COMPARATIVE EVALUATION OF THE FUEL AND HANDLING PROPERTIES OF SORGHUM AND MILLET BIOMASS BRIQUETTES PRODUCED USING LOW-PRESSURE DENSIFICATION (LPD) TECHNOLOGY

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Abstract

The fuel properties, bulk density and compressive strength of sorghum and millet biomass briquettes were studied and compared under low-pressure densification process. Effect of the binder concentration on the properties was also evaluated. The optimum calorific values of sorghum and millet biomass briquettes were 28.5MJ/kg and 27.8MJ/kg, respectively. The Bulk density of sorghum biomass briquettes ranged from 960.49 kg/m^3 to 1858.91 kg/m^3 compared to, 601.85 kg/m^3 to 824.49 kg/m^3 for millet biomass briquettes as binder concentration was increased from 10 to 30% respectively. Optimum compressive strength for sorghum and millet biomass briquettes was found to be 13.705 N/mm^2 and 9.295 N/mm^2, respectively at 0.5 mm particles size and 30% binder concentration. While briquettes' durability was enhanced with higher levels of binder quantity, the research also discovered that binder concentration had reduced the gross calorific value of both types of biomass briquettes. Sorghum biomass briquettes appear to have better fuel and handling qualities than millet biomass briquettes. The briquettes were found to have great potentials for energy extraction. The durability of briquettes in terms of the bulk density and compressive strength was enhanced by Grewia mollis used as a binder and therefore, compensates for its large ash contents, availability and low cost in areas where the biomass materials are largely produced.

Keywords: Comparative evaluation, sorghum and millet, briquettes, fuel and handling, properties, low-pressure densification.

1. INTRODUCTION

A considerable upturn in total annual energy consumption of all forms of primary energy was reported to reach an estimated total of 10,800 Mtoe in 2006. This was projected to attain a range of 14,300 to 23,900 Mtoe in 2050 [1]. The fluctuation in oil price causing severe economic disruption is primary to global energy crisis and has become a subject of serious concern. [2] affirms that a sustainable energy source should to a large extent be inexhaustible by its continuous usage, devoid of significant pollutants or other related environmental issues, health hazards and other social concerns. Renewable energy sources are usually more sustainable than fossil fuels, since they are in effect, inexhaustible and their use usually entails less greenhouse gases (GHG) and pollutant emissions. To guarantee the future of mankind, a halt in world energy crisis resulting from fluctuating oil price due to increased in energy consumption rates, most fossil fuels need to be substituted by other kinds of energy sources that have proven environmental safety and sustainability [1]. Agricultural wastes are an important source of renewable energy that is very common in developing countries. The Burning of these agricultural wastes in loose form results in loss of fuel and pervasive air pollution [3]. However, briquetting the wastes averts the aforementioned problems. Agricultural waste briquettes have advantages over the loose ones in terms of increase in the net calorific value per unit volume, ease in fuel transportation and storage, uniformity in size and quality.

Several studies have been carried out on briquetting process of agricultural residues such as rice husk [4] and [5], groundnut shells [6], sawdust [7], sorghum bio-color residue [8] and finger millet residue [9] among numerous others to substantiate their energy contents and handling qualities. The major agricultural crops grown in Nigeria are millet, sorghum, yam, cassava, rice groundnut and maize with cereal residues constituting up to 80% of the land area in the northern zones where they are largely produced and, only 50% of the biomass resources drawn from these crop products were being collected and converted into useful energy source [10]. The purpose of this research therefore was to investigate the energy content and the effect of binder concentration on the calorific values, the bulk density and compressive strength of sorghum biomass residue briquettes and to compare the outcomes to those of millet biomass briquettes using a low-pressure densification (LPD) technology.

