Physical Characteristics of Briquettes from Guinea Corn (sorghum bi-color) Residue

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ABSTRACT

The densification of Guinea corn residue, a source of biomass material is necessary for the purpose of handling and space requirements. The plant part of the Guinea corn residue was collected from the field at a moisture content of 9.08% dry basis (db), reduced and sieved into three particle sizes D_1, D_2; and D_3. Starch mutillage of 40, 45, 50 and 55% by weight of the residue was added as binder. The bulk density of the unprocessed and processed Guinea corn residue was determined using ASAE standards. Briquettes were produced using hydraulic press and a cylindrical die (56 mmϕ) at pressures of 7.5, 8.5, 9.5 and 10.5 MPa. The particle sizes were separated into three distinct size ranges of 4.7 mm (D_1), 1.7 mm (D_2) and 0.6 mm (D_3). The mean moisture content of the relaxed briquettes was 7.15% (db). The bulk density of the unprocessed material was 46.03 kg/m^3, and the mean relaxed briquettes bulk density was 208.15 kg/m^3 with a volume reduction of about 450%. The maximum density of the briquettes ranged from 789 to 1372 kg/m^3. The maximum and minimum axial relaxation occurred in the first 30 minutes of the extrusion with values 138.64 and 28% respectively in the longitudinal axis, the maximum and minimum radial relaxation were 11.5 and 1.4% respectively. The briquettes were kept safely for a period of six months without deterioration.

Keywords: Guinea corn, briquettes, residue, particle sizes

1. INTRODUCTION

Guinea corn ranks amongst the three major grain crops grown in Nigeria particularly the Northern states of the country. About 8.3 million hectares of the crop are cultivated yearly (FOS, 2005). Guinea corn is mostly harvested and processed for food manually, leaving a large volume of residue constituting waste on the farm, most of which are flared off in preparation for subsequent farming season.

The sorghum residue like any other organic wastes is heterogeneous varying in bulk density, moisture content, particle size and distribution depending on the mode of handling. It is usually of low bulk density with high moisture content of up to 40% when harvested from the farm in partially dried form (Bolufawi, 2008)). The residues range from light brown to dark brown color in the dried form. The panicles have a high percentage of glossy/lustrous spikelets, very discrete but less particulate in texture. These spikelets, when the grains are removed, have pelleted oval shapes, concave or convex depending on the view point.

As a result of the growing importance and need for briquettes, particularly from biomass materials, many renowned scholars such as Waelti and Dodie (1973), Mohsenin and Zaske (1976), Singh and Singh (1982), O'Dogherty and Wheeler (1984), Faborode and O'Callaghan (1987&1989), Faborode (1988), and Olorunnisola (2004), have worked on various aspects of briquetting, the nature of the materials, the behaviour and characteristics of such materials during and after briquetting. The behaviour and characteristics of biomass residue briquetting can be classified into physical, mechanical and biochemical processes depending on the measured parameters.

The subject of this paper is to evaluate some of the associated physical characteristics of guinea corn (*sorghum bi-color*) residue briquette.

2. MATERIALS AND METHODS

Guinea corn residues were sundried for about three days before stocking. The moisture content of the unprocessed materials and the relaxed briquettes were determined using ASAE standards (1998). The material was reduced by a combination of choppers (machetes, knives and other cutters) and milling machines (Hammer and Burr mills); and sieved into three particle size $D_{1,}$ D_2 and D_3 using Tyler sieve. The bulk density of the unprocessed material and the bulk density of the relaxed briquettes were determined using ASAE standard. Starch mutillage (binder) was added to the residues at 40, 45, 50 and 55% by weight of the residue. A steel cylindrical die (56 mmø) was filled with a fixed charge of residue, covered with a top plate and compressed manually in a piston press fitted with a pressure gauge. Pressures of 7.5, 8.5, 9.5 and 10.5 MPa were separately applied for each briquette formation and a device to monitor the depth of the plunger was fitted. A dwell time of 90 seconds was observed for the briquettes during formation. The initial, maximum and the relaxed density of the briquettes were determined using the die dimension and ASAE standard method of determining densities.

