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Article

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Research paper

Effect of binder type, binder concentration and compacting pressure on some physical properties of carbonized corncob briquette



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ABSTRACT

Biomass fuel properties determine the choice of agricultural waste to be used in production of briquette for industrial and domestic usage. Compaction of these agro-wastes would add more values to their bulk handling, conveyance and storage properties. This work determined the effect of different binders with varying concentrations and applied die pressures on some physical properties of briquette from carbonized corncob.

Cassava starch, corn starch and gelatine at three different concentrations of 10, 20 and 30% wt/wt were used as binders in the production of the briquettes at the predetermined compacting pressure levels of 50, 100, and 150 kPa using Hydraulic Press. A charcoal kiln and a punch and die were fabricated for carbonization and facilitation of the compaction of this corncob into briquettes. Physical properties such as moisture content, density and compressive strength were determined using standard procedures.

The results showed that the moisture content ranged between 4.43 and 7.62% (db), relaxed density of the briquettes produced were found in range of 729 to 987 kg/m³ and compressive strength ranged from 1.02 and 8.32 MPa. Both show technological advantage and a suitable situation for material package, storage and transportation. For all the three factors investigated, variables with cassava binder at concentration of 30% and compaction pressure of 150 kPa exhibited the most positive attributes than other variables. The higher the binder concentration and compacting pressure, the better the briquettes and this results in higher quality briquettes for both storage and transportation.

In conclusion, high quality and storable briquettes can be produced from the blend of carbonized corncobs and cassava starch, corn starch and gelatine. This is because the relaxed density and compressive strength of the briquettes produced are adequate; besides, the length of time or service life of the stored briquettes proved acceptable stability after some months of storage.

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1. Introduction

Nigeria is a nation endowed with natural resources; for instance, in terms of agricultural resources, Nigeria has a land area of 98.3 million hectares, out of which 79 million hectares is arable land as reported by [Oladimeji et al. \(2013\)](#). In the country, 60%–70% of the population is involved in agriculture and agricultural related activities contributing a large share of gross domestic product as recorded by [Udolisia et al. \(1994\)](#). These farming activities result in the production of various economic products from which many types of residues that are biomass materials containing enormous amount of energy are left as waste materials after harvest ([Fapetu, 2000a](#)). [Jekayinfa and Omisakin](#)

(2005) found out that these agricultural residues are neither utilized nor properly managed in all developing countries including Nigeria but can be used to play a significant role in meeting energy demand. Presently, agro wastes management practice in the country is that of burning or allowing them to decay on farm. Whichever approach causes environmental contamination and pollution aside from also resulting to enormous waste of resources. Burning of agricultural wastes on a farmland affects soil biodiversity, geomorphic process and volatilizes large amount of the nutrients in the soil including organic matter, while black carbon and particulate matters emitted into the atmosphere during the process is also worrisome ([Onuegbu et al., 2012](#)).

With man, life is a continuous process of energy conversion and transformation. This emphasize that the accomplishment of civilization has largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to

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extend human capabilities and ingenuity (Fapetu, 2000b). Sustainable, suitable and affordable energy is required for human continuity in term of development and growth so, provision of adequate energy is essential to improve living standard. According to Fapetu (1994), in Nigeria about 51% of total energy consumption is estimated to be met from various biomass resources (i.e., agricultural residues, animal dung, forest waste, firewood). While corncob can be directly utilized as fuels, they are nevertheless not directly suitable apparently because of their bulkiness, uneven nature, and having low energy density; characteristics that make them difficult to handle, store, transport, and utilize in their raw form; hence, there is the need to subject them to conversion processes in order to mitigate these problems as suggested by Oladeji (2010).