2. METHODOLOGY

2.1 Sourcing and Preparation of Raw materials

Sorghum and millet biomass residues were collected from Konan-dutse in Ardo-kola local government area while *dargaza* (Grewia *mollis*), the binding material was cut and collected from Gonggong-maliki in Jalingo local government areas of Taraba state and conveyed to the University of Nigeria Nsukka in Enugu state. All raw materials were cleaned, dried and subjected to size reduction using a hammer mill. The products were sieved and sampled in the Nigeria Liquefied Natural Gas (NLNG) laboratory of the University.

2.2 Briquette Production

Sorghum and millet biomass were sieved to 0.5, 1.0 and 2.0 mm particles size using standard graded sieves, respectively. Four binder levels of 10, 15, 20 and 30 % of the total weight of feed was used in sampling. Grewia *mollis* (*dargaza*) was used as the binding material. For every biomass type, twelve briquettes from three classes of samples apart from control were formed for each set of production. Each sample is mixed with a corresponding binder level/proportion using a liter of cleaned water at room temperature to form a biomass-binder paste. The heavily mixed paste was then fed into a manually operated hydraulic press fabricated by the National Centre for Energy Research and Development (NCERD) of the University of Nigeria Nsukka using a low densification pressure of 9.5MPa seen in fig 1. All sets of the samples were left for a maximum of 22 minutes as dwell time before being subjected to solar drying. Fully dried samples were collected from drying trays for safe storage in the laboratory. Briquettes remained under storage for close to 25 weeks before laboratory characterization with no noticeable physical damage. Prior to briquette production, a preliminary investigation to assess the proximate analysis of raw materials was carried out and the result was presented on table 1.

Table 1: Proximate composition of raw samples

Raw samples	Chemical composition				
	MC (%)	VM (%)	Calorific value (kJ/kg)	Ash (%)	FC (%)
Grewia *mollis* (Binder)	8.50	79.29	26,635.19	11.94	0.27
Sorghum biomass	9.10	84.87	28,510.77	5.73	0.30
Millet biomass	9.18	84.20	28,354.95	6.18	0.44

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Fig. 1: Manual hydraulic press (9.5 MPa capacity) and briquettes

2.3 Briquette characterization

The Calorific values (HHV) of all briquettes was determined in accordance with ASTM standard D5373-02(2003) procedures. The ratio of briquette mass to its volume (in Kgm^{-3}) was used in determining the bulk density of briquettes as used by [11] and, the Compressive strength of briquettes was determined in accordance with ASTM 1037-93(1995) using Computer-controlled testometric universal strength testing machine M500-25CT of load cell capacity of 25kN.

3. RESULTS AND DISCUSSION

The calorific value range of 28,332.32 – 27,839.02 kJ/kg obtained for both sorghum and millet biomass briquettes respectively, presented on table 2 were comparable to [12], Obi (2015) 27.15MJ/kg; [6], Lubwama and Vianney, (2017) 23MJ/kg,but much higher to [13], Ayub *et al.*, (2015) 19.58MJ/kg and [14], Ajimotokan *et al.*, (2019) 18.4MJ/kg and [15], Erikson and Prior (1990) 18MJ/kg. However, sorghum biomass briquettes show greater energy potentials compared to millet biomass briquettes. The Calorific values of briquettes of both biomass types decreased as the binder concentration is increased from 10 to 30% as can be observed in fig 2.

Table 2: Calorific value of sorghum and millet biomass briquettes

Biomass type	**Briquette Calorific value (in kJ/kg)**				
	0% Binder	10% Binder	15% Binder	20% Binder	30% Binder
Sorghum	28,510.77	28,332.32	28,229.43	28,135.65	27,948.10
Millet	28,354.95	28,182.97	28,096.99	28,011.00	27,839.02

