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# COMBUSTION AND MECHANICAL PROPERTIES OF BAMBOO (*BAMBUSA VULGARIS*) AND THREE INDIGENOUS WOOD CHARCOALS

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## ABSTRACT

***This study investigated the combustion and mechanical properties of bamboo (Bambusa vulgaris) charcoal and three indigenous wood charcoal (Teak ,Tectona grandis; Afara, Terminalia superba and Omo, Cordia millenii). Results revealed that there were no significant differences in the properties charcoal produced from bamvboo and the tree indigenous wood. Bamboo and Afara were the most efficient out of the charcoal samples considered in the study. Although the fuel value index of Bamboo was quite lower than that of Afara and other samples considered in the study, but its calorific value was higher than Afara. However, it has greater potentials to replace woody biomass as fuel. Bamboo can replace other wood species in the production of charcoal because of its faster growth rate.***

**Keywords:** Bamboo, Chacoal, Combustion, Mechanical, Calorific value, Energy utilization

## INTRODUCTION

Charcoal production and demand are on the increase in developing countries and international market respectively (Adeniji *et al.,* 2015). Developing countries account for nearly all of this consumption, and Africa alone consumes about half of the world's production. Charcoal production has increased by about a third from 1981-1992 and is expected to increase with the rapidly growing population in the developing world (Emerhi 2015).

In Nigeria, the wood charcoal enterprise is one of the major components of the wood fuel industry and it is the main source of domestic fuel in urban areas, accounting for more than half of the domestic energy consumption (Adeniji *et al.,* 2015). Awoyemi *et al*., (2006) maintained that charcoal is virtually available all over Nigeria as many local communities have perfected the technology of charcoal production. Some known charcoal depots are found in places like Oyo, Iseyin, Saki, Igbo-Ora, Ogbomoso - all in the western part of the country. There are depots in Jebba, Omu Aran, Egbe, Kabba in the Central States and found in abundance also in Minna, Jos and Kaduna.

For many urban poor, charcoal provides a reliable, convenient and accessible source of energy for cooking at a stable cost. While electricity and gas may be considered the most desired cooking fuels in urban areas, even if these are available most poor households cannot afford both the energy resources and the devices required to use these forms of energy. Many households, therefore, turn to using kerosene or charcoal. Since kerosene is not always available or too costly for many, this leaves charcoal as the most readily available fuel (Mugo and Ong, 2006).

In developing countries the predominant traditional sources of energy are fuel wood and charcoal, which are used primarily for cooking and heating homes. Presently, the major source of energy to the rural community is fuel wood because other sources of energy (electricity, gas and kerosene) are either not available or grossly inadequate and where available and they are beyond the reach of the masses (Ijagbemi *et al.,* 2014). Most fuel users prefer charcoal to firewood because it does not produce much smoke, it can be ignited easily, it emits heat for a longer period of time and most importantly it is relatively cheap (Ogunsanwo *et al.,* 2007).

The production of charcoal from locally available raw material has been performed for centuries in the North East of India, China and many other parts of the world using traditional methods of production in earth pits or mud kiln. Even in modern times charcoal production with traditional methods is very popular amongst rural communities in developing countries as it is used as a fuel for domestic purposes and generates income. It takes only 3-4 years for Bamboo culms to reach adequate height and weight for commercial production of charcoal. Therefore the production of Charcoal with bamboo is very attractive as the time required to harvest the starting biomass is lower compared to charcoal made from other sources. Charcoal made from bamboo inherently has 1.5 times the calorific value as compared to wood charcoal and nearly 2-3 times the surface area of wood charcoal due to the porous microstructure of bamboo (Arijit and Pinakeswar, 2013). Charcoal is a premium fuel, acceptable and readily used in villages and modern households. Commercial charcoal contains about 75% carbon, 20% volatile, and about 5% ash, depending on raw material types and conditions produced (Nakorn *et al.,* 2010).

Scientists have predicted that the burning of fuel wood by African households will release equivalent of 6.7 billion tonnes of greenhouse gases into the atmosphere by 2050, resulting in further climate change through clearing of tropical forests. Bamboo charcoal and briquettes must be produced in large quantities to serve a large number of rural and urban communities because they are ideal for cooking as they last for longer periods, produce less smoke and pollution than natural charcoal (INBAR, 2011).

According to INBAR (2011), bamboo may be the key to combating energy problem in Africa. As a partnership among African nations and communities, INBAR and China are working to substitute fuel wood with bamboo. Currently, 80% of the population in sub-Saharan Africa depends on wood for their fuel needs. The success recorded in Ethiopia and Ghana which have put bamboo biomass at the centre of renewable energy policies, are spurring interest across the continent and prompting calls for greater use of bamboo based charcoal production as a green bio fuel for fighting deforestation and climate change (INBAR 2011). Therefore, the objective of the study was to investigate the combustion and mechanical properties of Bamboo charcoal and compare them with three indigenous wood charcoal.