One of the promising technology solutions to these problems is the application of briquetting technology. Wilaipon (2007) defined it as a densification process for improving the handling characteristics of raw materials and enhancing volumetric calorific value of the biomass. The technology which is termed densification enhances physical and combustion characteristics. Briquetting using this technology had been extensively studied (Ndiema et al., 2002; Husain et al., 2002). Lately, many studies had been conducted on the production of briquettes from unprocessed or raw agricultural residues. For instance, briquettes from rice straw and rice bran were feasible to be converted into solid biomass fuel using a hot-pressing temperature (Chou et al., 2009). Eucalyptus wood and rice husk from Uruguay was used as an activated carbon briquettes (Amaya et al., 2007). Likewise, waste paper and coconut husk which had moisture content from 5.4% to 13.3% (Olorunnisola, 2007) and pelletized wastes (including refuse derived fuel, wood and paper). These briquettes when compared to coal has a prospective for coal replacement in vertical gasifier system (Marsh et al., 2008). Also, waste paper can be converted into briquette as a partial binder material alone or mixed with wheat straw (Demirbas and Sahin, 1998; Demirbas, 1999a), as well as the briquettes from cotton plant residues (Coates, 2000), hazelnut shells using 800 MPa pressure and 127 °C (Demirbas, 1999b) and sunflower stalk which had a high percentage of ash and 67% efficiency (Smith and Lindle, 1988). The findings from all these studies show that characteristics of briquettes are influenced by process and material parameters besides, different biomass materials required different optimum conditions for briquetting process. However, most of the research done in this area focused on briquetting of unprocessed biomass, but little information exists on processed biomass as briquettes. Zubairu and Sadiq (2014) in their work established that the conversion of corncobs biomass resources into briquette can be done by a processing called carbonization. Pallavi et al. (2013) carried out research on bagasse and coffee husk by converting them to char through carbonized process by an eco-friendly and continuous batch process. The char obtained was briquetted into a solid fuel form and later used as an efficient, clean source of fuel. This suggested that carbonizing the biomass before briquette production is another method of enhancing the properties of briquette. Carbonization is essentially the removal of volatile materials from the feedstock in the absence (or limited supply of) air. In this processing method, the biomass is first partially burnt in an environment where air is totally controlled to give char product that is high in carbon. So, this research aimed at investigating the effect of different binders with varying concentrations and applied die pressures on the physical properties of briquette produced from carbonized corncob.

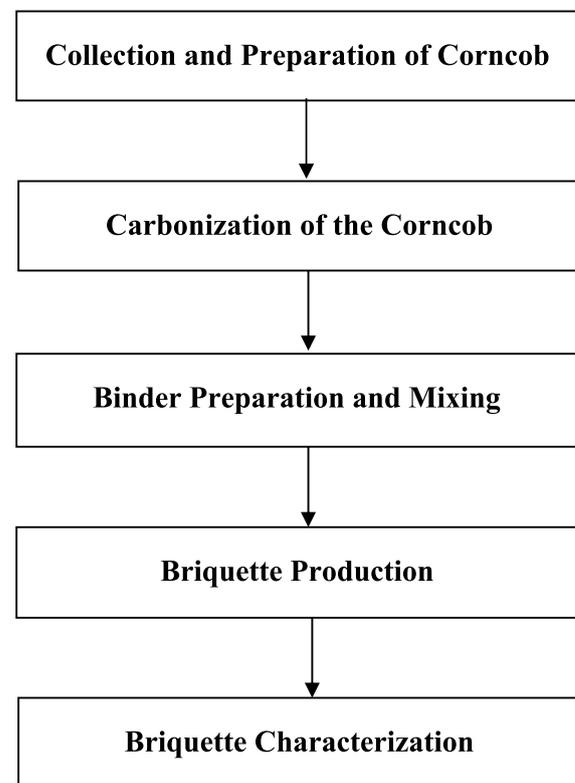


Fig. 2.1. Flowchart for the Production of Briquette.

2. Materials and methods

The study was carried out at the Agricultural and Environmental Engineering Department of Obafemi Awolowo University (OAU) Ile Ife. The feedstock used for this research was corncob carbonized in a fabricated kiln. The experiment was set up as a $3 \times 3 \times 3$ factorial in randomized complete block design (RCBD) replicated three times. The three factors considered are binder types (cassava, corn and gelatin), binder concentrations (10, 20 and 30%) and compacting pressures (50, 100 and 150 kPa). Data collected were then analysed with Statistical Analysis System (SAS) software. Fig. 2.1 shows the steps and procedures followed to accomplish this work and were discussed below.

2.1. Material collection and sample preparation

The corncob for this work was 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 whole corns were manually shelled and the cobs were subjected to sun drying until moisture content of 10.08% dry basis (db) was achieved, in accordance with Eriksson and Prior (1990) and ASAE, S269.4 (2003) specification.

2.2. Carbonization of the Corncob

The dried corncobs obtained were carbonized in an environment where fresh air is controlled to give a high carbon product char, (Pallavi et al., 2013). To accomplish this process, a kiln (1500 mm in height and 1000 mm in diameter) was fabricated; this was made of 2 mm iron sheet with two fire ports having doors of 200 mm by 70 mm provided at the lower side. The top was cut out to place the chimney while the bottom side of the drum was closed with iron sheets with 5 stands of height

