International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 12 - Issue 09 || September 2026 || PP. 01-08

The Conversion of Local Biomass Resources into Briquettes for Alternative Cooking Energy in Iresa Pupa Community, Oyo State

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Abstract: The increasing demand for affordable and sustainable cooking fuels has stimulated interest in converting locally available biomass residues into briquettes. This study evaluated the physicochemical and energy characteristics of briquettes produced from sawdust (SD), rice husk (RH), and melon shell (MS) using a three-component simplex-centroid mixture design. Seven formulation points comprising single, binary, and ternary biomass combinations were evaluated at a constant biomass-to-binder ratio of 90:10, with cassava starch as binder. Briquette density ranged from 202.2 to 425.6 kg/m³, with a mean of 286.33 ± 72.87 kg/m³. Moisture content ranged from 9–12%, while volatile matter, fixed carbon, and ash contents ranged from 20–62%, 4–55%, and 12–33%, respectively. The SD/MS blend recorded the highest fixed carbon content (55%), whereas pure SD had the lowest ash content (12%). Pure RH exhibited the lowest fixed carbon (4%) and highest ash content (33%). Calorific values varied from 11.71 to 32.17 MJ/kg, with the ternary SD/RH/MS formulation recording the highest value. Boiling time for 100 mL of water ranged from 9.5–10.4 minfor the briquettes, compared with 5.6 minfor charcoal and 4.7 min for liquefied petroleum gas (LPG), indicating lower heating-rate performance under the experimental conditions. Quadratic mixture-response models yielded R^2 values of 0.770, 0.779, 0.562, and 0.998 for fixed carbon, moisture content, volatile matter, and ash content, respectively. The findings indicate that biomass composition influences briquette physicochemical and energy characteristics, while blending can improve selected fuel properties. The mixture design provides a basis for further formulation optimization and independent validation.

Keywords: biomass; briquettes; cassava-starch; composition; mixture; sawdust, sustainable.

Introduction

Energy is fundamental to human existence and the development of every society. It is essential for cooking, lighting, industrial production, and transportation. In Nigeria, energy demand continues to rise daily due to population growth, urban expansion, and increasing industrial activities. However, the supply of conventional energy sources such as petroleum products, electricity, and liquefied petroleum gas (LPG) has been insufficient to meet this growing demand. The situation is more critical in rural areas, where many households rely predominantly on traditional biomass fuels such as firewood and charcoal for cooking and heating. Recent studies indicate that more than 70% of Nigerian households, particularly in rural communities, still depend on firewood for cooking (Nworie et al., 2024 and Zahra & Daryono, 2025). This heavy reliance on fuelwood has led to several challenges, including deforestation, desertification, soil fertility depletion, and increased greenhouse gas emissions. In addition, the high cost of kerosene and the limited availability of cooking gas have compelled more people to resort to fuelwood, thereby aggravating the problem (Umar & Academy, 2016).

Biomass energy in the form of briquettes has been recognized as a promising alternative to traditional fuels. A briquette is a compacted block of combustible material produced from agro-residues such as sawdust, rice husks, groundnut shells, melon seed shells, or waste paper. Briquettes offer several advantages: they are denser than raw biomass, burn more efficiently, emit less smoke, and are easier to handle, transport, and store (Hadiyanto et al., 2023).

Sawdust is one of the most common raw materials used for briquetting in Nigeria. It is generated in large quantities from sawmills and timber markets and is often disposed of in open areas, where it becomes an environmental nuisance. Rice husks are another abundant residue produced in significant amounts from rice mills. Melon seed shells, also known as egusi husks, are discarded in many households and local processing industries after oil extraction. When combined with a binder such as starch, these residues can be transformed into solid fuel briquettes. One of the major challenges associated with the use of sawdust and other lignocellulosic residues is the presence of hemicellulose, a class of carbohydrate that readily decomposes at relatively low temperatures. This characteristic reduces briquette strength and contributes to increased smoke emission during combustion. An approach that has demonstrated potential in addressing this issue is hydro-treatment, which entails the application of hot water or steam to partially remove hemicellulose prior to compaction of the sawdust into briquettes. Through the exclusion of hemicellulose, the resulting briquettes are expected to exhibit longer burning time, reduced smoke emission, and higher calorific value (Umar & Academy, 2016).

