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Energy Potential of Shea Kernel Cake Briquette as Solid Fuel for Domestic and Industrial Applications

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ABSTRACT
This study is aimed at the development and characterization of briquette fuel from Shea kernel cake as solid fuel for domestic and industrial applications. The proximate composition, ultimate composition, mechanical properties and calorific value of briquette were determined. The proximate composition of the briquette show that the fuel produced has a fixed carbon content of 31.2%, high volatile matter content (51.3%) and low ash content (2.8%). The result of ultimate analysis showed that briquette contains high amount of carbon (40%), oxygen (41%) hydrogen (8.3%) and relatively low quantity of sulphur (0.12%) which is within the standard values for briquettes except for nitrogen whose value was greater than 1 %. The heating value of Shea cake briquette was determined to be 19.89 MJ/kg. The high calorific value of the solid biomass fuel established its potential for domestic and small-scale industrial energy supply. Hence Shea cake briquette can be used as a clean solid renewable fuel for domestic and industrial energy supply.

KEYWORDS: Briquette, energy, fuel, shea kernel, cake

I. INTRODUCTION

GLOBALLY wood is the most predominant source of energy supply for household cooking and heating. It is described as an emergency alternate fuel. Wood fuel is presently occupying a vintage position in the global energy supply because large number of people in developing countries depends primarily on its usage for domestic energy supply. Over three billion people around the world use wood fuel for cooking on daily basis (Orhevba *et al*., 2016). At present the demand for wood and wood charcoal for energy supply is consistently growing in sub-Saharan Africa. The continuous usage of wood is associated with deforestation, desertification and hardship as the venerable group (women and young children) must walk long distance to collect these wood materials (Oroka and Akhihiero, 2003). Alternative solid fuels are presently being sourced for energy supply to reduce the pressure constantly mounted on forest reserve for wood fuel; besides wood and wood charcoal fuels emits toxic emissions responsible for a number of health problems (Antwi-Boasiako and Acheampong, 2016). In addition to the above the use of wood and wood charcoal has led to serious environmental degradation, and deforestation. The annual deforestation of the wood lands in the northern Nigeria is estimated to be about 92,000 hectares. The rate of wood fuel extraction from forest reserve in Nigeria is estimated to be about 3.85 times the rate of afforestation (Davies and Davies, 2013).

Biomass waste is an alternative form of fuel. Biomass waste are environmentally benign, sustainable, and inexpensive feedstock derived from processing of agricultural produce. Biomass can be converted into solid fuel and value-added chemical due to its abundant source of organic carbon and hydrogen (Hu *et al.*, 2011; Li *et al*., 2015).

Hence attention is presently focused on the use of low cost second generation feedstock such as lignocellulose biomass waste for biofuels production (Tran, 2016). Lignocellulosic biomass are possible raw materials for the synthesis of eco-friendly biofuels and chemicals (Volpes *et al*., 2018). Kabir and Hameed (2017), reported global production of lignocellulose biomass to be approximately 150 - 170×10^9 t annually. According to Nanda *et al.,* (2017) by the year 2050 lignocellulosic biomass will be probably supplying substantial part (250–500 EJ/year) of global energy supply. This amount can satisfactorily supply about 15-25% of global future energy demand. Lignocellulose biomass wastes are therefore key player in the global promotion of green energy technology and anticipated supply of sustainable raw materials for the future development of renewable biomass energy (Kabir and Hameed, 2017). Lignocellulosic biomass is made up of very large quantity of forest, agro-industrial, municipal solid wastes and agricultural residue (Duku *et al*., 2011; Olajuyigbe and Ogunyewo, 2016). Annually about 144 million tonnes of biomass waste is generated in Nigeria (Diji *et al.*, 2013).

The utilisation of raw biomass (agricultural residue) directly for energy generation is associated with several drawbacks such as lower energy density, low calorific value, large volume required for storage and problems in its transportation and distribution (Mythili and Venkatachalam, 2013). It is also characterized with poor ignition quality, excessive release of smoke and lower combustion efficiency during energy supply in boilers and furnaces (Garba *et al.,* 2012). To improve the characteristics of agricultural residue for storage and energy generation, it is necessary to upgrade the agricultural residue by increasing its bulk density through a densification process to produce a clean alternative solid fuel. Appreciable numbers of studies have been documented on the development of renewable eco-friendly briquettes from biomass.

