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Physical and Combustible Properties of Briquettes Produced from a Combination of Groundnut Shell, Rice Husk, Sawdust and Wastepaper using Starch as a Binder

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ABSTRACT: This study investigated the use of agro-wastes for the production of briquettes. Briquettes were produced from a combination of groundnut shell, rice husk, sawdust and wastepaper using the 20:70:10, 30:60:10, 40:50:10, 50:40:10, 60:30:10 and 70:20:10 ratio. The feedstock of each blend was fed into a square mould [60mm] and screw-pressed at 20 MPa in a dwelling time of 60 seconds. Moisture content, density and combustion characteristics (ignition time and calorific value) of the briquettes were determined. Data obtained were analysed using appropriate statistical tools. The moisture content of all the briquettes ranged between 8 to 15%. The briquettes density was in the range of 800 to 900 kg.m^{-3}, while the calorific value ranged from 0.03 to 0.19 and 0.02 to 0.27 MJkg^{-1}for Saw dust-rice husk- paper (SRP) and groundnut shell-saw dust-paper (GSP) briquettes. The quality of the briquettes in terms of density and burning time showed that 20% sawdust: 70% rice husk: 10% paper combination had a higher relaxed density of 387.4kg/m^3, while on the basis of moisture content and ignition time, 70% sawdust: 20% rice husk: 10% paper combination had the least moisture content and ignition time of 16.7% and 18seconds, respectively. RSP had higher calorific value, lower ignition time, but less durability than GSP. However, the compressed and relaxed densities of SRP and GSP briquettes were significantly difference ($p<0.05$). The durability of the briquettes improved with increased starch proportion. It can be concluded that production of SRP and GSP briquettes is an effective and efficient agricultural waste disposal technique.

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Agricultural biomass residues are sources of renewable and sustainable biofuels which can contribute significantly to mitigate the effect of greenhouse gas (GHG) emissions if properly managed and utilized (Maninder et al., 2012). Due to inefficient use and improper methods of disposal of agricultural residue and paper, these materials tend to pollute the environment thereby posing a health risk and hazard to man and the ecology. In order to curb the menace posed by these materials, efforts are to be geared towards controlling pollution resulting from these materials by converting them to briquettes. Agricultural residues in their natural forms will not bring a desired result because, they are mostly loose, low density materials in addition to the fact that their combustion cannot be effectively controlled (Maninder et al., 2012). Although, there are many conversion routes through which these residues can be converted into biomass energy, one of such promising technologies is that of the briquetting process. Maninder et al. (2012) described briquetting as a process of compaction of residues into a product of higher density than the original material, while Kaur et al. (2017) and Olurunnisola (2004) defined briquetting as a densification process. The use of briquettes can reduce drastically the demand for wood and therefore decrease deforestation. Besides, briquettes have advantages over firewood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage (Oladeji, 2011). Briquetting is the process of compacting low density and loose combustible organic materials that are inefficient into high-density solid fuel of convenient shapes. Briquetting improves the physical, chemical and combustion properties of the raw materials (Olaoye and Kudabo, 2017). The briquetting of agro-residues improves material handling, increases the volumetric calorific value, reduces transportation costs and makes them useful for a variety of applications. The shape and size of briquettes are dependent on the mould, while the appearance and (calorific values) are dependent on the type of feedstock and the level of compactness (Olaoye et al., 2003; Bianca et al., 2014). Briquetting technologies are generally categorised into three: namely high, medium and low compaction

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technologies and briquettes can either be formed with or without binders (Olurunnisola, 2004; Maninder et al., 2012). Olaoye and Kudabo (2017) reported that agricultural residues such as straws, tree leaves, maize husks, grass, rice ground nut shells, banana leaves, sawdust and castor Stover can be used for briquette production and that though some materials have better calorific value than others, the selection of feedstock is usually dependent on what is readily available. There are several types of briquetting machines available for densification and compaction of biomass and their mode of operation vary from one principle to another (Grover and Mishra, 1996; Kaur et al., 2017). These types of briquetting machines include screw press, manual piston press, hydraulic piston press and pellet press. The burning of fossil fuel and deforestation are major contributors to anthropogenic greenhouse gases (whose major components are carbon monoxide and carbon dioxide) emission into the atmosphere, which results to the destruction of the ozone layer (Olaoye and Kudabo, 2017). The abundantly available agricultural and wood residues can efficiently be used for resolving energy problems to a significant extent by adopting proper measures. Olorunnisola (2007) reported that of the various types of biomass processing technologies that are being considered for their potentially viable local markets in the country, it is evident that none of these alternatives can compete with the low capital investment that is required with the briquetting technology (Olorunnisola, 2007). Adoption of briquette technology will not only create a safe and hygienic way of disposing of the waste but turn into a cash-rich venture by converting waste into energy and also contributing towards a safer environment. Based on the aforementioned, agro-biomass briquettes can be used as substitutes for conventional fuels and wood fuel. The aim of this study was to investigate the physical and combustion characteristics of briquettes produced from Rice Husk, Sawdust and Paper (RSP) and Groundnut Shell, Sawdust and Paper (GSP) with blend of cassava starch gel.