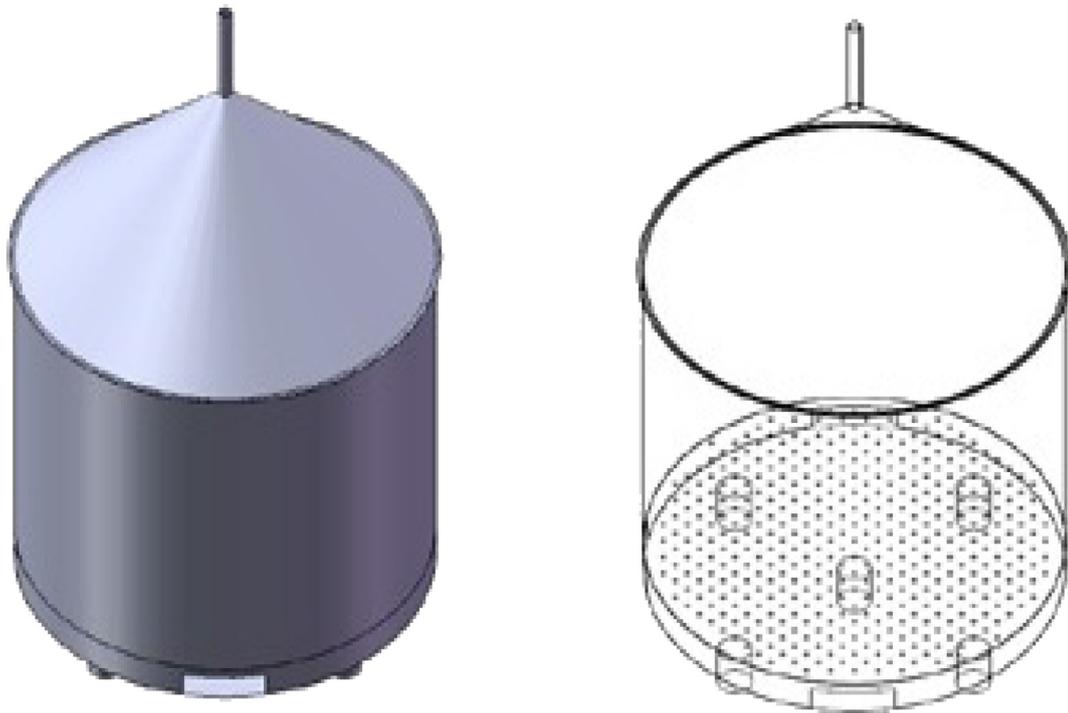


Fig. 2.2. Assembled view of the charring drum.

120 mm. An iron perforated sheet with holes was fixed at the base of the kiln to allow fire to spread through the holes above the firing portion to the corncobs placed inside for carbonization (Fig. 2.2 and Plate 2.1). For evidence of carbonization of corncobs, the black smoke coming out of chimney disappeared, cobs were brittle and easy to break and the centres of the cobs were totally black as shown in Plate 2.2. The carbonized corncobs were then pulverized with hammer mill and further processed with a bur mill to obtain fine particles that pass through a mesh size of 18 as shown in Plate 2.3. The surface area was increased to allow for good binding in accordance with ASAE, S424.1 (2003) specification.

2.3. Binder preparation and mixing

The carbonized granules were prepared by wet granulation method, this is a method of size enlargement in which fine powder particles are agglomerated or brought together into a larger, strong and relatively permanent structure called granules. Three types of binders, viz, cassava starch, corn starch and gelatine at three different concentrations of 10, 20 and 30% w/w were used to produce the carbonized briquettes. With 150 ml of distilled water, the binder was mixed and allowed to dissolve without any clogs or lumps; the binder solution was heated in a water bath at 100 °C for 10 min with continuous stirring until a whole paste was formed. An appropriate amount of carbonized corncob powder was weighed and thoroughly mixed manually with the prepared binder solution to obtain a homogeneous damp (wet) mass. The wet mass was sieved with a mesh number 12 to obtain wet coarse aggregate granules and dried in the oven at 60 °C. The dried granular mass was milled using a bur mill to breakdown the dried coarse aggregate then passed through a mesh number 16 to obtain uniform sized fine granules that was used for the production of the briquettes; Ngwuluka et al. (2010) stated that this process enhances adhesion and production of identical briquettes.



Plate 2.1. Charcoal kiln or carbonizer.

2.4. Briquette production

A manual method, punch and die with 30 mm internal diameter by 5 mm thickness by 50 mm height cylindrical die, made of hardened steel with a clearance of 0.1 mm was employed for



Plate 2.2. Charcoal kiln or carbonizer.



Plate 2.4. Punch and die (Manual briquetting machine).

