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Effect of Pretreatment on the Physical Properties and Heating Values of Briquettes

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ABSTRACT

Briquettes from agro-residues have been promoted as a better alternative to firewood and charcoals for heating and cooking in the rural communities. In this light, a study was carried out to investigate the effect of pretreatment methods on physical properties and heating values of briquettes produced from corncob. To accomplish this work, an experiment was designed as a 2 × 3 × 3 × 3 completely randomized with three replicates. The parameters are pretreatment methods (carbonized and uncarbonized), binder types (cassava, corn, and gelatin), binder concentrations (10, 20, 30 %), and compacting pressures (50, 100, and 150 kPa). A charcoal kiln was fabricated to obtain the pretreatment through pyrolysis and a punch and die was also fabricated to facilitate briquette densification. The physical properties tested were limited to moisture content (MC), density and compressive strength and were determined using a conventional method. The heating value of the briquettes produced was determined using bomb calorimeter. The results demonstrated that average moisture content ranged between 5.29-6.58 % and 12.75-13.72 %, mean relaxed density varied from 813-925 kgm^{-3} and 963-1166 kgm^{-3}, compressive strength ranged between 2.27-5.07 MPa and 5.97-10.12 MPa, and heating value ranged between 28.85-32.36 $MJkg^{-1}$ and 27.58-28.80 $MJkg^{-1}$ for carbonized and uncarbonized briquettes, respectively. Briquettes produced from carbonized corncob had a better moisture content and heating value, while briquettes produced from uncarbonized corncob had higher density and compressive strength. The study shows that pretreatment methods under different binder types and concentrations and the compacting pressure significantly affected the briquettes physical properties and heating values. Therefore, this technology can be successfully applied in rural off-grid areas by the government and other stakeholders in the energy sector as part of renewable energy technologies.

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1. INTRODUCTION

Corncobs can be described as by-products of corn plant obtained either dry or green. Nigeria is endowed with a huge amount of corn plants which could be roasted or boiled for human consumption upon harvested green. It can also be harvested dry; the grains threshed out of the cob can further be dried and stored or used for human consumption. In whatever forms, the grains are obtained and they allow an enormous quantity of corncobs which add to environmental wastes. Often, these corncobs are left on the farm, thereby polluting it and posing health risks to both human and ecology. The current management practice of corncob is usually that of burning in the open or dumping on the farm to decompose; any of these methods apart from resulting in a colossal waste of resources contribute to environmental degradation and pollution. This corncob can be directly utilized as fuel; however, it is not suitable apparently because it is bulky, uneven, and has low energy density [1]. However, some literature pieces have shown that corncob is a good resource for biofuel due to its lignocellulosic properties [1-3]. Therefore, it is necessary that the corncobs should be subjected to the conversion process to be able to produce a better fuel in such a way that it will alleviate the problem they pose when used directly.

Briquette technology has been discovered for use as a renewable fuel production from agricultural waste and by-products to solid biofuel in a sustainable way in many developing countries [2]. Briquetting is a densification process for enhancing some physical properties of solid fuel materials and the heating value of biomass [3]. A briquette, defined by Grainger and Gibson [4], is a block of compressed biomass that is used as fuel to start and maintain fire. Briquettes made of biomass that cost nothing to obtain such agricultural wastes

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represent an alternative source for domestic use for rural households or communities. Fuel wood remains a major source of fuel for rural communities since other energy sources (kerosene, gas, and electricity) are either unavailable or grossly inadequate where available and beyond the reach of the masses [1]. Hitherto, collection of fuel wood has grave consequences on forest conservation and sustainable forest resource management. However, briquette production reduces deforestation and its positive effects, thereby turning waste materials into fuel source. However, based on the type of raw materials utilized for the briquette production, they may burn cleaner at a greater heating value than fuel wood and charcoal. Therefore, briquette making has been found to be a promising renewable fuel that supplies additional energy demands for rural, urban, and industrial sectors, thus contributing significantly to expansion of the economy of developing countries.