MATERIALS AND METHOD

All the raw materials (sawdust, rice husk, paper and starch) were sourced from Ilorin metropolis, Kwara State capital. The apparatus and equipment used were screw press briquetting machine (designed and fabricated by the authors), digital weighing balance (NBL-2602e; 0.01g sensitivity), bunsen burner, stopwatch, meter rule, grinding machine, Sieve, Petri dish, bomb calorimeter (IKA C2000/Kv600) and Plastic basin. The briquettes were produced in a briquetting screw press – BSP, using compaction pressure of 18 MPa and compression times of 60 seconds. The briquettes were square in shape with dimensions of 60 mm × 60 mm and characterized by calorific value in accordance with ASTM D5865 - 04 (2004) standard. Moisture content in accordance with ASTM-E871-82 (2013) standard-and the ignition time was determined according to Davies et al. (2013) and Davies and Davies (2013). The samples for the ignition test were held under a 50 kW/m^2 heat flux for periods of over 10 seconds. Table 1 shows the calorific value of some agricultural wastes.

Table 1: Ash content (%) and Calorific Value of Some Agricultural Wastes

Biomass materials	Ash Content, %	Calorific value of the briquettes kCal/kg
Bagasse		4380
Bamboo dust		4160
Castor seed shells		3862
Coffee husk		4045
Coir pitch		4146
Jute waste		4428.
Groundnut shell		4524
Paper		4841
Paddy straw		3469
Palm husk		3900
Rice husks		3200
Sawdust		3898
Sunflower stalk		4300
Soya bean husk		4170
Sugarcane		3996
Tobacco waste		2910
Tea waste		4237
Wheat straw		4100
Wood chips		4785

Food and Agricultural Organization, (1996)

The bulk density of the loose biomass was determined according to ASTM D7481-09 (2009) standard.

$$\text{bulk density} = \frac{\text{initial mass of materials}}{\text{volume of cylinder}} \frac{\text{g}}{\text{cm}^3} \quad 1$$

Percentage water resistance capacity of the briquettes when immersed in distilled water at room temperature for 2 minutes was determined and the relative change in weight of the briquettes was measured. Percentage water absorption (PWA) was calculated using the following relationship:

$$\text{PWA} = \frac{M_i - M_f}{M_i} \quad 2$$

Where; M_i is the initial weight of briquette before immersion and M_f is the final weight of briquette after immersion.

$$\text{WRC}\ (\%) = 100 - \text{PWA} \quad 3$$

Where WRC is water resistance capacity

Ignition time was determined in accordancewith ASTM- E1321-13 (2013) standard test method for determining material ignition and flame spread properties. Each briquette was ignited by placing a bunsen burner on a platform 4cm directly beneath the briquette hanged on a tripod stand. The bunsen burner was used to ensure that the whole of the bottom surface of the briquette was ignited simultaneously after adjusting it to blue flame. It was ensured that the briquette was well ignited before the ignition time was recorded with the stopwatch.

Volatile matter determination: The dried samples of the briquettes left in the crucibles were covered with a lid and placed in an electric furnace maintained at 925° C for seven minutes. The crucibles were first cooled in air, then inside a desiccator and weighed again. Losses in weights were reported as volatile matter on percentage basis (Awulu et al., 2015).

$$\text{VM }\% = \frac{W_2 - W_1}{W_2 - W_3} \times 100 \qquad 4$$

W_1 = weight of empty crucible, g; W_2 = weight of crucible + sample, g; W_3 = weight of crucible + sample after heating, g

Ash content determination: The residual samples in the crucibles were heated without lid in an electric furnace at 700°C for one hour. The crucibles were then taken out, cool first in air then in desiccators and weighed. Heating cooling and weighing was repeated until a constant weight was obtained. The residues were reported as ash on percentage basis (Awulu et al., 2015).

$$\text{Ash content }\% = \frac{W_5 - W_4}{W_5 - W_6} \times 100 \qquad 5$$

Where VM is volatile matter, W_4 = weight of empty crucible, g; W_5 = weight of crucible + sample, g; W_6 = weight of crucible + sample after heating, g

Determination of fixed carbon (FC): This was determined using expression 6.

