

# Physicochemical properties and thermal characteristics of biomass briquettes with enhancement from coal additives

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## Abstract

*This study aims to determine the physical, chemical, and thermal characteristics of briquettes produced from local sugarcane bagasse from Jambil village and Maiganga coal. The samples were produced by mixing bagasse and coal with coal ranging from 5% to 20% in step of 5% and adding 0.081g, 0.102g, 0.263g, and 0.342g in samples BC5, BC10, BC15, and BC20 respectively. The sample with 0% coal and Ca(OH)<sub>2</sub> (g) is the BC0 and taken as control sample. Fixed carbon (FC), ash (AC), moisture (MC), and volatile matter (VM) contents in addition to carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) of all the samples were determined. Also, the density (ρ), Sulphur (S), sulphur dioxide (SO<sub>2</sub>), specific fuel consumption (SFC), and heating value (HV) were determined. The study shows that the produced sample BC20 had an increase in C and FC contents from 41% to 68% and 6% to 17% respectively as compared to BC0. S, N, and AC contents increased as coal content increased from 0%, 0.16%, and 3.99% respectively in the control sample to 0.79%, 1.68%, and 11.0% respectively in the BC20. The maximum SO<sub>2</sub> reduction of 22% was obtained in BC10. H, O, VM, and MC decreased with a decrease in bagasse content in the samples from 5.9%, 43.6%, 76.2%, and 8.2% respectively in the control sample to 5.7%, 23.3%, 50.2%, and 6.1% respectively in BC20 sample. These raised the density of the samples from 0.39 to 0.7kg/m<sup>3</sup>, which also increased the heating characteristics of the samples. SFC and boiling duration decreased as coal content increased and increased the heating value from 16MJ/kg to 22MJ/kg. All the produced samples had reduced S content and higher heating value than most of the common firewood used in the study area. The samples are suitable for use in domestic, small, and medium enterprises.*

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## 1. Introduction

Sustainable energy systems are needed to deal with increasing energy demand and reduce greenhouse gas (GHG) emissions and other polluting gases. The oldest known and used source of renewable energy is biomass which has reasonable fixed carbon contents and other fuel requirements hence an essential supplement for the world's energy resources. Even though biomass are the only renewable resource that can be used directly as fuel through combustion processes, they are not suitable for use as an energy source. This is due to their precarious characteristics. These characteristics include low bulk density, high moisture content, and low energy density, causing high transportation, storage, and handling costs [1, 2]. Among the various kind of biomass available, agricultural residues are the most promising choices for local cooking and heating source in developing countries like Nigeria as they can directly be used as fuel. Nevertheless, a majority of agro-waste is not suitable for an energy source because they are bulky, uneven, and porous and have a low energy density, and releases too much smoke. All these characteristics make them difficult to handle, store, transport, and utilized in their raw form [1, 3, 4].

Numerous agricultural residues and wastes are generated throughout the world every year, especially in developing countries. These agro wastes are poorly utilized since most of them are left to decompose or are burned in the field resulting in

environmental pollution and degradation [1, 2, 5]. However, several studies have iterated that a lot of potential energy is stored in these residues which can be converted to heat for domestic and industrial applications [2, 3, 5, 6]. Hence there is a need to subject them to the conversion process to improve their utilization potential and mitigate the problems associated with them [3, 4]. One of the promising solutions to these problems is the application of briquetting technology by improving energy density and reducing their inherent unwanted residue [2, 4, 7].

Bagasse is a fibrous by-product of sugarcane processing that is a potential energy source called sugarcane bagasse with a high calorific value of 17 MJ/kg to 19 MJ/kg dry mass bases. Bagasse contains about 35 to 50 wt. % cellulose, 20 to 30 wt. % hemicelluloses, 20 to 27 wt% lignin, and 8 to 12 wt.% extractives which are the major energy and binding components [8, 9]. Generally, the density of bagasse is difficult to determine due to the porosity of its particles and fibers. The dust-like particles have a much lower density of 220 kg/m<sup>3</sup> compared to the fibrous particles a density of 550 kg/m<sup>3</sup> of bagasse [9]. Olorunnisola [5], Mahmud and Anannya [9] and Usman, *et al.* [10] reported that average bagasse has a fixed carbon of 20.100%, volatile matter of 75.800%, ash content of 4.200%, and high heating value (HHV) of 18 MJ/kg. It also contains 44.100% carbon, 5.260% hydrogen, 44.400% oxygen, and 0.190% nitrogen.