The compaction ratio was obtained from the relationship in equation

$$\text{Compaction Ratio (r)} = \frac{\text{Max. Density } (Y_d)}{\text{Initial Density } (Y_o)} \qquad 1$$

Y_d = density of the material at any point of its cycle of the compression in the die
Y_o = Initial density of the material.

The briquette dimensions (height, h and diameter, Ø) cm after extrusion from the die were measured at time (t), where t = 0, 15, 30, 60, 1440 min respectively.
The percentage volume reduction was calculated from equation 2 .

$$\% \text{ Volume Reduction} = \frac{\text{Bulk Density of Relaxed briquettes (Yr)}}{\text{Bulk Density of Unprocessed briquettes (Yu)}} \ldots\ldots\ldots\ldots\ldots\ldots 2$$

The percentage expansion was expressed by $\left(\frac{I_f - I_i}{I_i}\right)100$; (Moshenin and Zaske, 1976).

I_i = initial height of briquettes, I_f = final height of briquettes. The heights were measured using the vernier calipers and micro meter screw gauge. Each briquette was replicated four times.

3. RESULTS AND DISCUSSIONS

The particle sizes were separated into three distinct size ranges of 4.7 mm (D_1), 1.7 mm (D_2) and 0.6 mm (D_3). The analysis showed a preponderance of D_1 (4.7 mm) size 52.45% over the D_2 (1.7 mm) and D_3 (0.6 mm) sizes which have 29.1 and 18.3% respectively. The implication of this observation is that more materials will be required if particle size order than D_1 is required for briquetting. The different particle size materials are shown in Plates 1, 2 and 3. The D_1 particle size material is brown and fibrous in nature while the D_2 particle size material is discrete and composed of assorted colours. It was observed that the spikelets of the sorghum particle constitute the bulk of this particle size. The D_3 particle size material is fine and brown in colour.

