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BURNING CHARACTERISTICS OF BRIQUETTE PRODUCED FROM SAWDUST OF *FICUS EXASPERATA* AND CASSAVA PEEL USING DIFFERENT BINDERS

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Abstract
Energy used for domestic application is expensive and utilization of an alternative energy has become imperative. The study evaluated the combustion properties of briquettes produced from sawdust particles of Ficus exasperata and Cassava peel using different binders. Sawdust was mixed with the binders at a ratio (60 : 40) top bond, (40 : 60) starch and (60 : 40) cow dung, while the cassava peel mixed with the binders at a ratio (40:60) top bond, (60 : 40) starch and (40 : 60) cattle dung. This is followed by admixture of sawdust and cassava peel with the binders at ratio (25 : 25 : 50) top bond, (25 : 25 : 50) sawdust and (25 : 25 : 50) cattle dung, and substrate mixed with binders at ratio (20 : 20 : 20 : 20 : 20) respectively. Data analysis was carried out using a two-way analysis of variance. The proximate composition result reveals that the percentage ash content was significant at $p<0.05$. Results on binders revealed that heating value (HV) was highest at starch (32.48Mj/kg) and lowest in cattle dung (30.9Mj/kg) while result on substrate reveals highest HV at sawdust (32.79Mj/kg) and lowest in cassava peel (30.39) with significant higher % ash content (9.5). Therefore, this study reveals that briquette of admixture of sawdust and cassava peel bonded with starch had the best burning characteristics and could be maximized as alternative source to energy.

Keywords: Briquette, sawdust, Cassava peel, Combustion properties, Binding agents, Proximate Analysis, heating value and Two-way ANOVA

1.0 INTRODUCTION

Energy is one of the necessities of life. It is needed to enhance ecosystems and increase comfort for humanity. There are several sources of energy that could serve as a preferable replacement for non-renewable energy sources, such as coal and other fossil fuels [1,2]. Biomass as a veritable source of energy is gaining research interest in both developing and developed countries [3,4]. Biomass remains a renewable source of energy that can reduce greenhouse gas emissions compared to fossil fuels, which have detrimentally contributed to global warming [5].

With rapidly rising global energy needs by the teeming world population [6], and rapid industrialization and urbanization [7], biomass-to-energy is a promising alternative energy technology [8]. Biomass (woody bio-residue) has gained prominence as one of the widely utilized sources of renewable energy fuel. This advantage is a result of the contribution made to the reduction of net greenhouse gas emissions and the security of the energy supply [9]. Moreover, woody bio-residues have continued to gain significant interest and attention because of their renewability, dense nature, and global availability [10].

Currently, there has been a strong worldwide interest in the development of technologies that can exploit renewable energy sources otherwise known as Green Energy, both for environmental and economic purposes. The rate at which wood is being used is increasing on daily basis, especially in the less technologically developed countries of the world, Nigeria inclusive [11]. This has mounted significant pressure on forest resources thereby aggravating the level of deforestation in our immediate environment. Therefore, heavy dependence on wood for domestic cooking would not proffer a solution to the current energy crisis; rather it would continue to aggravate the high level of deforestation or over–exploitation of trees or desertification resulting in further scarcity of this resource [12].

Tremendous wood wastes are generated during various wood conversion processes either in the form of twigs, edgings, trimmings, slabs, and dust. Also, large quantities of agricultural by-products (wastes) are generated. These by-products (wastes) contribute significantly to environmental pollution as they are burnt and when left, they constitute a nuisance in the environment hampering visibility and causing health hazards [13],[19]. Whichever way, this wood waste contributes to the wastage of available energy [13].

