Arid Zone Journal of Engineering, Technology and Environment, August, 2017; Vol.13(4):489-501
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Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

INFLUENCE OF PRODUCTION VARIABLES ON ECO-FRIENDLY BRIQUETTES FROM COCONUT AND BAMBARA NUT SHELLS

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Abstract
This study investigates the influence of production variables on the properties of molasses-induced fuel briquettes from Coconut (*Cocos nucifera* L.) and Bambara nut (*Vigna subterranea* L. Verdc.) shells. 1000g of the milled samples of each raw material was mixed with molasses content varied at 20, 25, 30 and 35% of the weight of biomass sample and briquetted using a Jack press at an average pressure of 1.2KN/m^2. A 3x4 factorial experiment in completely randomized design was used. The briquettes produced were subjected to both physical and combustion tests. The tests revealed that majority of the variations in briquette properties were largely influenced by the type of biomass residues used while molasses' content also contributed significant effect at $p < 0.05$. Coconut shell briquettes had higher compressed density though lower in relaxed form (0.80 g·cm^{-3}*vs* 0.78 g·cm^{-3}) when compared to Bambara nut shell briquettes (0.77 g.cm^{-3}*vs*0.75 g.cm^{-3}). Both physical and combustion properties were significantly improved when both bio-residue mixtures were used. Briquettes from the mixtures had the highest average fixed carbon and heating values of 85.21% and 32.80 MJ·kg^{-1} respectively, while it was 83.83% and 32.12 MJ·kg^{-1} for coconut shell briquette and 82.18% and 32.03 MJ·kg^{-1} for Bambara nut shell briquette. Therefore, based on physical and combustion characteristics, the best Bambara nut briquettes and its mixture with coconut shell were produced when molasses content was 30%. In contrast, the best coconut shell briquette was produced when molasses content was 35%. These two level are therefore recommended for production of quality briquettes from these agro-residues.

Keyword: Eco-friendly fuel, agro-residues, briquette production, molasses, bambara nut, coconut shell

1. Introduction

The effluents and sewage sludge discharged from many industries are the major causes of environmental pollution particularly in developing countries. The highly coloured effluents discharged during sugar production processes and molasses-based alcohol distilleries have remained one of the major environmental issues in many communities where sugar companies were sited (Akbar and Khwaja, 2006). These effluents, when released into water bodies and farmlands, pose serious threat to aquatic life, soil microbes, crops as well as human life (Saranraj and Stella, 2014). This has made the reuse of industrial effluents an attractive option. Molasses-based effluent which is a solution of lower purity (Saranraj and Stella, 2014) can be incorporated into fuel briquette technology.

This technology, in addition to being eco-friendly, can also help in reducing over dependent on forest trees for fuel energy supply and decrease environmental pollution (Aigbodion *et al.*, 2010). To enhance sustainable and efficient fuel briquette production, careful considerations must be given to biomass residue selection based on availability (Wilaipon, 2009) and its ability to form good bond with binder and other biomass residues (Jekayinfa and Omisakin, 2005). The technology must also consider the appropriate biomass-binder ratio and selection of binder that can positively influence the briquette properties (Sotannde *et al*., 2010a). The use of Agro-residues like Coconut Shell (CNS) and Bambara Nut Shell (BNS)in briquette production will help in reducing the Agro-waste disposal problem, and also provide a cheap and cleaner fuel alternative to fuel wood and fossil fuel in domestic energy needs. Likewise, a more efficient use of molasses-based effluent will help in no small measure in reducing environmental pollution arising its disposal.