In recent times, varieties of biomass materials were selected for research. However, a great number of these biomasses were practically applied or utilized with no pretreatment and were found not suitable for large-scale use, particularly in energy production, due to their low energy density. This issue leads to two methods of briquettes production: carbonized (pyrolyzed) and uncarbonized (non-pyrolyzed) methods used in this study. Carbonized method is basically pyrolyzing the biomass to remove volatile matters without or in the limited supply of oxygen. Explicitly, carbonized process entails partial burning of the biomass in an enclosed surrounding to produce char of high-quality carbon. On the other hand, the uncarbonized process is the production of briquettes without carbonizing the biomass without allowing it to pass through any form of heat. The main purpose of biomass pretreatment through pyrolysis is to produce smokeless briquettes that are environmentally friendly with high heating value, which is not feasible or reasonably not achievable for unpretreated biomass. The resulting fine particles obtained at the end of both methods are compacted into regular shape and size, which would not be separated during transportation, storage, or combustion. Fine particles are compressed without the addition of adhesives (binderless briquettes) if the fibres in the material are able to create a strong bond. However, often times, adhesive material is added to facilitate holding the particles of the material together, particularly if the raw material does not have an ability to bond together when compressed. Consequently, addition of adhesive material is to produce a compact briquette, which will suffer less damage during transportation and storage.

The physical properties of briquettes and heating values vary from one method to another and since briquettes can be made of a wide variety of methods, selection of the best briquettes must be made based on the method that has better fuel properties. Therefore, efficient briquette technologies used to extract energy from the biomass and convert it into a more useful form are required, being the essence of this study. Thus, this work aims to investigate the effect of pretreatment methods on the physical properties and heating values of briquettes.

2. MATERIALS AND METHODS

The experiment was designed as 2 × 3 × 3 × 3 which is completely randomized and replicated three times. These parameters are pretreatment methods (carbonized and uncarbonized), binder types (cassava, corn, and gelatin), binder concentrations (10, 20, 30 %), and compacting pressure (50, 100, and 150 kPa). The steps followed to achieve this work are shown in Figure 1 and discussed below.

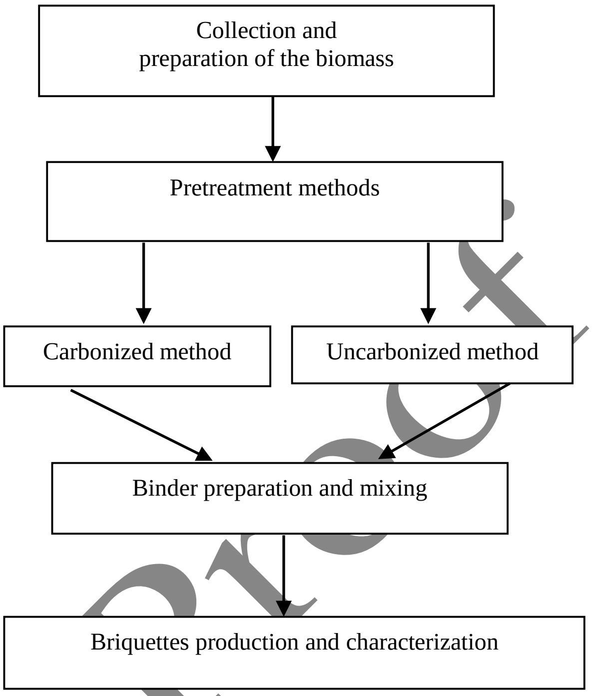

Figure 1. Steps for briquette production

2.1. Collection and preparation of the biomass

The biomass used in this work was the corncob derived from matured *Swan yellow* maize variety harvested from the teaching and research farm of the Obafemi Awolowo University Ile-Ife, Nigeria. The maize was threshed to obtain the corncobs which were later sun dried to 10.08 % (db) moisture content as opined by Eriksson and Prior [5] and ASAE [6]. The moisture content was achieved after drying for five weeks during the dry season of 2020 in Nigeria.

2.2. Pretreatments methods

2.2.1. Carbonized corncob

After collection and drying of the corncobs, they were subjected to pretreatment through pyrolysis facilitated by a fabricated metal kiln of 1.5 m high and 1 m diameter made of 2 mm iron sheet, as presented in Figure 2. An opening was made at the top to allow for the chimneypiece and the drum base was closed with a metal sheet and provided with the stand of 120 mm high. The collected corncobs were loosely packed into the kiln and by using a small amount of biomass to create an ignition in the kiln, the top of the kiln was closed tightly to allow fire to spread with a limited supply of air [7]. The disappearance of smoke coming out of the chimney top was evidence of completion of the carbonized process. The carbonized corncobs were allowed to cool and then, crushed using hammer mill and subsequently milled using bur mill to achieve finely particle size that passed through a mesh number of 18 for good binding in line with ASAE [8].

2.2.2. Uncarbonized corncob

For the uncarbonized process, the corncobs were prepared without allowing them to pass through any form of heat apart from pulverizing using hammer mill and then, they were milled using a bur mill to achieve a finely particle size that passed through a mesh number of 18 [8].

