A Comparative Study of Effects of Some Processing Parameters on Densification Characteristics of Briquettes Produced from Two Species of Corncob.

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ABSTRACT

Corncobs are potential sources for energy generation. This work investigated densification characteristics of briquettes produced from two species of corncobs. Corncobs were milled and sieved. Three compaction pressures (2.1, 4.2, and 6.6MPa), three binder ratio levels (20, 25, and 30%) and three particle sizes (4.70, 2.40, and 0.60mm) were employed. Briquettes were produced using a briquetting machine with cassava starch as binder. ASAE standard methods were used to determine the moisture contents and densities of the milled residues and briquettes. The compaction, density, relaxation ratios, and percentage expansion of the briquettes were also determined. Their mechanical properties and the heating value were determined using universal testing machine and ballistic bomb calorimeter, respectively.

The mean moisture contents of the corncob from white and yellow maize were 9.64 and 9.98%, respectively, while the corresponding values for relaxed briquettes were 7.46 and 8.18%. The values of bulk densities of the residue materials were 95.33 and 98.00kg/m^3 for corncob from white and yellow maize, respectively. The initial, maximum and relaxed densities ranged from 151-235kg/m^3; 533-981kg/m^3, and 307-417kg/m^3, respectively for briquettes produced from white maize corncob, while the corresponding values for yellow maize were 145-225kg/m^3; 502-871kg/m^3, and 314-464kg/m^3, respectively. The compaction ratio ranged from 2.27 to 6.50 and 2.23 and 6.01 for briquettes from corncob from white and yellow maize, respectively. The maximum percentage volume reductions were 626 and 635.7 %, respectively, for briquettes from white and yellow maize, while the corresponding axial relaxations were in the range of 0.62-9.85% and 0.40-8.47%.

Of the three processing parameters examined, binder ratio B_1 (20%), particle size S_3 (0.60mm) and compaction pressure P_3 (6.60MPa) exhibited most positive attributes, while briquettes from corncob from yellow maize appeared superior.

(Keywords: corncob, agro-residues, biomass fuel, briquettes, species, particle size, compaction pressure, percentage binder ratio)

INTRODUCTION

According to Food and Agricultural Organization (FAO) 2007 data, 589 million tons of maize was produced world-wide in the year 2005. The United States of America was the largest maize producer having 43% of world production. Africa produced 7% of the world's maize (Adesanya and Raheem, 2009). Nigeria was the second largest producer of maize in Africa in the year 2006 with 7.5 million tons (FOS, 2006). In Nigeria alone, twenty eight different food items can be prepared from maize (BCOS, 2010). In Africa, South Africa has the highest production of 11.04 million tons (Adesanya and Raheem, 2009).

Corncob is the agricultural waste product obtained from maize or corn. Maize is mostly harvested and processed for food, leaving a large quantity of corncob residue constituting waste on the farm, most of which are flared off in preparation for subsequent farming season, thereby posing health risks to both human and ecology. However, research had shown that most of these agricultural residues, corncob residues inclusive contain enormous amount of energy and if properly harnessed and utilized, can go a long way to mitigate the problem of global energy shortage (Jekayinfa and Scholz, 2009; Oladeji, 2011). However, corncob in its present form, just like any other agricultural residues, cannot be effectively used for energy conversion. This is because; utilization of agricultural residues is often difficult due to their uneven characteristics. It is widely accepted that the majority of the residues in their natural forms, have lower density, higher moisture content and lower energy density. Besides, the low bulk density and dusty characteristics of the biomass also cause problems in transportation, handling and storage (Husan et al., 2002). The application of biomass briquetting i.e. transforming the loose biomass into briquettes is an effective way to solve these problems and contribute towards alleviation of energy shortage and environmental degradation, (El-Saeidy, 2004; Garriot, 2004).

The corncob residue like any other organic wastes is heterogeneous, varying in bulk density, moisture content, particle size and distribution depending on the mode of processing. Corncob is usually of low bulk density with high moisture content of up to 45% when harvested from the farm in partially dried form (Oladeji, 2011).