Briquetting is a densification process by which the density of the biomass can be increased up to about 1000-1200 kg/m^3 compared to 30- 40 kg/m^3 of loose biomass which can lead to a reduction in volume by 8-10 times (Felfi *et al.*, 2011). It is a high-pressure process that leads to the production high density geometrically packed solid with improves handling characteristics and enhances volumetric calorific value in comparison with the biomass (Akowuah *et al*., 2012). Briquetting results into fuel with consistent combustion quality, reduction in biomass residues. Briquettes are characterize with higher energy potential (thermal stability, flame temperatures and lower moisture content) and excellent combustion properties (density, calorific value and less toxic emissions) in comparison to the raw biomass (Avelar *et al*., 2016). Successful briquette operations are found mostly in developed countries. However, briquetting operations are not successful in developing countries (Emerhi, 2011). This is mostly due to the high cost of production, lack of awareness on its sustainability, availability of market, poor packaging and distribution systems for the product (Akowuah *et al.*, 2012). In the present, there is shortage in petroleum derived fuel supply, continuous increase in the prices of these fuels, increasing energy demands and drive towards environmental sustainability. Briquettes have been widely perceived to be potential replacement for wood and wood charcoal in most of the developing part of the world for domestic energy supply, small scale industrial application, electricity and steam generation (Tumutegyereize *et al*., 2016). This is essentially because briquetting is the most applicable technology for the production of green energy in the form of solid fuel for household and industrial energy supply. There are several kinds of agricultural biomass sources, (sawdust, cake, rice husk, corn cob, cotton stalk, groundnut husk, rice husk, sugarcane baggase and shea butter nut cake) that can be used for briquette production (Akowuah *et al.*, 2012).

Shea butter tree (*Vitellaria paradoxa*) is indigenous to sub-Saharan Africa and belongs to the family *Sapotaceae*. It grows in the wild and has a huge economic and ecological potential (Abedin *et al.*, 2015). The tree is also called "The *Karite* tree", which means 'the tree of life' and mostly grows in the dry savannah belt of West Africa where the north central region of Nigeria falls under (Munir *et al*., 2012). At least 500 million production trees are accessible in West Africa which equates to a total of 2.5 million tons of dry kernel per annum based on 5 kg dry kernel per tree. Over two million people in 13 African countries including Nigeria process shea butter into finish product (Oddoye *et al*., 2012). Nigeria is the leading producer of Shea butter in the world with a production capacity of about 500,000 metric tons annually produced mainly from the use of crude implements (Ademola *et al*., 2012). After processing, the shea butter cakes are discarded into the environment thus leading to environmental degradation and pollution. Therefore, there is a need for the conversion of this biomass waste into an economical value added products.

This study is one of the first attempts to produce a biomass briquette from Shea kernel cake as a potential alternative clean solid fuel for energy supply. It aimed at the densification and evaluation of energy potential of shea kernel cake briquette as a solid clean fuel for relevant domestic and industrial applications.

II. METHODOLOGY

A. Material

Shea butter cakes were collected at a local shea butter processing center in Yekosa Masa village, Bida, Nigeria. The cassava starch was obtained at Tunga market in Minna, Nigeria State.

B. Methods

The biomass sample was dried at room temperature for 7 days and ground into smaller particles and there after sieved using a mesh size of 0.825 mm. This was followed by Preparation of binder. Twenty percent (20%) weight of biomass of corn starch and 3.6 L of water was used to prepare the binder. The corn starch was mixed with 10 cl of water to dissolve it. After this 50 cl of water was heated to a temperature of 100 ^{o}C and gradually poured into the dissolved corn starch until a semisolid paste was formed.