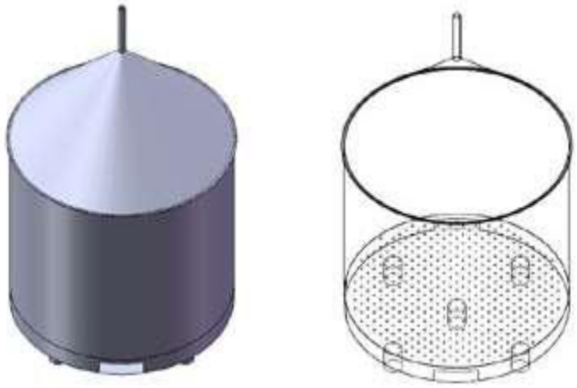

Figure 2. Assembled view of fabricated metal kiln for pyrolysis

2.3. Binder preparation and mixing

Three binders (cassava, corn, and gelatin) at three different proportions of 10, 20, and 30 % (wt/wt) were employed for the mixing. The distilled water of 150 ml was used to dissolve the binders with no form of clog or lump in the binder solution. Using a water bath at 100 °C, the solution was heated for 10 minutes and stirred continuously until it formed an entire binder paste. The wet granulation method, followed by pharmaceutical company, was employed in preparing the granular mass. By using this method, an appropriate number of the corncob fine particles (both in carbonized and uncarbonized forms) were weighed (separately) and carefully stirred together by hand with the binder solution to achieve a homogenous damp mass. After the mixing, the damp mass was allowed to pass through a sieve number 12 and subsequently, oven-dried at 60 °C for 30 minutes. The dried granular mass was sieved using a mesh number 16 to derive granules of uniform size used to produce the briquettes.

2.4. Briquettes production and characterization

A manual method of compaction was used for the production of the briquette. To this end, a mold (punch and die) of 50 mm cylindrical die height and 30 mm internal diameter by 5 mm thickness was fabricated using hardened steel and 0.1 mm allowance was observed for the escape of air. To achieve this production, the granules were compacted using a hand-powered hydraulic press (Hyspin AWS 22/32 Model) to produce briquettes of uniform shape. For each production, 10 g of the granular mass was employed to fill the mold after that compressed at a different applied pressure of 50, 100, and 150 kPa. The dwelling time for each press during the compaction period was maintained within 120 seconds [9]. The physical properties the briquette determined were limited to moisture content, density, and compressive strength, which were carried out in line with ASTM standards [10]. With ASTM standards, oven dry method was used in determining the moisture content and density was computed as the ratio of mass to volume of the briquette. Instron Universal Testing Machine (Model: 3369) was used in determining the compressive strength. The Oxygen Bomb Calorimeter (Leco AC-350) was used in determining the heating value in accordance with ASTM standards [11]. This was achieved by firing 2 grams each of the briquettes in the Oxygen Bomb Calorimeter connected to a computer set through which the heat values of the briquettes were automatically displayed and recorded. Data collected were analyzed using Statistical Analysis System (SAS) software. The data were analyzed for analysis of variance (ANOVA) using Statistical Analysis System software with input variables including pretreatment methods, binder types, binder concentrations, and compacting pressure. Treatment means and significant differences were evaluated using the Duncan Multiple Range test ($P \leq 0.05$). Correlations were run among parameters to establish their relationships.

3. RESULTS AND DISCUSSION

Table 1 shows ANOVA results with observation that corncob processing method, binder type, binder concentration, compaction pressure, and some of their interactions significantly affected all the briquette's physical properties and heating values. Table 2 presents the treatment means and their significant differences in the moisture content, density, compressive strength, and heating values of the briquettes.

Table 1. The ANOVA results showing the effect of treatments on moisture content, density, compressive strength, and heating value of the briquettes produced

Source	Moisture content (db)	Compressed density (kgm^{-3})	Relaxed density (kgm^{-3})	Compressive strength (MPa)	Heating value (MJkg^{-1})
PM	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
PRES	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
PM*PRES	0.7795	<.0001*	<.0001*	<.0001*	0.1356
CONC	<.0001*	<.0001*	0.0064*	<.0001*	<.0001*
PM*CONC	0.0019*	<.0001*	0.0549	<.0001*	<.0001*
PRES*CONC	0.4602	0.0871	0.9902	<.0001*	<.0001*
PM*PRES*CONC	0.8879	0.1254	0.9957	<.0001*	0.0061*
TYPE	<.0001*	<.0001*	0.0105*	<.0001*	<.0001*
PM*TYPE	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
PRES*TYPE	0.0021*	<.0001*	0.8810	<.0001*	0.0923
PM*PRES*TYPE	0.2968	0.0004*	0.9609	<.0001*	0.2732
CONC*TYPE	0.0086*	0.1269	0.9998	<.0001*	0.0156*
PM*CONC*TYPE	0.0987	0.2335	0.9968	<.0001*	0.0010*
PRESS*CONC*TYPE	0.5710	0.9479	1.0000	<.0001*	0.2940
PM*PRES*CONC*TYPE	0.0171*	0.9934	1.0000	<.0001*	0.1587

