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The Potentials of Using Carbonized Corncob to Produced Briquettes as an Alternative to Fuelwood

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ABSTRACT
Briquettes from agro-residues have been promoted as a better replacement to firewood and charcoals for heating, cooking and other industrial applications in both urban and rural communities. This study investigates the potentials of using carbonized corncobs to produced briquettes as an alternative to fuelwood with the view to curbing the menace of deforestation which depletes the ozone layer and mitigating the effect of greenhouse gas emission generated by the use of fallen trees as fuel wood. The study used three binders which were cassava starch, corn starch and gelatin and the briquettes were produced using three compaction pressure. A charcoal kiln was fabricated for carbonization of the corncob while a punch and die was fabricated to facilitate the densification of the carbonized corncobs into briquettes. Selected properties of the carbonized corncobs and the briquettes produced namely moisture content, volatile matter, ash content, fixed carbon and calorific value were determined. The effect of compaction pressure and binder concentration on the selected properties of briquette produced were discussed in respect of its trends and then analysed using Analysis of Variance (ANOVA) and Duncan Multiple Range (DMR) test. Results indicated that moisture content, volatile matter, ash content, fixed carbon and calorific value increased with increase in binder concentration and compacting pressure. The average moisture content, volatile matter, ash content, fixed carbon and calorific value ranged from between 4.43 to 7.62 %, 10.31 to 16.48 %, 3.03 to 5.06 %, 72.68 to 81.30 % and 28.85 to 32.36 MJ/kg respectively. The study established the potential of using carbonised corncob as alternative material for briquettes production. This will increase the sources of energy for domestic and industrial use in developing economy

Keywords: Briquette, binder, compacting pressure, calorific value, carbonized corncob

INTRODUCTION
Deforestation is one of the major environmental issues, not only in directly affected countries and locations, but also from a global perspective. The degree of international attention to deforestation is commensurate with the role of forests in the global, national and local ecosystems. Forests provide a wide variety of highly valuable ecological, economic and social services including the diversity, carbon storage, soil and water conservation, provision of employment, enhancement of systems, and improvement of urban and peri-urban living condition (FAO, 1997).

Obviously, those services differ widely in nature and therefore tend to be valued in different manners by different societies and different social groups. While some services are immediately visible, others are of a long-term nature and take their full sense only in the perspective of intergenerational equity – a critical view point in defining and assessing the sustainability of human development. The rate of deforestation currently exceeds the rate of forest renewal, due to human activities. Human activities thus significantly have adverse effects on the forest environments in the particular areas. Removal of woody biomass for fuel poses some far-reaching consequences on the structure and functioning of ecosystems worldwide. Fuel-wood extraction has been cited for increasing soil erosion, reducing soil moisture content and decreasing soil fertility as nutrient leaching is increased (Angelsen and Kaimowitz, 1999). Vegetative cover and subsoil nutrients are also fast declining through the charcoal activities. These are then associated with more extensive effects including reservoir siltation, flooding, water shortages due to shifting ground water regimes (Oguntunde *et al.*, 2008) and biological impacts such as reduced fauna abundance (Ogunkunle and Oladele, 2004) and loss of biodiversity. An exponential increase in deforestation has heightened desert encroachment and has led to environmental degradation that is evident in terms of climate change manifestations such as changes in weather patterns.

Biomass in developing nations is the main energy source for three-quarters of the population (Ahmed and Haboubi, 2010). Biomass fuels are mostly employed in its traditional form mainly for meeting domestic energy needs such as cooking and heating. The supply of wood for fuel (firewood and charcoal) is not sustainable as this tends to deplete forest resources. Agricultural wastes abound in the country, though, not much use is made of them as energy resources. A number of studies had however been carried out on the utilization of these wastes for energy production as reported by Fapetu (2000).