Accordingly, this project investigates the hydro-treatment of sawdust for hemicellulose exclusion in briquette production, utilizing rice husks, melon seed shells, and starch as supplementary materials. This strategy is intended to promote the development of a cleaner, more affordable, and sustainable energy alternative for Nigerian households. This research aims to:

1. Conduct treatment of sawdust using water soaking and air-drying method
2. Produce briquettesfrom single and mixture of biomass such as sawdust, rice husk, melon shell, and starch binder.
3. Evaluate the performance of the briquettes through a boiling test and compare the boiling time with that of charcoal.

The goal of this study is focused on the conversion of agricultural residues and waste into viable and efficient alternative fuel for rural community dwellers.

Materials and Method

Collection of Materials

Materials used in this investigation include sawdust (SD) (*Gmelinaarborea*), which was obtained from a local saw-mill at Iresa Pupa, Surulere LGA, Oyo State. Ricehusk (RH) and melon-shells (MS) were equally obtained from the local rice-mill and melon sellers respectively, in the same LGA. Also, dry cassava starch (binder) was equally obtained from the market square at Iresa Pupa. Potable water used was collected from the bore-hole situated at Science Laboratory Technology, Federal Polytechnic Ayede, Oyo State.

Raw Materials Preparation

The sawdust (SD) was screened with 4 mm mesh size andsoaked for three days in clean water closed to the PH-scale of approximately 7. The water was screen off after three days and the SD was spread under ambient open air for 14 days, during dry season, and was observed dried. The melon-shells (MS) was pounded to powder using local mortal and pestle and later sieved with the same screen size above. Three-component simplex-centroid mixing method as shown in *table 1*, was adopted together with binder inclusion, which was kept constant(Oguaghamba and Mama, 2018; Agunwamba et al., 2024). Locally made moulds were produced as formwork for the production of briquettes, while manual compaction method wasassumed, using a 300mm x 16mm iron rod.

Table 1: Three-component simplex-centroid mixture design for Briquettes Mixing

Run	Formulation	SD (g)	RH (g)	MS (g)	Starch (g)	Total (g)
1	SD	270	0	0	30	300
2	RH	0	270	0	30	300
3	MS	0	0	270	30	300
4	SD/RH	135	135	0	30	300
5	SD/MS	135	0	135	30	300
6	RH/MS	0	135	135	30	300
7	SD/RH/MS	90	90	90	30	300

The size of the formwork produced was approximately 70 mm x 50mm, this dimensions were approximate size of the briquettes produced in this study, respectively.

Assessment of Physical Properties of Briquettes

Density Determination

The density of briquetteswascalculated using the expressionbelow;

$$\rho = \frac{m}{v}$$

Where:

ρ = density (kg/ m^3)
m = mass (kg)
v = volume (m^3)

Proximate Analysis for Data Collection and Evaluation

Moisture Content

The moisture contents of the briquettes was assessed according to the standard given by ASTM D4442-16 (Nonsawang et al., 2024). This involved wet weighing, then drying was done at 105 ℃ for 24 hours in an oven, and then weigh again. The expression that used was:

$$MC = \frac{\text{w} - \text{d}}{w}\ x\ 100$$

Where:

MC = moisture content (% d.b)
w = wet weight (g)
d = dry weight (g)

Ash Content Determination

The ash content of briquettes can be describe as the percentage of incombustible residue that is left after the complete combustion of the briquettes (Amadi & Ikhazuangbe, 2020). This was also calculated by using the expression below:

$$AsC\ (\%) = \frac{W_2}{W_1}\ x\ 100$$

Where:
AsC = Ash content (%)
$W_1 =$ Initial weight of briquettes specimen (g)
$W_2 =$ Weight of ash after complete burning (g)