Densification of Shea Kernel Cake

About 300 g of Shea Kernel Cake and 60 g of binder was weighed carefully and mixed in a mixing pot until uniform mixture was attained. The mixture was then poured into the manual briquetting machine and a pressure of 8 MPa was applied to shape the biomass into a cylindrical mold. The sample was allowed to rest in the briquetting machine for 15 minutes before removing it to allow for better cohesiveness and drying of the biomass.

C. Characterization of Briquette

Proximate analysis was carried out according to ASTM standard techniques (Ikelle *et al*., 2014). The compressive strength of the briquettes was investigated by using a universal testing machine. The density was determined according to the method reported by Adetogun *et al.*, (2014). Heating value (HV) was calculated using the empirical correlation

$$HHV\left\{\frac{MJ}{kg}\right\} = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211A$$

Elemental chemical analysis (carbon, nitrogen and hydrogen) were determined by elemental analyzer and sulfur by atomic emission spectrometer. The oxygen was calculated by difference. Shatter resistance was determined according to method outlined by Birwatkar *et al.* (2014). Tumbling resistance test was carried out according to work of Khardiwar *et al*. (2013).

II. RESULTS AND DISCUSSSION

The Proximate and ultimate composition are shown on Tables 1 and 2. Moisture content plays a significant role on the resistance to solid biomass fuel to mechanical aberration, density, and burning efficiency (Orhevba *et al.*, 2016). Biomass contain high amount of moisture content which consequently will possess lower calorific, reduced maximum combustion temperature, increased feedstock residence time in combustion chamber, and increased emissions of toxic gases. Drying biomass to moisture contents of levels lower than 10-15% requires large installations and it is energy intensive (Maciejewska *et al*., 2006). The shea kernel briquette moisture content was determined to be 13.55%. Moisture content of briquette must always be below 15 % for effective energy generation (Onuegbu *et al*., 2012). The moisture content of briquette produced was consistent with this literature. The value obtained is appreciably higher than 10.9% and 12.2% reported for bio-coal briquettes made from groundnut shell and corncob respectively (Onuegbu *et al*., 2012). Ash content is a non-combustible component of biomass.

Table 1: Proximate and Ultimate Composition of Briquette

Proximate Composition	Value (%)	Coal
Moisture content	13.55	-
Ash content	2.8	20.97
Volatile matter	51.3	51.08
Fixed carbon content	32.35	22.64
Ultimate Composition		
Carbon	41.0	61.80
Hydrogen	8.3	4.43
Oxygen	40	32.26
Nitrogen	1.95	1.08
Sulphur	0.12	0.42
Heating value (MJ/kg)	19.89	23.74

The quantity of ash generated by solid fuel during combustion affects the stove operation efficiency and cleaning frequency (Tarasov *et al*., 2013). Ash content of good briquette fuel must always be very minute. The ash content of shea kernel cake briquette was determined to be 2.8%. This low value implies that cleaning frequency will be minimal when the fuel is employed for cooking in stove. The ash content reported in this study is lower than the ash content of coal (19.12%) and rice husk briquette (7.53%) respectively (Ikelle *et al*, 2014). Briquettes with higher ash content are usually characterized with low heating value (Loo and Koppejan, 2008). According to Supatata *et al.*, (2013) the ash content of a good briquette fuel must be less than 4% as higher ash content is an indication of higher amount of alkaline and alkaline earth metals (AAEM). AAEM are associated with lower fusion temperature and greater slagging tendency (Supatata *et al.,* 2013). Volatile matter is a representation of the carbon, hydrogen and oxygen contents available in the briquette during thermal devolitalization. It is usually a mixture of short and long chain hydrocarbons (Sriram *et al*., 2014). The volatile matter of briquette was recorded as 51.30%. The low volatile matter content of the briquette compares favourably with the value (51.08%) reported for Maiganga coal. This coal was however reported to have the potential for industrial power generation (Nyakuma *et al*., 2016). Fixed carbon of a fuel is the amount of fuel available for char combustion after the volatile matter is vaporised (Deepak and Jnanesh, 2015). The fixed carbon was determined to be 32.35%. This value is higher than 16.46% and 13.52% reported for soya bean and pigeon pea briquettes respectively by Khardiwah *et al*., (2013). Lower content of carbon in solid fuel results into longer cooking time due minimal release of heat energy. The fixed carbon of briquette was higher than 22.64% reported for Maiganga coal. Maiganga coal has the potential for industrial power generation (Nyakuma *et al*., 2016). Hence the briquette produced can be effectively used for same purpose.