Energy crises of the early 1970s and 1980s, and the manifestations of climate change have prompted a growing awareness of the detrimental consequences of greenhouse gases. This phenomenon has consequently reinforced the importance of renewable energy technologies (RETs), particularly biomass, as an emerging energy source in the developing countries. Biomass energy is fast gaining the world’s interest due to its environmental advantages. In this context, biomass appears to be an attractive energy resource because it is a domestic and environmentally friendly renewable fuel. The use of biomass residues and wastes as an energy source can meet the requirement of fostering sustainable development, due to their numerous positive environmental and socio-economic impacts, which include the improvement of degraded lands, creation of employment opportunities and raising the standards of living for poor communities in developing countries. The production of briquettes from sawdust and other agro-residues exemplifies the potential of appropriate technology for the utilization of biomass residues which abound in large quantities in developing countries. However, compared to developed countries where successful briquette operations are mostly found, briquettes have not been widely adopted in developing countries due to the high cost of production, lack of awareness on its sustainability, lack of ready market and poor packaging and distribution systems for the product (Emerhi, 2011).

Among the several kinds of biomass resources, agricultural residues such as sawdust, rice husk, corn stover, cotton stalk, groundnut husk, etc have become one of the most promising choices as cooking fuels due to their availability in substantial quantities as waste annually. However, the utilization of these biomass residues in their natural form as fuel is quite challenging due to their low bulk density, low heat release and the excessive amounts of smoke they generate (Amaya *et al.*, 2007). All of these characteristics make it difficult to handle, store, transport and utilize biomass residues in their raw form. One of the methods of improving the thermal value of such biomass is the application of briquetting technology (Suhartini *et al.* 2011; Wilaipon, 2007). This involves the densification of loose biomass to produce fuel briquette which has better handling characteristics and enhanced volumetric calorific value compared to the biomass in its original state (Oladeji, 2010). According to Style *et al.*, (2008) briquettes production provides a key technology for increasing biomass available for use in both electricity and heat generation.

Therefore, this study assessed the potentials of using carbonized corncobs to produced briquettes as an alternative to fuelwood with the view to curbing the menace of deforestation which depletes the ozone layer and mitigating the effect of greenhouse gas emission generated by the use of fallen trees as fuel wood.

MATERIALS AND METHODS

Corncobs were obtained from freshly harvested mature *Swan yellow* maize specie collected from the Teaching and Research Farm of the Obafemi Awolowo University Ile-Ife, Osun State, Nigeria. The corncobs were sun-dried to reduced moisture content to about 10.08% dry basis (Eriksson and Prior, 1990; ASAE S269.4, 2003) this was obtained after five weeks during the dry season in Nigeria. The corns were manually shelled and the cobs were subjected to sun drying until moisture content of 10.08% dry basis (db) was obtained (ASAE S269.4, 2003). The corncobs were carbonized using a locally made metal carbonization kiln, 1500 mm in height and 1000 mm in diameter. Then the carbonized corncobs were pulverized with hammer mill and further process with a bur mill to pass through a screen of 1 mm to get fine particles for good binding (ASAE 424.1, 2003). The carbonized granules were prepared by wet granulation method (Ngwuluka *et al*., 2010). Three types of binders of namely 1) cassava starch, 2) corn starch and 3) gelatin at three different concentrations of 10, 20 and 30% wt/wt were used. The binder was carefully mixed with 150 ml of distilled water and allowed to disperse without any clumps; the solution was heated in a boiling water bath at 100 ^{o}C for 10 min with continuous stirring until complete paste was form. In each case, appropriate amount of carbonized corncob powder was weighed and manually mixed with the prepared binder solution to obtain a homogeneous damp mass. The damp mass was sieved with a 1.70 mm sieve and then placed in the oven set at 60 ^{o}C to dry and the dried granular mass was then passed through a 1.18 mm sieve to obtain uniform sized granules, this process enhances adhesion and production of identical briquettes (Lachman, 1990; Ngwuluka *et al*. 2010). Therefore, carbonized corncob granules size of 1.18 mm was used for this study. A manual method using a punch and die operated by a hand-powered hydraulic press to compress the granules to achieve briquettes of uniform shape and size was employed for the briquettes production. A 30 mm internal diameter x 50 mm height cylindrical die, made of hardened steel was developed with a clearance of 0.1 mm provided between the punch and the die to allow for escape of air. For each experiment, the die was filled with 10.00 g of the briquetting material weighed using a digital balance (Model PM 4600, Mettler Instrument AG, Greifensee, Zurich) with an accuracy of ± 0.001 g; the samples were pressed at any of the following predetermined compacting pressure levels: 50, 100, and 150 kPa using Hydraulic Press Hyspin AWS 22/32 compression machine. The dwelling time for each press was maintained at 120 sec for all the pressing made (Oladeji and Enweremadu, 2012) This process was repeated for all the mixtures in three replicates each; the briquettes were collected and ready for physical analysis. Data was then analyzed for differences among treatment means based on physical properties (density, compressive strength and moisture content) using Statistical Analysis System software (SAS, 2010).