Coconut shell is an agricultural waste which is available in very large quantities throughout the tropical countries of the world. Taking into consideration that approximately 15% of a coconut consists of the shell, world regional total quantity of coconut shells is around 9.3Mt/yr (Lechtenberg, 2012). With a calorific value of approximately 5500kCal/kg, this quantity can replace about 6.9Mt/yr of coal (Lechtenberg, 2012). Regrettably in many developing countries, Nigeria inclusive, the shell is discarded as waste in ponds or burnt in open air thereby contributing significantly to carbon(IV)oxide (CO_2) and methane emissions (Bamgboye and Jekayinfa, 2006). Its use as a fuel source remained crude and limited to domestic cooking and blacksmithing (Amu *et al*., 2011; Madakson *et al*., 2012). Like coconut shell, bambara nut shells offer full potentials for briquette production (Tembe *et al*., 2014) due to its priceless abundance. Bambara nut is the third most important grain legume after peanut and cowpea in Sub-Sahara Africa (Hillocks *et al*., 2011). The annual world production is 330,000 tons, 45-50% of which are produced in West Africa (Plant Resources of Tropical Africa (PROTA), 2006).

Meanwhile, since briquette density and its moisture content can be linked to its combustion and handling characteristics (Olorunnisola, 2007; Sotannde *et al*., 2010a&b), information on the density of the briquette in both compressed and relaxed form will be critical in selecting any material for briquette production. Similarly, information on the volatile matter, ash content and percentage fixed carbon of the briquettes will help in no small measure in understanding the ignition behavior, mass loss of the briquette during combustion and energy value of the biomass materials.

2. Materials and Methods

2.1 Raw Materials Preparation

The biomass materials used for this study are coconut and bambara nut shells obtained as residues after extraction of the valuable nut from them. They were chosen based on their unique spread in Nigeria. Both residues were milled separately and sieved on a 1 mm sieve to remove oversized particles that may cause bonding failures during compression. Molasses, a by-product of sugarcane, was used as binder and was obtained from Savannah Sugar Company Limited, Numan, Adamawa State, Nigeria. The press employed for compression was made of metal frame fitted with hydraulic jack (similar to the wooden frame described in Dahlam and Forst, 2001). The press was equipped with a perforated cylindrical steel mold of 240mm long, 2 mm thick and 49mm inner diameter. Two metal plates with diameter slightly smaller than inner diameter of the mold were used as lids to cover both ends during production.

2.2 Briquette Production and Quality Evaluation

From the two agro-residues, three sample materials were prepared. Coconut shell (CNS), bambara nut shell (BNS) and 50:50 CNS-BNS mixture. For each briquette production batch, 1000g of each biomass sample was blended with molasses until mould-condition was achieved with molasses content varied at 20, 25, 30 and 35% of the weight of biomass sample based on performance ratio specified by Sotannde *et al*. (2010a). The biomass-binder blend was fed into an already oiled mould for easy extrusion, covered at both ends with a lid and compressed for ten minutes at a pressure of 1.2 x 10^3 N/m^2. Immediately after removal, the briquette was weighed and its dimensions determined with a digital caliper. The breakdown of the production variables is as presented in Table 1.

Table 1: Production Variables

Variables	Level
Biomass materials	3
Molasses level	4
Production per molasses level	10
Number of briquette produced	120

2.3 Physical Properties Determination

For physical properties evaluation, the compressed density, relaxed density and moisture content of four randomly selected briquette samples were determined. The compressed density of the briquettes was determined immediately after removal from the mould as a ratio of measured weight to calculated volume (Olorunnisola, 2007). For relaxed density determination, the sampled briquettes were air dried to constant weight and dimension. The relaxed density which is the density obtained after the briquette has remained stable in air dried condition was then evaluated as the ratio of the air-dry weight to air-dry volume of the briquette. The moisture content was determined after oven dried to constant weight at 105^{0}C using equation 1 (ASTM Standard D2016-77 (1989)).

$$M.C = \frac{W_0 - W_1}{W_1} \times \frac{100}{1} \quad (1)$$

where: *M.C* is the Moisture content (%), W_O is the initial weight (g) and W_1 is the final weight of the sample (g).

2.4 Combustion Properties Determination

The percentage of volatile matter, fixed carbon and ash of four randomly selected samples at each binder level were determined based on ASTM Standards. For percentage of volatile matter determination, 1g oven dried sample was heated at a 600^{o}C for 10 minutes in a furnace. The volatile matter was then estimated as expressed in equation 2 (ASTM Standard D3175-89 (1989)).

$$PVM = \frac{B - C}{B} \times \frac{100}{1} \quad (2)$$

where: *PVM* is the percentage volatile matter, *B* is the oven dried sample (g) and *C* is the weight (g) of the sample after heating in the furnace for 10 minutes.