Globally, biomass energy has continued to remain an important renewable energy component. It is an important part of the national energy mix both for developed and developing countries towards achieving sustainable energy for heating applications, reducing environmental impact, creating bio-economies, reducing over-dependence on fossil fuel, improving quality of rural and urban life, and for the production of various biofuels [14]. One of the challenges with the utilization of biomass is that they are mostly in loose form, having low energy density. Agricultural biomass residues have the potential for the sustainable production of biofuels and to offset greenhouse gas emissions [15]. Straw from crop production and agricultural residues existing in the waste streams from commercial crop processing plants have little inherent value and have traditionally constituted a disposal problem. These residues represent an abundant, inexpensive, and readily available source of renewable lignocellulosic biomass [15].

Briquetting is a densification process in which loose biomass is compacted under pressure so that the density of biomass residues could be increased up to about 1000–1200 kg/m^3 and the energy content be increased by 8–10 times of the loose biomass because higher density leads to higher energy burning characteristics which is desirable in terms of transportation, storage, and handling. Briquettes with higher density have a longer burning time thereby, densification process improved the mechanical properties of which influences the compressive strength, abrasion resistance and energy content of the briquettes [7]. The briquettes process can be categorized based on binder usage or not. Briquetting with or without a binder requires applied compaction pressure for biomass densification [16]. The making of fuel briquettes from blends of forest and agro-residues demonstrates the potential of appropriate technology for the use of biomass residues as energy fuel [17,18].

Briquetting biomass is a process involved in the production of a solid block material i.e., briquette, charcoal, and other biomass materials that lack plasticity, addition of a sticking or agglomerating material, preferably combustible is required to enable the formation of solid briquettes [17,19]. Frequently used binders are starch, top bond, gum arabic, soil, animal dung, or waste paper. Biomass briquettes in developing countries are mainly for household use. Biomass briquette, a densification technology, is one of the technologies used in improving the potential energy use of biomass primarily for household heating applications and power generation [20]. Biomass generally contains naturally occurring structural binders or stabilizing agents, such as lignin and proteins that are released and activated when biomass is densified at relatively high temperatures and pressure [18,21].

Briquettes could serve as to substitute for firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for firewood and charcoal. Besides, briquettes have well-known merits over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage [14,22].

The enormous quantities of forest and agricultural residues produced in Nigeria can play relevant roles in meeting her energy requirement. Most of these residues are biomass, which contains a large amount of energy [23]. However, these wastes are neither utilized efficiently nor effectively in many developing countries, including Nigeria [24-25]. Instead of allowing wood residues and agricultural by-products to be disposed of ordinarily, there is a need to put them into efficient usage through the production of solid material i.e. briquette as an alternative means to fossil fuel usage and thereby transforming waste to wealth.

Fuel briquettes made from agricultural and commercial residues such as sawdust, weeds, leaves, rice husks, carton board, and scrap paper are a unique, yet well-proven technology for an alternative energy source. results from other reports reveal that briquettes made with sawdust residue exhibited a little lower moisture content compared to coffee husk, khat waste, and dry grass residues and the presence of high volatile matter in wood increases its affinity to burning which results from briquettes formation with a high percentage of binding agent influences the burning rate of briquets, the calorific value was seen high in sawdust compared to other agricultural residues [41].

Therefore, this research aimed to evaluate the burning characteristics of briquettes produced from *Ficus exasperate* and cassava peels using various binding agents.

2.0 MATERIALS AND METHOD

2.1 MATERIALS

This study was carried out at the Wood Laboratory Unit of the Department of Forestry and Wildlife Management, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun state, Nigeria. The University is located at Alabata road in the North Eastern part of the town, Abeokuta, in Odeda Local Government Area. FUNAAB lies on latitude 70 30'N and longitude 30 54'E. It lies within the humid lowland forest region with two distinct seasons. The mean annual rainfall is 1113.1 mm with a mean temperature range of 22.9 °C to 36.32 °C and relative humidity is about 82.54% [26].

The sawdust was collected from a sawmill around FUNAAB Campus Abeokuta, Ogun State, casava peel and the binding materials were also collected within the area, and briquettes machine were locally fabricated.