PM: Pretreatment Method, TYPE: Binder Type, CONC: Binder Concentration, PRES: Compaction Pressure
* Factors that are significant at $P < 0.05$

Table 2. The effects of treatments on moisture content, density, compressive strength, and heating value of the briquettes produced

Variable	**Moisture content % (db)**		**Compressed density (kgm^{-3})**		**Relaxed density (kgm^{-3})**		**Compressive strength (MPa)**		**Mean heating value (MJkg^{-1})**	
Pretreatment method										
C	5.95^b		1191.85^b		863.73^b		3.63^b		31.13^a	
UC	13.19^a		1543.29^a		1066.71^a		7.91^a		28.24^b	
Binder type	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**
Cassava	5.29^c	12.84^c	1307.08^a	1421.09^c	925.28^a	1009.04^b	4.65^a	6.43^c	32.07^a	28.49^a
Corn	5.99^b	13.20^b	1170.02^b	1659.43^a	852.55^b	1119.95^a	3.37^b	9.43^a	30.87^b	28.26^b
Gelatin	6.58^a	13.53^a	1098.47^c	1549.35^b	813.37^c	1071.14^a	2.87^c	7.86^b	30.45^c	27.99^c
Binder concentration	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**
10	6.58^a	13.72^a	1269.03^a	1324.64^c	903.17^a	1071.19^a	4.68^a	5.97^c	30.68^c	28.11^c
20	5.99^b	13.09^b	1195.59^b	1560.45^b	866.15^b	1069.19^a	3.79^b	7.65^b	31.19^b	28.25^b
30	5.29^c	12.75^c	1110.95^c	1744.79^a	821.88^c	1059.76^a	2.42^c	10.12^a	31.52^a	28.37^a
Compacting pressure	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**	**C**	**UC**
50	5.59^c	12.87^c	1259.14^a	1747.63^a	898.49^a	1166.33^a	5.07^a	10.10^a	30.77^c	28.01^c
100	5.89^b	13.11^b	1197.02^b	1547.16^b	866.41^b	1070.80^b	3.55^b	7.73^b	31.20^b	28.27^b
150	6.37^a	13.57^a	1119.41^c	1335.08^c	826.30^c	963.01^c	2.27^c	5.90^c	31.41^a	28.45^a

* C: carbonized corncob; * UC: uncarbonized corncob
Means with the same letters are not significantly different at a level of 5 %

3.1. Moisture content of the briquettes as affected by processing parameters

The Moisture Content (MC) of the briquettes as affected by processing parameters is shown in Figure 3. It was observed that the average MC varied from 5.29-6.58 % and 12.75-13.72 % for carbonized and uncarbonized briquettes, respectively. The lowest MC was observed for the briquettes produced from carbonized corncob, while higher MC was observed for the briquettes produced from uncarbonized corncob, which is an indication that carbonized process method had the highest effect on the MC of the briquettes produced at a 5 % significant level (Table 2). This implies that the carbonized briquette will ignite faster and produce more heat, according to the conclusion of Akowuah et al. [12]. Cassava binder was observed to perform well at a 10 % concentration for the carbonized and uncarbonized briquettes produced when 150 kPa pressure was applied. Although there was an increase in MC as binder concentration increased, MC decreased with increased compacting pressure for all briquettes. This may be due to the fact that the feedstock is hygroscopic in form as increasing the concentration also increases the water available, as described by Aransiola et al. [13]. The result of carbonized briquettes agreed with Pallavi et al. [7], which suggested MC of 5-10 % for good quality briquettes. In general, the ignition of briquette is easy when MC is low and burnt without any slag; hence, a greater amount of heating is achieved. Higher MC in briquette causes a substantial amount of heat to be used in vaporizing the excess water which results in occasional tears of briquette into pieces followed by very low heating value, burning rate with quite minor emission of smoke.