The ash content determination followed the same procedure as volatile matter but in this case the sample was heated in the furnace for 3 hours and obtained as expressed in equation 3 (ASTM Standard D3174-89 (1989)).

$$PAC = \frac{D}{B} \times \frac{100}{1} \quad (3)$$

where: *PAC* is the percentage of ash content, *D* is the weight of ash (g) and *B* is the weight of oven dried sample (g).

The percentage fixed carbon and heating values were obtained as shown in Equations 4 (ASTM Standards E711-87 (2004)) and 5 (Bailey and Blankehorn, 1982).

$$C = 100 - (V + A) \quad (4)$$

where: C is the percentage of fixed carbon, V is the percentage of volatile matter, and A is the percentage of ash.

The heating value was calculated using this Gouthal formula (Bailey and Blankehorn, 1982) (Equation 5):

$$H_V = 2.326\,(147.6C + 144V) \quad (5)$$

where: H_V is the heating value in $MJ \cdot kg^{-1}$, C is the percentage of fixed carbon, and V is the percentage of volatile matter.

2.5 Data Analysis

A 3 x 4 factorial experiment in a completely randomized design was used with biomass materials at 3 levels and molasses contents at 4 levels. The effect of biomass material used namely; Coconut shell (CNS), Bambara nut shell (BNS) and 50:50 CNS-BNS mixture on the physical and combustion properties of the briquettes were subjected to analysis of variance at $\alpha_{0.05,0.01,0.001}$ and the significance of their P-values recorded. The degree of the influence of biomass materials and molasses on the briquette properties was assessed using variance component analysis while follow-up procedure was carried out using Duncan multiple range test. The mean and standard deviation of all the properties investigated were also computed while the influence of molasses contents on the physical and combustion properties of the briquettes produced were illustrated graphically using bar charts. All analysis was carried out using SPSS 20 and Microsoft excel 2016.

3. Results and Discussion

3.1 Compressed Density and Relaxed Density

The images of the briquettes produced are presented in Plate 1. The biomass material used and molasses content significantly influenced the compressed and relaxed densities of the briquette produced ($p < 0.001$). The type of biomass material used accounted for 40% and 61.5% of the total variations in compressed and relaxed densities of the briquettes while molasses content accounted for 51.4% and 25.1% respectively (Table 2). Coconut Shell (CNS) with coarser texture gave briquettes with higher compressed density averaged 0.80 $g.cm^{-3}$ but lower relaxed density (0.73 $g.cm^{-3}$) compared to Bambara Nut Shell (BNS) briquettes, which averaged 0.77 $g.cm^{-3}$ and 0.75 $g.cm^{-3}$ in both compressed and relaxed form respectively (Table 3). Both compressed and relaxed densities of the briquettes increased with binder level. This suggests that the biomass residues respond to the basic laws of stress and strain in different forms. Briquettes produced from the less coarse BNS attained the highest density when the binder level was 30% and had better elastic recovery over time compared to the coarser CNS which attained maximum at 35% binder level (Figure 1). Apart from this, the inherent chemical content of the biomass used could also be a contributory factor to the change in compressibility and relaxation of the briquettes (Shaw and Tabil, 2007). Meanwhile, the compressed (0.79 $g.cm^{-3}$) and relaxed (0.77 $g.cm^{-3}$) densities of the briquettes were significantly improved when both agro-residues were mixed in equal proportion with molasses (Table 3). Thus, biomass materials could complement each other in the briquette composite. The CNS with initial higher density can improve compressibility of the briquette with BNS producing stabilizing effect on the composite in relaxed form. This therefore offers attractive possibility of using heterogeneous biomass mixture in a briquette composite.