2.2 METHODS

2.2.1 Substrate Preparation

The sawdust particles of *Ficus exasperata* were soaked in hot water for 24 hours to reduce extraneous materials, make it easier to agglomerate with the binders, and produce a smokeless briquette. After soaking, it was sundried for 2 (two) days to reduce the excess moisture and later screened with the sieve of constant size 2mm to obtain uniform grain size distribution, see figure 1. The cassava peel was obtained manually from local farmers with the FUNAAB Campus and was sundried for 6 (Six) days to reduce the moisture content to between 8-12% which is within the acceptable operating limit and the cattle dung was obtained from the animal unit of the FUNAAB and sundried for 6 (six) days, see figure 2, for briquettes before it was shredded [27-28]. The top bond and starch were obtained from the market within the FUNAAB campus in Abeokuta.

2.2.2 Substrate and Binding ratio

Sawdust particles of *F.exasperata* and Cassava peels were bonded with different binding agents (cassava starch, top bond, and cattle dung). The choice of binders and substrates are often influenced by number of factors such as availability, cost, the raw material properties, moisture content, densification pressure and the desired energy content of the briquettes. The weight of the sample was used to determine the effect of the binder's concentration on the physical and chemical characteristics of the briquettes produced.

Different ratio was used by weighing raw materials (sawdust and casava peel) and corresponding binders using digital weighing scale, 60g of sawdust of *F.exasperata* was mixed with the 40g of the binder at a ratio (60 : 40) for the top bond, (40 : 60) for starch, and (60 : 40) for cattle dung, while the cassava peels were mixed with 40g of cassava peel with 60g of the binders in the ratio of (40 : 60) for the top bond, (60 : 40) for starch and (40 : 60) for cattle dung, followed by the combination of sawdust and cassava peels with 25g (sawdust), 25g (casava peel) and 50g of the binder at the ratio of (25 : 25 : 50) for the top bond, (25 : 25 : 50) for sawdust, (25 : 25 : 50) for cattle dung, and the mixture of sawdust, cassava peel mixed with top bond, starch, and cattle dung in the weight 20gram each of the substrate and binders ratio at (20 : 20 : 20 : 20 : 20) respectively. Binders have significant influence on the quality and properties of briquettes The binder was used to increase the heating time and strength of the output.

2.2.3 Briquette Production Processes

Each substrate (i.e. sawdust and cassava peel) and the binders were weighed on the top weighing scale to get the stipulated ratios, then each treatment was thoroughly mixed respectively with its binder and later the mixed treatment(s) was hand-fed into the locally fabricated rectangular shaped metallic briquette mold (10cm x 5cm) for the formation of briquette whereby a hand iron press of 100MPa was used to compress the treatment in other to give it strength and increase the binding ability of the binder in the mixture (treatments). Twenty cylindrical briquettes with diameter of 4cm and 2.5cm were produced from mixture rations of binders. The formed briquettes were sun-dried for 21 days in other to obtain suitable moisture content of about 12% and proximate analyses were investigated. Each sample produced was also subjected to a test for calorific value. Proximate analysis was carried out on the briquette samples to determine the percentage volatile matter content, percentage ash content, percentage content of fixed carbon, and heating value of the samples using formula equations (1, 2, 3, 4, 5 and 6) and the procedures of ASTM E711-876 [29] were adopted.

Figure 1: *Ficus exasperate* Sawdust

Figure 2: Cattle dung (8% Moisture Content)

Figure 3: Starch

Figure 4: Sawdust bond with Starch

Figure 5: Casava briquettes

2.3 DETERMINATION OF PHYSIOCHEMICAL PARAMETERS

2.3.1 Determination of Density (g/cm3)

This is one of the most important mechanical and combustion characteristics which determine the handling, storage, and transportation characteristics of solid fuel. The density of the briquette was determined according to ASAE S269.4 standards. Since density is a property of mass against volume, the process of determining the density of the briquette was accomplished as follows. The density of briquettes was then determined using Equation (1).

$$\rho = \frac{m}{v} \quad (1)$$

Where; ρ, m, v are sample density, mass and volume respectively.