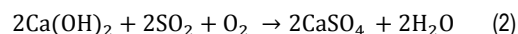
Coal is a natural organic material having high calorific value therefore, it is considered a fuel for domestic, electricity generation, and other industrial applications [11, 12]. Usman [11], Rahman, *et al.* [12], and Bowen and Irwin [13] reported that generally, coal has a moisture content of 2 to 60 %, ash content of 3 to 60 %, and volatile matter of 20 to 31 % which depends on the coal grade. They also show 98 to 40 % carbons, 1.3 to 0.1% sulphur, a calorific value of 4000 to 2200 kJ/kg, and a density of 1500 to 1100 kg/m<sup>3</sup> from anthracite to lignite coal. According to Usman [11] and Folahan *et al.* [14], Nigeria has several deposits of coal which include Iva, Chikila, Maiganga, Onyema, Lamja, Okpara, Okaba, and Lafia obi with an average carbon of 72.460%, hydrogen of 6.070%, nitrogen of 1.630%, sulphur of 1.410%, oxygen of 18.430% and heating value of 30.520 MJ/kg. They also have moisture content of 5.140%, volatile matter of 40.730%, ash content of 14.940%, fixed carbon of 39.180%, and 17.250% mineral matter. Usman [11] reported that Maiganga coal a deposit in the study area has an average moisture content of 4.18%, ash content of 49%, volatile matter of 31.11%, fixed carbon of 15.640%, a sulphur content of 0.920%, and a calorific value of 22.830 MJ/kg. This makes it suitable for domestic and industrial chemical and energy sources.

Briquettes are formed by carbonizing and compressing biomass with the aid of a suitable binder to an ingot in the form of pellets, disks, or cylindrical blocks. This process yields a high energy density, mass density, and calorific value and low moisture solid fuel which are easier to handle, store, and transport. It has been reported that briquettes produced under different conditions require different handling and storage characteristics and transportation methods. These characteristics are found to be strongly affected by the kind of raw material and its associated physical, mechanical, and chemical properties [1, 2, 6, 15].

There are several hundred tons of local bagasse available in northeastern Nigeria due to the high production of sugarcane for local and conventional sweets and sugar production and street consumption. Therefore, there is a need to find a suitable method for utilizing these abundant wastes. In addition, there exists a high thermal potential for coal deposits in the region. As stated earlier, the most technically feasible and environmentally friendly approach is the briquetting technology. Therefore, this study will evaluate the thermal, chemical, and physical characteristics of briquettes produced from bagasse obtained from local sugarcane squeezing factory for making local chocolate and sugar located at Jambil village Bauchi state. The effect of adding coal obtained from Maiganga village Gombe state in a reasonable percentage into the bagasse will also be examined.

## 2. Methodology

The raw materials used in this study include coal powder which was ground, washed, and dried, smaller chopped sugarcane bagasse, calcium hydroxide, and water. The coal was obtained from Maiganga village in Gombe State while local bagasse was obtained from Jambil Village in Bauchi State Nigeria. The study made use of calcium hydroxide collected at no cost from a roadside gas welding shop (a product of reacting calcium carbide and water) as a de-sulphurising agent. The raw materials were mixed according to the ratio shown in Table 1. There is no need for a binder in this study as sugarcane bagasse contains enough lignin that will bind the raw materials together. The mixture was compressed to a pressure of 50 MPa using a compression machine under a dwelling period of 30s. When coal is burned in the presence of oxygen (O); sulphur (S) present in the coal reacts with oxygen according to equation (1). The primary calcium reagent being widely utilized is hydrated lime or calcium hydroxide (Ca (HO)<sub>2</sub>) and the basic reaction that results in the capture of SO<sub>2</sub> is outlined in equation (2).