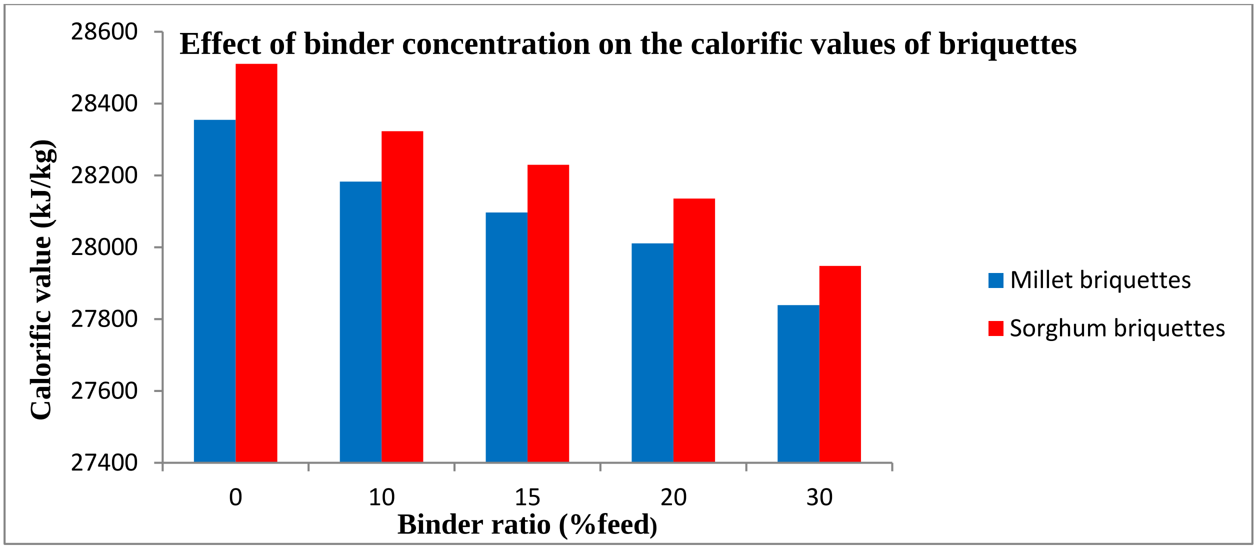

Fig 2: Effect of binder concentration on biomass briquettes

Bulk density of sorghum biomass briquettes ranged from 960.49 – 1858.91 kg/m^3; 1294.49 – 1448.45 kg/m^3 and 0 kg/m^3 compared to 601.85 – 824.49 kg/m^3; 521.88 – 688.89 kg/m^3 and 244.69 – 383.69 kg/m^3 as biomass particle sizes dropped from 2.0 to 0.5 mm and binder concentration increased from 10 to 30% respectively. The result presented on fig 3 and 4 showed that bulk density of both biomass briquettes drops with larger biomass particles size whilst it increased as binder concentration increased at all particle sizes. Optimum bulk density of 1858.91 kg/m^3 and 824.49kg/m^3 of sorghum and millet biomass briquettes, respectively was comparable to [16], Karunanithy *et al.*, (2012) 964 kg/m^3; [15], Erikson and Prior (1990) 700 kg/m^3 but, [8], Bamgboye and Bolufawi (2009) 208.15 kg/m^3.

