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ORIGINAL RESEARCH ARTICLE

Evaluation of Combustion and Mechanical Properties of Biobriquettes produced from sugarcane bagasse and sawdust with organic binders

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ABSTRACT

The valorization of agricultural residues into high-quality solid biofuels presents a sustainable pathway for waste reduction and renewable energy generation. This study aims to assess the combustion and mechanical properties of biomass briquettes made from sugarcane bagasse, sawdust using waste food, and potato peels as binders. It also compares carbonized and uncarbonized samples of these briquettes. Proximate analysis revealed significant differences in the evaluated parameters among the raw feedstocks, with sawdust exhibiting higher fixed carbon (59.53%) and combustion index (596.49), while bagasse showed higher volatile matter (81.24%) and ignition index (2.73). Carbonization substantially improved the HHV of the briquettes, increasing from an uncarbonized range of 13.5-14.5 MJ/kg to 18.5-20.5 MJ/kg for carbonised samples, with the highest HHV obtained from a 30:40:30 blend (bagasse, sawdust, and potato peels). Similarly, mechanical properties enhanced with carbonization, with compressive strength rising from 66-67 N/cm² to 73-74 N/cm², and shatter and water resistances improving by 4-10%. Combustion tests indicated that ignition occurs more quickly (37–40 seconds) in carbonized briquettes, while sustained combustion proceeds at a rate of 4.4–4.8 g/min. The distinctive feature of this work lies in the combustion improvements achieved through optimal feedstock blending and carbonization. Overall, carbonized briquettes, particularly with higher proportions of sawdust in the mix, demonstrated favourable energy density, strength, and combustion stability, suitable for both domestic and industrial applications.

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INTRODUCTION

As fossil fuel consumption has been shown to have detrimental impact, there is matched impetus for speeding up into renewable and sustainable energy forms. Given that biomass is adequate in supply and renewable in nature, it has been considered as one pathway by which to decrease reliance on fossil fuels and emissions of greenhouse gases. Among the different biomass energy carriers, briquetting has received great attention as it pays due regard to the conversion of loose biomass from agricultural and forestry residues into a dense solid fuel with easier handling, storage, and good combustion properties. Briquettes, being processed biomass, have more advantages than raw biomass: greater energy density, lesser transportation costs, and reduction of particulate matters during combustion (Kaliyan and Morey, 2009; Li *et al*., 2019).

The characteristics of biomass briquettes are determined by both the feedstock's composition and the processing methods applied. Sugarcane bagasse, a residue from the sugar industries, is rich in carbohydrate and volatile matter and so is suitable for fast ignition but achieves a lower energy density due to relatively less fixed carbon content. Sawdust originates from wood processing and possesses a greater fixed carbon content.

Carbonization is widely recognized as the principal technological operation that enhances biomass briquette properties. Through the thermal decomposition of the biomass with limited oxygen, carbonization raises the concentration of fixed carbon while decreasing the content of volatile matter and improving hydrophobicity. The end result is carbonized briquettes with greater calorific values, better mechanical integrity, and improved storage stability. Carbonization generally changes combustion behaviour; it is usually accompanied by decreased burning rates, with new feedstock blends having to be specially optimized to balance ease of ignition with sustained heat release (Onuegbu *et al*., 2010). Despite such

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benefits, very few researches have compared the performances of carbonized and uncarbonized briquettes from mixed feedstocks systematically, especially for blends involving sugarcane bagasse, sawdust, and Agro-wastes.

The specific aim of this work is to measure the fuel and mechanical performance of carbonized and uncarbonized briquettes made from different proportions of sugarcane bagasse, sawdust, waste food, and potato peels. The investigation mainly focuses on proximate composition, fuel indices, calorific values, and mechanical properties, including shatter resistance, compressive strength, and water resistance.

MATERIALS AND PROCEDURES

Sample Collection and Preparation

The main biomass feedstock used in this study was sawdust obtained from Katsina metropolis, 12° 59' 7.9116" N and 7° 37' 1.7184" E at Yankatako saw mill and sugarcane bagasse from Jikamshi, Rimi Local Government Area, 12°10'23.81" N, 7°46'27.26" E. Organic binders waste food and potato peels are collected from food vendors around Umaru Musa Yar'adua University (UMYU) and Batagarawa town, 12° 53' 8.92" N, 7° 34' 24.52" E, Katsina state. The sawdust and sugarcane bagasse were split into two: one half was carbonized at 3500C to 5000C, more or less, for about 30 minutes in a locally made carbonization pot, while the other half was not carbonized. All the feedstocks were air-dried to a moisture content below 18%, sieve to particle size of 2 mm, and kept in an airtight container before briquette formation.