The molar mass of sulphur (S) and oxygen (O<sub>2</sub>) is 32g/mol that of sulphur dioxide (SO<sub>2</sub>) is 64g/mol. It is obvious that the molar mass of SO<sub>2</sub> doubles that of sulphur. Maiganga coal contains about 0.9% sulphur by weight as reported by Usman [11]. For every 100g of Maiganga coal, it will contain 0.9g sulphur. Based on this, the amount of SO<sub>2</sub> that will be produced if this coal was burned is  $(2 \times 0.9) = 1.800g$  SO<sub>2</sub>. From equation 2, both calcium hydroxide and sulphur dioxide are in a mole ratio of 1:1. Molar mass of calcium hydroxide is 74g/mol and that of sulphur dioxide is 64g/mol. For complete desulphurization, 74g of Ca(OH)<sub>2</sub> will be required to remove 64g of SO<sub>2</sub>. Therefore, the quantity of Ca(OH)<sub>2</sub> that will remove 1.800g SO<sub>2</sub> is:

$$1.800 \times \frac{74}{64} = 2.080g \quad (3)$$

This research will make use of Ca/S ratio of 2:1 hence the amount becomes  $2 \times 2.080 = 4.160g$ . Using these relations (equations 1 to 3), the quantity of Ca(OH)<sub>2</sub> required for each sample is calculated. The samples were tagged by combination of bagasse and coal (BC) and numbered according to percentage coal content i.e. BC0 to BC20 as can be seen in Table 1.

Table 1: Experimental raw material mixture ratio

Raw material	Units	BC0	BC5	BC10	BC15	BC20
Bagasse	g (%)	42 (100)	39.900 (95)	37.800 (90)	35.700 (85)	33.600 (80)
Coal	g (%)	0 (0)	2.100 (5)	4.200 (10)	6.300 (15)	8.400 (20)
Ca(OH) <sub>2</sub>	g	0	0.081	0.182	0.263	0.342

Fixed carbon (FC), ash (AC), moisture (MC), and volatile matter (VM) contents in addition to carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) of all the samples were determined. Also, the density ( $\rho$ ), Sulphur (S), sulphur dioxide (SO<sub>2</sub>), calorific value (CV), and specific fuel consumption (SFC) of the produced samples using different stoves were determined. The detailed methodology was described in previous studies of Garkuwa [16] and Garkuwa, *et al.* [17]. The CV was obtained using ASTM standard E711-87 while SFC was calculated using the following equation 4 and utilizing the mass of the fuel consumed ( $m_f$ ) during boiling of a given mass or volume of water ( $m_w$ ).

$$S.F.C = \frac{m_f}{m_w} \quad (4)$$

## 3. Results and discussion

The chemical compositions of the samples are shown in Table 2. The chemical compositions of the produced samples as given in Table 2 have a substantial impact on the overall quality of the briquettes. Carbon, nitrogen, and sulphur contents increase from the control to BC20 with an increase in the percentage of coal addition in the samples. Carbon content increases as a more concentrated form of carbon are added to the sample (i.e. coal) from 41.212% in the control sample (i.e. 100% Bagasse) to a maximum of 68.112% in BC20 (i.e. 20% coal replacement). Sulphur also increases as more sulphur-bearing coal is added to the samples as can be seen from 0% sulphur in bagasse (i.e. BC0) to about 0.793% in the BC20 sample. The quantity of hydrogen and oxygen decreases with an increase in the

percentage of coal replacement in the samples from BC0 to BC20. There was a small decrease in hydrogen content from 5.911% in BC0 to 5.712% in BC20 which is about a 5.500%

reduction. There is a significant decrease in oxygen content from 43.582% to 23.322% for BC0 to BC20 respectively, which is about an 87% reduction as the number of coal increases.