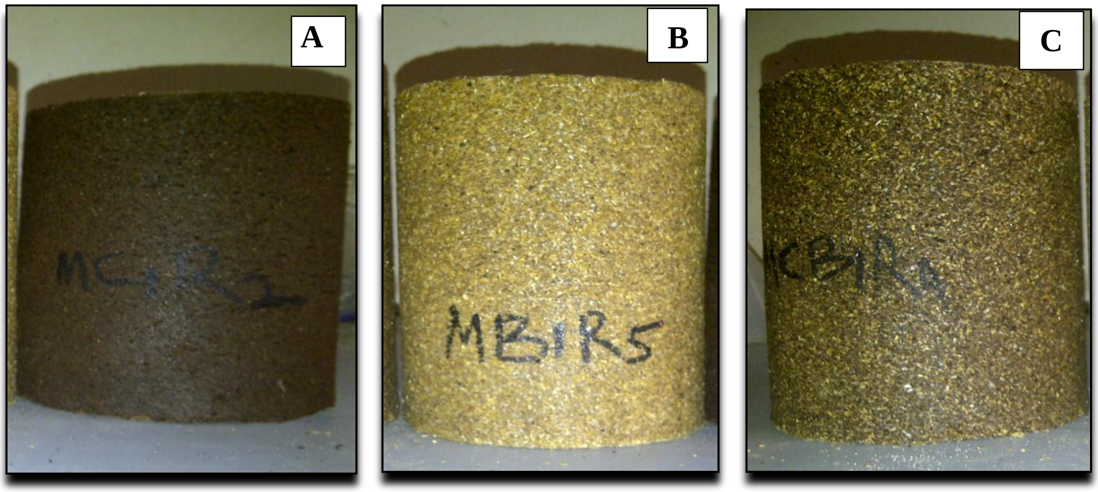


Plate 1: Photographs of briquettes produced from: A - Coconut shell, B - Bambara nut shell and C - 50:50 Coconut and Bambara nut shell mixture.

Table 2: Significance of p-values and variance components of the physical properties of the briquettes

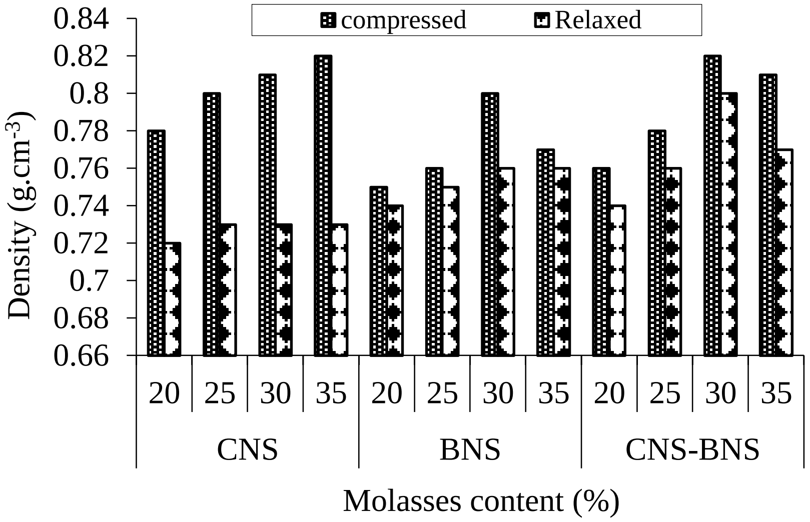
Sources of variation	Df	Density				Moisture content	
		Compressed		Relaxed			
		Sig.	VC (%)	Sig.	VC (%)	Sig.	VC (%)
Biomass material (BM)	2	***	40.0	***	61.5	***	64.6
Molasses Content (MC)	3	***	51.4	**	25.1	***	23.7
BM x MC	6	ns	5.7	*	11.5	*	11.2
Error	48		2.9		1.9		0.5
Total	59						

df = Degrees of freedom; Sig. = Significance; VC = Variance component; ns = not significant at 5% probability level; * = $P< 0.05$; ** = $p< 0.01$; *** = $p< 0.001$

Table 3: Mean ±SD values of compressed density, relaxed density and moisture content of the briquettes