Volatile matter Assessment

Volatile matter of briquette refers to the percentage of gaseous products (excluding moisture) that are released when the briquette is heated at a high temperature in the absence of air (Amadi & Ikhazuangbe, 2020). The expression is:

$$VM\ (\%) = \frac{W_2 - W_3}{W_1}\ x\ 100$$

Where:
VM = Volatile matter (%)
$W_1 =$ Initial weight of briquettes specimen (g)
$W_2 =$ Weight after drying (without moisture) (g)
$W_3 =$ Weight after heating at high temperature (g)

Fixed Carbon Determination

Fixed Carbon of briquettes is described as the solid combustible residue that remain after the removal of moisture and volatile matter during proximate analysis. This is the carbon which is available for combustion and it is accountable for sustained heat generation. This can be expressed as:

$$FC\ (\%) = 100 - (MC\ \% + VM\ \% + AsC\ \%)$$

Where: FC = Fixed carbon (%)
MC = Moisture content (%)
VM = Volatile matter (%)
$A_sC =$ Ash content (%).

Calorific Value Test

The calorific test was conducted by using the calorific equipment situated at the Institute of Agricultural Research and Training (IAR&T), situated at Apata area, Ibadan, see *figure 1*.

Figure 1: Bomb calorimeter testing equipment

Figure 2: Electric Furnace

Figure 3: Briquettes produced from biomass

Figure 4: Boiling of Water with Briquettes

Results and Discussion

The physicochemical and energy properties of briquettes produced from water-treated-sawdust, rice husk, and melon shell were evaluated using a three-component simplex-centroid mixture design. The results revealed meaningful variation across formulations, highlighting how changing the proportions of the three biomass materials influenced densities, moisture content, fixed carbon, volatile matter, ash content, and calorific value. Each parameter is presented and discussed individually in relation to briquette quality and combustion performance.

Determination of Briquettes Dry Density (kg/ m^3)

Table 2, showed that the density response across the seven formulations of the three-component simplex-centroid mixture design showed considerable variation among the biomass combinations. The observed density ranged from 202.20 to 425.60 kg/m^3, with an overall mean of 286.30 kg/m^3 and a median of 280.50 kg/m^3. The standard deviation was 0.729 kg/m^3, corresponding to a coefficient of variation of 25.45%, indicating appreciable variation in densities across the investigated mixture space.

The pure melon-shell (MS) formulation recorded the highest density (4.256 kg/m^3), followed by the sawdust–rice husk (SD/RH) blend at 3.238 kg/m^3. Rice husk (RH) alone produced a density of 2.637 kg/m^3, while sawdust (SD) recorded 2.280 kg/m^3. The SD/MS and SD/MS/RH formulations both produced a density of

2.805 kg/m³. In contrast, the MS/RH formulation gave the lowest observed density of 2.022 kg/m³(Amadi and Ikhazuangbe, 2020 ; Nobert et al., 2022).

The marked difference between the individual biomass components and their binary mixtures suggests that the density response was influenced by the manner in which the biomass materials were combined. In particular, the relatively high density of the pure MS formulation was not retained when MS was combined with RH, as the MS/RH mixture produced the lowest density among all seven formulations. Conversely, combining SD with RH resulted in a relatively higher density than either SD alone and the SD/MS blend.However, these values are relatively low for highly densified commercial briquettes. The reason being that it was particularly produced using relatively low-pressure/manual compaction.

Table 2: Mixture composition on dry densities of briquettes

Formulation	Composition (SD:MS:RH)	Density (kg/m³)
SD	1:0:0	2.280
MS	0:1:0	4.256
RH	0:0:1	2.637
SD/MS	0.5:0.5:0	2.805
MS/RH	0:0.5:0.5	2.022
SD/RH	0.5:0:0.5	3.238
SD/MS/RH	0.333:0.333:0.333	2.805

Effect of mixture composition on proximate characteristics

The proximate characteristics varied considerably across the seven biomass formulations as shown in *table 3*, demonstrating that the relative proportions of sawdust, rice husk and melon shell influenced the composition of the resulting briquettes. Fixed carbon showed the widest practical contrast among the formulations, ranging from 4 to 55%. The highest value was obtained from the sawdust–melon shell formulation, while pure rice husk recorded the lowest value. The relatively high fixed-carbon content associated with sawdust-containing formulations suggests that sawdust contributed substantially to the carbonaceous fraction of the briquette. The 50:50 sawdust–melon shell formulation was particularly notable, recording 55% fixed carbon.