Percentage FC = 100 – (%e VM + %e ash content) 6

Briquette Production: The sawdust, rice husk, groundnut shell and papers collected were sundried to reduce the moisture content to approximately 12%, which is within the acceptable operating limit for briquetting and then stored (Olaoye and Kudabo, 2017). The waste paper was pulverized before it was soaked to easy the process of messing. A sieve of 1.18 mm was used to obtain uniform grain size distribution for sawdust, rice husk, groundnut shell particles. The quantity of binder (starch) for the preparation of each of the mix ratios was 250g. The briquette samples were prepared using70:20:10 60:30:10, 50:40:10, 40;50:10, 30:60:10 and 20:70:1060:30:10, 50:40:10, 40;50:10, 30:60:10 and 20:70:10ratioto produce both risk husk: sawdust : paper and groundnut : sawdust : paper briquettes. These constituents were thoroughly mixed, moulded and screw pressed into briquettes. The compacted briquettes were collected from the machine and sun-dried, and proximate analysis was carried.

RESULTS AND DISCUSSION

Properties of Sawdust, Rice Husk, Groundnut Shell and Papers: Table 2 presented the weight of sawdust, rice husk and groundnut shell used for various mixing ratios. 10% of meshed/soaked waste paper weighed 39g. It was observed that the weight of the sawdust, rice husk and groundnut shell was in the range of 13 to 48 g, 19.1 to 67.9 g, and 18 to 45g, respectively. 20% of groundnut shell is 1.38 times heavier than 20% of sawdust.

Table 2: Mass of Sawdust, Rice Husk and Groundnut Shell at various composition

Percentage (%) of constituents	Mass of sawdust (g)	Mass of rice husk (g)	Mass of Groundnut shell (g)
10	11.5	16.3	15
20	13	19.1	18
30	20	24.7	20
40	26	40.3	27
50	33	50.7	33
60	39	60.9	39
70	48	67.9	45

Quality of the Briquette: The quality of the briquettes produced was determined by the calorific value, density, ignition time, moisture content, burning rate, carbon content and ash content.

Density of Briquette: Briquette density influences the burning of briquettes, the higher the density of a briquette, the longer the burning time and the heat released as briquette density is significantly affected by raw materials particle size and moisture content (AbdulRahman et al., 2015; Olaoye and Kudabo, 2017). The rice husk briquettes had higher bulk density than sawdust briquettes as shown in Table 3.

Bulk Density: Table 3 is the bulk density of RSP and GSP before compaction under the screw press.

$$\text{Bulk density, }(\text{g/cm}^3) = \frac{\text{Initial mass of materials}}{\text{volume of cylinder}} / \qquad 6$$

Table 3: Bulk Density of the Admixture

Mixing ratio	SRP (g/cm^3)	GSP (g/cm^3)
20 : 70 : 10	0.2845	0.2291
30 : 60 : 10	0.2868	0.2074
40 : 50 : 10	0.2692	0.2074
50 : 40 : 10	0.2604	0.2220
60 : 30 : 10	0.2281	0.2254
70 : 20 : 10	0.2315	0.2278

Compressed and Relaxed Density: The compressed and relaxed density was determined in accordance with the American Society of Agricultural Engineering Standard (ASAE, S269.4.2003) and the result is presented in Table 4. As the sawdust percentage increases, the density of the briquettes increases compared to when groundnut shell is increasing. As rice husk percentage decreased in the mixture, the density of briquette increased, but the density increased as the percentage groundnut shell decreased in GSP. The density of SRP increased from 1009.6 to 1010.3 kg/m^3, while the density of SGP increased from 0.29 to 0.41 g/cm^3. RSP Briquette had the highest density of 787kg/m^3 while GSP briquettes had the lowest density of 711.33kg/m. This could be because rice husk particles have better compactibility with less void spaces than GSP Briquettes. AbdulRahman et al. (2015) reported that empty fruit bunches (EFL) fuel briquettes had the highest density of 950 kg/m^3 and Oladeji and Oyetunji (2013) reported a relax density of 86.4 kg/m^3 and 12.54 kg/m^3 for cassava and yam peels briquettes.