Variables	Compressed density ($g.cm^{-3}$)	Relaxed density ($g.cm^{-3}$)	Moisture content (%)
Biomass material			
Coconut shell (CNS)	0.80 ± 0.02^{a}	0.73 ± 0.03^{c}	6.94 ± 1.06^{a}
Bambara nut shell (BNS)	0.77 ± 0.02^{b}	0.75 ± 0.02^{b}	6.02 ± 1.45^{b}
CNS-BNS	0.79 ± 0.03^{a}	0.77 ± 0.02^{a}	5.47 ± 0.56^{c}
Molasses content (%)			
20	0.76 ± 0.03^{c}	0.73 ± 0.04^{c}	6.13 ± 1.79^{b}
25	0.78 ± 0.02^{b}	0.75 ± 0.03^{b}	5.95 ± 0.56^{c}
30	0.81 ± 0.01^{a}	0.76 ± 0.03^{a}	6.30 ± 0.49^{a}
35	0.80 ± 0.02^{b}	0.75 ± 0.04^{b}	6.17 ± 1.72^{b}

SD = Standard deviation. Values with same alphabet in the same column are not significantly different using DMRT at α 0.05. Each value is an average of four replicates

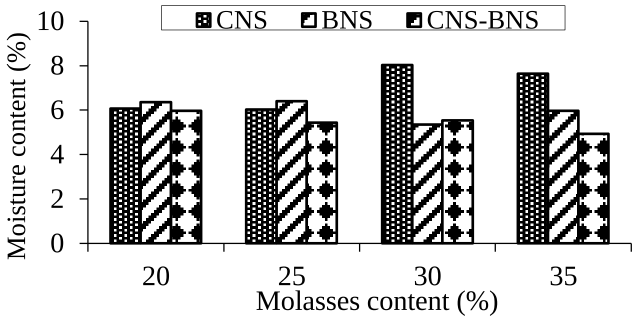


BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 1: Influence of molasses content on the briquette density

3.2 Moisture Content of the Briquettes

Moisture content is one of the major indices for predicting durability and ignition behaviour of a briquette. As shown in Table 2, the biomass material, binder level and their interactions had marked effects on moisture content of the briquettes ($p < 0.001$). About 65% of the total variation in moisture content of the briquette was due to the biomass material used while molasses content accounted for about 24%. The moisture content of the briquettes ranged from 4.93 – 8.02% with average of 6.94% in CNS briquette, 6.02% in BNS briquette and 5.47% CNS-BNS mixture (Table 3). However, no particular trend was obtained with increase in molasses content. With exception of CNS, briquettes produced from other biomass materials had the least moisture content when the molasses content was 30% (Fig. 2). The moisture content range of the briquettes produced from the three biomass materials was quite encouraging and compared well with average of 7.10% recorded for sawdust briquette of *Albizia zygia* (Aina *et al*., 2009), 2.50 – 6.76% for sawdust briquette from neem wood (Sotannde *et al*., 2010a) and 7.50 - 8.00% for some selected herbaceous plants (Onuegbu *et al*., 2012). The low moisture content of the briquettes is expected to influence the durability and lower the energy required for water evaporation during combustion.



CNS = Coconut Shell; BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 2: Influence of molasses content on the briquette moisture content

3.3 Combustion Characteristics of the Briquettes

3.3.1 Percentage of Volatile Matter

The volatile matters are mainly the waxes, oils, resins, fats, tannins and aromatic compounds in a biomass material. They determine largely the ease of ignition and to some extent production of smoke during biomass combustion. The results from the study revealed that the biomass materials and molasses content had significant effects on the volatile matter content of the briquette ($p < 0.001$) but their interactions between them did not ($p = 0.569$) (Table 4). The ease of ignition of the briquettes is largely dependent on the biomass material used as evidenced in 73.4% of the variance component while the binder content contributed 22%. Briquettes produced from BNS had the highest volatile matter averaged 11.38%, followed by 10.58% and 9.96% obtained in blend of CNS-BNS and CNS briquettes respectively (Table 5). The fuel related to smokeless grade is known to contain no more than 20% mass volatile substances (Ivanov *et al*., 2003). The values obtained in this study are much lower, so they can be considered as smokeless fuel. Meanwhile, the volatile matter of the briquettes from the three biomass materials decreased with increase in molasses content up to 30%. Beyond this level (30% molasses content), further increase in molasses content resulted in lower volatile matter (Figure 3). Thus, binder content had significant effect on the burning rate of the briquettes.