Many renowned researchers such as Grover and Mishra 1996, Singh2007, Olorunnisola 2007, Wilaipon 2009, and Kaliyan and Morey 2009, have worked on various aspects of briquetting, the nature of the materials during and after briquetting. The behavior and characteristics of biomass briquetting can be classified into physical, mechanical and biochemical processes depending on the measured parameters. Therefore, the main aim of this work was to evaluate the effects of some processing parameters on physical and densification characteristics of briquettes produced from corncob from two species of maize, with a view to determining which of the two species will exhibit more positive attributes of biomass energy.

MATERIALS AND METHODS

Corncob residues from two species of maize were obtained from corn processing mill. They were sun-dried and their moisture content was determined using ASAE S269.4 (2003). The residues were subjected to size reduction process through the use of hammer mill equipped with different screens in compliance with procedure described in ASAE 424.1 2003. Three particle sizes S_1 (4.70 mm), S_2 (2.40 mm) and S_3 (0.60 mm) representing coarse, medium and fine series respectively were selected for each species. The bulk density of the unprocessed materials and relaxed briquettes were determined using ASAE standard. Starch mutillage (binder) was added to the residues at 20 (B_1), 25 (B_2), and 30 % (B_3) by weight of the residue. A briquetting machine was used for formation of briquettes with a compaction pressures of 2.40 (P_1), 4.40 (P_2) and 6.60 (P_3) MPa. A dwell time of 120 seconds was observed for the briquettes to form. The initial, maximum and the relaxed densities of the briquettes were determined using the mould dimension, the relaxed briquette's dimension and ASAE standard method of determining densities.

The compaction ratio was obtained from the relationship as expressed in Equation 1.

$$\text{Compaction Ratio} = \frac{\text{Maximum Density}}{\text{Initial Density}} \qquad \textbf{(1)}$$

The density ratio was calculated as expressed in Equation 2:

$$\text{Density Ratio} = \frac{\text{Relaxed Density}}{\text{Maximum Density}} \qquad \textbf{(2)}$$

While the relaxation ratio was obtained from the relationship in 3:

$$\text{Relaxation Ratio} = \frac{\text{Maximum Density}}{\text{Relaxed Density}} \qquad \textbf{(3)}$$

The briquette dimensions (length, breadth and height) in cm after extraction from the mould were measured.

The percentage volume reduction was calculated from Equation 4.

$$\%\ \text{Volume Reduction} = \frac{\text{Bulk Density of Relaxed briquettes}}{\text{Bulk Density of Unprocessed briquettes}} \qquad \textbf{(4)}$$

The percentage expansion was obtained from equation 5 as expressed by Mohsenin and Zaske, 1976.

$$\%\ \text{Expansion} = \frac{l_f - l_i}{l_i} \times 100 \qquad \textbf{(5)}$$

l_i = initial height of briquettes, l_f = final height of briquettes. The heights were measured with the aid of vernier callipers and micro meter screw gauge. Each measurement was replicated three times.

RESULTS AND DISCUSSIONS

Bulk Density of Untreated Corncobs

The results of bulk density of unprocessed corncobs from white and yellow maize are presented in Table 1.

The mean values of bulk density of raw corncob (unprocessed) were 50.32 and 51.44 kg/m^3 for corncob from white and yellow maize respectively. These values are higher than the minimum value of 40 kg/m^3 recommended by Kaliyan and Morey (2009) and Mani et al. (2006a) for wooden materials.

Bulk Density of Ground Particles of Corncob

The bulk densities of the ground (treated) particles of corncob residue from white and yellow maize are presented in Table 2.

The bulk density of ground (treated) corncob residue from white maize was found to be 95.33 kg/m^3, while that of corncob from yellow maize was 98.00 kg/ m^3. This is an improvement over the bulk density of the untreated raw corncob. The implication of this is that subjecting biomass residues to one kind of processing or the other improves their physical and handling characteristics (Kaliyan and Morey, 2009).