Binder Preparation

Potato peels and waste food were sun-dried for 6 days within the range of 8-12 % moisture content. Binders were made by heating mixtures of 1:2 to 1:3 binder-to-water ratios to about 80-90°C and maintaining the gelatinizing slurry for a time between 10 and 30 minutes with constant stirring toachieve uniformity of paste. The mixture was then set aside to cool to room temperature before use.

Briquette Formulation and Production

The briquettes were prepared from different combinations of biomass and binder with the weight ratios shown in Table 1.

Table 1: Biobriquette Formulation

Carbonized Samples	Bagasse %	Sawdust %	Waste Food %	Potato Peels %
UC 1	40	30	30	0
UC 2	30	40	0	30
UC 3	35	35	15	15
Un-carbonized				
UC1	40	30	30	0
UC2	30	40	0	30
UC3	35	35	15	15

Each of the mixtures was manually homogenized before being pressed into briquettes using a locally made mould. The briquettes were cylindrical in shape (4 cm diameter and 2.5 cm height) and were sun-dried for 21 days to achieve moisture content of ~12%. The schematic flow chart of the process is depicted in Figure 1.

Proximate Composition

Ash Content (%)

Approximately 2 g of each briquette sample was weighed out into a pre-weighed porcelain crucible. The crucibles with the sample were placed in a muffle furnace, at 550 ± 10°C, for ash content determination for 4 hours (ASTM D2866, 2011). The crucibles were removed from the furnace and placed in a desiccator to cool and prevent moisture absorption. The crucibles then weighed without delay:

$$AC(\%) = \frac{\text{Weight of Ash}}{\text{Initial sample weight}} \times 100$$

Moisture Contents (%)

Moisture was determined using (ASTM D3173, 2017a). The oven at 105 ± 2°C was used to dry 2 g of sample for 24 hours until it reached constant weight. The weight difference between the initial and dried sample was calculated as a percentage of the original sample weight.

$$C(\%) = \frac{\text{Initial weight - oven-dry eight}}{\text{Initial weight}} \times 100$$