2.3.2 Determination of Moisture Content (wt %)

The percentage moisture content was determined using the standard method of ASTM D2444-16 according to [42] 2 g of each sample briquette was weighed out in a washed glass. The sample was placed in an oven dryer for 24 hours at 105 ± 3°C. This procedure was repeated until a constant weight was obtained. The percentage of moisture content was calculated using the following equation (2).

$$\text{PMC} = \frac{\text{wet weight(W1)} - \text{Dry weight(W2)}}{\text{weight wet(W1)}} \times 100 \qquad (2)$$

Where; W1 is initial weight, W2 is weight after drying, and PMC is the percentage moisture content.

2.3.3 Percentage Ash Content (PAC)

The Percentage Ash Content (PAC) was determined as described by Abere,[27] and Olayiwola et al.,[47]. 2g of the briquette sample was converted to ash in the muffle furnace at a temperature of 550 °C for 4 hours and weighed after cooling it in a desiccator to obtain the weight of ash (C). The procedure the ASTM standard D5373-02 was adopted to obtained the parameters. The PAC was determined using Equation (3)

$$\text{PAC} = \frac{C}{A}100 \qquad (3)$$

Where; C is Weight of the ash after cooling in desiccator, and A is Weight of the oven-dried sample.

2.3.4 Percentage Volatile Matter (PVM)

The Percentage of Volatile Matter (PVM) was described by Imeh et al.,[34]. 2g of the briquette was pulverized and oven-dried until a constant weight was obtained using the ASTM standard method CEN/15148. The briquettes were then kept in a furnace at a temperature of 550 °C for 10 minutes and weighed after cooling in a desiccator. The PVM was calculated using Equation (4).

$$\text{PVM} = \frac{A-C}{A}100 \qquad (4)$$

Where; C is Weight of the sample after 10min in the furnace at 550°C, and A is Weight of the oven-dried sample

2.3.5 Percentage Fixed Carbon

$$\text{Fixed Carbon} = 100\% - (PVM + PAC + PMC) \qquad (5)$$

Where; %V is percentage volatile matter, and %A is percentage ash content

2.3.6 Heating Value/ Caloric Content

The specific Heat Value of Combustion (HC) was calculated using Equation (6).

$$\text{Hc} = 2.326\,(147.6c + 144\,v) \qquad (6)$$

Where; HV is Heating value, C is Percentage fixed carbon, and V is Percentage volatile matter, ASTM, D5865-13 [42].

2.4 STATISTICAL ANALYSIS

The statistical analysis was performed using a computer software program (statistical package for social science (SPSS) version 20. Significant differences between variables were determined using Duncan Multiple Range Test ($DMRT_{0.05}$) to separate the variable means at $P < 0.05$. Descriptive statistics were also carried out on the data entry and analysis and to creates tables and graph.

3.0 RESULTS AND DISCUSSION

3.1 PROXIMATE ANALYSIS OF THE BRIQUETTE'S SUBSTRATES AND DIFFERENT BINDERS

Table 1 shows the Randomized Complete Block Design (RCBD) (Two-way ANOVA) of briquette properties according to the substrates and the binders.

The result revealed that there was no significant difference (P>0.05) in the effects of the substrates on the proximate composition properties. However, for the substrates and binders, there were significant differences (P<0.05) in the effects of the binders on the proximate properties except for PAC binders that has no significant difference at (P>0.05) however the effect of the binders is similar as shown in the result table 1. $DMRT_{0.05}$ was used to determine which of the binders differs from one other based on the percentage of volatile matter, percentage of fixed Carbon, and the heating values but not based on the percentage of ash content since they have a similar effect based on the effect of substrate. The result on binders revealed that there were significant differences between the percentage of volatile matter, percentage of fixed carbon, and heating value while the result on substrate revealed they are not significantly different.