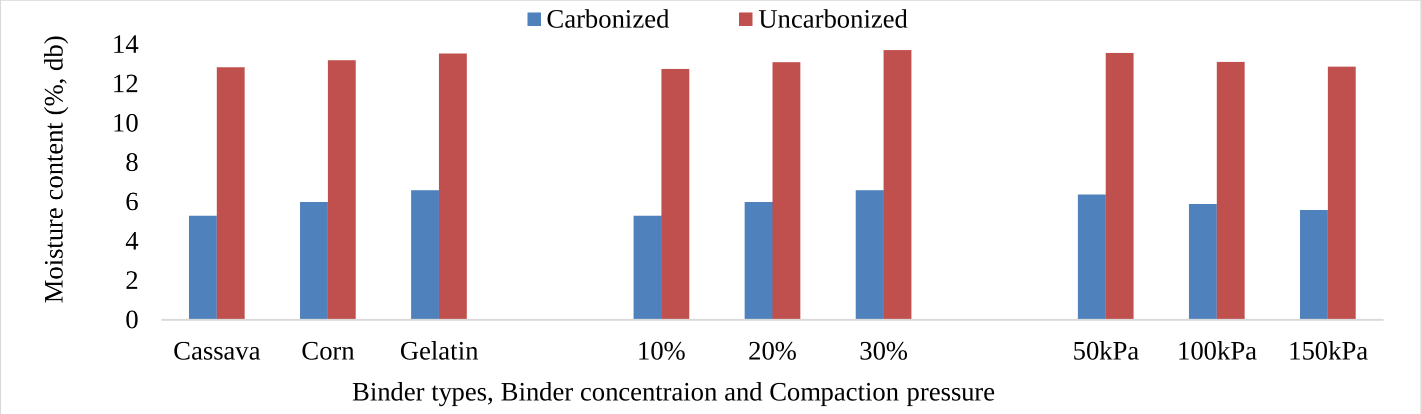

Figure 3. Moisture content of the briquettes as affected by processing parameters

3.2. Compressed density of the briquettes as affected by processing parameters

The compressed density of the briquettes as affected by processing parameters is shown in Figure 4. The mean values of compressed density ranged between 1098-1307 kgm^{-3} and 1324-1747 kgm^{-3} for carbonized and uncarbonized corncobs, respectively. The lowest compressed density was observed for briquettes produced from carbonized corncob, while the highest compressed density was observed for briquettes produced from uncarbonized corncob, which is an indication that uncarbonized pretreatment method had highest effect on the briquettes produced (Table 2). However, the carbonized briquette will store more and in a relatively smaller space and good in transportation more than the uncarbonized briquettes. Cassava starch at 30 % binder concentration acts well for carbonized briquettes and corn starch at 10 % binder concentration performs well for uncarbonized briquettes, both under 150 kPa applied pressure. It was discovered that there was an increase in compressed density as binder concentration increased for briquette produced from carbonized corncob, but compressed density increased with a decrease in the binder concentration for the briquettes produced from uncarbonized corncob.

This might be expected since it is possible that increasing the quantity of binder concentration cause higher resistance in the uncarbonized briquettes during densification causing more pores per unit volume, hence decrease in compressed density. Also, it is noted that at high levels of pressure, compressed densities are high, while they are low at lower pressure; this might be as a result of a significant amount of air being expelled during compaction.

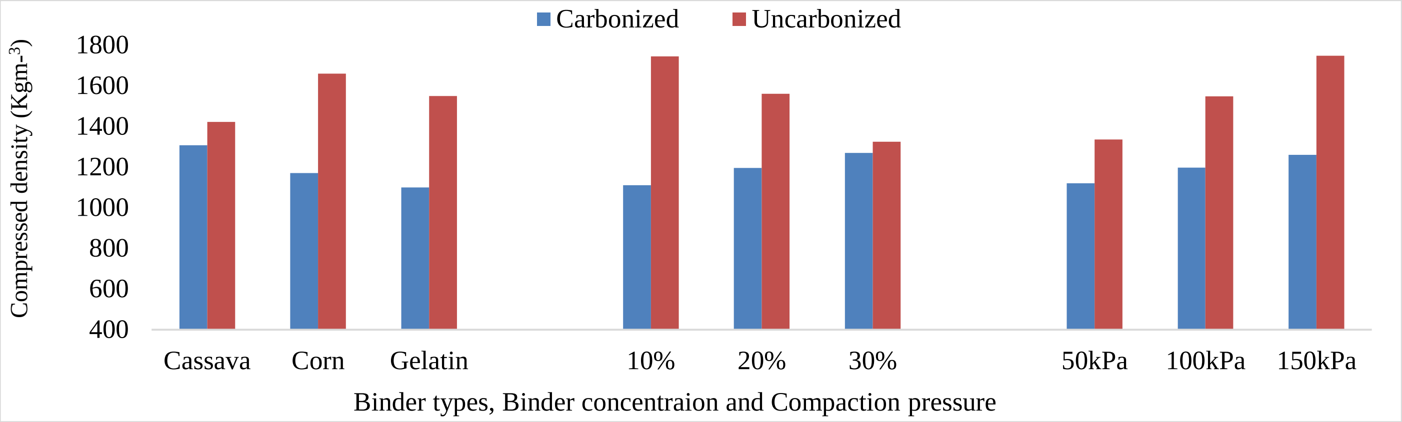

Figure 4. Compressed density of the briquettes as affected by processing parameters