Figure 1: Sorghum Residue of Particle Size D_1 =4.7mm

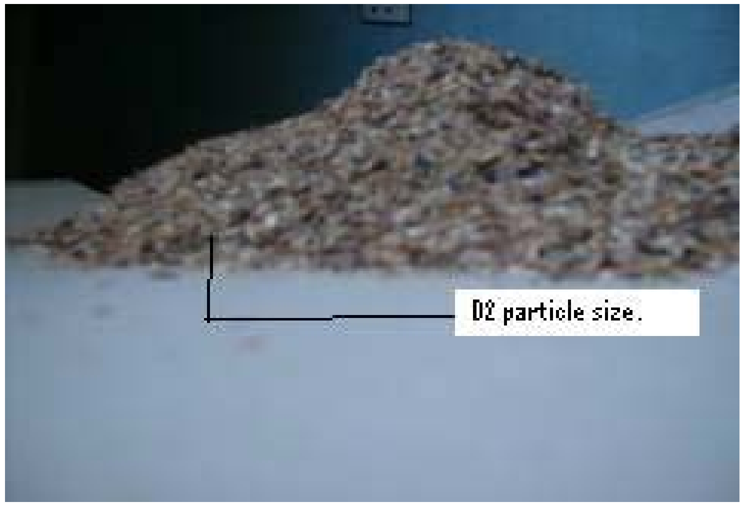

Figure 2: Sorghum Residue of Particle Size D_2=1.7 mm

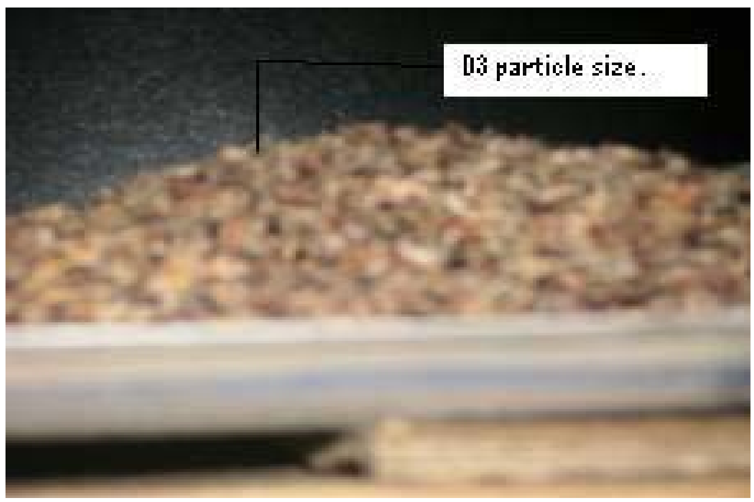

Figure 3: Sorghum Residue of Particle Size D_3 = 0.6 mm

The mean moisture content of the residue was 9.08% dry basis. This is within the acceptable operating moisture content of 8 - 12% (db) for making briquetting (Eriksson and Prior, 1990). However, the moisture limit in most cases can be up to 15% (db) for briquetting of materials, although some materials with up to 20% (db) moisture content can be densified in a piston press. It should be noted that moisture content above 10% (db) might lead to excess steam production which can lead to steam explosion. The moisture content obtained in this work is safe for briquette production. The materials should not also be too dried because, for drier material there will be friction which may increase energy demands. The differences in material moisture content can cause higher variation in energy requirement than those between materials. This factor limits the lower end of the moisture range acceptable in presses at 5% (db). Averagely, the moisture content of the relaxed briquette was 7.15% (db) which is okay for this purpose.

The mean bulk density of the unprocessed sorghum residues and the relaxed briquettes were 46.03 kg/m^{3}and 208.15 kg/m^3, hence the percentage volume reduction of about 450%. The result is in agreement with the suggested range of agricultural residue bulk densities observed by Eriksson and Prior (1990).

The density of the uncompressed mixture at different binder ratio and particle size varied from 141 to 250 kg/m^3 as shown in Table 1. The density of the uncompressed mixture increased with reduction in the particle size and increased with an increase in the binder ratio level. It could be explained that the finer the particle, the less the pore spaces and more mass of the material per given volume which is good for briquetting.

Table 1 Initial density of uncompressed sorghum residue

Binder ratio (%)	Initial Density kg/m^3		
	Particle size, D_1 4.7 mm	Particle size D_2 1.7 mm	Particle size D_3 0.6 mm
B_1 (40)	141	175	208
B_2 (45)	143	205	212
B_3 (50)	146	216	240
B_4 (55)	149	247	250

The maximum densities for the particle size D_1, D_2 and D_3 varied from 789 to 1372 kg/m^3 as shown in Table 2. These values are much higher than the initial density of the uncompressed mixture of 141 to 250 kg/m^3. Thus the process has been able to achieve increased density which is a valuable factor in briquetting. The values did not differ much from the values of 1200–1400 kg/m^3 obtained by Eriksson and Prior (1990) for agricultural wastes. An increase in the maximum density was observed for particle sizes as pressure increased. It was also observed that the maximum density decreased with increasing binder ratio.

Table 2 Maximum density of briquette at different pressures (P_1-P_4), binder ratios (B_1-B_4) and sizes (D_1-D_3)

Particle size mm	Binder Ratio (%)	Relaxed Density, kg/m^3			
		P_1	P_2	P_3	P_4
D_1	B_1	1161	1204	1292	1372
	B_2	1018	1074	1192	1307
	B_3	899	924	987	1050
	B_4	798	888	917	1015
	B_1	917	980	1030	1110
D_2	B_2	899	960	996	1093
	B_3	892	932	994	1053
	B_4	872	911	932	938
	B_1	821	960	1015	1093
D_3	B_2	798	928	960	980
	B_3	789	861	917	960

As shown in Table 3, the relaxed densities of the briquette varied from 235 to 435 kg/m^3. These values are lower than 789 to 1372 kg/m^3 obtained in this study for the maximum densities, but higher than the initial densities of 141 to 250 kg/m^3 for all particle sizes. This is expected because of the expansion in volume that takes place after extrusion which will increase the volume of the materials. The increase in volume with fixed mass will ultimately result in reduction in the density. The briquette that expands more after extrusion will have the least relaxed density and vice versa.