3.2 MEAN PROXIMATE ANALYSIS OF THE BRIQUETTES ACCORDING TO THE BINDERS

The mean effect of the briquettes based on the binders' proximate properties was presented in Table 2. The % of moisture content means was 10.43±1.99. Starch had the highest at 12.51 while the least was seen in cattle dung at 8.55. The % volatile matter mean has 83.5 ± 6.1. Starch had the highest 88.0 ± 2.0, followed by Top Bond 86.0 ± 3.83 while cattle dung had the least 76.5

± 7.42. The mean percentage of Ash content was 19.67 ± 2.21. Result reveals that the percentage of ash content was significant produced by the briquettes for all the binders. The highest was obtained with the use of the top bond (44.75 ± 4.66) followed by cattle dung 11.0 ± 6.63 while starch had the least 3.25 ± 0.96 percentage ash content. Percentage carbon content was significant in cattle dung had the highest 15.0 ± 4.08 followed by starch at 8.75 ± 2.87 while the Top bond had the least 7.5 ± 2.38. Mean of heating value was 31.58±0.81MJ/kg. Starch had the highest heating value at 32.48±0.34MJ/kg followed by Top bond (31.38 ± 0.79MJ/kg), and the cattle dung 30.9 ± 3.63MJ/kg had the least. There are no significant differences in the % fixed carbon, % volatile matter, and heating value but the % ash content has a significantly different effect on briquettes produced by the binders ($p<0.05$).

3.3 MEAN PROXIMATE ANALYSIS OF THE BRIQUETTE'S SUBSTRATES AND THE MIXTURE

The mean effects of the substrates (Sawdust with Cassava peel, sawdust with top bond, and sawdust with cattle dung) based on the briquette's properties were presented in Table 3. %Volatile matter mean was 82.28 ± 2.91. The highest value was recorded on sawdust (85.5 ± 5.43) followed by cassava peel (81.5 ± 8.09) while the mixture had the least (79.83 ± 5.49). %Ash content was 6.67 ± 2.62 and cassava peels recorded the highest at (9.5 ± 5.99) followed by mixture (6.17 ± 3.76) while sawdust had the least (4.33 ± 1.63) %Ash content. %Carbon produced by the substrates was 11.05 ± 1.80. However, the mixture had the highest % carbon (12.33 ± 3.2) followed by sawdust (11.83 ± 5.71) and cassava peels had the least (9.0 ± 2.61). The heating value mean was 31.33± 1.28MJ/kg. Briquette produced by sawdust had the highest heating value 32.79 ± 1.41MJ/kg followed by that produced with the mixture (30.81 ± 1.77) MJ/kg and that produced with cassava peel had the least (30.39 ± 1.98) MJ/kg.

Table 1: Showing the proximate composition of the briquettes according to the substrates and different binders

Sources of Variation	DF	SS	MS	F Cal	P-Value	F-Crit
Substrates	1	24.0	24.0	1.71	0.21	18.51[d]
PVM Binders	2	41984.5	2099.45	1499.45	0.01	19.0[a]
Error	2	28.0	14.0			
Total	**5**	**42036.5**				
Substrates	1	40.04	40.04	4.20	0.07	18.51[c]
PAC Binders	2	347.63	173.82	18.20	0.177	19[cd]
Error	2	19.08	9.54			
Total	**5**	**406.75**				
Substrates	1	2.042	2.042	0.505	0.21	18.51[d]
PFC Binders	2	578.13	289.06	71.55	0.04	19[ab]
Error	2	8.08	4.04			
Total	**5**	**588.25**				
Substrates	1	4.54	4.54	4.284	0.10	18.51[cd]
HV Binders	2	5874.26	2937.13	2770.87	0.03	19[ab]
Error	2	2.12	1.06			
Total	**5**	**5876.38**				

Mean values with the same subscript in the same column are not significantly different ($P \leq 0.05$)

