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Characterization Of Oil Palm Empty Fruit Bunch and Coconut Shell for The Production of Fuel Briquettes

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ABSTRACT

In this study, characterization of agricultural waste (oil palm empty fruit bunch, coconut shell and cassava peel) was done before and after carbonization. Briquettes were produced from the carbonized OPEFB and CS blends with CP as binder. Muffle furnace was used for the carbonization of both biomass; CS was carbonized at 7000C at 60 minutes residence time and OPEFB was carbonized at 4000C at 30 minutes residence time. Proximate analysis showed that raw OPEFB and CS had volatile matter of 70.89 and 63.76wt% which indicates easy ignition but high burning rate. They had low fixed carbon of 18.13 and 17.60wt% for OPEFB and CS respectively which accounted for their low calorific value of 19.61 and 20.70 MJ/kg respectively. Ultimate analysis showed insignificant nitrogen and sulfur content from both biomass. The carbonized OPEFB and CS showed improved Calorific value of 28.38 and 27.91 MJ/kg respectively. This was as a result of devolatilization of the biomass with enrichment of carbon from 45.04 to 69.28wt% for OPEFB and 48.02 to 75.50wt% for CS. The briquettes formed had a mean calorific value, compressive strength, burning rate and density of 27.40 MJ/kg, 2.138 N/mm2, 1.110 g/min and 912.26 kg/m3respectively. With these performance indicators, these selected agricultural wastes biomass could be helpful for production of fuel alternatives for domestic heating in developing and underdeveloped countries that produce such waste.

KEYWORDS
Briquettes
Characterization
Carbonization
Coconut shell
Oil palm empty fruit bunch

INTRODUCTION

A sharp hike in global energy prices began in the second half of year 2021. A further rise was a consequence of Russia's unprovoked and unjustified aggression against Ukraine in year 2022 [1]. The Group of Seven (G7) had previously pledged to phase out coal and decarbonize power plants as at May 25, 2021 in Cornwall, south-west England [2]. With the Russian gas currently not accessible due to policies, the coal power plants have made a comeback, which will further impact

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the climate [3]. Developing and underdeveloped countries are bearing the brunt of the energy crises. With fuel costs accounting for 90% of the rise in average costs for electricity generation worldwide; according to international energy agency (IEA), millions of people with access to electricity cannot afford it; as revealed by the exorbitant price of electrical units in Nigeria. In view of the above, large section of the population cannot afford to make food with clean energy, returning instead to biomass [4].

The rate of tree cover loss per annum in Nigeria stands at 99,200 hectares as at year 2020 [5]. The rate of national fuel wood consumption stands at 88.43 mt/day [6]. Agriculture accounts for 23 % of Nigeria's gross domestic product (GDP), with maize, cassava, guinea corn, yam, sorghum, palm oil, palm kernel oil and soybean meal, but to name a few, as must cultivated crops. Production of palm oil in Nigeria, as of 2021, stands at 1.4×10^6 mt [7] while production of coconut fruits stands at 224,184.26 t in year 2021 [8]. For every 1 kg of palm oil produced, approximately 4 kg of dry biomass is produced. 1/3 of this biomass is oil palm empty fruit bunch [9] and 15% of a coconut fruit is coconut shell [10]. If this agricultural waste could be harnessed, it could go a long way in addressing the problem of forest depletion because of domestic fuel needs.

Characterization of these agricultural wastes will help in predicting their thermal behavior and possible ways of treating them before utilizing them for domestic heating. Proximate analysis indicates composition with respect to moisture content, volatiles, ash content and fixed carbon. This gives an overview of the thermal behavior of the biomass with respect to ignition temperature, devolatilization temperature and rate of decomposition [11]. Ultimate analysis determine the elemental composition of biomass such as carbon (C), hydrogen (H), oxygen (O), Nitrogen (N) and Sulfur (S). This helps in determining biomass heating values and their impact on the environment under combustion [12].

With biomass having low bulk density and energy value in comparison to coal, briquetting is found to be an adequate technology for the application of these low-grade waste's materials [13]. In this study, OPEFB and CS were characterized before and after carbonization to investigate the suitability of thermal treatment in improving their energy quality and environmental friendliness. Briquettes were produced from these biomasses and tested to evaluate their suitability for domestic heating.

METHODOLOGY

Materials

OPEFB was sourced from local palm oil producers in Akwanga, Nasarawa state, CS were obtained from coconut fruit merchants at Yelwa market, Bauchi and cassava peels were sourced from cassava plantations in Akwanga, Nasarawa state.