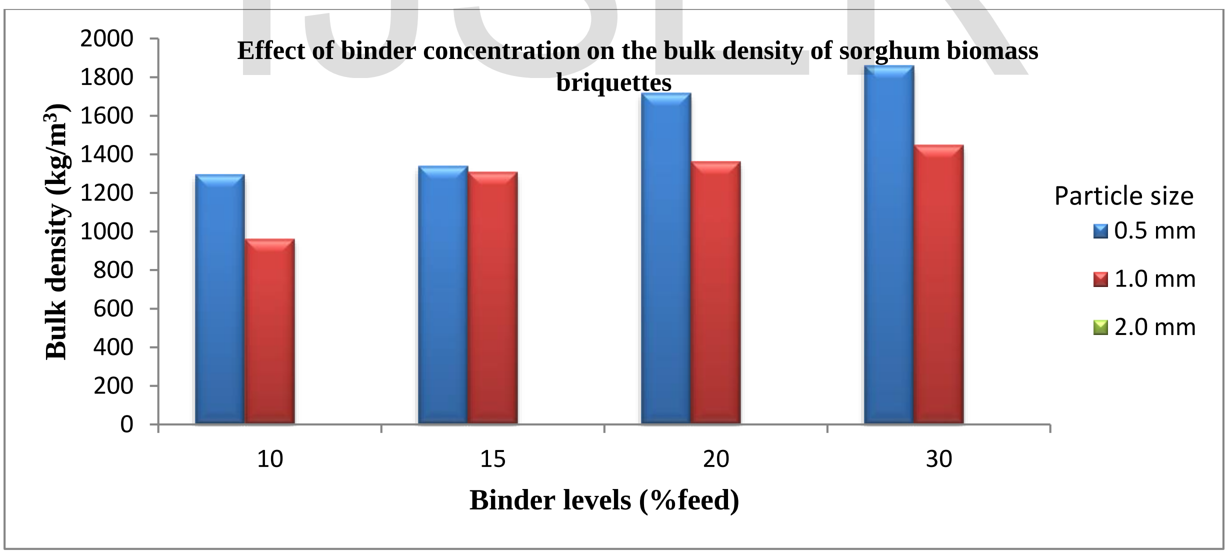

Fig. 3: Bulk density of sorghum biomass briquettes

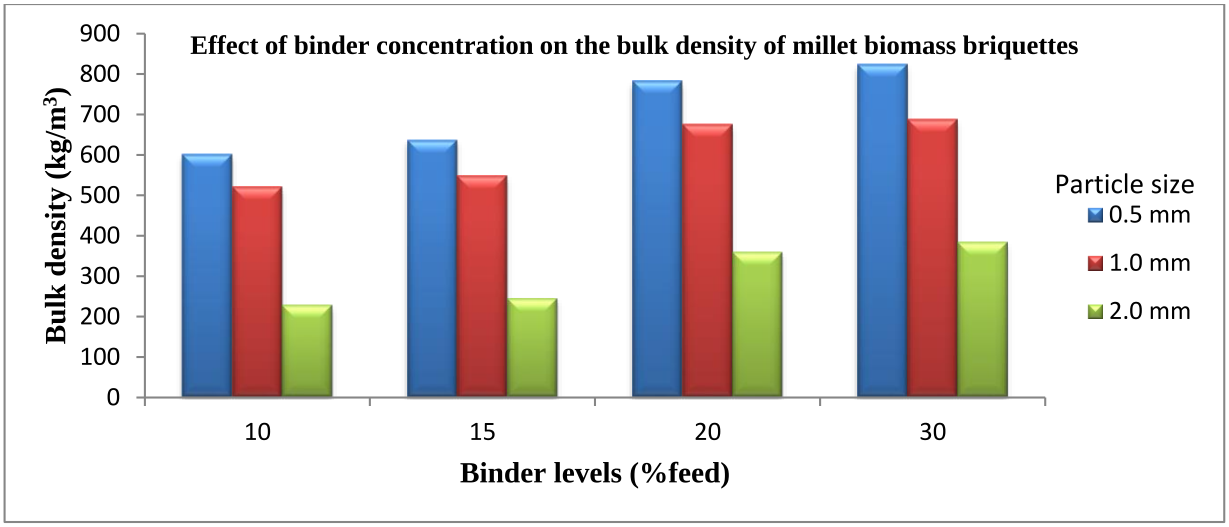

Fig. 4: Bulk density of millet biomass briquettes

Compressive strength of sorghum biomass briquettes ranged from 3 – 13.71 N/mm^2 compared to 3.49 – 9.29 N/mm^2 of millet biomass briquettes as binder concentration was increased from 10 - 30%. The compressive strength of both sorghum and millet biomass briquettes showed a linear relationship with binder concentration. However, it declines with larger biomass particle sizes. The result also showed greater strength for sorghum briquettes compared to millet briquettes at higher binder levels. Optimum compressive strength of 13.7 and 9.29 N/mm^2 of both sorghum and millet biomass briquettes, respectively is comparable to [17], Ayub (2017) 7 – 11 N/mm^2 and [18], Mitchual *et al.*,(2013) 1.30 - 15.81N/mm^2. Briquettes durability is enhanced with higher levels of binder quantity