Table 2: Chemical composition of the produced briquettes

Elements	Symbols	Percentage of Coal in Samples				
		BC0	BC5	BC10	BC15	BC20
Carbon	C	41.212	61.981	63.001	65.101	68.112
Hydrogen	H	5.911	5.882	5.821	5.732	5.712
Nitrogen	N	0.161	1.192	1.332	1.453	1.682
Sulphur	S	0.000	0.671	0.712	0.762	0.793
Oxygen	O	43.582	30.161	29.072	25.322	23.322
Volatile Matter	VM	76.151	70.001	62.042	53.503	50.222
Ash Content	AC	3.991	8.582	9.172	9.973	11.001
Fixed Carbon	FC	5.642	14.602	14.932	15.892	17.233
Moisture Content	MC	8.212	7.612	7.323	6.773	6.161

Volatile matter and moisture contents decrease from 76.151% to 50.222% and 8.212% to 6.161% respectively as the percentage of coal replacement increases. This reduction was due to the inclusion of higher density and more compacted coal into the loose, porous, and scattered bagasse samples as seen in Table 2.

As reported by different authors the process of densification of coal increases the carbon content and reduces the VM and MC of the biomass. Also, reducing the VM and MC means increasing the concentration of other minerals oxides in the coal which end up becoming ash after burning thereby

increasing the ash content in the samples. These can be seen from the decreasing nature of oxygen in the samples. Fixed carbon contents increase as the percentage of coal replacement in the briquettes samples increases. The variations of chemical compositions is also explained in the physical and thermal properties of the produced samples. Increasing in carbon densely material (coal) increases the mass and energy density of the briquettes which consequently increases the heating value and reduces specific briquette's consumption and time taken to boil a given quantity of water as can be seen from Figures 1 to 5.

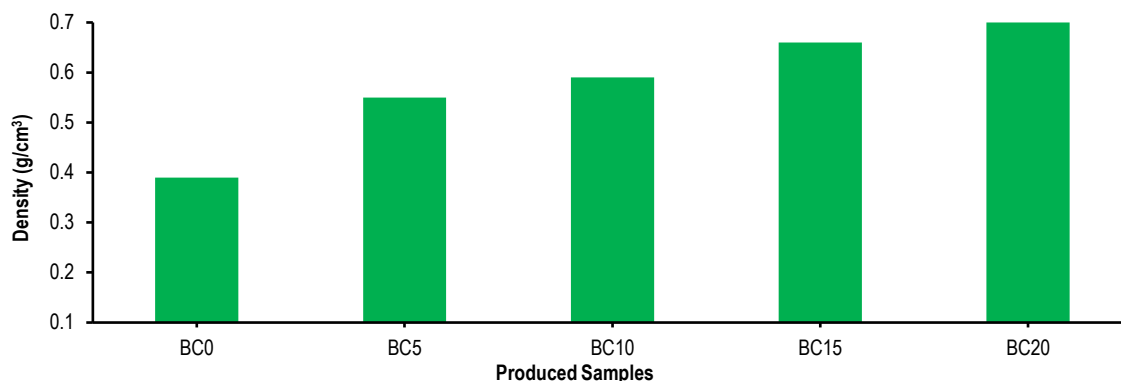
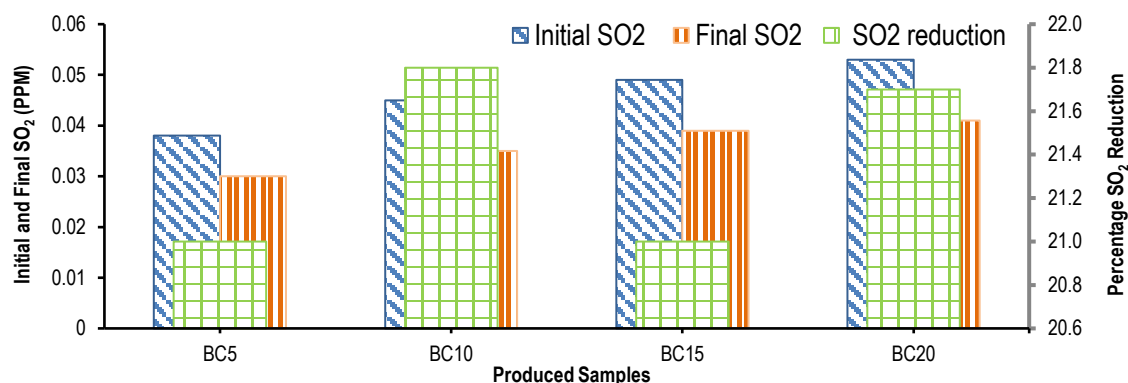