Determination of moisture content

The percentage moisture content (PMC) was calculated by weighing 2 g of the briquette sample in a crucible of known weight; the crucible with the sample was put in an oven set at 103 $\pm$ 2 °C for 1 hr. The crucible was removed and put in a desiccator, allowed to cool to room temperature and reweighed. This was repeated until the weight after cooling was constant and was recorded as the final weight; the sample's moisture content was determined using equation (1).

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

where:
W_1 is the initial weight of sample and
W_2 is the final weight of dried sample.

Determination of volatile matter

The percentage volatile matter (PVM) was determined by pulverising 2 g of the briquette sample in a crucible and placing it in an oven until a constant weight was obtained. Then, the briquette was kept in a furnace at a temperature of 550 °C for 10 min and weighed after cooling in a desiccator. The PVM was calculated using equation (2)

$$PVM = \frac{W_2 - W_3}{W_3} \times 100 \quad (2)$$

where:
W_2 is the weight of the oven-dried sample (g)
W_3 is the weight of the sample after 10 min in the furnace at 550 °C (g)

Determination of ash content

The percentage ash content (PAC) was determined by heating 2 g of the briquette sample in the furnace at a temperature of 550 °C for 4 hr and weighed after cooling in a desiccator to obtain the weight of ash. The PAC was determined using equation (3).

$$PAC = \frac{W_4}{W_2} \times 100 \quad (3)$$

where:
W_2 is the weight of oven dried sample (g) and

W_4 is the weight of ash (g)

Determination of fixed carbon

In accordance to Akowuah *et al.* (2012), the percentage fixed carbon (PFC) was calculated by subtracting the sum of PVM, PAC and PMC from 100 as shown in the equation (4).

Fixed carbon = 100 - PMC − PVM − PAC (4)

Determination of calorific value of the briquettes

The calorific value which is the major combustion property of the briquette was determined using Oxygen Bomb Calorimeter according to ASTM standard E711-87(2004). Leco AC-350 Oxygen Bomb Calorimeter interfaced with a computer was set up to assess the heat values of the produced briquettes. Two grams each of the briquettes was measured and the screw mould bracket was used to remould the briquette to the appropriate calorimeter bucket size. Ten (10) ml distilled water was poured into the bomb placed inside a canister bracket containing distilled water and the bomb lid was covered; it was then filled slowly with oxygen at pressure range of 2.5-3.0 MPa for a minute from an industrial oxygen cylinder connected to the bomb. The switch was turned on and the computer was set for the determinations which automatically calibrate and measure the energy values and display the values on the screen after feeding the necessary data on the briquettes, data and results of the experiment displayed on computer screen were recorded (Obi *et al.*, 2013).

RESULTS AND DISCUSSION

The physico-chemical properties of the briquettes produced from carbonized corncobs were limited to moisture content, volatile matter, ash content, fixed carbon and calorific value.

