Communication in Physical Sciences 2025, 12(5): 1673-1683

Physical And Mechanical Properties of Composite and Pure Briquettes Produced from Rice Husk, Groundnut Shell and Palm Kernel Shell Using Cassava Starch

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Received: 12 March/Accepted: 13 June 2025/Published: 25 June 2025

https://dx.doi.org/10.4314/cps.v12i5.18

Abstract: The increase in agricultural and industrial wastes, coupled with inadequate disposal methods, has led to severe environmental challenges. One sustainable solution is converting these wastes into bio-briquettes for domestic and industrial energy applications. This study evaluated the physical and mechanical properties of briquettes produced from rice husk (RH), groundnut shell (GS), and palm kernel shell (PKS), using cassava starch as a binder. The briquettes, both composite and single biomass, were assessed for relaxed density, water absorption, water resistance, shatter index, shatter resistance, and compressive strength. The relaxed densities ranged from 250 to 370 kg/m³, water absorption from 40.8% to 61.3%, and water resistance from 38.86% to 59.19%. Shatter index values were between 2.64% and 10.82%, with corresponding shatter resistance of 89.2% to 97.4%. The compressive strength, measured using a universal testing machine (UTM), ranged from 1.10 to 1.80 kN. Among the samples, the composite briquette with a 40:30:30 ratio of RH: GS: PKS showed superior mechanical strength and structural integrity, making it the most suitable for fuel applications.

Keywords: *Biomass briquettes relaxed densities, water absorption, water resistance, shatter index, shatter resistance and compressive strength*

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1.0 Introduction

In recent years, there has been a growing global concern regarding the depletion of fossil fuel reserves and the environmental challenges posed by their combustion, including greenhouse gas emissions, deforestation, and air pollution (Armynah *et al*., 2018; Necoleta *et al*., 2018). Developing countries like Nigeria face a dual burden: heavy dependence on firewood and charcoal for domestic energy, and an ever-increasing volume of agro-waste, which is often improperly disposed of, contributing to environmental degradation (Nguyen *et al*., 2017). Nigeria alone produces over 90 million tonnes of biomass annually, with rice husk, groundnut shell, and palm kernel shell constituting a significant proportion of this waste stream (Ahmed *et al*., 2018; Simeon *et al*., 2020).

The need for sustainable and renewable energy alternatives has led to increased interest in biomass briquetting — a process that converts loose biomass residues into compact, energy-dense fuel briquettes (Kabok *et al.,* 2018). Briquettes are advantageous due to their improved handling characteristics, higher combustion efficiency, and reduced smoke generation. Unlike traditional firewood, biomass briquettes can reduce indoor air pollution and deforestation when adopted widely (Oriaku *et al.,* 2017). Furthermore, they offer a pathway to waste-to-energy conversion, aligning with circular economy principles and sustainable development goals (Philippe *et al.,* 2018).

Among various biomass types, rice husk, groundnut shell, and palm kernel shell are abundantly available in Nigeria. These materials have been studied for their calorific value, availability, and low-cost sourcing, making them ideal candidates for biofuel production (Idah and Mopah, 2013). However, they typically require a binder to form stable briquettes. Cassava starch, another abundant agricultural product in Nigeria, has been found to serve effectively as a natural binder due to its strong adhesive properties, low cost, biodegradability, and renewability.

While previous studies from the work of Tembe *et al*. (2014) and Abdel Al *et al*. (2023) have investigated the briquetting of single biomass types, limited comparative analyses exist on composite biomass blends, particularly those bound with cassava starch. Moreover, there is a research gap in the systematic assessment of the mechanical properties (e.g., compressive strength, shatter resistance), water absorption behaviour, and density of such composite briquettes. These parameters are critical to ensuring that the briquettes are durable, water-resistant, and energy-efficient during handling, storage, and usage (Graham *et al*., 2017).

This study aims to bridge this gap by producing composite briquettes from rice husk, groundnut shell, and palm kernel shell using cassava starch as a binder. It specifically investigates:

(i) The physical properties (density and water absorption)
(ii) Mechanical performance (compressive strength and shatter resistance)
(iii) The influence of raw material combination and binder proportion on briquette quality.

A process flow diagram was developed to track all stages of material collection, preprocessing, briquette formation, drying, and characterization. The study also seeks to contribute to the local production of clean and efficient biofuels and enhance the valorization of agro-waste in Nigeria.