3.3. Relaxed density of the briquettes as affected by processing parameters

The effect of processing parameters on the relaxed density of briquettes is shown in Figure 5. The average relaxed density ranged between 813-925 kgm^{-3} and 963-1166 kgm^{-3} for the carbonized and uncarbonized briquettes, respectively. The values obtained were more than the uncompressed feedstock's initial density, which are 363.64 and 331.33 kgm^{-3}, for carbonized and uncarbonized corncobs, respectively. Therefore, both carbonized and uncarbonized corncobs were able to improve the expected briquettes density as it is required in briquette making from agricultural wastes and the result corresponds to the findings of Eriksson and Prior [5]. Also, the obtained values were higher than the minimum value of 600 kgm^{-3} suggested by Mani et al. [14] and Gilbert et al. [15] for efficient transportation and safe storage. These values are lower than the compressed density of 1098-1307 kgm^{-3} and 1324-1747 kgm^{-3} for carbonized and uncarbonized briquettes, respectively, in this study. The lowest relaxed density was observed for the briquettes produced from carbonized corncob, while the highest compressed density was observed for the briquettes produced from uncarbonized corncob. This indicates that the uncarbonized pretreatment method had the highest effect on the briquettes produced, and both pretreatment methods were significantly different from each other at a significance level of 5 % (Table 2). However, the carbonized briquettes store more in a relatively smaller space and perform well in transportation than the uncarbonized briquettes. Cassava starch at 30 % binder concentration performed well for briquettes produced from carbonized corncob, while corn starch at 10 % binder concentration performed well for briquettes produced from carbonized corncob under compaction pressure of 150 kPa. Common development of increased relaxed density of carbonized and uncarbonized briquettes was noticed when the applied pressure increased. This is possible due to the strong bond between the feedstock and the binder as a result of increase in pressure and reduction in elastic recovery during relaxation of the briquettes. Also, relaxed density increased as the binder concentration increased for the briquette produced from carbonized corncob, which conforms with works of Sotannde et al. [16] and David et al. [17]; separate studies discovered that density of briquettes was affected by binder concentration. Conversely, relaxed density increased with decreasing binder concentration for the briquettes produced from uncarbonized corncob; this might be expected since a higher binder concentration level can provide higher resistance during compression [17], resulting in the presence of more pore spaces per unit volume of the briquette, thus lower density.

3.4. Compressive strength of the briquettes as affected by processing parameters

The compressive strength of the briquettes as affected by processing parameters is shown in Figure 6. For carbonized and uncarbonized briquettes, the average compressive strength varied from 2.27-5.07 MPa and 5.97-10.12 MPa, respectively.

The lowest compressive strength was observed for briquettes produced from carbonized corncobs, while the highest compressed density was observed for the briquettes produced from uncarbonized corncobs. This depicts that uncarbonized pretreatment method had the highest effect on the compressive strength and both pretreatment methods were significantly different from each other at 5 % level (Table 2). However, the result indicates that briquettes from uncarbonized corncobs suffer less damage during transportation and storage than briquettes from carbonized corncobs. The compressive strength increased with increasing binder concentration for carbonized briquettes and decreased with increasing binder concentration for the uncarbonized briquettes. Also, compressive strength was the highest with cassava as a binder compared to briquettes made with the other two binders for carbonized briquettes and was the highest with corn as a binder in comparison to briquettes made with the other two binders for uncarbonized briquettes. The compressive strength of the briquettes increased as die pressure increased for the briquettes produced from both pretreatment methods. The three compacting pressures gave different compressive strength levels; the highest compressive strength was observed for 30 % cassava binder at 150 kPa for carbonized briquettes and 30 % corn binder at 150 kPa for uncarbonized briquettes. This was due to very good sticky binding characteristics of cassava starch and its homogenous mixing with carbonized corncobs and corn starch and its homogenous mixing with uncarbonized corncobs with increase in briquetting pressure.