Table 1: Mean values of moisture content (%) for carbonized briquettes

Pressure kPa	Binder Conc. % wt/wt	Cassava Starch	Corn Starch	Gelatin Starch
50	10	5.23	6.30	5.78
	20	5.63	6.63	6.96
	30	6.06	7.09	7.62
100	10	4.82	5.03	5.69
	20	5.29	5.88	6.56
	30	5.72	6.52	7.53
150	10	4.43	4.68	5.64
	20	5.08	5.59	6.29
	30	5.34	6.17	7.13

From Table 1, it was observed that the average moisture content for the briquette produced ranged between 4.43 and 7.62% (db); however, generally, the moisture content of briquette increased with increase in binder concentration and decreased with increase in compaction pressure for all briquettes. The lowest moisture content of 4.43% (db) was observed for carbonized briquette made with cassava binder under 150 kPa compacting pressure and highest moisture content of 7.62% (db) was observed for carbonized briquette made with gelatin at 30% concentration under compaction pressure of 50 kPa; this might be attributed to the hygroscopic nature of materials and the additional water availability from binders with increase in concentration. The results obtained agree with Pallavi *et al.*, (2013) who recommended moisture content of 5-10% for good quality briquettes. Generally, when the moisture content is low, the briquettes will easily be ignited, no slagness during burning will occur and higher calorific values are expected from the fuel. With high moisture content in briquettes, much of the heat will be used to vaporize the surplus water and sometimes tears briquettes into pieces with low burning rate and less heat generated and lot of smoke emitted (Akowuah *et al*., 2012.

Table 2: Mean value of volatile matter (%) of carbonized briquettes

Pressure kPa	Binder Conc. % wt/wt	Cassava Starch	Corn Starch	Gelatin Starch
	10	13.99	14.56	16.48
50	20	12.06	13.88	15.23
	30	10.95	12.27	13.74
	10	13.02	14.30	16.41
100	20	11.25	13.16	15.06
	30	10.49	12.27	13.44
	10	12.22	13.32	15.78
150	20	11.07	12.49	14.57
	30	10.31	11.31	12.89

There was variation in the results of volatile matter of carbonized briquettes produced as shown in Table 2. The volatile matter varied from 10.31-16.48% carbonized briquettes. The lowest volatile matter of 10.31% was observed for briquettes produced with cassava starch of 30% concentration and 150 kPa compaction pressure and gelatin binder with 10% concentration and 50 kPa compaction pressure produced briquettes with the highest volatile matter of 16.48%. High volatile matter of a briquette is an indication of easy ignition, fast burning and proportionate increase in flame length but low heating values. The carbonized briquette produced in this research is within 20% volatile matter for good quality briquettes; a good quality briquette should have volatile matter range from 10 to 25%. High volatile briquette is easy to ignite but may burn with smoky flame while low volatile charcoal is difficult to ignite but burns with less smoke.

Table 3 Mean value of ash content (%) of carbonized briquettes

Pressure kPa	Binder Conc. % wt/wt	Cassava Starch	Corn Starch	Gelatin Starch
	10	3.21	3.76	5.06
50	20	3.18	3.37	4.15
	30	3.22	3.37	3.67
	10	3.20	3.64	4.85
100	20	3.09	3.54	4.38
	30	3.03	3.49	3.15
	10	3.14	3.60	4.28
150	20	3.13	3.35	3.81
	30	3.05	3.34	3.34

As shown in Table 3, the values of ash content of the briquettes produced ranged from 3.03 to 5.06%. This is expected because the briquettes were produced from already burnt corncob materials for which much of the ash were released during the carbonization. Cassava starch bonded briquettes recorded the lowest ash content of 3.03% at binder level of 30% for carbonized while gelatin recorded the highest ash content of 5.06% at 10% binder level. Low ash content offers higher heating value for briquettes but high ash content results into dust emissions which lead to air pollution and affects the combustion volume and efficiency (Obi *et al*. 2013). The higher the ash content, the lower its calorific value and vice versa this is because ash content influences the burning rate due to minimization of the heat transfer to fuel's interior parts and diffusion of oxygen to the briquette surface during char combustion (Chaney, 2010).

