88	9.27 ± 0.61	28,495.33 ± 2532.46
Mean				

AB – Afzelia Africana + Terminalia superb, AC – Terminalia superb + Melicia ecelsa, BC – Afzelia Africana + Melicia ecelsa

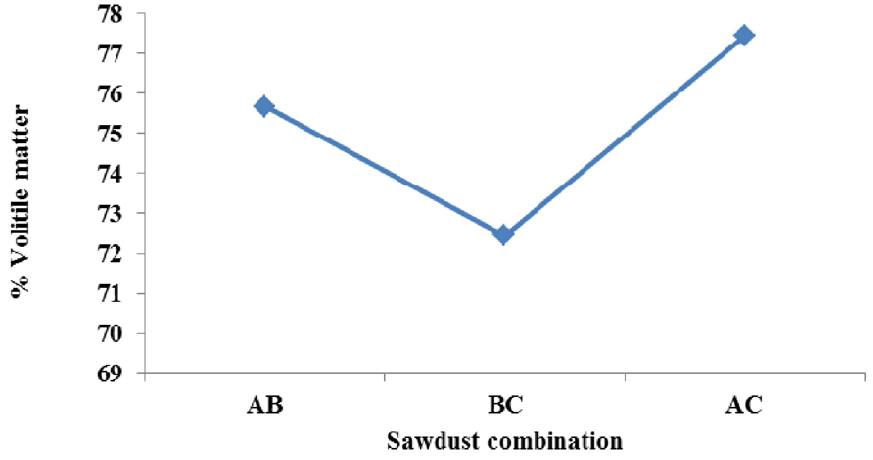

Fig. 1: Mean volatile matter of the briquettes

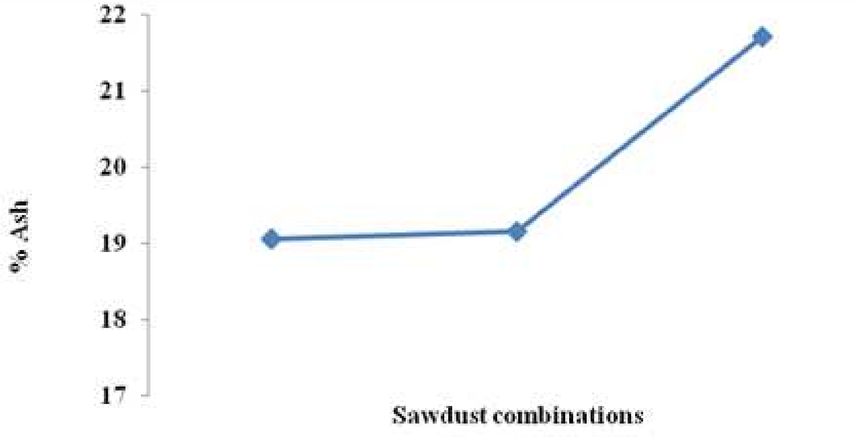

Fig. 2: % Ash of the briquettes

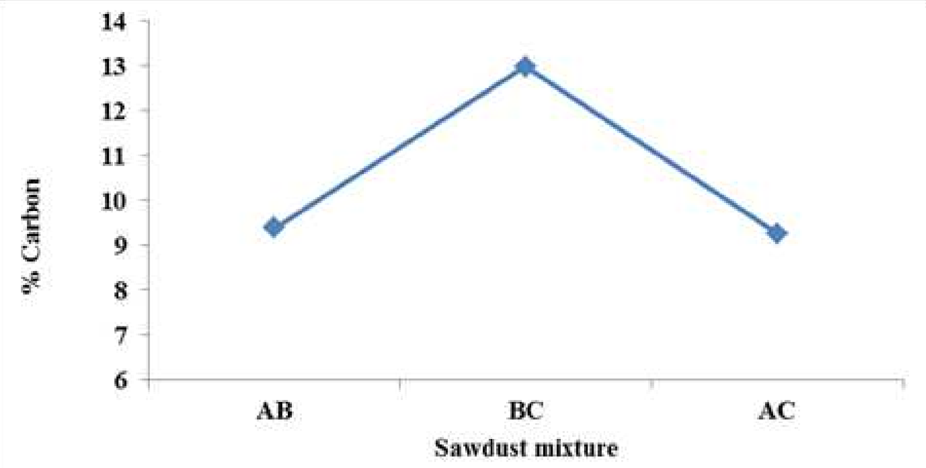

Fig. 3: % Carbon of the briquette

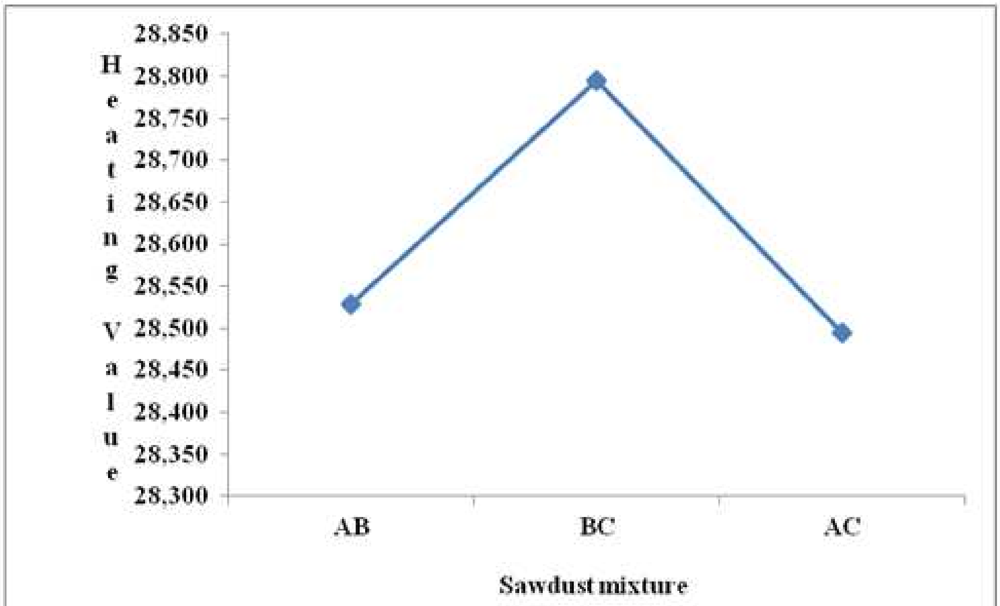

Fig. 4:Heating value of the briquettes

DISCUSSION

[5] reported that many of the developing countries are producing huge quantities of agro and sawmill residues which are used inefficiently, causing extensive pollution to the environment. The major agro residues are rice husk, coffee husk, sugar cane bagasse, groundnut shells, maize cobs and cotton stalks. Sawdust is a milling residue that is also available in huge quantity. Apart from the problems of transportation, storage, and handling, the direct burning of loose biomass in conventional grates is associated with very low thermal efficiency and widespread air pollution

[5]. Greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage are notable merits reported for briquettes [6;7].

The calorific properties of the briquettes produced in this study showed that sawdust from tropical hardwood species, in addition with the type of binder used, are very suitable for briquette production. Sawdust are waist from primary conversion of logs in the sawmills while the binders are raw materials that can be sourced locally too. The efficiency of the use of different agricultural waists and organic binders has been demonstrated by many researchers. But in this work, briquettes produced with cassava starch has the best physical and combustion properties when compared with those produces with cow dung and wood ash. Cassava starch is a good organic binder and its efficiency in briquette production has been demonstarted. [13] observed a better performance with briquettes bonded with starch based on the heating value of 33.09 $MJ \cdot kg^{-1}$, percentage of fixed carbon of 84.70% and low ash and volatile matter of 3.35% and 11.95%, respectively. His values, for the briquettes made from the sawdust of *Azadiractha indica,* were very similar to those obtained in this study. Since the aim of briquetting is to produce good and efficient energy source that can support combustion, [13] recommended the use of sawdust-starch ratio and sawdust-gum arabic ratio for briquetting. In his own study, [14] found sodium silicate to be a better binding agent than molasses for briquette preparation. He reported that among all types of briquettes, saw dust briquettes with sodium silicate at 25% concentration were better in terms of compressive strength, shattering resistance, bulk density and calorific value and hence better for transportation, storage and for burning purposes.