Figure 1: Densities of the produced briquettes

Density is an important property of solid fuel as high-density products are more desirable in terms of transportation, storage, and handling. It has been stated that the density of biomass briquettes depends on the original biomass. The result of density in Figure 1 shows that density increases with increase in the percentage of coal in the samples as coal is by far denser than sugarcane bagasse due to its high porosity and loose shape. The density increases from 0.397 g/cm<sup>3</sup> in sample BC0 (as it contains no coal in the sample) to a maximum of 0.703 g/cm<sup>3</sup> obtained in sample BC20 (as it contains the highest quantity of coal as compared to all the samples). According to Olorunnisola [5], the average compressed density of the briquettes (i.e., density determined immediately after compression) ranged from 8.100 g/cm<sup>3</sup> to 11.200 g/cm<sup>3</sup>, while the average dry density ranged from 3.700 g/cm<sup>3</sup> to 6.300 g/cm<sup>3</sup>. These values give a

relaxation ratio (i.e. ratio of compressed density to relaxed density) of between 1.8 and 2.5. Marrero, *et al.* [2] reported densities from different studies and used different biomass in the production of briquettes which show similar variation to the present studies. Mulindwa, *et al.* [4] reported a density increase from 214 to 941 kg/m<sup>3</sup> and 869.100 to 958.300 kg/m<sup>3</sup> when using homogeneous and heterogeneous combinations of carbonized maize cobs, bamboo poles, and charcoal dust. Suttibak and Loengbudnark [18] reported a density of 1,494±10.100 kg/m<sup>3</sup>, 1,146±23.700 kg/m<sup>3</sup>, and 696.2±6.000 kg/m<sup>3</sup> when determining the effect of sugarcane bagasse (SB), cassava rhizomes (CR) and water hyacinth (WH) on charcoal briquettes respectively. Even though some used a different material, the variation when adding biomass to charcoal briquettes is similar to the current study.

Figure 2: Reduction of SO<sub>2</sub> gas emitted from the briquettes

The result of the percentage decrease in the amount of SO<sub>2</sub> gas emitted by the samples of sugarcane bagasse-coal briquette is shown in Figure 2. It shows the results of four samples i.e. BC5, BC10, BC15, and BC20, this is because they are the samples containing Maiganga coal, and BC0 is assumed to be green (no sulphur). The percentage reductions in the samples were 21.000%, 21.800%, 21.400%, and 21.700% respectively for BC5, BC10, BC15, and BC20. This is because the de-sulphuriser added to the samples depends on the amount of coal in the samples which also depends on the sulphur content; these amounts were calculated based on mass balance

technique equation 2. The presence of sulphur in the fuel is undesirable if the amount of pollutants emitted during combustion exceeds the standard limit. The standard limit is 0.1ppm, (part per million) for SO<sub>2</sub> [14, 19]. The results shown in Figure 2, indicate that the value obtained is well below the permissible limit for SO<sub>2</sub> gas. These show that all the samples produced have reduced sulphur content better than most of produced briquettes around the world. The other most important factor determining the quality of briquettes is the quantity of the briquette's fuel consumed during domestic application which can be seen in the following Figure 3.