## MATERIALS AND METHODS

### Materials

Bamboo (*Bambusa vulgaris*) and three other wood species namely: Teak (*Tectona grandis*), Afara (*Terminalia superba)* and Omo *(Cordia millenii)* are locally available abundantly in the southwestern Nigeria. These dried wood samples (planks) were collected from the local charcoal producers near Abeokuta in Ogun State, Nigeria. A dried matured bamboo culm was also collected from Afojuowo, a few kilometers from Abeokuta, Ogun State.

### Wood Samples Conversion

The selected wood samples (planks) and Bamboo culm were taken to the Department of Forest Products Development and Utilization Wood Workshop, Forestry Research Institute of Nigeria (FRIN) Ibadan, Oyo State for proper conversion in accordance with Forest Products Laboratory 1999. They were dimensioned for mechanical properties determination using the American Society for Testing and Materials (ASTM D 143–83, 1983) Standard Methods of Testing Small Clear Specimens of Timber. The converted samples were later carbonized to charcoals and their mechanical properties determined. They result of the tests were later subjected to Statistical Analysis

### Carbonization of Wood Samples

The converted Bamboo and three wood samples were later moved to the Soil and Nutrition Laboratory of Bioscience Department of Forestry Research Institute of Nigeria for carbonization into charcoals. The carbonization was done using a portable laboratory kiln (as shown in plate 35) at the temperature of $400^0$C. After the carbonization the samples were subjected to further analyses to determine their combustion characteristics.

### Combustion Characteristics Analyses

The charcoal samples were taken to the Department of Agronomy, University of Ibadan, Oyo State and subjected them to Proximate, Ultimate and Structural Analyses (Combustion Characteristics) using American Society of Testing and Materials (ASTM) standards according to Ijagbemi *et al.,* 2014; Troy and Scott 2014; and Sadiku *et al.,* 2016

### Fuel Value Index

Fuel Value Index was calculated using calorific value, wood density, and ash content of the biomass sample according to Sadiku *et al.,* (2016) Equation 1

$$FVI = \frac{Calorific\ Value \times Density}{Ash\ Content} \qquad 1$$

### Determination of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

The MOR was given was determined using Equation 2

$$\mathrm{MOR} = \frac{3PL}{2bd^2} \qquad 2$$

Where MOR was in N/mm$^2$

P is the load at some point below the proportional limit (N), L is the distance between supports for the beam (mm), b is beam width (mm), and d = thickness (depth) of the beam (mm)

MOE was obtained using Equation 3

$$\mathrm{MOE} = \frac{PL^3}{4bd^3\ \Delta} \qquad 3$$

Where, P is the load at some point *below* the proportional limit (N) , L is distance between supports for the beam (mm), b is beam width (mm), d is the thickness (depth) of the beam (mm) and $\Delta$ is deflection

Compressive Strength was obtained from Equation 4

$$MCS = \frac{P}{bd} \qquad \underline{\text{P}}$$

MCS = bd N/mm$^2$

4

Where, MCS is Maximum Compressive Strength in N/mm$^2$, b is width in mm, d is depth in mm and P is Load in Newton

## RESULTS AND DISCUSSIONS

The results of the proximate, ultimate, structural composition analyses and mechanical properties are presented in Tables 1 to 4

### Combustion Characteristics of Charcoal Samples

### Ash Content

AS shown in Tables 1 and 2, Omo had the least ash content of 2.20 % and also the lowest calorific value of 2300 kcal/kg and this was a deviation from the submissions of Joel (2010); Dutta *et al.,* (2013); and Sadiku *et al.,* (2016) who reported that the higher the fuel's ash content, the lower its calorific value and heat of combustion. Afara had the highest ash content of 2.85 % and a higher calorific value of 2,425 kcal/kg compared to Omo with 2300 kcal/kg. Bamboo had 2.68 % ash content with a calorific value of 2,500 kcal/kg. However, Teak had a slight higher ash content value than Omo and it had the greatest calorific value of 2,725 kcal/kg among the samples. Teak and Bamboo can be considered as better samples based on ash content in relation to calorific value, since they would produce less ash and more heat.

Analysis of variance revealed that there is no significant( $p > 0.05$) difference in the mean values of Bamboo, Afara, Teak and Omo.