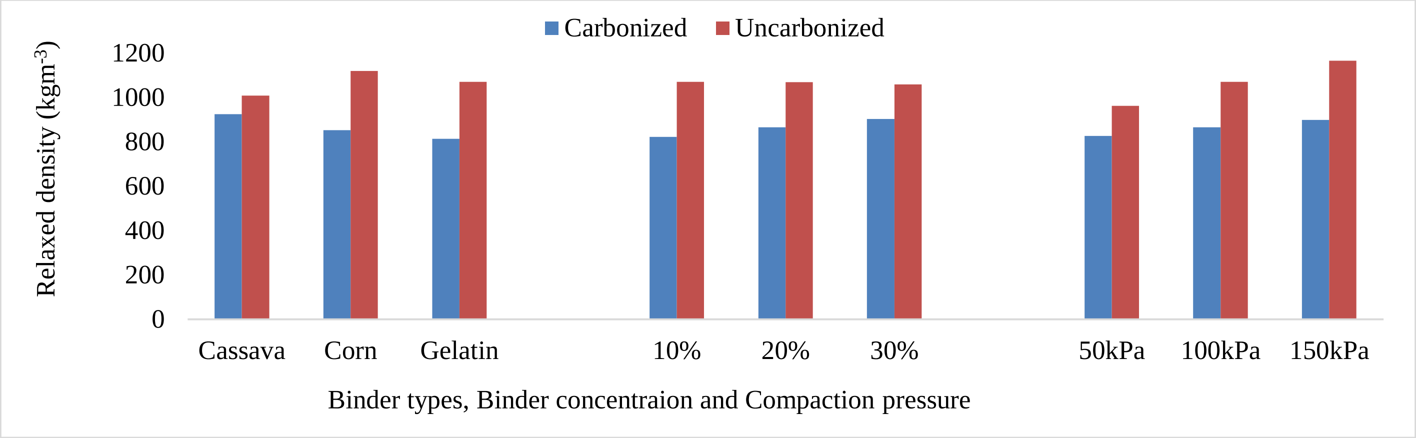

Figure 5. Relaxed density of the briquettes as affected by processing parameters

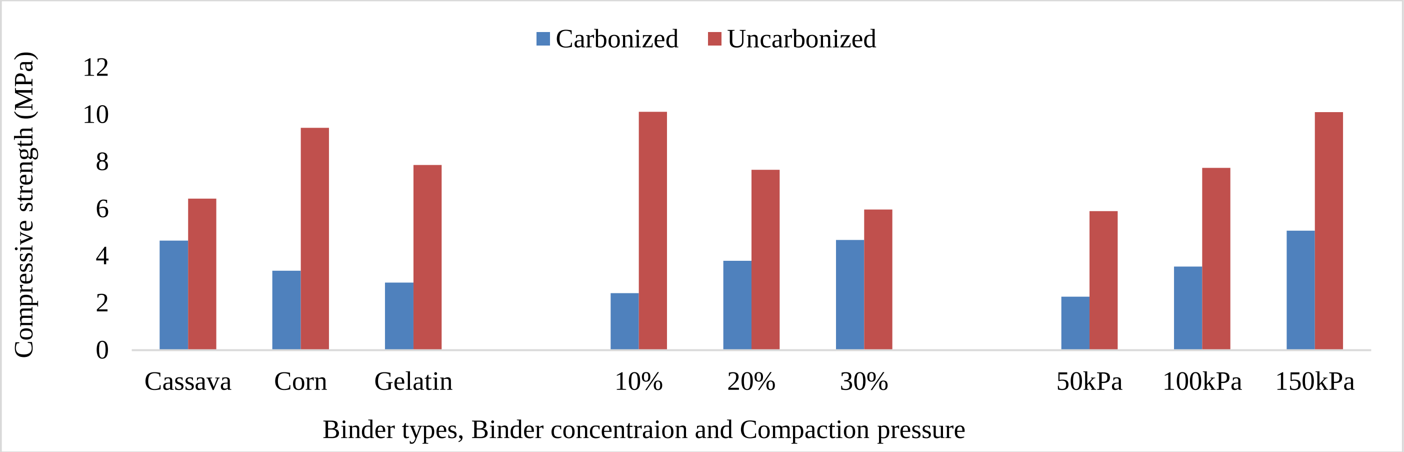

Figure 6. Compressive strength of the briquettes as affected by processing parameters