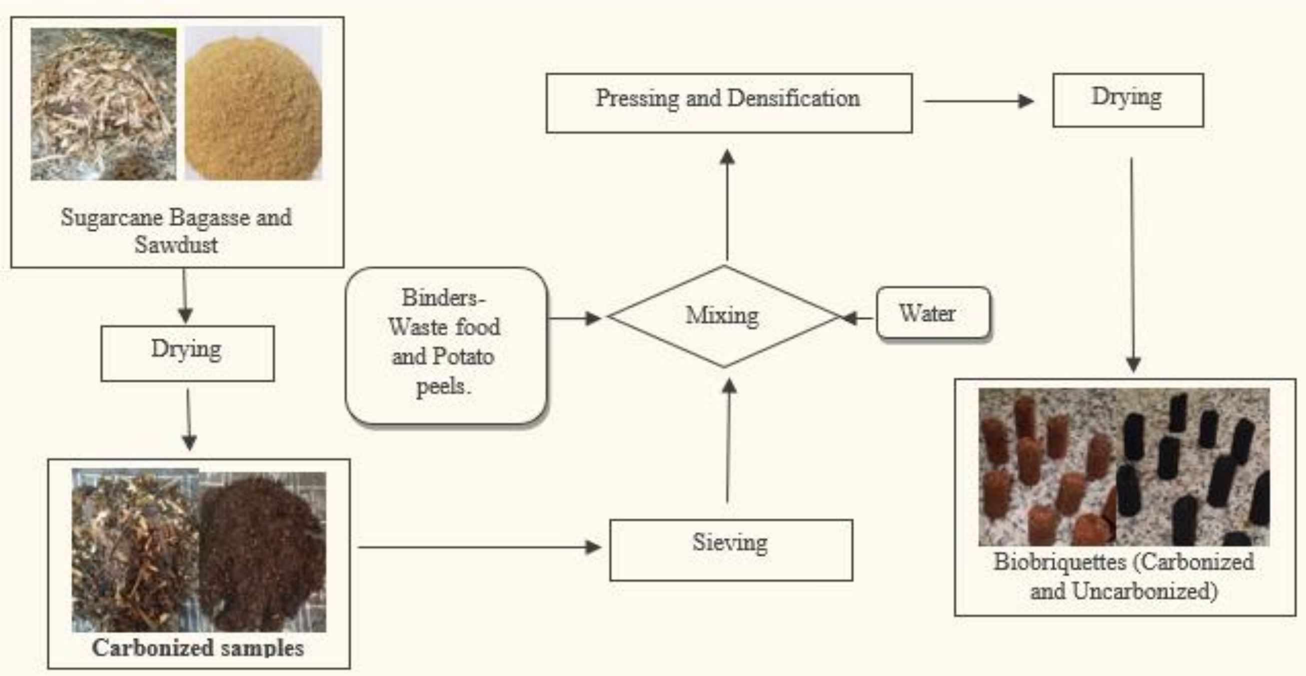

Figure 1: Biobriquette production process

Crude Protein (%)

The Kjeldahl method (AOAC, 2005) was used to determine the protein content. Nitrogen was converted to ammonium sulphate through concentrated sulfuric acid digestion of the samples with a catalyst present. The digest was neutralized with sodium hydroxide before distillation to release ammonia which was then titrated with standard acid. The crude protein value was obtained by multiplying the total nitrogen content by 6.25.

$$CP\ (\%) = otal\ itrogen \times 6.25$$

Crude Fibre (%)

The method described in (AOAC 962.09, 2005) was used to analyze crude fibre. The first step involved defatting the samples using petroleum ether. The residue underwent two sequential boiling steps with 1.25 % H_2SO_4 and 1.25 % NaOH to remove soluble materials. The insoluble part was dried before being weighed and then ashed at 550°C. The fibre content was calculated as the difference between dried residue and ash weight.

$$CFibr\ (\%) = Weight\ of\ dry\ residue - Ash\ weight$$

Crude Fat (%)

Fat was extracted using the Soxhlet extraction method (AOAC, 2005). Approximately 2 g of the sample was extracted with petroleum ether for 6–8 hours until no more fat was recovered. The solvent was evaporated, and the residue was weighed to determine stark paunchy.

$$Cfat\ (\%) = \frac{\text{Weight of extracted fat}}{Sample\ weight} \times 100$$

Carbohydrate (%)

Carbohydrate was obtained by difference using the formula (AOAC, 2005):

$$Carbohydrate(\%) =$$

$$100 - (Protein + Fat + Fibre + Ash + Moisture).$$

Fuel Properties

Volatile Matter (%)

unstable matter was measured using (ASTM D3175, 2017b). Samples were heated in covered crucibles at 950 ± 20°C for 7 minutes. The loss in mass, excluding moisture, was expressed as unstable matter.

$$VM(\%) = \frac{\text{Weight oss (excluding oisture)}}{\text{Initial eight}} \times 100$$

Fixed Carbon (%)

Fixed carbon was determined according to (ASTM D3172-13, 2017a) using the formula:

$$FC(\%) = 100 - (Ash + Moisture + VM)$$

Fuel Ratio (FC/VM)

Calculated as the ratio of fixed carbon to unstable matter (Parikh *et al*., 2005).

$$FR = \frac{FC}{VM}$$

Energy Density (MJ/m³)

Energy density was determined by multiplying the higher heating value (HHV) of each briquette (measured using a bomb calorimeter) by its bulk density (ASTM, 2013).

$$ED(MJ/m^3) = HHV \times BulkDensity$$

Combustion Index (CI)

The combustion index was calculated by multiplying the unstable matter by the fixed carbon and then dividing the product by the ash content (Parikh *et al*., 2005):

$$CI = \frac{VM \times FC}{\text{Ash}}$$

Volatile to Ash Ratio (V/A.