A general trend of increase in the relaxed density was observed with increased pressure at different particle size. The increase in relaxed density with increased pressure could be due to the possible compactness of the material as pressure increases and the reduction in elastic recovery during relaxation of the formed briquette. An increase in the relaxed densities was observed generally as the binder level increases.

Table 3. Relaxed density of sorghum briquette at various pressure (P), particle size (D) and binder ratio (B)

Particle size mm	Binder Ratio (%)	Relaxed Density, kg/m^3			
		P_1 MPa	P_2	P_3	P_4
D_1	B_1	235	242	244	248
	B_2	238	240	244	235
	B_3	239	240	240	238
	B_4	281	304	289	292
	B_1	347	357	352	248
D_2	B_2	334	334	328	245
	B_3	329	330	325	243
	B_4	324	323	323	292
	B_1	389	405	415	435
D_3	B_2	427	435	424	433
	B_3	388	400	397	406

The percentage rate of expansion of the briquettes is shown in Figs 1, 2 and 3. The maximum and minimum axial expansions were 138.64% and 28% respectively. The values are lower than the percentage axial expansion of 207 and 178 for unshredded and shredded hay respectively after 2hours of extrusion obtained by (Moshenin and Zaske, 1976) and higher than 6.8 to 20% for Rattan waste briquettes heavily dozed with binder material (Olorunnisola, 2004).

The first thirty minutes of the briquettes extrusion was observed to be crucial to its axial expansion characteristics. The highest and most rapid expansion took place within this period. One hour after its extrusion and up to 24 hours, the axial expansion was minimal. This observation is supported by the works of Moshenin and Zaske (1976), O'Dogherty and Wheeler (1984), and Olorunnisola (2004) who all concluded that nearly all the expansion of briquettes takes place within 30 minutes of its extrusion. The compressed agricultural residue responds to the basic laws of stress and strain in diverse forms. The material rebounds according to its viscoelastic properties, which may continue for several days naturally with slight increments with a considerable portion of this rebound taking place within a short time after unloading. (Sitkei, 1986).

There was a general decrease with increasing percentage axial expansion with increasing pressure due to more of the plastic deformation taking place at higher pressure.