Carbonization and binder preparation

Dirt was removed from OPEFB and CS by washing with water and sun dried for 7 days to reduce the moisture content of the biomass. Carbonization was carried out using a muffle furnace. 500

g of OPEFB was placed in a crucible, which was then placed in a muffle furnace and heated to a temperature of 700 oC for 60 minutes residence time, after which it was cooled in a desiccator to avoid oxidation. 500 g of CS was placed in a crucible and introduced into the muffle furnace. The furnace was heated to a temperature of 400 oC for 30 minutes residence time, it was then discharged into a desiccator to cool. The char obtained were pulverized and passed through a 4 mm sieve. The binder was prepared from the cassava peels. It was sun dried for 14 days after which it was pulverized using mortar and pestle. It was then sieved through a 1 mm sieve. The pulverized cassava peels were gelatinized with hot water.

Determination of Proximate Analysis

Moisture content

Moisture content was determined by oven-dry method in accordance with [14]. Each biomass was weight and then oven-dried at 105 ±3 oC to constant mass in 24 h. the loss in mass, expressed as a percentage of final oven-dried mass was taken as the moisture content of the biomass. The moisture content was calculated using the equation below.

$$MC = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

Where MC = moisture content, W_1 = wet weight, W_2= weight after drying.

Volatile matter content

2 g of each oven dried biomass sample was measured and placed in a crucible of known mass and was placed in a furnace for 10 min at 550 oC and was weight afterwards. The volatile matter was calculated using the formula given below.

$$Volatile\ matter\ (\%) = \frac{W_2 - W_3}{W_2} \quad (2)$$

Where W2 = weight of oven-dried biomass, W3 = weight of biomass after heating for 10 min at 550 C.

Ash content

2 g of oven dried biomass was placed in a crucible. The crucible was then placed in the furnace for four hours at 550 oC to obtain the ash weight. Percentage ash content was calculated using the equation below.

$$Ash\ content(\%) = \frac{W_4}{W_2} \quad (3)$$

Where W4= weight of ash and W2 = weight of oven dried biomass.

Fixed carbon content

The percentage fixed carbon was calculated by subtracting the sum of percentage volatile matter and percentage ash content from 100% as shown in the equation below.

$$Fixed\ carbon\ (\%) = 100\% - (\%Vm + \%Ash) \tag{4}$$

Determination of Ultimate Analysis

The ultimate analysis was carried out according to the techniques postulated by [15]. Oxygen (O), hydrogen (H) and carbon (C) were determined using volatilization gravimetry while nitrogen (N) and sulfur (S) were determined by precipitation gravimetry.

Briquetting Process

Briquettes were produced from carbonized OPEFB and CS blends, using cassava peels as binder according to the design matrix in Table 1. Calorific value, compressive strength, burning rate and density of the briquettes were tested.

Table 1. Design matrix for briquette production

Runs	OPEFB:CS (ratio)	Calorific value (MJ/kg)	Compressive strength (N/mm^2)	Burning rate (g/min)	Density (kg/m^3)
1	100:0	-	-	-	-
2	80:20	-	-	-	-
3	50:50	-	-	-	-
4	20:80	-	-	-	-
5	0:100	-	-	-	-

RESULTS AND DISCUSSION

Proximate analysis of selected biomass

Proximate analysis was used to determine the moisture content, volatile matter, fixed carbon and ash content as presented in Table 2, Figure 1 and Figure 2.

Table 2. Characterization of selected biomass before and after carbonization

Condition	Raw			Carbonized	
Properties	**OPEFB**	**CS**	**CP**	**OPEFB**	**CS**
Proximate Analysis (wt%)					
Moisture Content	5.66	10.10	7.29	1.92	1.32
Volatile Matter	70.89	63.76	69.16	11.05	5.52
Fixed Carbon	18.13	17.60	19.63	72.85	74.78
Ash Content	5.32	8.54	3.92	14.18	18.38
Ultimate Analysis (wt%)					
C	45.04	48.02	47.21	69.28	75.50

Condition	Raw			Carbonized	
Properties	**OPEFB**	**CS**	**CP**	**OPEFB**	**CS**
H	5.00	6.40	6.43	1.87	3.15
N	1.83	0.10	1.35	1.00	0.05
S	0.07	0.60	0.04	-	0.01
O	48.06	44.88	44.97	27.85	15.34
Calorific Value (MJ/kg)	19.61	20.70	17.22	28.38	27.91