The unstable to ash ratio is obtained by dividing the unstable matter by the ash content (Basu, 2010):

$$V/A = \frac{VM}{\text{Ash}}$$

Ash to Fixed Carbon Ratio (A/FC)

The ash to fixed carbon ratio is calculated by dividing the ash content by the fixed carbon content (Basu, 2010):

$$A/FC = \frac{\text{Ash}}{FC}$$

Theoretical air requirement (TAR)

The Theoretical air requirement is determined using the ultimate analysis of the fuel (Gupta and Wall, 2006). It is calculated by combining the primitive contributions of carbon, hydrogen, oxygen, and sulphur according to the formula:

$$TAR = \frac{11.6C + 34.8\left(H - \frac{O}{8}\right) + 4.35S}{100}$$

where C, H, O, and S represent primitive percentages.

Ignition Index (II).

The ignition index is calculated by multiplying the ratio of Volatile matter to ash by the fixed carbon content (Parikh *et al*., 2005):

$$II = \left(\frac{VM}{\text{Ash}}\right) \times FC$$

Mechanical Properties

Shatter Resistance

Following (ASTM D440, 2007) briquettes were dropped from a height of 2 m onto a steel plate ten times. The retained mass after recurrent drops was expressed as a percentage of the initial mass to indicate durability. $SRI(\%) = 100 - \frac{W1-W2}{W1} \times 100$

Compressive Strength

Using (ASTM D2166, 2016) briquettes were placed between compression platens of a comprehensive testing machine and loaded axially at an invariant rate until failure. Compressive strength was calculated as the maximum load divided by the cross-sectional area.

$$CS\ (N/m^2) = \frac{Maximum\ load\ (N)}{Cross\ Sectional\ area\ (m^2)}$$

Water Resistance

Briquettes were weighed (W_1) and immersed in water for 30 minutes. After surface drying, the samples were reweighed (W_2), oven dried at 105°C, and weighed again (W_3). Water resistance was expressed as:

$$WR(\%) = \frac{W_3}{W_1} \times 100$$ (Grover and Mishra, 1996).

Combustion Properties

Ignition Time

Briquettes were placed under a steady flame, and the time taken to achieve self sustained combustion was recorded according to the method described by Demirbas, (2004).

$$IT = Time\ to\ self\ sustained\ combustion$$

Burning Rate

Burning rate was determined using (ASTM E1354, 2015). Briquettes were weighed before combustion (M_1) and after complete combustion (M_2). Total combustion time (t) was recorded, and burnig rate was calculated as:

$$BR(g/min) = \frac{M_1 - M_2}{t}$$

RESULTS AND DISCUSSIONS

Proximate Analysis

The Proximate analysis of the feedstocks reveals profound differences between sugarcane bagasse and sawdust, which directly influence briquette performance as reported in Table 2. Sawdust exhibits a considerably higher fixed carbon content (59.53%) compared to bagasse (13.52%), making it inherently additional energy dense but with lower volatile matter. Conversely, bagasse shows higher volatile matter (81.24%) and carbohydrate content (79.26%), suggesting quicker ignition but possibly less sustained combustion. These findings align with earlier studies, such as Onuegbu *et al*., (2010) and Yin, (2011), which reported that high fixed carbon and low volatile matter are suitable for prolonged burning, while higher volatiles facilitate quick ignition. Fuel property indices (Table 3) further confirm these trends, with sawdust showing a superior fuel ratio (1.71) and combustion index (596.49), meaningful of better hot stability, whereas bagasse demonstrates a higher ignition index (2.73), supporting its fast ignition potential.

Table 2: Proximate Analysis of Briquette Samples

Biomass Type	Ash (%)	Moisture (%)	Protein (%)	Fibre (%)	Fat (%)	Carbohydrate (%)	Volatile Matter (%)	Fixed Carbon (%)
Sugarcane Bagasse	2.20	3.04	1.21	13.16	1.13	79.26	81.24	13.52
Sawdust	3.48	2.11	0.31	59.44	0.00	34.66	34.88	59.53

These values are within the range reported by Obioh *et al.* (2013) for biomass briquettes (18–22 MJ/kg for carbonized and 12–16 MJ/kg for uncarbonized), confirming the effectiveness of the selected biomass blends

Table 3: Fuel properties

Fuel Properties	Sugarcane Bagasse	Sawdust
Fuel Ratio (FC/VM)	0.17	1.71
Energy Density (MJ/m^3)	18713.5	8344
Combustion Index (CI)	499.26	596.49
Volatile to Ash Ratio (V/A)	36.93	10.02
Ash-to-FC Ratio (A/FC)	0.16	0.058
Theoretical Air Requirement	1432.1 kJ/g O_2	593.3 kJ/g O_2
Ignition Index (II)	2.73	0.168