Moisture content, expressed on a dry basis, varied within a relatively narrow range of 9–12%. The lowest observed value occurred in the rice-husk and equal-proportion ternary formulations, whereas pure sawdust recorded the highest value. The limited variation suggests that moisture condition was relatively consistent across the formulations.

Volatile matter varied from 20 to 62%. The sawdust–melon shell mixture recorded the lowest value, whereas the equal-proportion ternary formulation produced the highest. A high volatile-matter fraction generally indicates the presence of a substantial proportion of components that are released during thermal decomposition. Such a characteristic may influence ignition and the initial rate of combustion. However, high volatile matter cannot independently be used to designate a superior briquette because fuel quality also depends on fixed carbon, ash, moisture, density and combustion behaviour.

Ash content ranged from 12 to 33%. Pure rice husk produced the highest ash content, whereas pure sawdust produced the lowest. This result is important because the mineral fraction of ricehusk can contribute substantially to the residual ash after combustion. The lower ash values observed in sawdust-containing formulations indicate that blending may reduce the relative contribution of the high-ash feedstock and produce a more favourable residue characteristics(Zahra & Daryono, 2025).

Mixture-response behavior

The second-order Scheffé'smixture models provided different levels of descriptive agreement with the measured responses(Oguaghamba and Mama, 2018;Agunwamba et al., 2024). The coefficients of determination were 0.770 for fixed carbon, 0.779 for dry-basis moisture content, 0.562 for volatile matter and 0.998 for ash. The very high R^2 obtained for ash indicates that the observed ash response followed the mixture composition closely within the experimental region. The models for fixed carbon and moisture also showed reasonably strong descriptive relationships, while volatile matter was less consistently explained by the mixture proportions.

The lower fit obtained for volatile matter may indicate that factors other than the simple proportions of the three biomass components contributed to the observed response. Differences in particle characteristics, inherent biomass composition, processing conditions and analytical variation may all influence volatile matter. Since independent replicate observations were unavailable, these possible sources of variation could not be separated statistically in the present experiment.

Table 3: Mixture composition on proximate characteristics

Formulation	Fixed-Carbon (%)	Moisture Contents (%)	Volatile Matter (%)	Ash Content (%)
SD	50	12	26	12
RH	4	9	54	33
MS	9	11	54	26
SD/RH	40	11	30	19
SD/MS	55	11	20	14
RH/MS	20	10	47	23
SD/RH/MS	13	9	62	16

Calorific value

Table 4, correspondingly revealed that the available calorific-value measurements, which showed appreciable differences among the formulations. The mean values ranged from 11.71 MJ kg^{-1} for sawdust to 32.17 MJ kg^{-1} for the equal-proportion ternary mixture. The sawdust–rice husk formulation also produced a comparatively high mean calorific value of 24.37 MJ kg^{-1}, while the rice husk–melon shell mixture recorded 20.61 MJ kg^{-1}*table 4*.

The comparatively high calorific value of the ternary formulation indicates that combining the three biomass resources may provide a favourable energy characteristic under the conditions of the experiment. However, calorific value alone is insufficient for selecting an optimum briquette. For practical cooking-fuel application, the selected formulation should also provide acceptable moisture, ash, fixed carbon, ignition characteristics, combustion duration, mechanical integrity and residue production(Chipangura et al., 2024&Zahra & Daryono, 2025).