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

	Proximate composition					
Binders	**%MC(wt.%)**	**%VM(wt.%)**	**%AC(wt.%)**	**%FC(wt.%)**	**CV(MJ/kg)**	Mean
Starch	12.51±3.0[a]	88.0 ± 2.0[a]	3.25 ± 0.96[d]	8.75 ± 2.87[b]	32.48 ± 0.34[a]	28.99±15.55[b]
Top Bond	10.22±4.01[ab]	86.0 ± 3.83[ab]	44.75 ±4.66[a]	7.5 ± 2.38[bc]	31.38 ± 0.79[b]	35.97±14.27[a]
Cattle dung	8.55±2.60[b]	76.5 ± 7.42[b]	11.0 ± 6.63[c]	15.0 ± 4.08[a]	30.9 ± 3.63[b]	28.39±12.64[c]
Mean	10.43±1.99[ab]	83.5 ± 6.14[ab]	19.67 ± 22.07[b]	10.41 ± 4.01[ab]	31.59 ± 0.81[b]	31.09±7.65[ab]

Mean values with the same subscript in the same column are not significantly different ($P \leq 0.05$)

Table 3: Mean proximate analysis of the briquettes according to the Substrates and the mixtures

	Proximate composition			
Substrate	**%Volatile Matter**	**%Ash**	**%Carbon**	**Heating Values**
Sawdust	85.5 ± 5.43[a]	4.33 ± 1.63[c]	11.83 ± 5.71[a]	32.79 ± 1.41[a]
Cassava peel	81.5 ± 8.09[b]	9.5 ± 5.99[a]	9.0 ± 2.61[b]	30.39 ± 1.98[b]
Mixture	79.83 ± 5.49[c]	6.17 ± 3.76[ab]	12.33 ± 3.2[a]	30.81 ± 1.77[b]
Mean	82.28 ± 2.91[ab]	6.67 ± 2.62[ab]	11.05 ± 1.80[ab]	31.33±1.28[ab]

Mean values with the same subscript in the same column are not significantly different ($P \leq 0.05$)

3.4 PROXIMATE ANALYSIS

The result from Figure 4 reveals better performance with starch as a binder, from the result of analysis conducted on the briquette produced with different substrates and binders, the heating value/calorific content produced from the mixture of sawdust and cassava peels using cassava starch (see figure 3) as a binder gave the best physical and combustible properties when compared with those produced from sawdust or cassava peel using cassava starch, top bond, and cattle dung, see figure 5.

3.4.1 Heating Value

The gross or high heating value is the amount of heat produced by the complete combustion of a unit quantity of fuel. The heating value produced by the mixture of sawdust and cassava peel bonded with starch was 33.11MJ/kg, and is within the range of 33.09 MJ/kg and 30075.39-31796.94 KJ/kg recorded by Abera [27] and Idah and Mopah [31], on rice husk, maize cob, groundnut shell, and sugar cane bagasse.

The result compares favorably with the results of the heating value reported by Obi [20] on sawdust feedstock and Biomass Briquette Binders and Quality. The calorific values of the briquettes were in the range of 19.4–24.9 MJ/kg [6] which is less than the calorific value of the result from this study. This could be a result of the initial carbonization of the charcoal. The heating value determines the energy content of a fuel. It is affected by the chemical composition and moisture content. It is the most important fuel property [32].

The heating value from this result proves to be suitable for domestic use such as cooking, barbequing, and small-scale cottage applications [33]. The calorific value determines the amount of heat energy present in a material., From the result obtained from table 3, the highest calorific value was seen in sawdust at the value of 32.79±1.41MJ/kg shown in table 3, and lowest in cassava peel with a value of 30.39±1.9832.79±1.41MJ/kg. These differences observed from the findings of these studies could be attributed to the manufacturing condition of the briquette such as temperature and pressure can influence the briquette's proximate composition value [34].