Table 4: Compressed and Relaxed Density

Mixing ratio	SRP Compressed density (g/cm^3)	SRP Relaxed density (g/cm^3)	SGP Compressed density (g/cm^3)	SGP Relaxed density (g/cm^3)
20 : 70 : 10	1.0096	0.3874	0.86	0.29
30 : 60 : 10	1.0005	0.3535	0.91	0.33
40 : 50 : 10	1.0232	0.3417	0.95	0.36
50 : 40 : 10	1.0129	0.3312	0.98	0.37
60 : 30 : 10	1.0118	0.3264	1.04	0.40
70 : 20 : 10	1.0103	0.3044	1.07	0.41

The Relaxation and Compaction Ratio: Presented in Table 5 are the SRP and SGP relaxation and compaction ratio of the briquette. These properties were determined in accordance with the American Society of Agricultural and Biological Engineering (ASABE, S269.4.2003).

Relaxation Ratio = Compressed density/Relaxed density (4)

Compaction Ratio = Compressed density/Bulk density (5)

Table 5: Relaxation and Compaction Ratio

Mixing ratio	SRP Relaxation ratio	SRP Compaction ratio	GSP Relaxation ratio	GSP Compaction ratio
20 : 70 : 10	2.61	3.55	2.97	3.75
30 : 60 : 10	2.83	3.49	2.76	4.39
40 : 50 : 10	2.99	3.80	2.64	4.58
50 : 40 : 10	3.06	3.89	2.65	4.41
60 : 30 : 10	3.09	4.44	2.60	4.61
70 : 20 : 10	3.32	4.36	2.61	4.70

The values of compaction ratio obtained in this study compared favourably with that reported by Davies and Davies (2013). Compaction ratio varied from 3.55 to 4.36 for SRP briquettes and varied from 3.75 to 4.70 for GSP briquettes- The compaction ratio of SRP increased with increasing ratio of sawdust, while the compaction ratio of GSP briquettes increased with increasing ration of groundnut shell to 40% and then decreased to 4.41 at groundnut shell ratio of 50%. The higher the compaction ratio the higher the compressed and relaxed density, and the higher the potential of having a high calorific value (Awulu et al., 2015). Relaxation ratio values were in the range of 2.61 to 3.32 and 2.60 to 2.97 for SRP and GSP briquettes, respectively. The obtained range of relaxation ratio in this study was, however, high than the range of 1.11 to 1.32 and 1.17 and 1.34 for briquettes produced from charcoal and Arabic gum and charcoal and cassava starch, respectively, as reported by Davies and Davies, 2013. The obtained valuesof relaxation ratio signified that briquettes of low relaxation ratio exhibited low elastic property and more stability, vice versa (Awulu et al., 2015). Lower values ratio indicates a more stable briquette, while higher value indicates a high tendency towards relaxation, that is, less stable briquette (Awulu et al., 2015).

Calorific Value: The implication of high a calorific value is that more thermal energy is released during combustion. The calorific value was conducted according to nationally adopted international standard STN ISO 1928 (441352), 2003, Solid fuels: Determination of the combustion heat by a calorimetric method in the pressure tank and calculation of the calorific value (Olaoye, 2001; Olaoye and Kudabo, 2017). Calorific values were determined by calorimeter C5000 (IKA®-Werke GmbH & Co. KG, Germany). The calorific value of briquettes is one of the most influential factors affecting the burning rate of a briquette. The higher the calorific value, the easier and better burning efficiency. The calorific value obtained for all the samples were presented in Table 6. Furthermore, the calorific value of a briquette depends on the type of biomass materials used in its production. The calorific value of GSP briquette was in the range of 0.02 to 0.61 MJ/kg, while the calorific value of RSP briquette was in the range of 0.03 to 0.33 MJ/kg. The calorific value of the briquettes produced from the combination of groundnut shells, sawdust and paper were presented in Table 6. GSP (30:60:10) briquettes had a higher Calorific value of 0.27 MJ/kg, while RSP (60:30:10) had 0.19 MJ/kg. This was also in line with previous researchers Oladeji and Oyetunji (2013), who reported calorific values of 2,765 kJ/kg and 17,348 kJ/kg for cassava and yam peels briquettes, respectively, AbdulRahman et al. (2015) recorded Calorific value in the range of 23.13 to 21.23 MJ/kg for EFL briquettes and Onuegbu (2010) reported 20.64 MJ/kg for coal briquette. The reason for this trend was because RSP produced less ash content meaning that almost all the content was used during combustion, thereby given off high heat energy content than SGP briquettes.