Densities of Uncompressed and Compressed Mixture

The results of the determination of the initial densities of uncompressed mixture at different binder ratio and particle size are shown in Table 3 for white and yellow maize, while Table 4 shows the results of maximum densities of compressed mixture at different binder ratio, particle size and compaction pressure.

Table 1: Bulk Density of Untreated Corncob.

No of experiment	Mass of container (kg)	Mass of container + ground residue (kg)	Mass of the residue (kg)	Volume of the container (m^3)	Density kg/m^3
White Maize (at 9.64 % Moisture Content)					
1	1.50	5.55	4.05	0.081	50.00
2	1.50	5.58	4.08	0.081	50.37
3	1.50	5.60	4.10	0.081	50.62
Mean	1.50	5.57	4.07	0.081	50.32
Yellow Maize (at 9.98 % Moisture Content)					
1	1.50	4.63	4.13	0.081	50.99
2	1.50	5.70	4.20	0.081	51.85
3	1.50	5.67	4.17	0.081	51.48
Mean	1.50	5.33	4.17	0.081	51.44

Table 2: Bulk Density of Ground Particles of Corncob.

No of experiment	Mass of container (kg)	Mass of container + ground residue (kg)	Mass of the residue (kg)	Volume of the container (m^3)	Density kg/m^3
White Maize (at 9.64 % Moisture Content)					
1	1.20	6.20	5.00	0.05	100.00
2	1.20	5.70	4.50	0.05	90.00
3	1.20	6.00	4.80	0.05	96.00
Mean	1.20	5.97	4.76	0.05	95.33
Yellow Maize at 9.98 % Moisture Content					
1	1.20	6.00	4.80	0.05	96.00
2	1.20	6.10	4.90	0.05	98.00
3	1.20	6.20	5.00	0.05	100.00
Mean	1.20	6.10	4.90	0.05	98.00

Table 3: Initial Densities of Uncompressed Mixture at Different Binder Ratio and Particle Size for Corncob Residue (kg/m^3).

Binder Ratio (%)	Particle Size (mm)					
	S_1 (4.70)		S_2 (2.40)		S_3 (0.60)	
	Corncob					
	White	Yellow	White	Yellow	White	Yellow
B_1 (20)	151	145	185	165	218	190
B_2 (25)	154	150	216	193	220	215
B3 (30)	157	153	233	215	235	225

Table 4: Maximum Densities for Briquettes produced from Corncob from White and Yellow Maize (kg/m^3).

Particle size	Binder ratio (%)	Compaction Pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	750	802	981
	B_2 (25)	636	692	802
	B_3 (30)	554	570	624
S_2 (2.40 mm)	B_1 (20)	605	672	695
	B_2 (25)	596	650	670
	B_3 (30)	567	618	635
S_3 (0.60 mm)	B_1 (20)	600	643	678
	B_2 (25)	575	621	646
	B_3 (30)	533	598	621
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	770	820	871
	B_2 (25)	717	757	797
	B_3 (30)	680	692	773
S_2 (2.40 mm)	B_1 (20)	650	670	703
	B_2 (25)	626	659	697
	B_3 (30)	596	636	673
S_3 (0.60 mm)	B_1 (20)	550	587	625
	B_2 (25)	535	567	592
	B_3 (30)	502	540	575

The density of the uncompressed mixture at different binder ratio and particle size varied from 151 to 235 kg/m^3 for corncob from white maize, while that of corncob from yellow maize varied from 145 to 225 kg/m^3. The density of the uncompressed mixture increased with reduction in the particle size and increased with an increase in the binder ratio level for both white and yellow maize species. This could be explained that, the finer the particle is, the less the pore spaces and more mass of the material per given volume, which is good for briquetting.