Table 4: Significance of p-values and variance components of the combustion properties of the briquettes

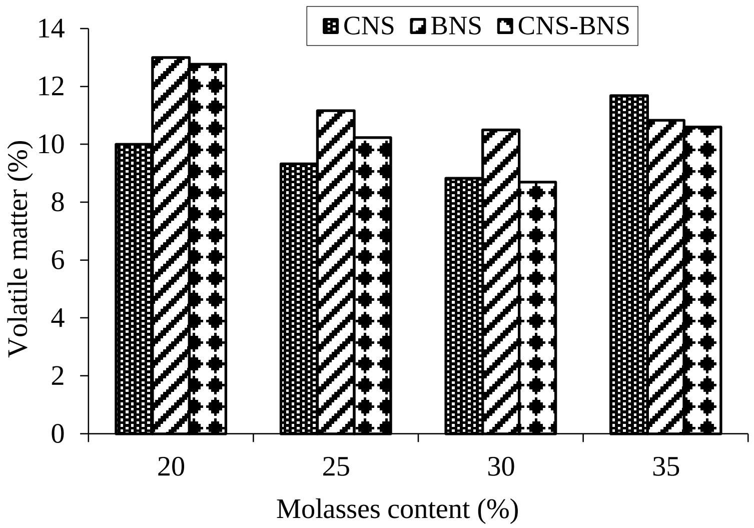
Sources of variation	Df	Volatile matter		Ash content		Fixed carbon		Heating value	
		Sig.	VC (%)	Sig.	VC (%)	Sig.	VC (%)	Sig.	VC (%)
Biomass material (BM)	2	***	73.4	***	69.8	***	85.0	***	75.7
Molasses Content (MC)	3	**	22.2	***	22.6	***	12.3	***	17.3
BM x MC	6	ns	3.3	*	5.7	ns	2.2	**	6.1
Error	24		1.1		1.9		0.5		0.9
Total	35								

Df = Degrees of freedom; Sig. = Significance; VC = Variance component; ns = not significant at 5% probability level; * = $P< 0.05$; ** = $p< 0.01$; *** = $p< 0.001$

Table 5: Mean ±SD values of the average volatile matter, ash content, fixed carbon and heating values of the briquettes

Variables	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Heating value ($MJ.Kg^{-1}$)
Biomass material				
Coconut shell (CNS)	9.96 ± 0.84^{c}	6.21 ± 1.56^{a}	83.83 ± 1.64^{b}	32.12 ± 0.76^{b}
Bambara nut shell (BNS)	11.38 ± 0.57^{a}	6.44 ± 0.78^{a}	82.18 ± 0.94^{c}	32.03 ± 0.38^{b}
CNS-BNS	10.58 ± 0.84^{b}	4.48 ± 1.11^{b}	85.21 ± 0.81^{a}	32.80 ± 0.54^{a}
Molasses content (%)				
20	11.92 ± 2.23^{a}	6.89 ± 1.11^{a}	81.55 ± 1.66^{d}	31.99 ± 1.11^{c}
25	10.24 ± 2.13^{bc}	5.68 ± 2.26^{b}	84.07 ± 3.10^{b}	32.29 ± 0.73^{b}
30	9.34 ± 2.53^{c}	4.36 ± 1.54^{c}	86.30 ± 1.96^{a}	32.75 ± 0.53^{a}
35	11.04 ± 2.56^{b}	5.90 ± 1.83^{b}	83.06 ± 2.87^{c}	32.21 ± 0.89^{b}

SD = Standard deviation. Values with same alphabet in the same column are not significantly different using DMRT at α=0.05. Each value is an average of four replicates