Table 4 Mean value of fixed carbon (%) of carbonized briquettes

Pressure kPa	Cassava	Corn	Gelatin
	77.57	75.38	72.68
50	79.13	76.12	73.66
	79.77	77.27	74.97
	78.96	77.03	73.05
100	80.37	77.42	74.00
	80.76	77.72	75.88
	80.21	78.40	74.30
150	80.72	78.57	75.33
	81.30	79.18	76.64

Table 4 shows the mean fixed carbon of carbonized briquettes; from the study the mean fixed carbon of the briquettes obtained in this study varied from 72.68-81.30%. It was observed that carbon content increases with an increase in binder concentration and pressure with the highest carbon content of 81.30% when cassava starch at binder level of 30% concentration was used. While the least fixed carbon content of 72.68% was recorded for gelatin at binder level of 10% concentration. These results for fixed carbon indicate that carbonized briquette correspond with the result of Pallavi *et al*. (2013) that reported the suitability of briquettes with fixed content of 80.5% for domestic applications. The higher the fixed carbon content of a fuel, the greater the calorific value the smaller the volatile matter, the lower the ash and moisture content and the better the quality of the fuel as stated by Moore and Johnson, (1999).

Table 5: Mean value of calorific value (MJ/kg) of carbonized briquettes

Pressure kPa	Cassava	Corn	Gelatin
	31.78	29.13	28.85
50	31.93	30.78	30.39
	32.04	31.16	30.87
	31.96	30.71	30.05
100	32.09	30.99	30.45
	32.19	31.32	31.08
	32.09	31.05	30.47
150	32.15	31.16	30.74
	32.36	31.50	31.15

Table 5 shows the average heating values of the briquettes that ranged between 28.85 and 32.36 MJ/kg, for the carbonized briquettes. Generally, the calorific value was observed to increase with increasing binder concentration and compaction pressure. The highest calorific value of 32.36 MJ/kg was obtained for carbonized briquettes when produced with cassava starch at 30% concentration level and compacting pressure of 150 kPa while the least value of 28.85 MJ/kg was obtained when gelatin was used at 10% binder level and compacting pressure of 50 kPa.

All the briquette samples produced were found to have heating value high enough to meet the heat requirement for household cooking and small-scale industrial cottage applications. The results of the calorific values of the carbonized corncob briquettes produced in this work compare well with that of the calorific value of charcoal and sawdust briquette by Wakchaure and Mani, (2011).

Table 6: Mean effect of physical properties of carbonized corncob briquettes

Variable	Moisture Content %	Volatile Matter %	Ash Content %	Fixed Carbon %	Calorific Value MJ/kg
Binder Type					
CASSAVA	5.2889c	11.7067c	3.1389c	79.8656a	32.0656a
CORN	5.9878b	13.0622b	3.4956b	77.4544b	30.8667b
GELATIN	6.5778a	14.8444a	4.0767a	74.5011c	30.4500c
Binder Concentration					
30	6.5756a	11.9633c	3.2956c	78.1656a	31.5189a
20	5.9900b	13.1967b	3.5556b	77.2578b	31.1867b
10	5.2889c	14.4533c	3.8600a	76.3978c	30.6767c
Compacting Pressure					
150	5.5944c	12.6622c	3.4489b	78.2944a	31.4078a
100	5.8933b	13.2667b	3.5967ab	77.2433b	31.2044b
50	6.3667a	13.6844a	3.6656a	76.2833c	30.7700c

Means with the same letters are not significantly different at 5% level using Duncan's multiple range tests.

From the Duncan Multiple Range test, Table 6 mean values of moisture content shows that effect of binder types were significant different ($p<0.05$); gelatin binder had the highest effect with a mean value of 6.5778 %, corn starch and cassava starch having 5.9878 and 5.2889 %, respectively. On the other hand, there were significant different ($p<0.05$) when considering the effect of binder concentration on the moisture content of briquettes produced, binder concentration of 30 % had the highest effect with a mean value of 6.5756 % followed by 20 % then 10 % with mean values of 5.9900 % and 5.2889 %, respectively. Compaction pressure equally had significant effect ($p<0.05$) on the moisture content, 50 kPa had the highest effect on mean value of 6.3667% followed by 100 kPa with mean value of 5.8933% then 150 kPa with 5.5944.