Ultimate analysis is useful in determining the quantity of air required for combustion and the volumetric composition of the combustibles gases present (Raju *et al*., 2014). The ultimate analysis is shown in Table 1. Carbon contributes immensely to the combustibility of briquettes. The more carbon content present, the more the fuel content of the biomass (Efomah and Gbabo, 2015). From the above result, Shea kernel cake briquette has high carbon content (41%). The shea kernel cake briquette contains 9.3% of hydrogen. According to Joseph *et al*., (2012) the standard amount of hydrogen present in biomass should be above 6%. The results obtained in this study agree with this standard. Sulphur content must be below 1%. Thus the sulphur content is within the acceptable standard of 1% (Raju *et al*., 2014). Excess of 1% nitrogen content is an indication of toxic oxides formation during combustion. It has been observed that nitrogen content of the briquettes far exceeds 1% by 0.95%. The oxygen content of the shea cake briquette is 40%. The value obtained in this study shows approximate proximity to 39% reported for rice straw and sugar cane leaves (Jittabut, 2015) but lower than 47.60% when compared to the oxygen content of rice husk briquettes (Efomah and Gbabo, 2015).

Heating value or calorific value determines the energy content of a fuel. Calorific value depends on its chemical composition and moisture content. It is the most important fuel property of a briquette (Aina *et al*., 2009). The heating value of shea cake briquette was determined to be 19.89 MJ/kg. This shows close proximity to the calorific value of 20.89 MJ/kg and 21. 345 MJ/kg reported for cornstalk and corncob briquette (Oladeji *et al*., 2016). But appreciably higher than 17.57 and 17.03 MJ/kg reported for Oil Palm Empty Fruit Bunches and Spear grass by Nyakuma *et al.* (2014) and Oladokun *et al*., (2015) respectively. Solid biomass fuel of energy values within this range can be effectively employed in the production of iron, steel, or cement, and generation of electricity (Nyakuma *et al*., 2016). According to Akowuah *et al.* (2012) high calorific value of this nature can satisfactorily meet domestic and small-scale industrial energy supply requirement.

Table 2: Mechanical properties of briquettes

Parameters	SKCB
Compressive strength (kN/m^3)	1.98
Tumbling resistance (%)	90
Shatter resistance (%)	91.66

Compressive strength is measure of the durability of briquette. The result of compressive strength of the briquette shows that the shea kernel cake briquette has a compressive strength of 1.98 kN/m^3. This compressive strength is greater than 1.058 kN/m^3, 1.109 kN/m^3 and 1.083 kN/m^3 reported for pigeon pee stalk, cotton stalk and soy stalk briquette respectively (Mythili and Venkatachalam, 2013). Shatter resistance is used for determination of the briquettes ability to resist impact force. The shea kernel cake briquette resists shattering by 91.66%. The shatter resistance of the briquette shows close similarity to shatter resistance of 93 and 92% obtained for densified raw mango leaves and acacia leaves mixed with cow dung and saw dust as composite briquettes (Birwatkar *et al*., 2014). Tumbling resistance is a measure of the briquettes ability to resist fracture (Birwatkar *et al*., 2014). The tumbling resistance was observed to be 90%. This value compares with a tumbling resistance of 92.1% and 90% obtained for briquettes made from raw mango leaves and acacia leaves respectively (Birwatkar *et al*., 2014).

IV. CONCLUSION

This study is one of first attempt to produce a biomass briquette from Shea kernel cake as a potential alternative clean solid fuel for energy supply. The proximate compositions of the briquette produced fuel were consistent with documented literatures. The ultimate analysis showed that the properties of briquette fall within the standard values for briquettes except for nitrogen whose value was greater than 1%. The calorific value of Shea cake briquette was determined to be 19.89 MJ/kg. The properties of the briquette showed that the produced solid fuel can be used for relevant domestic and industrial application.

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