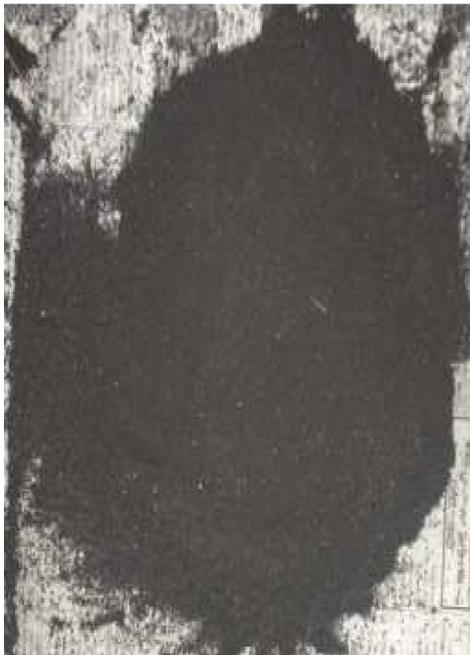


Plate 2.3. Carbonized corncob powder.



Plate 2.5. Carbonized corncob briquettes.

the briquettes production (Plate 2.4). This punch and die method was operated by a hand-powered hydraulic press to compress the granules to achieve briquettes of uniform shape. Ten grams of the granules was weighed using a digital balance, Model PM 4600. This was put in the die for each experiment carried out. The samples were compressed at the predetermined compacting pressure levels using Hydraulic Press Hyspin AWS 22/32 compression machine. For all the press made, the dwelling time for each press was maintained at 120 s to achieve a stable briquette in agreement with [Oladeji and Enweremadu \(2012\)](#). Plate 2.5 shows the carbonized briquette produced.

2.5. Briquette characterization

The physical properties of the briquettes characterized in this study were limited to moisture content, compressed and relaxed density, relaxation and compaction ratio and compressive strength. Conventional methods were used to test for the physical properties.

2.5.1. 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 ± 2 °C for 1 h. 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:

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

where:

W_1 is the initial weight of sample (g)

W_2 is the final weight of dried sample (g)

2.5.2. Determination of compressed and relaxed density

The compressed density of the briquette was determined immediately after removal from the press while the relaxed density of the briquette was determined after the briquette has remained stable 30 days after removal from the press (ISO 3131, 1975). Both densities were computed as the ratio of mass to the volume of the briquette in accordance with the method used by Rabier et al. (2006).

$$\rho = \frac{M}{V} \quad (2)$$

where:

ρ = density of the briquette produced (gcm^{-3})

M = Mass of the briquette produced (g)

V = Volume of the briquette produced (g)

The mass of briquettes was obtained by using a digital weighing balance (Model PM 4600, Mettler Instrument AG, Greifensee, Zurich) while the volume was calculated using $\pi r^2 h$ by taking measurement of the height and width with the help of a digital vernier caliper.

2.5.3. Determination of relaxation and compaction ratio

The compaction and relaxation ratios were also determined:

$$\text{Compaction Ratio} = \frac{\text{Compressed Density}}{\text{Initial Density of the mixture}} \quad (3)$$

$$\text{Relaxation Ratio} = \frac{\text{Compressed Density}}{\text{Relaxed Density}} \quad (4)$$

To determine the initial density of the mixture, an empty container (30 ml) was weighed using a digital balance (Model PM 4600, Mettler Instrument AG, Greifensee, Zurich) with an accuracy of ± 0.001 g. The container was filled with the sample and the material was slightly compacted by tapping to ensure absence of large void spaces; the initial density was then calculated using the following equation:

$$D_i = \frac{W_2 - W_1}{V} \quad (5)$$

where:

D_i = initial density of the mixture of corncob powder and binder (gcm^{-3})

W_2 = weight of the container and sample (g)

W_1 = weight of the container (g)

V = Volume of the mixture of corncob powder and binder (cm^3)

2.5.4. Determination of compressive strength of the briquettes

The compressive strengths of the briquettes were determined using an Instron Universal Testing Machine (Model: 3369) in accordance with ASTM Standard D1037-93 (1995). A 1000 kN load was applied at a constant rate of 5 mm/min until the briquette failed by cracking or breaking using three samples for each experiment and the average compressive stress derived from the stress-strain was analysed.

2.5.5. Data analysis

The experiment was set up as a $3 \times 3 \times 3$ factorial in randomized complete block design (RCBD) replicated three times adopted from statistical procedures used by Gomez and Gomez (1984). Data was then analysed for differences among treatment means based on physicochemical and combustion properties (density, compressive strength, moisture content, volatile matter, ash content, fixed carbon content, calorific value, and gas emission) using Statistical Analysis System software (SAS, 2010). Analysis of variance (ANOVA) was performed and treatment means separated using Waller–Duncan Test to test for significance differences ($p \leq 0.05$) in the properties exhibited by the different briquettes.