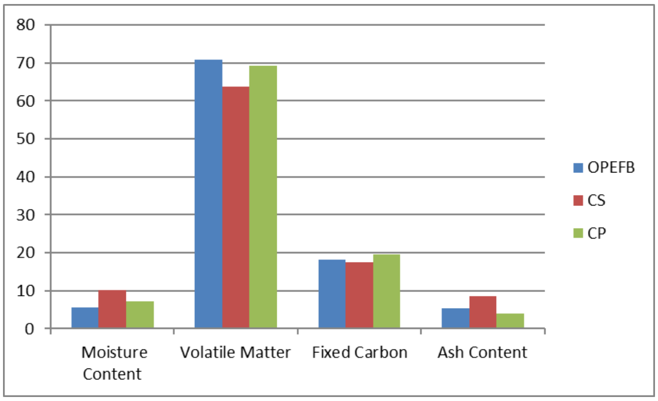

Figure 1. Proximate analysis of raw selected biomass

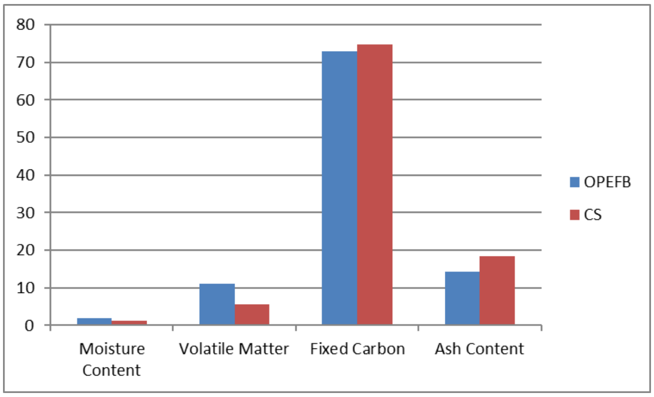

Figure 2. Proximate analysis of carbonized selected biomass

The moisture contents of the raw biomass residues were calculated to be 5.66, 10.10 and 7.29wt% for OPEFB, CS and CP respectively. OPEFB was found to have the least moisture content because it was sundried adequately for 2 weeks prior to the analysis. With these low moisture contents, the raw biomass will quickly ignite. Upon carbonization of OPEFB and CS, their moisture contents dropped to 1.92 and 1.32wt% which makes them easier to ignite.

The volatile matters of the raw biomass' residues were calculated to be 70.89, 63.76 and 69.16wt% for OPEFB, CS and CP respectively. OPEFB was found to have the highest volatile matter due to its high cellulose content in comparison to CS and CP. These high volatile contents make these raw residues easy to ignite. Devolatilisation of these biomass during combustion will yield more oxygen functional groups like hydroxyl and carbonyl which are reactive at low temperature and gives these biomass their low heating value and volatiles are emitters of unwanted elements during combustion [16]. After carbonization of OPEFB and CS, their volatiles dropped to 11.05 and 5.52wt% respectively. This reduction contributes to the improvement of the heating value of the biomass.

The fixed carbon of the raw biomass residue was found to be 18.13, 17.60 and 19.63wt% for OPEFB, CS and CP respectively. CP has the highest amount of fixed carbon because it is a product of a carbonaceous plant. Fixed carbon content is an indicator the energy value of the biomass. With fixed carbon this low, the biomass will have low calorific value. After carbonization, the fixed carbon content of OPEFB and CS was found to be 72.85 and 74.7 wt% respectively. Carbon enrichment was achieved, hence a better heating/energy value.

The ash content of the biomass was found to be 5.32, 8.54 and 3.92wt% for OPEFB, CS and CP respectively. Combustion of the raw biomass will yield low ash which is an interesting quality because high ash content reduces heat transfer efficiency of a combustion process [17]. Carbonized OPEFB and CS showed increased ash contents of 14.18 and 18.38wt% respectively, which is not significant during combustion.

Ultimate analysis of selected biomass

Ultimate analysis of the biomass residues shows the elemental constituents of the biomass as represented in Table 1, Figure 3 and Figure 4.