2.0 Materials and Methods

2.1 Materials

The agricultural wastes used in this study were rice husk, groundnut shell, palm kernel shell, and cassava starch. All biomass materials were collected locally from agricultural processing facilities in Niger State, Nigeria. The materials were sun-dried to a moisture content of approximately 10% and sieved to remove large particles. Cassava starch was obtained from a local food processing vendor and used as a binder without further purification.

2.2 Methods

2.2.1 Briquettes Production

The composite and pure biomass briquettes were produced using a briquetting machine in the NRF-2021 laboratory department of physics at the Federal University of Technology, Minna, Nigeria. The process of the piston press method was adopted, which involves the high-pressure briquetting technique. Briquettes were formed in a cylindrical mold with an inner diameter of 50.00 mm, a height of 70.00 mm and a rod with a 15.0 mm outer diameter placed in the centre to create a hole in the middle of the briquette. The hole helps to increase porosity and oxygen supply, thereby improving briquette combustion. The mould was filled with each agglomerate from rice husks, groundnut shells and palm kernel shells and densified under constant operating conditions (temperature of 30 ºC, pressure of 120 bar) with a manually operated air hydraulic piston press (Model HBP020). A dwelling time of 5 min was allowed for each of the bio-residues consolidations in the mold to prevent the compressed biomass from spring-back effect. Twelve (12) briquettes were produced from each sample and their initial masses were measured immediately after ejection from the mold. The briquettes produced were placed on a flat surface and sun dried in an open space with adequate air to achieve constant weight for 21 days before testing the properties or characterization. Thereafter, relaxed densities, water absorption, water resistance, shatter index, shatter resistance and compressive strength were measured and calculated.

2.2.2 Determination of relaxed density

The density of briquettes was determined according to ASTM D2395-17. The density of the briquette was calculated by dividing the mass of the briquette by its volume. The volume was determined by measuring the diameter, height and central diameter at different points using a Vernier calliper, while the mass was measured with a digital weighing balance (Model AND GF 3000). The density of briquettes was determined 30 days after the briquetting process using equation 1 (Tembe *et al*., 2014; Kpalo *et al*., 2020)

$$\text{Bulk Density}(\rho) = \frac{M}{V} \quad (1)$$

where ρ = Density, M = mass of biomass briquette, V = volume of biomass briquette

Plate 8: Twelve (12) Mold Briquetting Machine

Plate 9: Briquettes Production

2.2.3 Water absorption

Water Absorption is a measure of the minimum or maximum water a briquette can absorb, especially during storage. The water absorption test was carried out following the procedure described in the work of Kpalo *et al*. (2020). A digital weighing balance (Model AND GF 3000) was used to measure the initial weight of each sample briquette and then dunked in water for 2 min. A stopwatch was used to time the process. The briquette's weights were measured again and the relative weight change was recorded. The percentage of water absorbed was calculated using the following equation.

$$\% \, water \, absrobed \, by \, briquette = \frac{w_2 - w_1}{w_1} \times \frac{100}{1} \quad (2)$$

where W_2 = final weight of briquette after immersion and W_1 = initial weight of briquette before immersion (Tembe *et al.*, 2014; Kpalo *et al.*, 2020).

2.2.4 Water resistance

Water Resistance determines the hydrophobic or water rejection index of the briquettes.

$$H_2O \, resistance \, (\%) = 100 - \%H_2O \, adsored \quad (3)$$

2.2.5 Shatter index

Shatter index measures the index level of briquette to resist breaking during falling. This property was determined according to ASTM D440-86. The procedure involved weighing and recording the initial mass of the briquette, followed by subjecting the sample to a gravitation fall from a constant 2-m height. The drop is repeated three times and each time the sample was passed through a sieve of aperture 1.00 mm, while the mass of the briquette retained on the sieve was recorded. The fraction of the briquette retained was used as an index of briquette breakability. The shatter index of each briquette was calculated by the equations (Tembe *et al.*, 2014; Kpalo *et al.*, 2020)

$$\text{Shatter Index (K)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (4)$$

where K = shatter index, W_1 = weight of briquette before shattering, W_2 = weight of briquette after shattering

2.2.6 Shatter resistance

Shatter resistance measures the percentage of remaining weight after falling (Kpalo *et al.*, 2020).

$$\text{Shatter resistance (\%)} = 100 - \text{percentage weight loss} \quad (5)$$