The maximum densities for the particle size S_1, S_2 and S_3 varied from 533 to 981 kg/m^3 for briquettes produced from corncob from white maize, while the corresponding values for briquette from corncob from yellow maize was between 502 and 871 kg/m^3. These values are higher than the initial densities of the uncompressed mixture of 151 to 235 kg/m^3 for corncob from white maize and 145 to 225 kg/m^3 for corncob from yellow maize. It was also observed that the higher the compaction pressure, the higher the density. From this result, it is evident that the briquetting process has been able to obtain increased density, which is a valuable factor in briquetting. The values of maximum densities obtained are more than the minimum value of 600 kg/m^3 recommended by Mani et al. (2006b) and Gilbert et al. (2009) for efficient transportation and safe storage. An increase in the maximum density was observed at all particle sizes as pressure increased. It was also observed that the maximum density decreased with increasing binder ratio.

There was an observed reduction of density with decreasing particle size. This observation was also noted by Wilaipon (2007). This is because fine particles are in compact state with relatively less void compared to coarse particle series resulting in lesser compressibility. At binder level of 30% (B_3), there was reduction in the value of maximum density for the three particle sizes. This might be due to the fact that, the pores within the particles have been filled by the semi-fluid binder resulting in limited compressibility of the material

Bulk Densities of Relaxed Briquettes

The results of determination of bulk densities of relaxed briquettes are presented in Table 5.

The mean bulk density of the combined relaxed briquettes for the three particle sizes was 315 kg/m^3, for corncob from white maize, while a mean value of 327.67 kg/m^3 was obtained for corncob from yellow maize. The values obtained are desirable for group packaging and transportation of the briquettes, especially when compared with the initial bulk densities of treated and untreated raw residues, which are 95.33 kg/m^3 and 50.32 kg/m^3, respectively for briquettes from corncob from white maize. The corresponding values for briquettes from corncob from yellow maize are 98 kg/m^3 and 51.44 kg/m^3, respectively.

Relaxed Densities

The results of relaxed densities are presented in Table 6. Relaxed densities of the briquettes for corncob from white maize varied from 307 to 417 kg/m^3 for all the particle sizes giving average values of 336.1, 351.1 and 406.6 kg/m^3 for particle size S_1, S_2 and S_3, respectively (Table 6). For briquettes produced for corncob from yellow maize, relaxed densities varied from 314 to 464 kg/m^3 for the three particle sizes giving average values of 327.4, 347.1 and 435.3 kg/m^3 for particle size S_1, S_2 and S_3, respectively (Table 6).

These values are lower than 533 to 981 kg/m^3 and 502 to 871 kg/m^3 obtained for maximum densities for briquettes produced from corncob from white and yellow maize respectively. However, these values are higher than the initial densities of the uncompressed mixture of 151 to 235 kg/m^3 for corncob from white maize and 145 to 225 kg/m^3 for corncob from yellow maize. This might be as a result of expansion in volume that took place after extrusion. The increase in volume with fixed mass would ultimately result in reduction in the density and it is evident that, the briquette that expands more after extrusion would have the least relaxed density and vice versa.

The general trend is that as the pressure increased, the relaxation in briquettes was reduced. From the tables obtained for relaxed densities, it was observed that an increase in the amount of binder ratio resulted in decrease in the relaxed density of the briquettes. This is in complete agreement with work of Chin and Siddiqui (2000), where increasing the amount of binder decreased the relaxed density of the briquettes produced from sawdust and coconut fiber. However, in another work carried out by the same author, increasing the amount of binder ratio increased the relaxed density of the briquettes produced from palm fiber and peanut shells.

Table 5: Bulk Density of Combined Relaxed Briquettes produced from Corncob from White and Yellow Maize.

No of experiment	Mass of container (kg)	Mass of container + combined briquettes (kg)	Mass of the combined briquettes (kg)	Volume of the container (m^3)	Density (kg/m^3)
White Maize					
1	1.20	17.20	16.00	0.05	320.00
2	1.20	17.70	15.50	0.05	310.00
3	1.20	15.95	15.75	0.05	315.00
Mean	1.20	16.95	15.75	0.05	315.00
Yellow Maize					
1	1.20	16.75	15.55	0.05	311.00
2	1.20	18.20	17.00	0.05	340.00
3	1.20	17.80	16.60	0.05	332.00
Mean	1.20	17.58	16.38	0.05	327.67

Table 6: Relaxed Densities for Briquettes Produced from Corncob from White and Yellow Maize (kg/m^3).