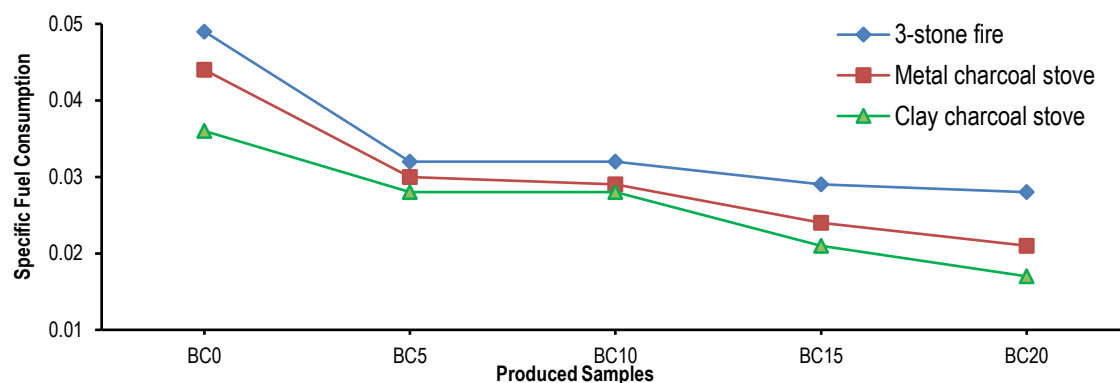


Figure 3: Specific fuel consumption of the briquette samples

SFC measures the quantity of fuel required to boil one litre of water. From the results in Figure 3, the SFC values decrease with increasing coal concentration in the briquette samples. The lower the SFC the more economical the briquette would be as it determines the quantity of fuel used in the process. The most economical briquette sample is BC20 with a value of 0.017, 0.021 and 0.028 which were obtained when using a clay stove, metal stove, and 3-stone, respectively. The highest values were 0.036,

0.044 and 0.049 occurring in a sample BC0 using a clay stove, metal stove, and 3-stone, respectively. The result shows that the lowest value was obtained in sample BC20 when using a clay stove which means BC20 is the better sample and the clay stove is the best. The next important parameter to determine the quality of the produced briquettes is the time taken for briquettes to boil one liter of water as can be seen in Figure 4.

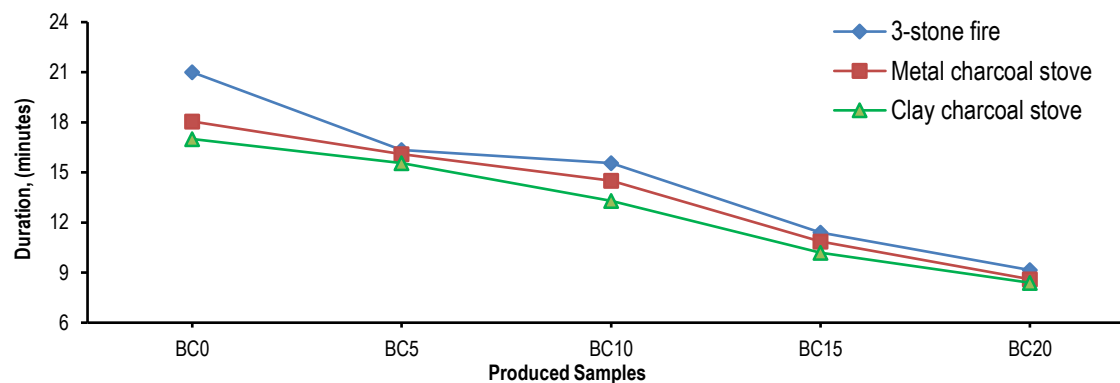


Figure 4: Variation of time taken by the briquette to boil one litre of water

From Figure 4, the time taken by the samples to boil one litre of water decreases with an increasing percentage of coal in the samples as shown. For the three stones, the time taken ranges between 9.150 to 21.000 min, 8.600 to 18.050 min for the metal stove, and 8.39 to 17.0 mins for the clay stove in samples BC0 to BC20. These results show that the least time obtained was 8.390 mins on the clay stove while the longest time is 21.000 mins on three stones in BC20 and BC0. In all three stoves, the duration increases with an increase in the amount of bagasse in the samples. These explain the fact that burning rate alone is not the only factor influencing the duration, but also calorific value,

chemical composition, and geometry of material all have an effect on the burning rate of the material. The higher heating value and its transfer to the water in the experiment determined the time taking for the water to boil. The heat content of the samples depends on their total carbon content and hence heat value and their ability to boil the water fast. The calorific value of fuel determines the quantity of heat it releases when it is burned. Figure 5 shows the calorific value of the produced briquette samples compared with the calorific values of some wood species.