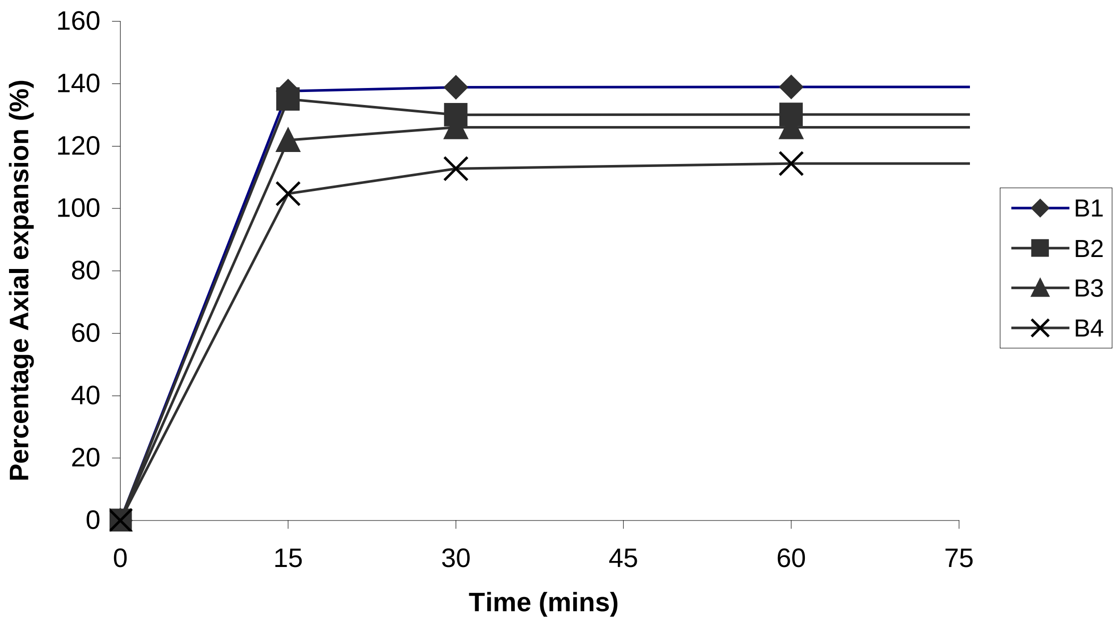

Fig 1: Percentage Rate of Expansion of Briquettes with Binder ratio (D_1P_1)

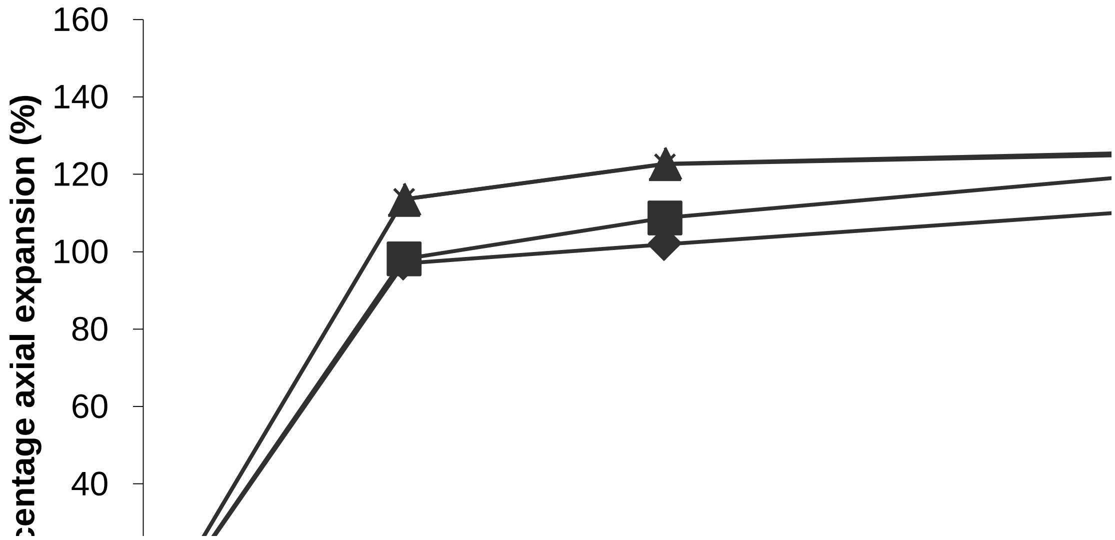

Fig 2: Percentage Rate of Expansion of Briquettes with Binder ratio (D_1P_2)