2.2.7 Universal testing machine

The compressive strength of a briquette is measured by the maximum load it can withstand before cracking or breaking. This load estimates the weight a briquette can withstand during storage (Onchieku, 2018). However, the compressive strength of briquettes was determined using a universal testing machine with serial number ET8828-16A with a load cell capacity of 20T/200kN and a cross-head speed was 1mm/min at Federal University of Technology Minna, Department of Building Tecin accordance with ASTM D2166-85. The briquette was placed in between the plates of the machine and was subjected to uniform loading until the rupture or failure of the briquette structure. The maximum force the briquette withstand was then recorded and used to determine the compressive strength of the briquette with the formula from the work Kuhe *et al*. (2013)

$$\text{Compressive strength } (\sigma) = \frac{\text{Force(N)}}{\text{Area of the briquette}(A_o \, /\text{m}^2)} \quad (6)$$

3.0 Results and Discussion

3.1 Results

To evaluate the performance of the briquettes produced from varying ratios of rice husk (RH), groundnut shell (GS), and palm kernel shell (PKS) using cassava starch as binder, key physical and mechanical properties were measured. These included relaxed density, water absorption, water resistance, shatter index, shatter resistance, and compressive strength. The data for all eight briquette samples (labelled with A–H based on composition) are presented in Table 1**.**

Fig. 1 illustrates the physical and mechanical properties of the briquettes produced from varying combinations of rice husk (RH), groundnut shell (GS), and palm kernel shell (PKS). The parameters evaluated include relaxed density (g/cm^3), water absorption (%), water resistance (%), and shatter index (%),

shatter resistance (%), and compressive strength (kN). The graphical representation enables a clearer comparison of the performance characteristics of each briquette sample (A–H), based on their respective biomass compositions.

Table 1: Physical and Mechanical Properties of the Produced Briquettes

Sample Code	Relaxed Density (g/cm^3)	Water Absorption (%)	Water Resistance (%)	Shatter Index (%)	Shatter Resistance (%)	Compressive Strength kN
A	0.30	52.12	47.88	6.30	93.70	1.80
B	0.30	51.80	48.20	8.95	91.10	1.60
C	0.31	51.18	48.82	7.39	92.60	1.40
D	0.28	55.41	44.59	5.30	94.74	1.30
E	0.26	54.40	45.63	2.86	97.14	1.60
F	0.30	46.15	53.85	2.64	97.40	1.60
G	0.25	61.30	38.96	6.95	93.05	1.50
H	0.37	40.81	59.19	10.82	89.20	1.10

A = RH40:GS30: PKS30, B = RH60:GS20: PKS20, C = RH80:GS10: PKS10, D = GS50: PKS50, E = RH50:GS50, F= RH100, G= GS100 and H= PKS100.

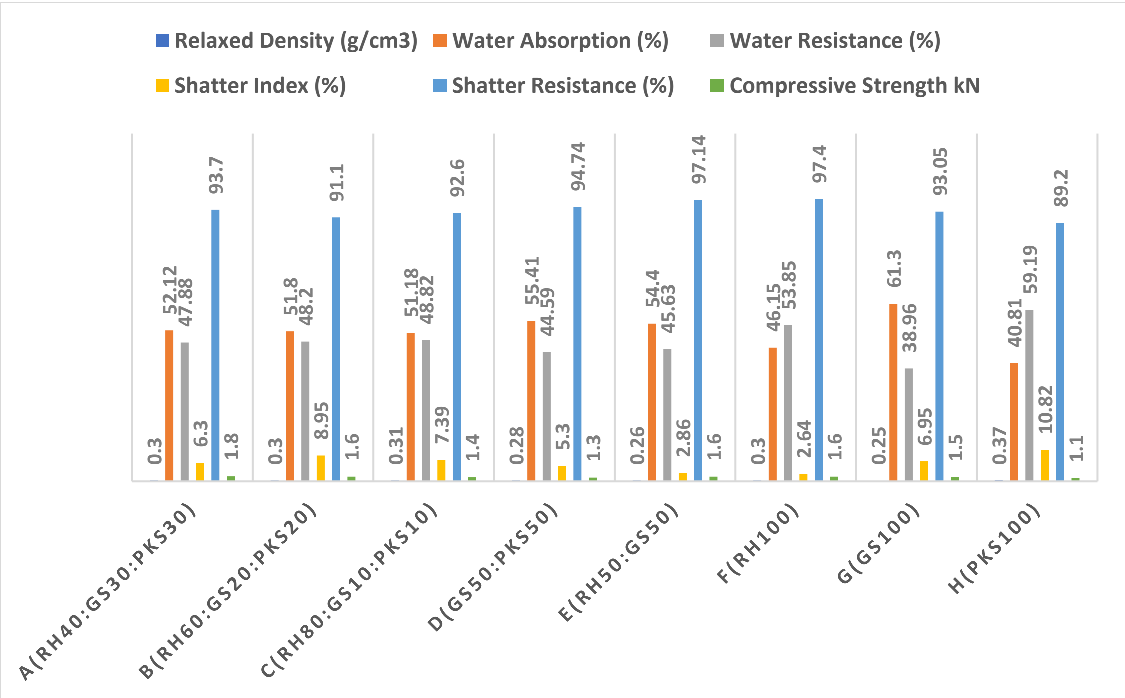

Fig.1: The plot of the physical and mechanical properties of the produced briquettes