Fuel properties and calorific values

As shown in Table 4 and Figure 2, the calorific values of the biobriquettes demonstrate a clear enhancement upon carbonization, with HHV increasing from 13.5–14.5 MJ/kg and 18.5–20.5 MJ/kg for uncarbonized and carbonized samples respectively. This increase reflects the removal of volatiles and concentration of carbon, consistent with findings by Muthusamy *et al*., (2020), who noted analogous improvements in carbonized agricultural residues. Among the carbonized samples, C2 (30% bagasse, 40% sawdust, 30% potato peels) achieved the ultimate HHV (20.5 MJ/kg), suggesting that higher sawdust content coupled with moderate bagasse and supplementary biomass yields optimum energy potential. The uncarbonized samples followed an analogous trend, with UC2 showing the ultimate HHV (14.5 MJ/kg).

Table 4: Calorific Value of Biobriquettes Produced

Samples	Ratios	HHV (MJ/Kg)
Carbonized		
C1	SBSWP 40:30:30:0	19.0
C2	SBSWP 30:40:0:30	20.5
C3	SBSWP35:35:15:15	18.5
Uncarbonized		
UC1	SBSWP 40:30:30:0	13.5
UC2	SBSWP 30:40:0:30	14.5
UC3	SBSWP 35:35:15:15	13.5

Mechanical properties and Combustion Properties of Biobriquettes produced

Mechanical properties (Table 5) likewise favoured carbonized briquettes, with shatter resistance, compressive strength, and water resistance all importantly higher than their uncarbonized counterparts. For instance, compressive strength enhanced from 66–67 N/cm^2 in uncarbonized samples to 73–74 N/cm^2 in carbonized briquettes, suggesting improved constructive integrity due to carbonization. C1 (40% bagasse, 30% sawdust, 30% waste food) and C3 (35% bagasse, 35% sawdust, 15% each of waste food and potato peels) performed comparably, though C2 offered a somewhat lower water resistance. analogous improvements have been genuine by Kaliyan and Morey (2009), who attributed higher durability in carbonized briquettes to enhanced binding and low moisture. These mechanical strengths exceed the 50 N/cm² negligible recommended for commercial grade briquettes, indicating suitability for handling and transport. Combustion characteristics reveal that carbonized briquettes not entirely ignite quicker but likewise burn additional steadily, as evidenced by low ignition times (37–40 s for carbonized vs. 41–45 s for uncarbonized) and lower burning rates (4.4–4.8 g/min vs. 4.9–5.3 g/min). The slower burning rates in carbonized samples suggest extended energy release, a suitable trait for domestic and developed heating. Literature supports these observations: Li *et al.*, (2019) reported that carbonized biomass maintains combustion stability by reducing unstable emissions and concentrating fixed carbon. Overall, the results indicate that carbonized briquettes, especially C2, provide superior fuel quality by balancing high hot value, strong mechanical durability, and effective combustion. These findings confirm that optimum blending of high fixed carbon (sawdust) and high unstable (bagasse) components, with minor additives, produces briquettes meeting both energy and mechanical performance standards genuine in biomass fuel research.

Table 5: Mechanical Properties and Combustion Properties of produced Biobriquette

Sample	Shatter Resistance (SRI, %)	Compressive Strength (CS, N/cm²)	Water Resistance (WRI, %)	Ignition Time (IT, s)	Burning Rate (BR, g/min)
C1	80.85	73.70	79.75	37.35	4.77
C2	80.33	73.15	78.65	40.50	4.41
C3	80.59	73.42	79.20	38.92	4.59
UC1	77.00	67.00	72.50	41.50	5.30
UC2	76.50	66.50	71.50	45.00	4.90
UC3	76.75	66.75	72.00	43.25	5.10