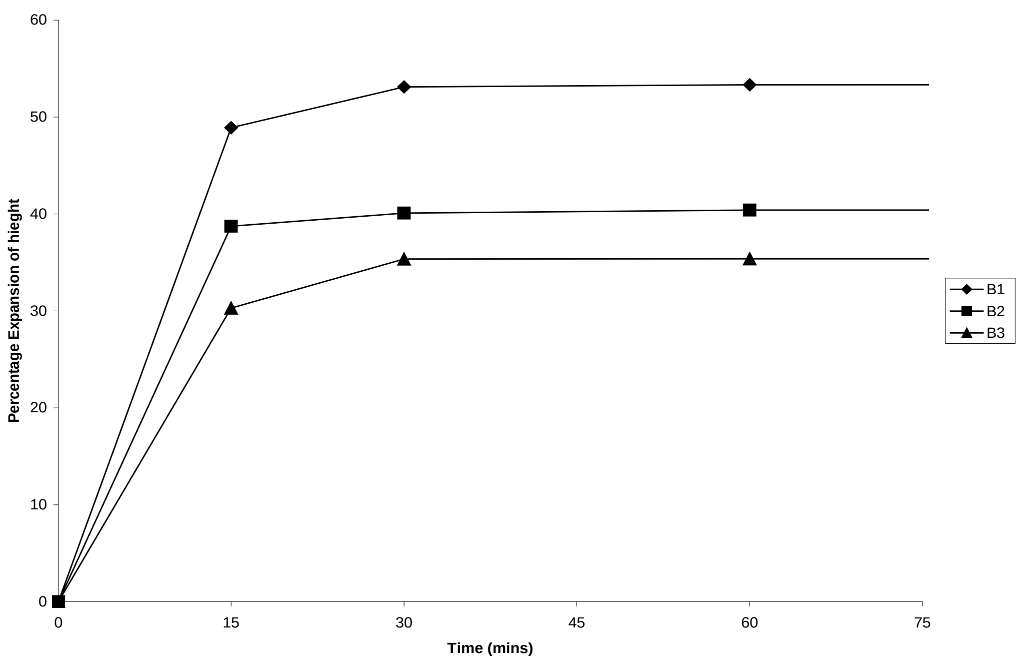

Fig 3: Percentage Rate of Expansion of Briquettes with Binder ratio (D_1P_3)

The maximum and minimum radial expansions were 11.50 and 1.40% respectively. This was low compared to the axial expansion and for many practical purposes is usually ignored.

The compaction ratios are shown in Table 4 for different particle sizes. It varied from 3.194 to 9.730 for all pressure and binder ratio considered. Higher compaction ratio implied more void in the compressed materials. It was observed that the compaction ratio increased with increasing pressure and decreased with increasing binder ratio. This shows that the void spaces are expelled at higher pressures while less void spaces are present in the residue with higher binder quantity. There is more resistance to compression as the binder ratio increased. According to Faborode and O'callaghan (1987) the percentage of voids in an unconsolidated mass of materials is considered important to its mechanical behaviour as it affects such processes concerned with air flow, heat flow and compressibility.

Table 4 Compaction ratio of the briquette from sorghum residue

Particle size mm	Binder Ratio (%)	Compaction ratio, r			
		P_1 MPa	P_2	P_3	P_4
D_1	B_1	8.234	8.540	9.163	9.730
	B_2	7.119	7.510	8.337	9.140
	B_3	6.158	6.329	6.760	7.192
	B_4	5.356	5.960	6.264	7.047
	B_1	5.137	5.600	5.888	6.346
D_2	B_2	4.351	4.683	4.859	5.332
	B_3	4.038	4.218	4.602	4.875
	B_4	3.530	3.773	3.775	3.798
	B_1	3.947	4.615	4.880	5.255
D_3	B_2	3.764	4.377	4.528	4.623
	B_3	3.194	3.588	3.820	4.000

The briquettes from sorghum showed no perceivable sign of disintegration for D_1 and D_3 particle size briquettes after six months of storage; however, the D_2 particle size briquettes failed by crumbling into smaller lumps. The observation with D_2 particle size briquettes could be explained by the glossy and discrete nature of the particles which made binding not as much firm than for the other particles.

4. Conclusion

The sorghum briquette characteristics determined has reasonably added to the data base of the existing research data about sorghum. It has been shown that sorghum residues can be appropriately briquetted. For packaging, the percentage volume reduction of as much as 450, has justified the densification process. It is observed that given the same treatment D_1 and D_3 particle sizes will form a more stable briquette. For further work, a comparative study of the briquettes made from whole stock should be made alongside with the reduced particle size briquettes to determine the desirability or otherwise of reducing the materials to smaller particle sizes.

A. Bamgboye and S. Bolufawi. "Physical Characteristics of Briquettes from Guinea corn (sorghum bi-color) Residue. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1364.

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