[15] produced briquettes from coconut husk and obtained relatively high calorific values that ranged between 18.1 and 20.8 MJ/Kg, coupled with relative low ash content of between 3.5 - 6%. His values are lower than what were obtained in this present study. This shows that briquettes produced from wood sawdust have higher calorific or heating value than those produced with coconut husk and other agricultural residues. This may have to do with the density of wood species, which is higher than coconut husk and any other agricultural residues. Also, the particle size and shape are of great importance for densification. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results [5].

The heating value of the briquettes in this study is also higher than the values of [16] of 19,534Kj/Kg for briquettes from a mixture of palm kernel cake (PKC) and sawdust and 18,936Kj/Kg for sawdust of some hardwood species. The heating value in this study is also above the DIN 51731 minimum of 17,500Kj/Kg before a material can be regarded as having adequate calorific value. The percent ash is higher than 2.35 and 1.63% reported by [16] for PKC and sawdust and sawdust only respectively. The minimum ash content recommended by DIN 51731 is 0.7% which is far lesser than the range obtained in this study. The percentage volatile matter of 67.98 and 86.53% for briquettes from rice husk and corn cob respectively, that were obtained by [10], are similar to the mean volatile matter obtained in this study. He also obtained a carbon content that ranged between 19.42 and 42.10%, and ash content of between 1.4 and 18.6% and the heating value of 13,389 – 20,890Kj/Kg for the agricultural residues he used. These values are within the range also obtained for the briquettes in this present study. They also compared well with biomass energy obtained from briquettes of groundnut (12,600 kJ/kg); [17], cowpea (14,372.93 kJ/kg), and soybeans (12,953 kJ/kg) reported by [18]. [19]obtained an average heating value and % volatile matter of 4723Kcal/kg and 92.9% for briquettes made from the saw dust of *Albizia zygia* which is little higher than the values in this study.

The energy values and combustion qualities of the briquettes produced in this study are sufficient enough to produce the required heat for domestic cooking and also for industrial application especially the energy requirement of the small-scale industries. The physical properties, especial the low carbon content, make them to be environmental friendly and very safe for the users. There is less risk of lung infection as common with the use of fuel wood. To reduce carbon emissions and greenhouse gas effects, [20] reported that biomasses can be used to replace some coal in power plants. He reported further that briquettes are easy to transport, have better handling and storage, and are very efficient to use as an alternative fuel to coal and firewood. He claimed that the high temperature developed during the high pressure densification process usually assists the inherent lignin, which is the binder in the biomass, to bind the biomass and form a densified fuel called briquettes. In his work, he produced briquettes from four kinds of biomasses (mango leaves, eucalyptus leaves, wheat straw, and sawdust) and discovered that they have more heating value than coal and as a result, they can be used as an alternative to coal and firewood.. [21] reported that the cconversion of sawdust in the briquette factory could potentially save about 5,600 tonnes of trees/year that would have been cut from the forest and that the adoption of sawdust briquetting nationwide could be of immense benefit to any country in terms of climate change mitigation.

CONCLUSION AND RECOMMENDATION

This work was carried out to examine the physical and combustion properties of briquettes produced from sawdust of some selected tropical hardwood species using different binding agents. The quality of the briquettes was influenced by the type of binding agent that was used. The quality of the briquettes that were produced using starch as binder was higher than those bonded with cow dung and ash. There was a little variation in the quality of the product from the mixture of the sawdust of the selected wood species The sawdust from these three hardwood species, in which ever form they are combined, are very suitable for briquette production for domestic and industrial uses. The use of these types of briquettes is environmental friendly, release lesser carbon to the atmosphere, reduce health hazard associated with the use of fuel wood and reduce deforestation and its attended complications.

The best strategy for producing briquette from sawdust that is recommended would include pressing a blend of sawdust with starch. This is done so as to yield maximum heating or calorific value. The use of briquette should be given wide publicity in Nigeria due to the imminent wood shortage and scarcity of other energy sources.

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