A 3 by 4 factorial experiment for the Analysis of variance (ANOVA) was used to study the effect of particles size on the compressive strength of briquettes using SPSS version 16 software. The result presented on table 4 showed that there is a statistical significant difference in the compressive strength for millet briquettes across all particle sizes at 95% confidence level. However, from the p-values on table 5, it was concluded that the compressive strength at 0.05 significant level was same with both sorghum and millet biomass briquettes at any binder level

Table 3: Compressive strength of sorghum and millet biomass briquettes

Binder level	Biomass type	Compressive strength of briquettes (N/mm^2)		
		0.5mm	1.0mm	2.0mm
10 %	Sorghum	5.430	3.588	*
	Millet	*6.439*	*5.506*	*3.487*
15 %	Sorghum	5.700	3.770	*
	Millet	*7.445*	*5.548*	*3.717*
20 %	Sorghum	5.850	4.430	*
	Millet	*7.931*	*6.561*	*4.639*
30 %	Sorghum	13.705	4.518	*
	Millet	*9.295*	*7.509*	*6.657*

* Failed sample, not tested.

Table 4: ANOVA of the effects of particle sizes on the compressive strength of millet and sorghum briquettes holding the binder levels constant

	Sum of	df	Mean Square	F	P value

		Squares				
Compress. strength of millet briquettes	Between Groups	19.893	2	9.947	6.781	.016
	Within Groups	13.202	9	1.467		
	Total	33.095	11			
Compress. strength of sorghum briquettes	Between Groups	117.865	2	58.932	10.764	.004
	Within Groups	49.276	9	5.475		
	Total	167.140	11			

Table 5: ANOVA for the compressive strength of Millet and Sorghum briquettes compared at all the binder levels

		Sum of Squares	df	Mean Square	F	p-value (Sig.)
Compress. strength of millet briquettes	Between Groups	12.497	3	4.166	1.618	.260
	Within Groups	20.598	8	2.575		
	Total	33.095	11			
Compress. strength of sorghum briquettes	Between Groups	18.876	3	6.292	.340	.798
	Within Groups	148.264	8	18.533		
	Total	167.140	11			

4 CONCLUSIONS

Sorghum and millet biomass briquettes show substantial energy potentials for use in cooking and heating, and so can be used in place of fossil fuels used for those purposes. The decline in the calorific values of both sorghum and millet biomass briquettes with increased binder (Grewia *mollis*) concentration might have been caused by the large ash contained in the binder (seen on table 1) since ash caused enormous blockages to air vents during combustion.

From the study, it was found that for both biomass types, the smaller the biomass particle size the greater the adhesive forces in the briquettes and this is lost as soon as the particle size becomes larger as large void spaces becomes a possibility. Similarly, biomass becomes easily bonded and hardened with larger quantities of the binding agent. Grewia *mollis* has the qualities to be used in improving the bonding capacity of agricultural waste as fuel briquettes especially when low-pressure densification is considered. It was found to be cheaper than some binding agents like the industrial starch because of its availability and accessibility.

Briquettes showed good durability as strength was increased with large quantities of the binder material, apparently resulting from the binding capacity of the Grewia *mollis* material. Large biomass size creates larger pore space which reduced the compressive strength as the compacting force was dissipated in closing up pores.

Low-pressure densification process can mostly be achieved only with binder material, Grewia *mollis* showed a good prospect for use with rural skills and technologies where the burning of loose biomass is a common practice. These results compensate for the large ash content, low cost, and availability of the binder material in most parts of northern Nigeria where these crops are largely produced.

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