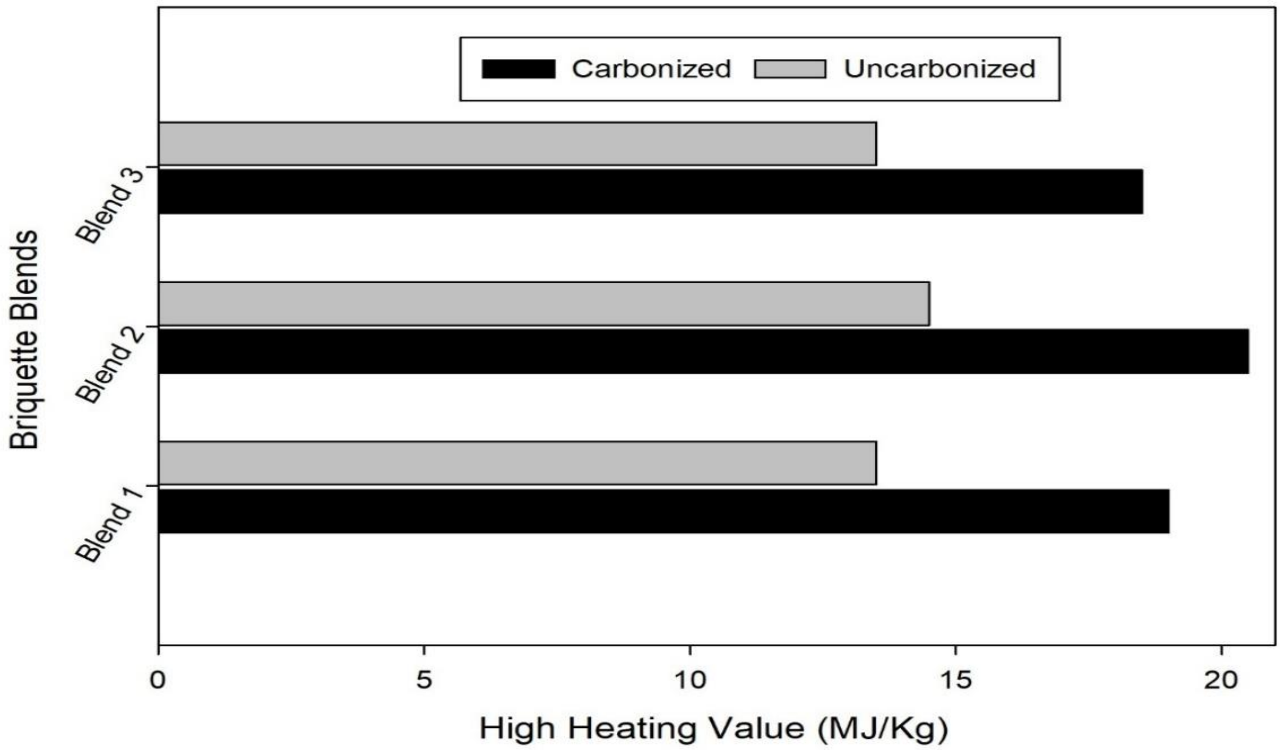

Figure 2: Higher heating values of Carbonized and uncarbonized Briquettes

CONCLUSION

This study demonstrates that biomass briquettes produced from sugarcane bagasse, sawdust, waste food, and potato peels exhibit sharp variations in mechanical and combustion performance depending on carbonization and blend composition. Carbonized briquettes systematically outperformed uncarbonized samples, showing higher hot values (18.5–20.5 MJ/kg), improved mechanical properties (compressive strength up to 74 N/cm²), enhanced shatter, water resistance, and additional effective combustion characterized by quicker ignition and slower burning rates, all of which align with, and in some cases surpass, commonly referenced solid biofuel quality standards such as ISO 17225-3 and FAO guidelines for household and industrial briquettes. Among the blends, the 30:40:30 composition (bagasse: sawdust: potato peels) achieved the ultimate energy potential, while mixtures with balanced sawdust and bagasse proportions offered good constructive durability and combustion stability. These findings align with old studies indicating that carbonization concentrates fixed carbon and reduces volatiles, thereby improving both energy density and mechanical resilience. The use of waste food and potato peels as binders not entirely supports sustainable waste management but likewise contributes to good binding strength and fuel performance. Overall, carbonized briquettes, especially those with higher sawdust content, meet the energy and mechanical requirements for domestic and developed applications. forthcoming work should focus on scaling up production, conducting long storage and emissions tests, and performing techno economic analyses to assess commercial feasibility. The optimized briquette formulations presented here provide a pathway for integrating agricultural and food residues into renewable energy systems, supporting both environmental sustainability and energy security.

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