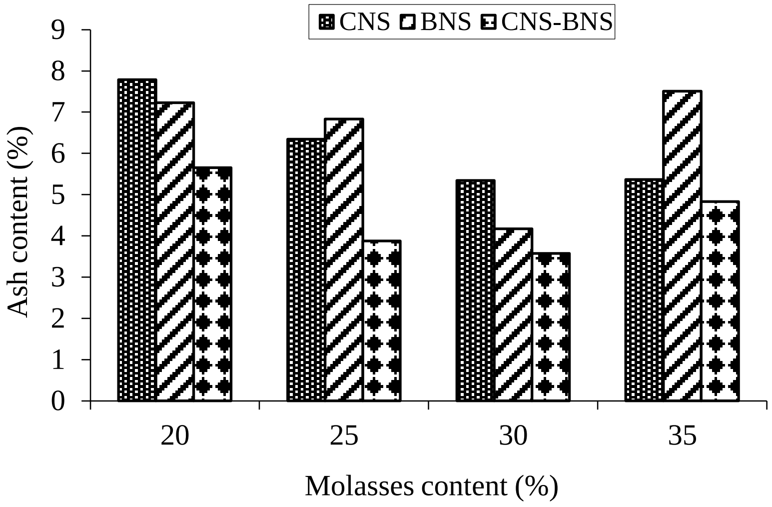


BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 3: Influence of molasses content on the briquette volatile matter

3.3.2 Percentage of Ash in the Briquette

Ash content is a function of the totality of inorganic mineral content in a biomass material notably calcium, potassium, magnesium, manganese and silica. They account for combustion remnant in form of ash. High ash content lowers the heating effect of the briquette (Sotannde *et al*., 2010b). The biomass materials and molasses content produced significant effects on the ash content of the briquette ($p < 0.001$). About 70% of the total variation in the ash content of the briquette could be attributed to the biomass material used with molasses constituting about 23% (Table 4). Briquettes produced from CNS-BNS mixture had the least ash content (4.48%) while CNS briquettes had the highest ash (6.21%). Consistent with volatile matter, the ash contents of the briquettes produced from both BNS and CNS-BNS mixture decreased with increase in molasses content and reached minimum when molasses content was 30%while minimum ash was obtained when molasses content was 35% in CNS briquettes (Figure 4). The relatively low ash content between 5.34-7.79%, 4.17-7.51% and 3.57-5.65% in CNS, BNS and CNS-BNS briquettes respectively compared well with 3.5-6% obtained in coconut husk briquettes (Jekayinfa and Omisakin, 2005). Similarly, the results compare well with 3.50 – 6.25% in charcoal briquettes from neem wood (Sotannde *et al*., 2010b) and, average of 4.35% and 6.09% obtained in briquettes produced from spear grass and elephant grass, respectively (Onuegbu *et al*., 2012). The low ash briquettes have characteristic high heating energy value and are therefore suitable for both domestic and industrial fuel energy supply.

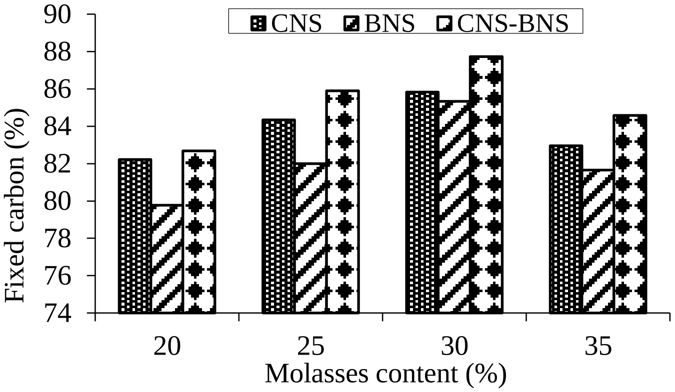


BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 4: Influence of molasses content on the briquette ash content