It was also observed from Table 6 that gelatin had the highest effect followed by corn starch and cassava starch had the least with mean value of 14.8444, 13.0622 and 11.7067%, respectively. The result also showed that binder concentration had significant effect ($p<0.05$) on the volatile matter where 10 % had the highest effect followed by 20 % and 30 % had the least with mean value of 14.4533, 13.1967 and 11.9633 %, respectively. Compaction pressure equally had significant effect ($p<0.05$) on the volatile matter of briquettes produced where 50 kPa had the highest effect followed by 100 kPa and 150 kPa had the least with mean value of 13.6844, 13.2667, and 12.6622 %, respectively.

When considering the effect of binder type on the ash content of the carbonized briquettes produced (Table 6), it was observed that there was a significant ($p<0.05$) effect with highest effect from gelatin followed by corn starch and cassava starch had the least with mean value of 4.0767, 3.4956 and 3.1389%, respectively. The result also showed that binder concentration had significant effect ($p<0.05$) on the ash content where 10% had the highest effect followed by 20% and 30% had the least with mean value of 3.8600, 3.5556 and 3.2956%, respectively. Compaction pressure equally had significant effect ($p<0.05$) on the ash content of briquettes produced where 50 kPa had the highest effect followed by 100 kPa and 150 kPa had the least with mean value of 3.6656, 3.5967 and 3.4489%, respectively.

However, from Table 6 where the mean values are shown; among the binders, mean value of fixed value shows that cassava binder had the highest effect value of 79.8656 %, followed by corn binder with 77.4544 % and gelatin binder having the least value of 74.5011 % and their effects were significantly different ($p<0.05$). Binder concentration of 30 % had the highest effect on fixed carbon with a mean value of 78.1656 % followed by 20 % then 10 % with mean values of 77.2578 % and 76.3978 %, respectively. Compacting pressure shows significant effect ($p<0.05$), 150 kPa had the highest mean value effect on fixed carbon with value of 78.2944 %, followed by 100 kPa with value of 77.2433 % and 50 kPa having the least mean value of 76.2833 %. The analysis of variance (ANOVA) of briquettes produced indicates that processing material, binder type, binder concentration, compacting pressure and some of their interactions have significant effects on the calorific value of briquettes produced. From Table 6, the mean values of calorific value showed that cassava starch had the highest effect followed by corn starch and gelatin had the least with mean value of 32.0656, 30.8667 and 30.4500 MJ/kg, respectively. Also, the result for binder concentration showed that 30 % had the highest effect followed by 20 % and 10 % had the least with mean value of 31.5189, 31.1867 and 30.6767 MJ/kg, respectively. Compaction pressure of 150 kPa had the highest effect followed by 100 kPa and 50 kPa had the least with mean value of 31.4078, 31.2044 and 30.7700 MJ/kg, respectively.

CONCLUSION

This study investigated the potentials of using carbonized corncobs to produced briquettes as an alternative to fuelwood using three binder materials of cassava starch, corn starch and gelatine; while considering three concentration levels of the binders, and processing under three compression pressures. The study also established the potential of using carbonised corncob as alternative material for briquettes production. This will increase the sources of energy for domestic and industrial use in developing economy. The findings of this study have shown that charcoal briquettes produced from sawdust meet recommended briquettes characteristics and potential of charcoal.

The physico-chemical characteristics of the briquette assessed in this study showed that briquettes manufactured from carbonized corncob had low moisture content (4.43 %), low volatile matter (16.48 %), low ash content (3.03 %), high fixed carbon (81.30 %) and high calorific value (32.36 MJ/kg). Cassava starch at 30% binder concentration level and compaction pressure of 150 kPa exhibited the most positive attributes of physic-chemical properties than the other variables for briquettes from carbonized corncob. It can then be concluded that corncob generated in large quantities and usually burned to pollute the environment can be converted into high-quality and durable solid fuel briquettes that will be suitable for both domestic and industrial energy production for heat generation.

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