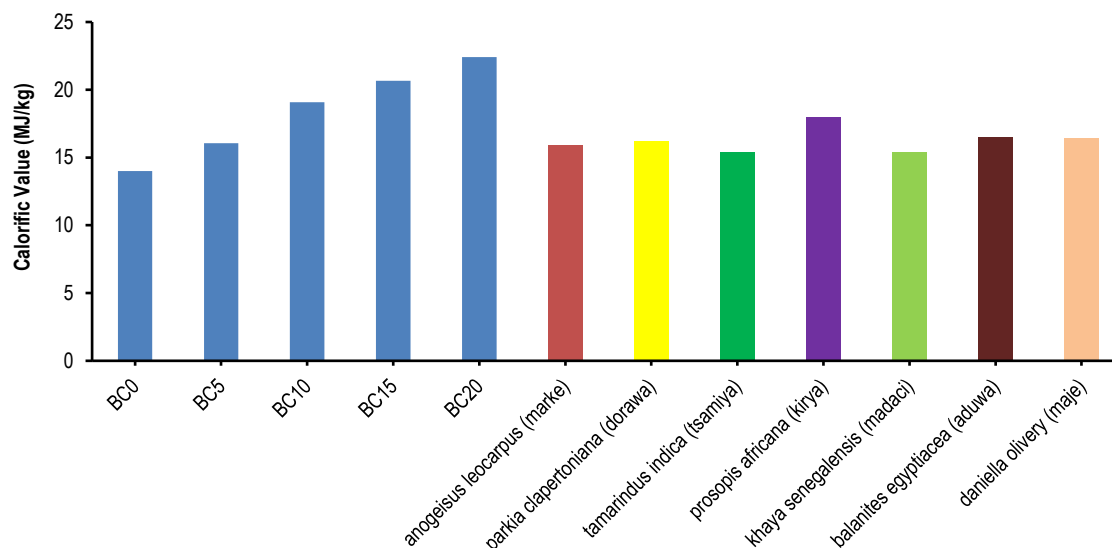


Figure 5: Comparison of calorific values of produced briquette with some wood species

The comparison of calorific values between the produced sugarcane bagasse-coal briquettes and some local and common wood species in the study area is described in Figure 5. These results show that blending biomass (sugarcane bagasse) with coal (Maiganga) increases the heating value of the fuel. The heating value increases with an increase in the percentage of carbon content in the sample from BC0 to BC20 with heating values of 14.010 to 22.400 MJ/kg respectively. All the produced samples have higher calorific values than the common wood species except for BC0 with 14.010 MJ/kg which is lower than all the wood species. This means that only briquettes made of only bagasse have lower calorific value than most of the wood species used around the study area. The highest calorific value from the wood species is *Prosopis Africana* (kirya) with 18.000 MJ/kg as reported in previous studies by Adeyemi, et al. [20]. They also reported the lowest wood species of 15.400 MJ/kg in *Tamarindus Indica* (Tsamiya) and *Khaya Senegalensis* (Madaci).

#### 4. Conclusions

The study was conducted and concluded that carbon, nitrogen, and sulphur contents increase from the control to BC20 with an increase in the percentage of coal addition in the samples. Carbon content increases as a more concentrated form of carbon are added to the sample (i.e. coal) from 41.212% in the control sample (i.e. 100% Bagasse) to a maximum of 68.112% in BC20 (i.e. 20% coal replacement). Sulphur also increases as more sulphur-bearing coal is added to the samples as can be seen from 0% sulphur in bagasse (i.e. BC0) to about 0.793% in the BC20 sample. The quantity of hydrogen and oxygen decreases with an increase in the percentage of coal replacement in the samples from BC0 to BC20. There is a small decrease in hydrogen from 5.911% in BC0 to 5.712% in BC20 which is about a 5.5% reduction. There was a significant decrease in oxygen

content from 43.582% to 23.322% between BC0 to BC20 is achieved. This is about an 87% reduction of oxygen content as the quantity of coal increased.

Volatile matter and moisture contents decrease as the percentage of coal replacement increases from 76.151% to 50.222% and 8.212% to 6.161% respectively. Reducing the VM and MC means increasing the concentration of other minerals oxides in the coal which end up becoming ash after burning thereby increasing the ash content in the samples. Increasing in carbon densely material (coal) increases the mass and energy density of the briquettes which consequently increases the heating value and reduces specific briquette's consumption and time taken for the briquettes to boil a given quantity of water.

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