Particle size	Binder ratio (%)	Compaction pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	314	346	352
	B_2 (25)	332	337	348
	B_3 (30)	307	314	335
S_2 (2.40 mm)	B_1 (20)	351	377	398
	B_2 (25)	360	365	370
	B_3 (30)	314	328	340
S_3 (0.60 mm)	B_1 (20)	390	397	405
	B_2 (25)	412	420	417
	B_3 (30)	404	405	410
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	340	380	392
	B_2 (25)	365	371	382
	B_3 (30)	335	314	351
S_2 (2.40 mm)	B_1 (20)	370	392	415
	B_2 (25)	375	383	395
	B_3 (30)	350	361	383
S_3 (0.60 mm)	B_1 (20)	406	417	436
	B_2 (25)	425	435	449
	B_3 (30)	434	452	464

The implication of this is that densification characteristics of briquettes produced differ from one biomass to another and there exists optimum value for each biomass residue.

Compaction Ratio

The results of determination of compaction ratios for briquettes produced from corncobs from white and yellow maize are shown in Table 7 for different particle sizes.

The results showed that compaction ratio varied from 2.23 to 6.50 for all pressures and binder ratios considered. Higher compaction ratio implied more void in the compressed materials. Higher figure indicates more volume displacement which is good for packaging, storage and transportation and above all, it is an indication of good quality briquettes.

From Table 7, it was observed that the compaction ratio increased with increasing pressure and decreased with increasing binder ratio. The implication of this is that, the void spaces are expelled at higher pressures while less void spaces are present in the residue with higher quantity of binder ratio. Hence, it could be concluded that, there is more resistance to compression as the binder ratio increased. Furthermore, the values of compaction ratio obtained in this study compare and compete favorably well with notable biomass residues. For example, compaction ratio of 3.80 was obtained during briquetting of rice husk (Oladeji, 2010a), while compaction ratios of 4.2 and 3.5 were obtained during briquetting of groundnut and melon shells respectively (Oladeji et al., 2009).

Relaxation Ratio

The results of determination of relaxation ratios for briquettes produced from corncobs from white and yellow maize are tabulated in Table 8.

The maximum and minimum relaxation ratios of briquettes produced from corncob from white maize were found to be 2.86, 1.82; 1.89, 1.67; and 1.70, 1.33 for particle sizes S_1, S_2 and S_3 respectively, while the corresponding values for briquettes produced from corncob from yellow maize were 2.27, 1.96; 1.75, 1.67; and 1.45, 1.16 respectively.

Table 7: Compaction Ratios for Briquettes Produced from Corncob from White and Yellow Maize.

Particle size	Binder ratio (%)	Compaction pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	4.96	5.31	6.50
	B_2 (25)	4.12	4.49	5.20
	B_3 (30)	3.52	3.63	3.97
S_2 (2.40 mm)	B_1 (20)	3.27	3.63	3.75
	B_2 (25)	2.76	3.01	3.10
	B_3 (30)	2.43	2.65	2.72
S_3 (0.60 mm)	B_1 (20)	2.75	2.95	3.11
	B_2 (25)	2.61	2.82	2.94
	B_3 (30)	2.27	2.54	2.64
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	5.31	5.65	6.01
	B_2 (25)	4.78	5.04	5.31
	B_3 (30)	4.44	4.52	5.05
S_2 (2.40 mm)	B_1 (20)	3.93	4.06	4.26
	B_2 (25)	3.24	3.41	3.61
	B_3 (30)	2.77	2.96	3.13
S_3 (0.60 mm)	B_1 (20)	2.89	3.09	3.29
	B_2 (25)	2.48	2.63	2.75
	B_3 (30)	2.23	2.40	2.56

Table 8: Relaxation Ratios for Briquettes Produced from Corncob from White and Yellow Maize.