3. Results and discussions

3.1. Characterization of some physical properties of the briquette produced

3.1.1. Moisture content

From Table 3.1, 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 briquettes made with cassava binder with 10% binder ratio under 150 kPa compacting pressure and highest moisture content of 7.62% (db) was observed for briquette made with gelatine at 30% concentration under compaction pressure of 50 kPa; this might be credited to the hygroscopic character of the carbonized corncob material used and the availability of water presence in the binders with increase in concentration.

The results obtained agree with Pallavi et al. (2013), who proposed moisture content of 5%–10% for good quality briquettes from their work. Generally, briquettes will easily be ignited with no occurrence of slagness during burning when the moisture content is low; in this condition, higher calorific values are expected. Higher moisture content in briquettes will cause much of the heat to be used in vaporizing the surplus water and sometimes tears briquettes into pieces with low burning rate and lot of smoke is emitted.

3.1.2. Compressed density

The average compressed density of the carbonized briquettes obtained in this study varied from 952 to 1437 kg/m^3 (See Table 3.2). The values obtained were higher than the minimum value of 600 kg/m^3 recommended by Mani et al. (2006) for efficient transportation and safe storage; hence, carbonized briquettes of good quality in term of density good enough for transportation may be achieved using percentage binder ratio between 10%–30%. The highest compressed density of 1437 kg/m^3 was obtained for briquettes made of cassava binder at 30% binder concentration under 150 kPa compacting pressure, while the lowest value of 952.46 kg/m^3 was obtained from gelatin binder at 10% binder concentration under 50 kPa compacting pressure. It was observed that the compressed density of the briquettes increased with increase in binder ratio and compaction pressure.

3.1.3. Relaxed density

Table 3.3 shows the mean values of the relaxed density of the carbonized briquettes. It is noticed that the relaxed density of the briquettes ranged between 729 and 986 kg/m^3 which is in agreement with Oladeji and Enweremadu (2012). These values were found to be higher than the initial density of the uncompressed mixture of 363.64 kg/m^3 and lower than 952 to 1437 kg/m^3 for the compressed density in this study. This is as

Table 3.1

Mean values of moisture content (%) of briquettes produced.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine 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

Table 3.2Mean values of compressed density (kg/m^3) for carbonized briquettes.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine starch
50	10	1159.94	1008.09	952.46
	20	1239.83	1090.24	1024.44
	30	1332.62	1172.63	1094.47
100	10	1202.00	1094.94	1035.96
	20	1306.28	1191.48	1098.61
	30	1393.22	1268.13	1182.52
150	10	1299.11	1155.54	1090.51
	20	1393.32	1240.34	1175.75
	30	1437.42	1308.75	1231.53

Table 3.3Mean values of relaxed density (kg/m^3) for carbonized briquettes.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine starch
50	10	851.41	768.11	729.09
	20	896.42	812.97	772.88
	30	937.81	854.22	813.78
100	10	874.52	811.13	777.97
	20	925.84	863.66	812.16
	30	965.24	903.66	863.50
150	10	927.47	848.25	808.94
	20	962.77	892.78	855.90
	30	986.04	918.15	886.11

Table 3.4

Mean values of relaxation ratio for carbonized briquettes.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine starch
50	10	1.36	1.31	1.31
	20	1.38	1.34	1.33
	30	1.42	1.37	1.34
100	10	1.37	1.35	1.33
	20	1.41	1.38	1.35
	30	1.44	1.40	1.37
150	10	1.40	1.36	1.35
	20	1.45	1.39	1.37
	30	1.46	1.43	1.39

Table 3.5

Mean values of compaction ratio for carbonized briquettes.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine starch
50	10	3.19	2.77	2.62
	20	3.41	3.00	2.82
	30	3.66	3.22	3.01
100	10	3.31	3.01	2.85
	20	3.59	3.28	3.02
	30	3.83	3.49	3.25
150	10	3.57	3.18	3.00
	20	3.83	3.41	3.23
	30	3.95	3.60	3.39

a result of increase in volume of the briquettes resulting from expansion in dimensions that takes place after removal from the briquetting machine. The highest relaxed density of 986 kg/m^3

was observed for briquette made with cassava binder at 30% binder concentration under 150 kPa compacting pressure and the lowest value of 729 kg/m^3 was for gelatin at 10% binder

Table 3.6
Mean values of compressive strength (MPa) for carbonized briquettes.

Pressure kPa	Binder conc. % wt/wt	Cassava starch	Corn starch	Gelatine starch
50	10	1.60	1.28	1.02
	20	3.23	2.22	1.88
	30	4.20	2.73	2.23
100	10	2.57	2.28	2.03
	20	4.32	3.63	2.97
	30	6.66	4.16	3.33
150	10	4.23	3.70	3.05
	20	6.76	4.88	4.24
	30	8.32	5.42	5.05

Table 3.7

Extract from Analysis of variance (ANOVA) for some of the physical properties of the briquette produced.