Table 4: The Mixture Component on Calorific value (MJ kg^{-1})

Formulation	Composition (SD:MS:RH)	Average Calorific value (MJ kg^{-1}**)**
SD	1:0:0	11.71
MS	0:1:0	16.00
RH	0:0:1	22.72
SD/MS	0.5:0.5:0	24.37
MS/RH	0:0.5:0.5	19.67
SD/RH	0.5:0:0.5	20.61
SD/MS/RH	0.333:0.333:0.333	32.17

Implications for briquette formulation

The results demonstrated that the three biomass resources contribute differently to the resulting fuel characteristics. Sawdust was associated with relatively high fixed carbon and low ash, rice husk with low fixed carbon and high ash, while melon shell provided an intermediate contribution to several of the measured properties. The binary and ternary mixtures consequently provided combinations of characteristics that differed from those of the individual feedstocks.

The results therefore support the use of mixture design as a useful approach for investigating biomass combinations. Nevertheless, the present seven-point experiment should be regarded as a preliminary formulation study. The descriptive models of the observed experimental region wereadopted.

Boiling Time of 100 cl of Water

The boiling test showed clear differences in the time required to boil 100 cl of water using the briquettes, charcoal and liquefied petroleum gas (LPG), *see figure 5*. Among the briquette formulations, boiling times ranged from 9.5 to 10.4 min. The shortest time was recorded for melon shell (MS) briquettes (9.5 min), followed by thesawdust/melon shell (SD/MS) and SD/MS/rice husk (RH) ternary briquettes (9.9 min each). Sawdust (SD) briquettes required 9.7 min, while rice husk (RH) and the MS/RH mixture required 10.3 and 10.4 min, respectively. In comparison, charcoal boiled the water in 7.7 min, whereas LPG was substantially faster at 4.8 min.

The relatively narrow range of 9.5–10.4 min among the briquette formulations suggests that changes in biomass composition had only a modest effect on their boiling performance under the test conditions. The MS formulation gave the best boiling performance among the briquettes, indicating that its fuel characteristics and combustion behaviour were comparatively favourable for heat transfer to the cooking vessel. Conversely, the MS/RH formulation recorded the longest boiling time, which may be associated with differences in ignition behaviour, combustion rate, ash formation and the proportion of heat effectively transferred to the water. Rice husk is particularly notable for its relatively high ash content, which can restrict effective combustion and heat transfer when present in a greater proportion.

The SD/MS and ternary SD/MS/RH briquettes, both requiring 9.9 min, demonstrated intermediate performance. This suggests that blending the biomass residues can produce a reasonably consistent cooking fuel, although the mixtures did not improve boiling time beyond the best-performing MS formulation. The results therefore indicate a practical performance trade-off between formulation composition and cooking efficiency rather than a simple linear improvement with increasing number of biomass components.

Despite their slower performance compared with charcoal and LPG, the briquettes demonstrated useful cooking potential. Their boiling times were only about 1.8–2.7 min longer thancharcoal**,** whereas LPG achieved boiling approximately 4.7–5.6 min fasterthan the briquettes. The slower performance of the briquettes relative to LPG is expected because LPG is a highly controllable gaseous fuel with rapid and efficient combustion, while solid biomass briquettes require ignition and sustained combustion before maximum heat release is achieved. Charcoal also generally provides a relatively steady heat output once established, explaining its shorter boiling time.

From a practical standpoint, the results demonstrated that the produced briquettes can serve as a viable solid-fuel alternative for domestic cooking, particularly where charcoal or LPG is expensive, inaccessible or less readily available. However, their longer boiling times indicate that improvements in briquette formulation, density, moisture content, combustion characteristics and stove design could further enhance their thermal performance. Overall, MS briquettes provided the best boiling performance among the tested formulations**,** while LPG remained the most efficient fuel and charcoal performed better than all the briquettes under the experimental conditions(Umar, 2016 and Ezeokolie et al., 2024).