3.2 Discussion of Results

3.2.1 Relaxed density

Relaxed Density is an important parameter for the briquetting process. However, it was observed from table 1 and Figure 1 that value of the relaxed density range between 0.25-0.37 g/cm^3 in composites and pure samples E and G briquette contained only groundnut shell displayed the lowest density of 0.26 g/cm^3 and 0.25 g/cm^3 respectively while the sample H briquette contained only palm kernel shell had the highest density at 0.37 g/cm^3. The relaxed densities (0.30 g/cm^3, 0.30 g/cm^3, 0.31 g/cm^3, 0.28 g/cm^3 and 0.30 g/cm^3) of samples A, B, C, D and F briquettes are not significantly different and this can be related to variation or non-homogeneous in the materials particle size, result from highest porosity of the briquettes. The observed difference between samples F, G and H briquettes, which contained only rice husk, groundnut shell and palm kernel shell, can be attributed to the higher fineness in the particle size. This was confirmed by Mitchual *et al.*

(2013), suggesting that raw material with finer particles provides larger surface areas for bonding, which results in the production of briquette with high densities. Owing to the inclination to absorb water, the lower values of GS briquettes could be due to a decrease in the briquette weight or a rise in the briquette volume after drying and stabilizing, as observed by Okot *et al*. (2018). The values of relaxed density observed in this study are similar to briquettes produced with a carbonized coffee husk (0.30–0.39 g/cm^3) using different manual presses (Onchieku, 2018). And in the rice husk and bran briquettes (0.44 g/cm^3) made with cassava starch wastewater (Yank *et al*., 2016). It was observed that blending RHS, GNS and PKS will improve the density of the briquettes and with a higher proportion of PKS material, the higher their densities.

3.2.2 Water resistance and absorption

From Table 1 and Fig. 1, it was observed that water resistance ranges from 38.86% to 59.19% and the water absorption ranges from 40.81 to 61.30% respectively. Water resistance test studies the rate at which briquettes can withstand degradation in high humidity or water exposure (Olorunnisola, 2007). PKS briquette recorded the highest resistance to water penetration with a value of 59.19% and the GNS briquette with the lowest value of 38.86%. This situation reversed as indicated in the water absorption, with the PKS briquette having the lowest water absorption value 40.81% and the sample briquette of GNS having a value 61.30%. The sample briquette of GS recorded the least water resistance, most likely due to the low density and higher porosity of GNS particles. Earlier, Pinto *et al*. (2012) had observed that particle porosity from the existence of a capillary network in corn cob gives rise to its tendency to absorb water.

Contrastingly, the briquettes showed a gradual rise in resistance to water penetration. This is an indication that with increased quantity of PKS material, the hygroscopic property of the briquettes showed a decrease in water absorption capacity (Sukiran *et al*., 2017). And this shows that PKS has a positive effect on structure which resulting in improvement of briquette’s water resistance (Yaman *et al*., 2001; Onoja *et al*., 2019). The values obtained in this work were in agreement with Rajaseenivasan *et al*. (2016) for sawdust and neem powder briquettes.

Generally, Necoleta *et al*. (2018) and Kpalo *et al*. (2020) observed that briquettes absorbed moisture from the air during handling, transportation and storage. If this is prolonged, they will swell to decrease the density and lead to total disintegration. Water resistance also influences the combustion of briquettes as it affects their heat values. The lifetime of briquettes is limited under humid conditions and thus the reason why they should be stored under dry cover. It is important that briquettes display a high resistance to water penetration to avoid decay and growth of fungi during storage, particularly if the feedstock is agricultural residues. Ajimotokan *et al*. (2019) observed that the moisture content of fuels affects combustion characteristics. Thus, it should be as low as possible because the high moisture content is a challenge when burning and would require excessive energy for drying.