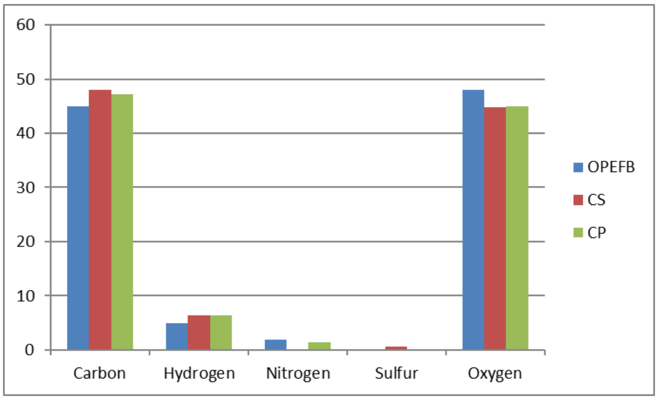

Figure 3. Ultimate analysis of raw selected biomass

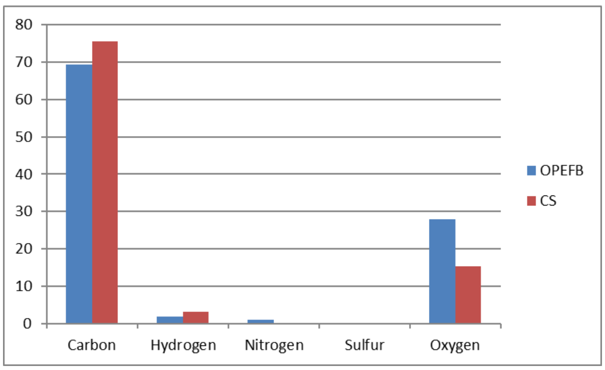

Figure 4. Ultimate analysis of carbonized selected biomass

Elements such as carbon (C), hydrogen (H) and oxygen (O) constitute the major composition of the biomass at 45.04, 5.00 and 48.06 wt% for OPEFB and 48.02, 6.40 and 44.88 wt% for CS respectively. This gives the biomass high H:C and O:C ratio. The low energy contained in C-O and C-H bonds explains the low energy value of the biomass. After carbonization, elements such as oxygen and hydrogen decreased while carbon increased to 69.28 and 75.50 wt% for OPEFB and CS respectively. This will result in more C-C bond. Hence, the increased energy value of the biomass to 28.38 and 27.91 MK/kg for OPEFB and CS respectively [18]. The low nitrogen (N) and sulfur (S) content of the biomass after carbonization signifies the cleaning effect of the carbonization process. Combustion of the biomass after carbonization will yield almost 0% NOx and SOx.

Performance of briquettes produced from carbonized OPEFB and CS

For briquettes to be suitable for domestic heating applications, they must be of high calorific value, high compressive strength (ease in handling, transportation and storage), low burning rate, high density (higher energy density per volume of stove combustion chamber) and low emissions for health and environmental reasons. The calorific value, compressive strength, burning rate and density of the briquettes are presented in Table 2.

Table 3. Performance of the briquettes

Runs	OPEFB:CS (ratio)	Calorific value (MJ/kg)	Compressive strength (N/mm^2)	Burning rate (g/min)	Density (kg/m^3)
1	100:0	28.11	2.14	1.050	748.11
2	80:20	27.81	2.87	1.113	960.24
3	50:50	27.77	1.81	1.592	891.40
4	20:80	26.53	2.00	0.989	1034.62
5	0:100	26.76	1.87	0.805	926.95

The briquette blends produced had a calorific value in the range of 26.53 to 28.11 MJ/kg, compressive strength in the range of 1.87 to 2.87 N/mm2, burning rate of 0.805 to 1.592 g/min and density of 748.11 to 1034.62 kg/m3. These are better than the results obtained by [19], [20] and [21]. These briquette performances shows that the carbonization of biomass prior to densification improves the performance of the briquettes with regards to calorific value, compressive strength, burning rate and density as opposed to direct briquetting of raw biomass with low heating value, high burning rate and low density.

CONCLUSION

Biomass of agricultural waste origin are generating interests as potential fuel source. Carbonization of OPEFB and CS showed vital improvements in the biomass properties with increase in calorific values from 19.61 to 28.38 MJ/kg for OPEFB and 20.70 to 27.91 MJ/kg for CS, decrease in volatile matters from 70.89 to 11.05wt% for OPEFB and 63.76 to 5.52wt% for CS, increase in fixed carbon from 18.13 to 72.85wt% for OPEFB and 17.60 to 74.78wt% for CS, and significant decrease in nitrogen and sulfur contents of the biomass. These improvements enhanced the quality of briquettes made from these biomasses with mean calorific value of 27.40 MJ/kg, mean compressive strength of 2.138 N/mm2, mean burning rate of 1.110 g/min and mean density of 912.26 kg/m3. This shows that carbonization of agricultural waste biomass in terms of OPEFB and CS goes a long way in improving their properties for quality briquette production for domestic heating.

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