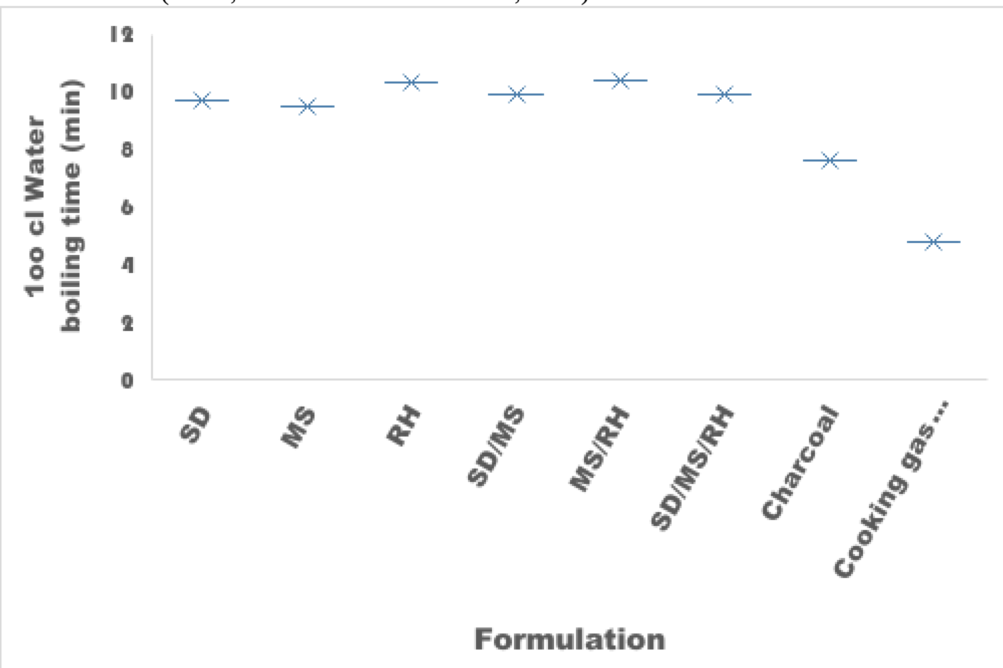

Figure 5: Mixture Composition Effect on Water Boiling Time

Conclusion

This study demonstrated the feasibility of converting sawdust, rice husk, and melon shell into combustible briquettes using cassava starch as a binder and a three-component simplex-centroid mixture design. The results showed that biomass composition influenced the physicochemical and energy characteristics of the briquettes, particularly density, fixed carbon, ash content, and calorific value. The ternary SD/RH/MS formulation produced the highest observed calorific value of 32.17 MJ/kg, while the SD/MS blend exhibited the highest fixed carbon content (55%). In contrast, pure rice husk was characterized by relatively high ash content (33%) and low fixed carbon (4%), indicating that single-feedstock briquetting may not always provide the most desirable fuel characteristics.

Although the briquettes required longer boiling times than charcoal and LPG under the experimental conditions, their successful conversion from locally available agricultural and wood-processing residues demonstrates their potential as alternative solid cooking fuels. The quadratic mixture-response models also provided useful predictive relationships for the evaluated fuel properties, with particularly strong model performance for ash content. Overall, blending the biomass residues offers an opportunity to balance individual feedstock characteristics and improve selected fuel properties. Further studies should focus on numerical optimization of the mixture proportions, mechanical durability, combustion emissions, storage stability, and independent validation of the optimized formulation before recommending large-scale household or commercial application.

Recommendation

1. Independent experimental replication should be incorporated in subsequent experiments, preferably with a minimum of three independently produced briquette batches per formulation, to permit estimation of experimental error and valid inferential statistical testing.
2. The sawdust–melon shell formulation should be investigated further because it recorded the highest observed fixed-carbon content (55%) and a relatively low ash content (14%).
3. The equal-proportion ternary formulation should undergo confirmatory calorific-value testing because it produced the highest available measured mean calorific value of 32.17 MJ kg^{-1}.
4. Rice-husk-rich formulations should be evaluated carefully with respect to ash generation because pure rice husk recorded the highest observed ash content (33%).
5. Future studies should include briquette density, compressive strength or durability, ignition time, burning rate, combustion duration and water-boiling performance alongside proximate composition and calorific value.

Acknowledgement

This is to appreciatesthe full support of Tertiary Education Trust Fund (TETFUND), Nigeria, through the Federal Polytechnic Ayede, Oyo State, Nigeria. This research work, without any doubt will be useful as academic contributions in the area of the current agricultural era.

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