3.5. Heating value of the briquettes as affected by processing parameters

The effect of processing parameters on the heating value of briquettes is shown in Figure 7. The average heating values achieved in this work ranged between 28.85-32.36 MJkg^{-1} and 27.58-28.80 MJkg^{-1} for carbonized and uncarbonized briquettes, respectively. It was observed that the heating values of the uncarbonized briquettes in this study had high values compared to the ones reported in existing literatures which could be an indication of wet granulation method used. The highest heating value was observed for briquettes produced from carbonized corncob, while the lowest was observed for briquettes produced from uncarbonized corncob. This indicates that the carbonized pretreatment method had the highest effect on the heating value of the briquettes produced and both materials were significantly different from each other at a 5 % significance level (Table 2). The highest heating value of 32.36 MJkg^{-1} was observed for briquette made from carbonized corncob for 30 % cassava binder at a die pressure of 150 kPa, while briquettes from uncarbonized corncob exhibited the lowest heating value of 28.80 MJkg^{-1} for the same binder at the same level of binder and pressure. The results of heating values from this study were compared well with the average heating value of 32.43 MJkg^{-1} from the corncob briquette obtained by Zubairu and Sadiq [18] and with 28.5 $MJkg^{-1}$ from sawdust briquette by Wakchaure and Mani [19]. All the briquette samples produced in this work were found to have higher heating values, but the heating value of the briquette produced from the carbonized process of corncob competed well with the heating value of fuel wood and charcoal at 31.8 $MJkg^{-1}$ according to FAO [20]. These energy values can produce enough heat for household cooking and small-scale industrial cottage applications.

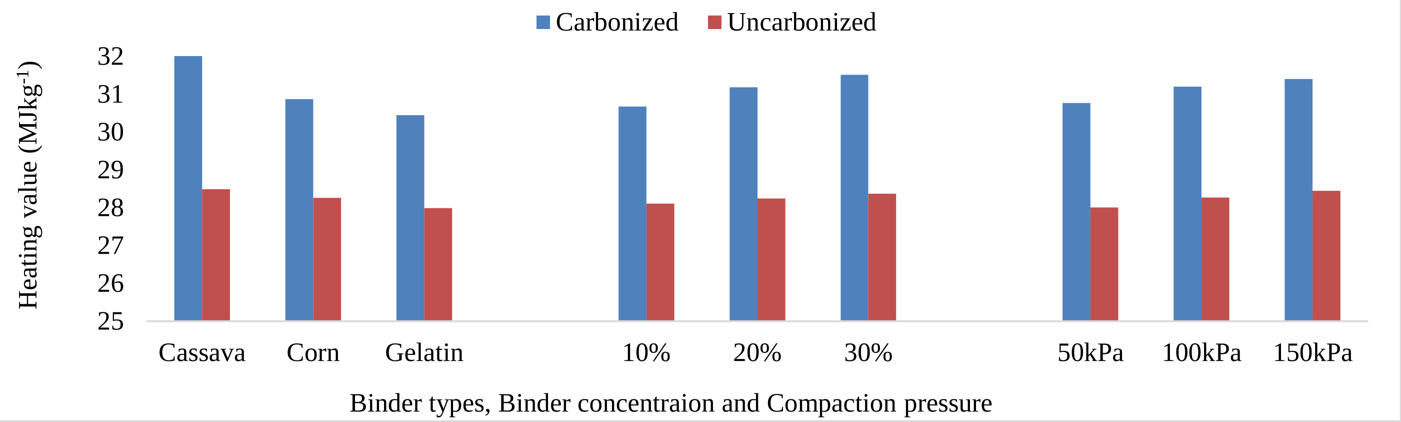

Figure 7. The heating value of the briquettes as affected by processing parameters

4. CONCLUSIONS

This comparative study investigated some physical properties and heating values of briquettes produced from carbonized and uncarbonized processing methods of corncobs using three different types of the binder at three different concentrations and compacting pressures. The results showed that average moisture content ranged between 5.29-6.58 % and 12.75-13.72 %, mean relaxed density varied from 813-925 kgm^{-3} and 963-1166 kgm^{-3}, compressive strength ranged between 2.27-5.07 MPa and 5.97-10.12 MPa, and heating value ranged between 28.85-32.36 $MJkg^{-1}$ and 27.58-28.80 $MJkg^{-1}$ for carbonized and uncarbonized briquettes, respectively. Based on the results obtained, all the processing parameters studied had significant effects ($P < 0.05$) on the briquette's moisture content, density, compressive strength, and heating value. The briquettes produced from carbonized corncob had a better moisture content (5.29-6.58 %) and heating value (28.85-32.36 $MJkg^{-1}$), while the briquettes produced from uncarbonized corncob had higher density (1324-1747 kgm^{-3}) and compressive strength (5.97-10.12 MPa). Therefore, this study shows that pretreatment methods under different binder types and concentrations and the compacting pressure significantly affected the physical properties and heating values of briquettes. Furthermore, carbonized and uncarbonized corncobs were suitable materials for briquettes production suited for domestic and industrial applications. However, this technology can be successfully applied in rural off-grid areas by the government and other stakeholders in the energy sector as part of renewable energy technologies.

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