Table 6: Calorific Value of Briquette

Mixing Ratio	RSP Calorific Value, (MJ/kg)	GSP Calorific Value (MJ/kg)
20:70:10	0.16	0.61
30:60:10	0.03	0.27
40:50:10	0.17	0.12
50:40:10	0.16	0.09
60:30:10	0.19	0.05
70:20:10	0.33	0.02

*Ignition Time***:** The mean Ignition time presented in Table 7 shows that SRP and GSP had ignition time range between 18 to 49 seconds and 45 to 79 seconds, respectively. SRP had a lower ignition time than GSP in all combinations of the components-what is the implication of this on the combustion and other properties of the briquettes. The least ignition time of 18 seconds was recorded for the 70:20:10 combination of SRP, while 20:70:10 combinations of GSP briquettes had the least ignition time of 45 seconds. This result is comparable to that obtained by Olaoye and Kudabo (2017), who an ignition time range of 80 -105 seconds for Sorghum Stovers briquette.

Table 7: Mean Ignition Time

Mixing ratio	SRP Mean Ignition time (seconds)	GSP Mean Ignition time (seconds)
20:70:10	49	45
30:60:10	29	51
40:50:10	23	62
50:40:10	22	69
60:30:10	20	71
70:20:10	18	79

Moisture Content of Briquette: The moisture content of the briquettes was in the range of 1.61 – 2.32 % and 1.98 – 2.34 % dry basis for SRP and GSP. According to Hussein and Nozdrovický (2009), moisture content plays a major role in determining density and strength of the densified biomass. An increase in the moisture content of biomass considerably decreased the pellet density. The result of the dry basis moisture content showed that SRP (20:70: 10) had the lowest moisture content, while SRP (70:20: 10) had the highest moisture content of 2.32. This is because the high percentage of rice husk present in SRP allowed more compaction thereby eliminating void which could retain some form of moisture within its microstructure (Awulu *et al*., 2015). In GSP, as the percentage composition of saw dust decreased and percentage composition of groundnut shell increased the moisture content of the briquettes decreased. This was as a result in the reduction of the inter-particle spaces, which was as a result of the decrease in the percentage composition of saw dust. The particles of saw dust have a higher moisture retaining capacity that groundnut shell and paper.

Volatile Matter and Ash Content: The proximate analysis is shown in Table 8. The table shows that GSP briquettes had the highest volatile matter of 68.89% as compared to RSP briquettes with 59.8%. Similar result was obtained by Oladeji (2011). For fixed carbon RSP had the highest value of 19.68 % when compared to GSP with a value of 9.01 %. This was in line with results obtain by AbdulRahman et al. (2015) obtained from the proximate analysis of EFB briquettes. The high level of fixed carbon in RSP was due to the rich husk which has a large volume and high density organic matter to be burnt as compare to GSP briquettes. The ash content of GSP briquettes was 25.15 %, while RSP had ash content value of 17.05 % because GSP briquettes had a higher percentage of combustible particles than RSP briquettes, therefore, resulting higher residues. Onuegbu (2010) reported 18.27, 30.65 and 43.33% for ash content, fixed carbon and volatile matter for coal briquette, respectively.

Conclusions: This study showed that the various combination of materials in different proportions had a significant effect on both the physical and mechanical properties of the briquettes. The findings of this study showed that briquettes from a combination of saw dust, rice husk, groundnut shell and waste paper is a good alternative source of thermal energy to fossil fuel and it is an economical and environmental friendly waste disposal method for agro-wastes. Starch showed good potential as a binder and has combustibility characteristics. Briquette production from agro-wastes is cheap source of energy for domestic application.

Table 8: Proximate Analysis of Briquettes

Briquette	Volatile Matter, %	Ash Content, %	Fixed Carbon, %
SRP	68.89	17.05	14.06
GSP	59.8	25.15	16.66

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