### Moisture Content

According to Dora (2008) the lower the moisture content of the biomass, the more desirable it is as a biofuel. Bamboo had the least moisture content of 3.25 % with a calorific value of 2,500 kcal/kg while Afara had the highest moisture content of 6.25 % with lower calorific value of 2,425 kcal/kg compared to both Bamboo and Teak. Teak with the highest calorific value had 5.05% moisture content. Based on moisture content in relation to calorific value, both Bamboo and Teak would be better biomass for biofuel.

### Volatile Matter

Teak had the highest volatile matter of 25.95 % followed by Bamboo with 22.70 %, Afara with 21.25 % and Omo with 20.00 %. Akowuah *et al.,* (2012) reported that Low volatile content results in smouldering and incomplete combustion which lead to significant amount of smoke and toxic gases being released. Moreover, high volatile matter content of a biomass material means that during combustion, most of it will volatilize and burn as gas in cook stove applications (Akowuah *et al.,* 2012). Using volatile matter result, Teak would not be desirable followed by Bamboo, only Afara could be considered because its calorific value was closer to that of Bamboo.

### Calorific Value

Teak had the highest calorific value of 2,725 kcal/kg followed by Bamboo with 2,500 kcal/kg, Afara 2,425 with kcal/kg and Omo kcal/kg 2,300 kcal/kg. The calorific value (or heating value) is the standard measure of the energy content of a fuel. (Joel 2010; FAO 2015). Both Teak and Bamboo could be regarded as better fuels than Omo and Afara.

### Carbon, Oxygen and Hydrogen

Omo had the highest carbon and fixed carbon contents of 59.90 and 72.25 % respectively. However, its oxygen and hydrogen contents of 37.20 and 2.90 % were the lowest among all the samples. According to Dora (2008) and Akowuah *et al.,* (2012) the amount of carbon, oxygen and hydrogen content contributes immensely to the combustibility of any substance in which they are found. The higher their contents the more likely the higher the heating value of the biofuels. However, Omo had a lower calorific value among them, though it had the highest concentrations of fixed carbon and carbon.

### Nitrogen and Sulphur

Low sulphur and nitrogen contents in a fuel are indications there will be minimal release of sulphur and nitrogen oxides which are harmful emissions into the atmosphere and will not pollute the environment (Dora 2008; Akowuah *et al.,* 2012). Their oxides are also corrosive and cause problems in boilers (Dora 2008). Omo had the least concentration of nitrogen, 0.07 % followed by Afara with 0.08 %, teak 0.10 % and Bamboo 0.13 %. Teak had the least sulphur content of 0.09 % and Bamboo with 0.11 %.

### Hemicellulose and Cellulose

The data obtained in Table 3showed that both Bamboo and Afara had the highest hemicellulose content of 1.2 % followed by Omo with 0.09 %. However, Teak had a very low content of 0.4 % compared to others. Dora (2008) reported that high concentrations of hemicelluloses are desirable in plant species meant for the combustion process. Both Bamboo and Afara could be regarded as better fuels than other samples.

Omo and Teak had cellulose content of 0.4 % while Bamboo had 0.5 % and Afara with 0.3 %. Nemesthoty (2008) cited that for any species to be viable as an energy crop, the cellulose content must be high since it is the major combustible and principal compound in biomass. Bamboo had the highest content among the samples considered.

### Lignin and Extractives

According to Nemestothy (2008), heating values increase with an increase in extractive content. The three samples Afara, Teak and Omo had 0.5 % extractives' contents and Bamboo with 0.2 %. Teak had the highest lignin content of 1.6 % followed by Omo with 1.4 %, Bamboo with 1.3 % and Afara with 1.1 %. However, Cassida *et al.*, (2005) and Boateng *et al.*, (2008) reported that high lignin content is desirable though the extent of its effect is not well known.

### Mechanical Properties

Table 4 shows that the density of Bamboo was 4.0 kg/m$^3$ the least among the samples followed by Omo with 8.5, Afara 10.3 and Teak 11.7 kg/m$^3$ respectively. Teak had the highest density value with the highest corresponding Fuel Value Index (FVI) of 14,130. It can be seen that a higher the density corresponded to higher FVI and this was in line with Sadiku *et al.,* (2016) reporting that the high-density materials present a higher mass per volume and have an advantage of resulting in a higher combustion yield. Likewise, from the table it can be seen that the hardness increased with FVI. Teak had the highest MOE, MOR and Compressive strength of 501.7, 18.2 and 18.7 N/mm$^2$ respectively. This was followed by Afara with MOE, MOR and Compressive strength of 350, 10.7 and 11.0 N/mm$^2$ respectively. Bamboo had lowest values of mechanical properties largely due to its morphological structure compared to the tree species, it is woody perennial grass.

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