Particle size	Binder ratio (%)	Compaction pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	0.42	0.43	0.35
	B_2 (25)	0.52	0.48	0.43
	B_3 (30)	0.55	0.55	0.53
S_2 (2.40 mm)	B_1 (20)	0.58	0.56	0.58
	B_2 (25)	0.60	0.56	0.57
	B_3 (30)	0.55	0.53	0.54
S_3 (0.60 mm)	B_1 (20)	0.65	0.62	0.59
	B_2 (25)	0.72	0.67	0.65
	B_3 (30)	0.75	0.68	0.66
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	0.44	0.46	0.45
	B_2 (25)	0.51	0.49	0.48
	B_3 (30)	0.49	0.45	0.45
S_2 (2.40 mm)	B_1 (20)	0.57	0.58	0.59
	B_2 (25)	0.60	0.58	0.57
	B_3 (30)	0.59	0.58	0.57
S_3 (0.60 mm)	B_1 (20)	0.74	0.71	0.69
	B_2 (25)	0.79	0.76	0.75
	B_3 (30)	0.86	0.83	0.80

These values compare favorably well and good enough as they are close to the values obtained by Olorunnisola (2007), which gave the relaxation ratio raging between 1.80 and 2.25 for coconut husk briquette and Oladeji et al. (2009), which gave values 1.97 and 1.45 for groundnut and melon shell briquettes respectively. Furthermore, O'Dogherty (1989) reported a comparable relaxation ratio in the range of 1.65 to 1.80 for briquetted hay materials, while Oladeji (2010a) obtained a relaxation ratio of 2.33 during the briquetting of rice husk. Lower value of relaxation ratio indicates a more stable briquette, while higher value indicates high tendency towards relaxation i.e. less stable briquette. The values of relaxation ratio obtained in this study indicated that briquettes from the finer particles are more stable than the coarse particles. A reciprocal relationship was observed between density ratio and relaxation ratio of the briquettes.

Briquettes Stability

The stability of briquettes produced from the two species examined in this study was determined in terms of dimensional expansion in the axial and lateral directions. Tables 9 and 10 showed dimensional change of briquettes in the axial and lateral directions.

Table 9: % Axial Expansion for Briquettes Produced from Corncob from White and Yellow Maize.

Particle size	Binder ratio (%)	Compaction pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	3.47	2.16	1.97
	B_2 (25)	6.53	4.73	3.56
	B_3 (30)	9.85	7.01	5.35
S_2 (2.40 mm)	B_1 (20)	2.53	1.07	0.98
	B_2 (25)	4.36	2.56	1.75
	B_3 (30)	6.11	4.15	2.63
S_3 (0.60 mm)	B_1 (20)	1.76	0.80	0.62
	B_2 (25)	2.03	1.02	0.90
	B_3 (30)	3.04	2.14	1.30
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	2.25	1.68	1.38
	B_2 (25)	4.69	3.57	2.13
	B_3 (30)	8.47	6.13	4.56
S_2 (2.40 mm)	B_1 (20)	1.35	0.83	0.63
	B_2 (25)	3.10	1.98	1.24
	B_3 (30)	5.63	3.03	2.11
S_3 (0.60 mm)	B_1 (20)	0.90	0.61	0.40
	B_2 (25)	1.15	0.92	0.61
	B_3 (30)	2.63	1.40	0.95

Table 10: % Lateral Expansion for Briquettes Produced from Corncob from White and Yellow Maize.