3.2.3 Shatter index and resistance

Shatter indices are a direct means of gauging the strength of briquettes for the purposes of handling, transportation and storage. From Table 1 and Fig. 1, it was observed that the shatter index ranges from 2.64-10.82% and the shatter resistance ranges from 89.20-97.40% respectively. However, the PKS briquette recorded the highest shatter index of 10.80% which was closely followed by the sample B briquette with a value of 8.90%. And RH recorded the lowest shatter index of 2.64%, due to the addition of binder responsible for the agglomeration of the materials, which resulted in a strong bonding of particles (Yaman *et al*.,2001; Caroll and Finnan, 2012). Similarly, a higher ratio of binder resulted in a higher percentage of shatter resistance of briquettes (Kpalo *et al*., 2020). Ajiboye *et al*. (2017) and Borowski *et al*. (2017), observed that the shatter index of briquettes should be at least 9%. And the minimum value of 5% was considered an acceptable shatter index for fuel briquettes developed for industrial and domestic applications (Kpalo *et al*., 2020). The higher the value of the shatter index, the better the quality of the briquette Antwi and Acheampong, 2016; Ujjinappa *et al*., 2018), which is an indication of high durability to gravitational deterioration.

3.2.4 Compressive strength

Apart from the shatter index, compressive strength is another index used to assess a briquette's ability to be handled, packed and transported. Compressive strength is the maximum crushing load a briquette can withstand before cracking or breaking. Table 1 shows that the values for compressive strength of briquettes ranged from 1.10 to 1.80 KN. The PKS has the lowest compressive strength of 1.10 KN and sample briquette A, combined with RH, GNS and PKS has the highest compressive strength of 1.80 KN. The low compressive strength of PKS may be attributed to the low adhesiveness and cohesiveness of the particle size or binder used. The strength of briquettes depends on factors such as particle size, moisture content, compaction parameters and material type (Gendek *et al*., 2018). The sample briquette D, which comprised RH and GNS, displayed the lower value of 1.30 KN, while other briquettes exhibited higher compressive strengths similar to their reported density values. The results are also consistent with the observation by Jamradloedluk *et al*. (2007) that briquettes produced from materials with higher density can withstand higher ultimate stress in comparison to those of lower density materials. Wu *et al*. (2018) observed that the extremely high compressive strength suggests the presence of strong bonding forces between the particles within the biomass briquette. Aside from the density of the raw materials, the cassava starch used as a binder in this work also contributed to the compressive strength of the briquettes. An increase in the quantity of cassava starch correspondingly increased the compressive strengths of briquettes in the work of Yaman *et al*. (2001). Generally, it was observed that cassava starch does not crumble when compacted properly due to having excellent binding ability. Compressive strength increases the lifespan of briquettes by reducing the absorbing ability of moisture (Kers *et al*., 2010). A minimum value of 0.38 MPa was given as an acceptable compressive strength for briquette, which was established from a test performed on commercial fuel briquettes (Adila *et al*., 2018). Similarly, Borowski and Hycnar (2013) suggested a minimum value of 1.0 MPa. The high compressive strength of the briquettes makes them safer to store or transport and will not break or wear off very easily, in agreement with (Nwabue *et al*., 2017)

4.0 Conclusion

The physical and mechanical characteristics of fuel briquettes made from rice husk, groundnut shells, palm kernel shells and their agglomerates using gelatinized cassava starch as the binder were examined. The mixing ratios variation of the biomass samples had significant effects on all the properties investigated in the briquette produced. An increase in the palm kernel shell particles increased the water resistance and lowered the water absorption. While increased in rice husk and groundnut shells increase the shatter resistance and compressive strength and reduced shatter index, The best relaxed density was obtained from pure palm kernel particle briquette (sample H) and those briquettes produced from samples A, B C and F. Physical and mechanical values analysis such as relaxed density of the produced fuel briquettes depicted that they have better handling, storage, transportation for complete combustion process when compared to the raw or non-densified. Thus, the produced briquettes made from groundnut shells, particles and palm kernel shells agglomerates would be a good source of energy for domestic and industrial applications.

Acknowledgements

The authors acknowledge the financial support by the Tertiary Education Trust Fund

(TETFUND) through grant No. Ref: TETF/ES/DR&DCE/NRF/2021/SETI/PAE/ 00012/VOL.I

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

Funding

There is no source of external funding.

Authors' Contribution

Bala Yakubu Alhaji conceptualized the study and supervised the project. Ahmadu U. developed the methodology and conducted briquette production. Halilu Ibrahim Jume carried out physical and mechanical testing. Sharifat Olalonpe Ibrahim analyzed the data and contributed to manuscript drafting. Mohammad Mohammad Ndamitso ensured technical accuracy and reviewed the manuscript. Alhassan Muazu contributed to the literature review and theoretical framework. Moses Agida performed statistical analysis, while Bello Abdulkadir provided technical support during mechanical testing and assisted with manuscript formatting.