Source	Pr > F					
	Moisture content	Compressed density	Relaxed density	Relaxation ratio	Compaction ratio	Compressive strength
PRESS	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
BCONC	<.0001*	<.0001*	0.0064*	<.0001*	<.0001*	<.0001*
BTYPE	<.0001*	<.0001*	0.0105*	<.0001*	<.0001*	<.0001*
PRESS*BCONC	0.7262	0.6119	0.3679	0.4445	0.6021	<.0001*
PRESS*BTYPE	0.0012*	0.4561	0.3579	0.1462	0.4261	<.0001*
BCONC*BTYPE	0.0014*	0.7780	0.9728	0.0035*	0.7637	<.0001*
PRESS*BCONC*BTYPE	0.3531	0.9868	0.9908	0.3424	0.9876	<.0001*

BTYPE: Binder Type, BCONC: Binder Concentration, PRESS: Compacting Pressure.

*Factors that are significant at $p < 0.05$ **Table 3.8**

Effect of factors on some physical properties of carbonized corncob briquette.

Variable	Moisture content (db)%	Compressed density kg/m ³	Relaxed density kg/m ³	Relaxation ratio	Compaction ratio	Compressive strength MPa
Binder type						
Cassava	5.29c	1307.08a	925.28a	1.41a	3.59a	4.65a
Corn	5.99b	1170.02b	852.55b	1.37b	3.22b	3.37b
Gelatine	6.58a	1098.47c	813.37c	1.35c	3.02c	2.87c
Binder concentration						
30	6.58a	1269.03a	903.17a	1.40a	3.49a	4.68a
20	5.99b	1195.59b	866.15b	1.38b	3.29b	3.79b
10	5.29c	1110.95c	821.88c	1.35c	3.06c	2.42c
Compacting pressure						
150	5.59c	1259.14a	898.49a	1.40a	3.46a	5.07a
100	5.89b	1197.02b	866.41b	1.38b	3.29b	3.55b
50	6.37a	1119.41c	826.30c	1.35c	3.08c	2.27c

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

concentration under 50 kPa compacting pressure. An increase behaviour in the relaxed density was observed with increase in binder concentration and compacting pressure; this is due to the consolidation of the char–binder mixture and decreasing elastic recovery during relaxation of the formed briquette. The high value of relaxed density obtained is a description of a good quality briquette.

3.1.4. Relaxation ratio

From Table 3.4, it was observed that the maximum and minimum relaxation ratios of briquettes produced were found to be 1.31 and 1.46. This result showed that the three binders gave relatively stable briquettes as suggested by Yang et al. (2005). This is because, the lower the value of relaxation ratio and the higher the value of relaxed density the higher is the stability of briquettes produced. The highest relaxation ratio of 1.46 was observed for cassava binder at 30% binder concentration under 150 kPa compacting pressure while the lowest was observed for both corn and gelatin binders at 10% binder concentration under 50 kPa compacting pressure.

3.1.5. Compaction ratio

Table 3.5 shows the mean values of compaction ratio for carbonized corncob briquettes from which it can be observed that

compaction ratio ranged from 2.62–3.95; the implication is that more volume are displaced (i.e. fewer voids), good for packaging, storage and transportation and above all, it is an indication of good quality briquettes in accordance to the findings of Davies and Mohammed (2013). It was observed that the compaction ratio increased with increasing pressure and binder ratio; this shows that the void spaces are removed at higher pressures, hence, briquette with higher binder quantity has fewer void spaces. Cassava binder at highest concentration and compaction pressure displayed the best result; this is justified by the findings of Faborode and O'Callaghan (1987) who concluded that the number of voids in an incoherent mass of materials affects such processes concerned with air flow, heat flow and compressibility.

3.1.6. Compressive strength

From Table 3.6, it was observed that the maximum and minimum compressive strength of briquettes produced were found to be 1.02 and 8.32 MPa. The highest compressive strength of 8.32MPa was observed for briquette made of cassava binder at 30% binder concentration under 150 kPa compacting pressure while the lowest was observed for briquette made of gelatine at 10% binder concentration under 50 kPa compacting pressure. The consequence is that, briquettes made of cassava binder will suffer

smaller extent of damage or breakage during transportation and storage compare to briquettes made from other binders.