Particle size	Binder ratio (%)	Compaction pressure (N/m^2)		
		P_1(2.10)	P_2(4.20)	P_3(6.60)
White Maize				
S_1 (4.70 mm)	B_1 (20)	1.40	0.92	0.64
	B_2 (25)	2.04	1.36	0.96
	B_3 (30)	3.63	2.58	1.76
S_2 (2.40 mm)	B_1 (20)	1.08	0.88	0.46
	B_2 (25)	1.96	1.42	0.91
	B_3 (30)	2.08	1.76	1.20
S_3 (0.60 mm)	B_1 (20)	0.98	0.72	0.48
	B_2 (25)	1.24	1.02	0.83
	B_3 (30)	1.76	0.94	0.65
Yellow Maize				
S_1 (4.70 mm)	B_1 (20)	0.95	0.47	0.24
	B_2 (25)	1.43	0.71	0.94
	B_3 (30)	2.01	1.54	1.27
S_2 (2.40 mm)	B_1 (20)	0.75	0.54	0.21
	B_2 (25)	1.15	0.96	0.70
	B_3 (30)	1.98	1.01	0.92
S_3 (0.60 mm)	B_1 (20)	0.82	0.48	0.22
	B_2 (25)	0.98	0.76	0.54
	B_3 (30)	1.08	0.89	0.69

From Tables 9 and 10, it was observed that briquettes expanded largely in the axial direction than in the lateral direction. The change in briquette dimensions in the axial direction was up to 9.85% for briquettes from corncob from white maize and 8.47% for briquettes from corncob from yellow maize compared to maximum of 3.63% and 2.01% for briquettes produced from corncobs from white and yellow maize respectively in the lateral direction. Similar expansion trend was also reported by Mani et al. (2004) during compaction of corn stover and Al-Widyan et al. (2002) during briquetting of olive cake. The axial expansion of briquettes increased as the percentage binder ratio increased, which resulted in reduced relaxed density. However, the overall axial and lateral expansions reduced with an increase in pressure. Therefore, it was observed that percentage binder ratio had a significant effect on briquette stability.

CONCLUSIONS

The present work examined the effects of processing parameters, specifically the effects of compaction pressure; % binder ratio and particle size on physical and combustion characteristics of briquettes produced from corncobs. Based on the various results obtained and the findings of this study, the following conclusions have been made:

i. This study has found that, the handling (processing) parameters such as particle size, % binder ratio and compaction pressure significantly affected the combustion characteristics of briquettes produced from corncob.

ii. Subjecting corncob residues to one kind of processing or the other had greatly improved their physical and handling characteristics.

iii. The high value of relaxed density (362.9 kg/m^3 for briquettes from white maize and 369.9 kg/m^3 for briquettes from yellow maize) obtained in this study suggests that corncob briquettes could be transported over a long distance without disintegration.

iv. The moisture contents of relaxed briquettes, which are 7.46% and 8.18% for briquettes produced from white and yellow maize corncob respectively are generally less than moisture contents of the residue materials (9.64% for yellow corncob and 9.98% for white corncob) by about 2.0%. In the similar trend, the bulk densities of the relaxed briquettes which are 315 kg/m^3 for white corncob and 327 kg/m^3 for yellow corncob are higher than the residue materials which are 50.32 kg/m^3 and 51.44 kg/m^3 for white and yellow corncobs respectively. This translated into percentage volume reduction of between 626 – 636% of the material. It also provides technological benefits and a desirable situation for material storage, packaging and transportation. The initial, maximum and relaxed densities ranged from 151-235 kg/m^3; 533-981 kg/m^3 and 307-417 kg/m^3, respectively for briquettes produced from white maize corncob. The corresponding values for briquettes produced from yellow maize corncob are 145-225 kg/m3; 502-871 kg/m^3 and 314-464 kg/m^3, respectively.

v. For all the three processing parameters examined in this study, variables with particle size S_3, (0.60 mm), binder ratio B_1 (20%) and compaction pressure P_3 (MPa) exhibited the most positive attributes than the other two variables. It can then be concluded that, the finer the particle size is, the more positive attributes of good quality briquette such particle has. In the similar manner, the lower the binder ratio, the better the briquettes, while higher compaction pressure will result in more quality briquettes. However, it must be noted that getting fine particles attracts additional cost and as such, balance must be struck between the particle size and the production cost.

vi. Briquettes produced from corncob from yellow maize have more positive attributes of biomass fuel than briquettes produced from white corncob

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