3.4.2 Fixed Carbon Content

High percentage fixed of carbon content of 12.33% was recorded for the mixture which is lower as compared with coffee husk and sawdust with waste paper as a binding agent as report by Abera [27] which has higher fixed carbon of 23.30%, these must have been responsible for the high heating value obtained from the mixture of sawdust and cassava peel bonded with starch. This is because carbon supports the combustion of materials. The presence of starch content also has a major effect on the burning and heating value of the briquette produced. The increase in fixed carbon when compared to the overall constituents is most likely due to the concentration of binders in briquette preparations [33], [35].

3.4.3 Volatile matter

The volatile matter of briquettes obtained from this study was greater than VM produced from the production and characterization of coffee husk and sawdust briquettes with potato peel, waste paper, and molasses as binding agents [27]. The amount of volatile matter therefore strongly influences the thermal decomposition and combustion behavior of solid fuels i.e. briquettes VM are gases that are expelled from incomplete combustion which contribute to release significant amount of smoke and toxic gases, these gases include CO_2, CH_4, SO_2, and ash content generally increases, this shows the number of volatile gases that will be emitted during ignition or burning process of briquettes [44]. It is the inorganic matter left out after the complete combustion of the biomass.

From the result, the values of volatile matter and ash content of 84.5 % and 2.5% respectively are good and acceptable when compared with 3.35% of ash content and 84.7% of the volatile matter recorded by Sotande et al., [36] with percentage fixed of carbon 11.95. The sample with the least volatile matter is expected to have the highest percentage fixed of carbon and the highest Volatile matter will have the highest heating value [34].

3.4.4 Ash content

The ash content of the briquettes produced in this study was lowest in sawdust at 4.33% and highest at cassava starch at 9.5% which is lower to report reported on ash content from rice husk and coffee husk at 16% and 10.73% respectively [27]. However, recommended ash content of fine quality ash content is 3%, and the result of the study reveals higher than the specified range. This might be due to the effects of binders used to bind the combustible biomass (cassava starch and sawdust.

3.4.5 Moisture content

The moisture content of briquettes produced in this study had smaller moisture content than the briquette produced from rice husk which was 12.67% [45]. The quality specification of charcoal usually limits the moisture content by 5-15%. Therefore, the MC of briquettes obtained in this study was in-line with specifications, however, to facilitate heat transfer, MC should be as low as possible [46].

The analysis conducted in this study showed that the briquette made by the mixture of sawdust and cassava peel using starch as binder has the higher heating values than the durian peel conducted by Awulu et al., [37] with the heating mean value of 20.265MJ/Kg and compares favorably with the results of the heating value of sawdust briquette obtained by Chaiklangmuang et al., [38] and other researchers like Adegoke and Ogunsanwo [39] whose finding on heating mean value agrees at 32.43MJ/kg which has worked on the following biomass briquettes produced from Bio Char sawdust from *Gmelina arborea*. The amount of ash content tells the extent of clogging up of the medium. From the result of the study, the high ash content of cassava peel was 9.5±5.99 decreasing the burning rate and reducing the heating value of fuel at 30.39±1.98 as seen in table 3, which confirmed a similar report of [34], [40].

4.0 CONCLUSION

The following conclusions were deduced based on the experimental investigations.

1. From this study, it was clear that both the sawdust of *Ficus exasperata* and cassava peels successfully produced briquettes that could serve as an alternative to kerosene and gas whose costs are increasing at an alarming rate which would also reduce the increasing pressure on the forests.
2. A combination of briquettes mixture of sawdust and cassava peels exhibited the best properties from the study and the quality of the briquette produced were influenced by both the types of biomass material and binding agents that were used as starch to produce the best briquettes.
3. The quality of the briquettes that was produced using starch as a binder was higher than those bonded with top bond and cattle dung and the fuel generated by the briquettes is eco-friendly i.e it releases lesser amount of carbon to the atmosphere which minimizes global warming effect resulted from the use of fuel wood.

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