3.2. Analysis of variance (ANOVA) and mean effect for some physical properties of the briquette produced

3.2.1. Moisture content

Analysis of variance for the moisture content of briquettes produced showed that binder type, binder concentration, compacting pressure and interactions between compacting pressure and binder type; as well as binder type and binder concentration had significant effects on the moisture content of briquettes produced (Table 3.7). The multiple coefficient of determination value R^2 and the root mean square error for the ANOVA model are 0.9311 and 0.2800, respectively, thus, it could be deduced that binder type, binder concentration, compacting pressure and their interactions explained about 93.11% of the variability of the moisture content of the briquettes produced.

From the Duncan Multiple Range test, Table 3.8, the three binder types were significantly different ($p < 0.05$) in their effects on the mean moisture content of the briquette. Gelatine binder had the highest effect with a mean value of 6.58%, corn starch and cassava starch having 5.99 and 5.29%, respectively. In addition, the three levels of binder concentration were also significantly different ($p < 0.05$) in their effects on the moisture content of briquettes produced; binder concentration of 30% having the highest effect (6.58%) followed by 20% then 10% with mean values of 5.99% and 5.29%, respectively. The three compaction pressures were equally significantly different ($p < 0.05$) in their effect on the moisture content with 50 kPa having the highest effect of 6.37% followed by 100 kPa with mean value of 5.89% then 150 kPa with 5.59%.

3.2.2. Compressed density

The analysis of variance of briquettes produced indicates that only individual variables like binder type, binder concentration and compacting pressure without any interaction had significant effects ($p < 0.05$) on the compressed density of briquettes produced as shown on Table 3.7. The multiple coefficient of determination value and the root mean square error for the ANOVA model were 0.9592 and 30.96, respectively. It could therefore be deduced that binder type, binder concentration, compacting pressure could explain about 95.92% of the variability in the compressed density of the briquettes produced.

Duncan Multiple Range test (Table 3.8) indicates that the three binder types were significantly different ($p < 0.05$) in their effects on the mean compressed density of the briquette. Cassava binder had the highest effect with a mean value of 1307.08 kg/m³, corn starch and gelatine having 1170.02 and 1098.47 kg/m³ respectively. In addition, three levels of binder concentration were significantly different ($p < 0.05$) in their effects on compressed density of the briquette produced. Binder concentration of 30% having the highest effect of 1269.03 kg/m³ followed by 20% then 10% with mean value of 1195.59 kg/m³ and 1110.95 kg/m³, respectively. The three levels of compaction pressure were significantly different ($p < 0.05$) in their effects on compressed density with 150 kPa having the highest effect of 1259.14 kg/m³ followed by 100 kPa with mean value of 1197.02 kg/m³ then 50 kPa with of 1119.41 kg/m³.

3.2.3. Relaxed density

It is noted from the analysis of variance of the relaxed density of briquettes produced that binder type, binder concentration and compacting pressure have significant ($p < 0.05$) effects on the relaxed density of briquettes produced; with the multiple coefficient of determination value R^2 value of 95.46% and the root

mean square error 17.23, respectively which shows a high level of reliability of the result.

However, Table 3.8 shows Duncan Multiple Range test, the three binder types were significantly different ($p < 0.05$) in their effects on the mean relaxed density of the briquette. Cassava binder had the highest effect with a mean value of 925.28 kg/m³, corn starch and gelatine having 852.55 and 813.37 kg/m³ respectively. In addition, three levels of binder concentration were significantly different ($p < 0.05$) in their effects on relaxed density of the briquette produced. Binder concentration of 30% having the highest effect of 903.17 kg/m³ followed by 20% then 10% with mean value of 866.15 and 821.88 kg/m³, respectively. The three levels of compaction pressure were significantly different ($p < 0.05$) in their effects on relaxed density with 150 kPa having the highest effect of 898.49 kg/m³ followed by 100 kPa with mean value of 866.41 kg/m³ then 50 kPa with of 826.30 kg/m³.

3.2.4. Relaxation ratio

From Table 3.7, Analysis of variance indicates that binder type, binder concentration, compacting pressure and some of their interactions had significant effects ($p < 0.05$) on the relaxation ratio of briquettes produced. The multiple coefficient of determination value and the root mean square error for the ANOVA model were 0.9674 and 0.0089, respectively, indicating an acceptable level of reputability and reliability of the result on relaxation ratio.

Meanwhile, from Table 3.8, the mean effects of the relaxation ratio are shown; the three binder types were significantly different ($p < 0.05$) in their effects on the mean relaxation ratio of the briquette produced. Cassava starch had the highest effect with a mean value of 1.41, corn starch and gelatine having 1.37 and 1.35, respectively. Also, the three levels of binder concentration were significantly different ($p < 0.05$) in their effects on the mean relaxation ratio of the briquette produced. Binder concentration of 30% having the highest effect of 1.40 followed by 20% then 10% with mean values of 1.38 and 1.35, respectively. The three levels of compacting pressure were equally significantly different ($p < 0.05$) in their effects on relaxation ratio with 150 kPa having the highest effect of 1.40 followed by 100 kPa with mean value of 1.38 then 50 kPa with 1.35.