3.3.3 Percentage Fixed Carbon of the Briquettes

The fixed carbon content varied significantly with biomass material and binder level used in briquette production ($p < 0.001$). The fixed carbon content of the briquette is largely dependent on the biomass material used in its production while the binder level accounted for 12.3% (Table 4). Briquettes produced from blend 50:50 CNS-BNS had the highest fixed carbon content averaged 85.21% while those from solely BNS had the least which averaged 82.18% (Table 5). The fixed carbon content increased with molasses content and attained 85.83%, 85.33% and 87.73% in CNS, BNS and blend of CNS-BNS briquettes when the molasses content was 30% (Figure 5). This attests to the fact that the binder content in a briquette composite could also influence its fixed carbon content (Sotannde *et al*., 2010b). Apart from the binder content, the difference could also be attributed to nature of briquetting materials and their compressed densities. Meanwhile, the percentage fixed carbon obtained in these briquettes is very high and within 84.7-96.9% obtained in carbonized Velenje lignite at varying temperature (Zapusek *et al*., 2003). It is expected that the high percentage of fixed carbon and its smokeless flame will enhance the heat value and combustion duration of the briquette.

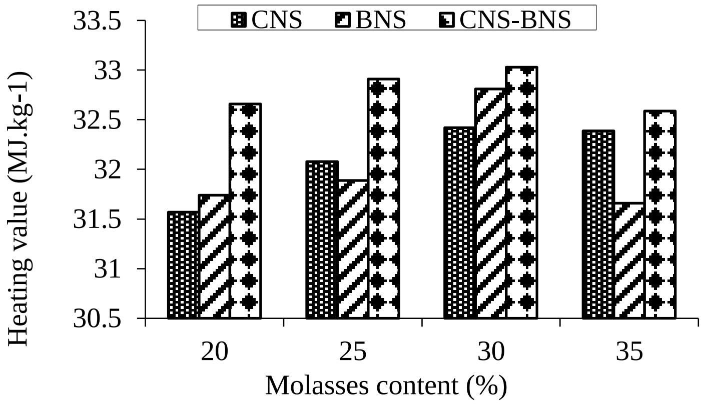


BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 5: Influence of molasses content on the briquette fixed carbon content

3.4 Heating Value of the Briquette

This is the most important combustion property for determining the suitability of a biomass material for fuel. It gives an indication of the quantity of fuel required to generate a specific amount of heat energy. The summation of the previous tests was reflected in the heating value. The biomass material used and percentage of molasses content influenced the heating values of the briquettes significantly ($p < 0.001$). Approximately 76% of the total variation in heating value of the briquettes is traceable to the type of biomass material used in its production. Binder level on the other hand accounted for 17% of the heating value (Table 4). Briquette produced from the blend of CNS-BNS had the highest energy value approximately, 32.80 MJ·kg^{-1} while those from CNS and BNS had 32.12 MJ·kg^{-1} and 32.03 MJ·kg^{-1}, heating values respectively (Table 5). Similar to volatile matter and fixed carbon content, the heating value increased with molasses content and peaked at 30% binder level. Beyond this, further increase in binder level resulted in significant decrease in the heating value (Figure 6). The values obtained for the three biomass materials were higher than 28.49-28.79 MJ·kg^{-1} obtained in briquettes of some blends of tropical hardwoods (Emerhi, 2011) and between 18.09-18.53 MJ.kg^{-1} in briquettes of blends of spear grass and elephant grass with coal (Onuegbu *et al*., 2012). This further showed the great potential of using coconut and bambara nut shells for production of briquette of high heat energy value for domestic and commercial cooking.



BNS = Bambara Nut Shell; CNS-BNS = Coconut Shell and Bambara Nut Shell Mixture

Figure 6: Influence of molasses content on the briquette heating value

4. Conclusion

From the study, the following can be concluded:

1. Briquettes with good physical and combustion properties can be produced from both coconut and bambara nut shells. But the best quality briquette was produced when both biomass residues were combined.
2. Majority of the variations in briquette qualities were attributed to the type of biomass residues used with binder level also contributing significant effect.
3. For quality specification, the optimum molasses content required for effective bonding of bambara nut shell and its mixture with coconut shell was 30% while it was 35% for coconut shell briquettes.
4. These two level (30% molasses content for BNS and CNS-BNS briquettes, and 35% for CNS briquettes) are therefore recommended for production of quality briquettes from these agro-residues.

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