3.2.5. Compaction ratio

Analysis of variance indicates that the binder type, binder concentration and compacting pressure had significant effects ($p < 0.05$) on compaction ratio of the briquettes (Table 3.7). The multiple coefficient of determination value and the root mean square error for the ANOVA model were 0.9589 and 0.0855, respectively. Thus, it could be deduced that binder type, binder concentration, compacting pressure could explain about 95.92% of the variability in the compaction ratio of the briquettes produced.

Duncan Multiple Range test (Table 3.8) indicates that the three binder types were significantly different ($p < 0.05$) in their effects on the mean compaction ratio of the briquette. Cassava binder had the highest effect with a mean value of 3.59, corn starch and gelatine having 3.22 and 3.02, respectively. In addition, three levels of binder concentration were significantly different ($p < 0.05$) in their effects on compaction ratio of the briquette produced. Binder concentration of 30% having the highest effect of 3.49 followed by 20% then 10% with mean value of 3.29 and 3.06, respectively. The three levels of compaction pressure were significantly different ($p < 0.05$) in their effects on compaction ratio with 150 kPa having the highest effect of 3.46 followed by 100 kPa with mean value of 3.29 then 50 kPa with of 3.08.

3.2.6. Compressive strength

From Table 3.7, analysis of variance (ANOVA) showed that all factors and various interactions had significant effects ($p < 0.05$) on the compressive strength with a multiple coefficients of determination value and root mean square error $R^2 = 99.98$ and 0.4052 respectively which explain about 99.98% of the variability in the compressive strength in cleft of the briquettes produced.

From the Duncan Multiple Range test, Table 3.8, the three binder types were significantly different ($p < 0.05$) in their effects on the mean compressive strength of the briquette. Cassava starch had the highest effect with a mean value of 4.65 MPa, corn starch and gelatine having 3.37 and 2.87 MPa, respectively. In addition, the three levels of binder concentration were also significantly different ($p < 0.05$) in their effects on the compressive strength of briquettes produced; binder concentration of 30% having the highest effect of 4.68 MPa followed by 20% then 10% with mean values of 3.79 and 2.42 MPa, respectively. The three compactions pressure were equally significantly different ($p < 0.05$) in their effect on the compressive strength with 50 kPa having the highest effect of 5.07 MPa followed by 100 kPa with mean value of 3.55 MPa then 150 kPa with 2.27 MPa.

4. Conclusion

This study examined the production of briquettes from carbonized corncobs using three binder materials of cassava starch, corn starch and gelatine; while considering three concentration levels of the binders, and processing under three compacting pressures. It was found that, the handling (processing) parameters such as binder type, binder concentration and compaction pressure, significantly affected the physical characteristics of briquettes produced from carbonized corncobs. Statistically, the analysis of variance of briquettes produced indicates that binder type, binder concentration and compacting pressure have significant effects ($p < 0.05$) on all the physical characteristics considered. Some of the interactions such as binder type and compacting pressure, binder type and binder concentration have no significant effects ($p < 0.05$) on the moisture content, compressed density, relaxed density, compaction ratio and relaxation ratio. Also, interaction of binder type and binder concentration have no significant effects ($p < 0.05$) on both compressed density and relaxed density. However, all the interactions have significant effects ($p < 0.05$) on the compressive strength. Yet, the Duncan's Multiple Range Test show that cassava binder had the highest effect on compressed density, relaxed density, compaction ratio, relaxation ratio and compressive strength followed by corn then gelatin but reverse is the case for moisture content. Meanwhile, binder concentration at 30% had the highest effect on all the physical parameters examined followed by 20% then 10%. Conversely, compacting pressure of 150 kPa had the highest effect on compressed density, relaxed density, compaction ratio, relaxation ratio and compressive strength followed by 100 kPa then 50 kPa but reverse is the case for moisture content.

Therefore, based on the results obtained, high quality and storable briquettes can be produced from the blend of carbonized corncobs and cassava starch, corn starch and gelatine. This is because the relaxed density and compressive strength of the briquettes produced are adequate; besides, the length of time or service life of the stored briquettes proved adequate and acceptable stability even after some months of storage. It can then be concluded that for carbonized corncob briquettes, the higher the binder concentration, the better the briquettes, while higher compaction pressure will result in higher quality briquettes for both storage and transportation.

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