

PROCESSING BRIQUETTES FROM *TERMINALIA CATAPPA* LEAF BIOMASS AS ENVIRONMENTAL MANAGEMENT STRATEGY

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Abstract:

*This study investigated the production and evaluation of briquettes from Tropical almond (*Terminalia catappa*) leaf using cassava starch as a binding agent. Briquettes were produced by mixing 60 g of *Terminalia catappa* leaf biomass with cassava starch (binder) at ratios 1:1=S, 1:2=SS, 1:3=ST, and 1:4=SF as binder to biomass by weight. One hundred milliliters (100 ml) of hot water were used to prepare the starch (binder). The mixtures were thoroughly homogenized and compressed using a briquetting moulding at a pressure of 10.4 kg/cm². Each treatment was replicated five (5) times, resulting in a total of twenty (20) briquette samples. The produced briquettes were air-dried under controlled conditions for two days before oven drying. The briquettes produced were assessed based on their physical and energy properties. Analysis of variance using R software and Post-hoc analysis using Least Significant Difference (LSD) were carried out. The briquettes made from ST exhibited highest density 1.06 g/cm³ while SF had the highest shatter index of 97.91%, indicating that they possess adequate mechanical strength for handling and transportation. The energy value showed that SS briquettes had the lowest volatile matter (72.00 %) and ash content (8.50 %), highest fixed carbon (19.70 %) was obtained in SS while highest calorific value (28.73 MJ/kg¹) was obtained in SF briquettes. High ash content could be due to the amount of mineral elements present in the plant. While high calorific value could be attributed to significant amount of volatile matter and carbon which release energy efficiently during combustion. The findings of this study establish that briquettes derived from *Terminalia catappa* leaf biomass could be used for renewable energy generation and biomass waste utilization. *Terminalia catappa* leaf biomass is a recommended raw material for briquette production using cassava starch as a binding agent.*

Key words: alternative energy, combustion properties, density, shatter index, residue.

INTRODUCTION

Environmental degradation, energy insecurity, and ineffective waste management remain the major challenges confronting many developing countries, including Nigeria (United Nations Environment Programme [UNEP] 2021; World Bank 2023). Rapid population growth and urbanization have led to increased generation of organic waste, much of which is poorly managed, resulting in environmental pollution and public health risks (FAO 2020).

Globally, the demand for energy continues to rise, while reliance on fossil fuels has been identified as a major contributor to climate change and environmental degradation. As a result, there has been increasing global interest in renewable and sustainable energy sources that are environmentally friendly and economically viable. Biomass energy, derived from organic materials such as agricultural residues, forest waste, and leaf litter, has been recognized as a key renewable energy option capable of addressing both energy and environmental challenges (International Energy Agency 2019; Nubi *et al.* 2022).

Biomass briquetting has emerged as a sustainable technology for converting loose and low-density biomass materials into compact, efficient, and environmentally friendly solid fuels. Briquettes are produced through the densification of biomass under pressure, with or without the use of binders, to form solid blocks that burn more efficiently than raw biomass. Compared to firewood and traditional charcoal, biomass briquettes offer advantages such as higher energy density, reduced smoke emissions, improved handling, and lower transportation costs (Ibitoye *et al.* 2023; Fadele *et al.* 2021; Akinola and Oluwole 2026; Ngene *et al.* 2024).

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Leaf biomass, though often overlooked, represents a significant and underutilized resource for briquette production. Leaves are renewable, abundant, and readily available in urban and institutional environments. However, their low bulk density, irregular shape, and poor combustion characteristics limit their direct use as fuel. Briquetting overcomes these limitations by improving the physical and combustion properties of leaf biomass, thereby transforming waste materials into valuable energy resources (Ibitoye *et al.* 2023; Kaliyan and Morey 2019).

Terminalia catappa, commonly known as tropical almond, is a widely distributed tree species across Nigeria and other tropical regions. The tree is commonly planted in institutional environments, residential areas, and along roadways because of its aesthetic value and broad, shade-providing canopy. *Terminalia catappa* sheds large quantities of leaves annually, particularly during the dry season, leading to rapid accumulation of leaf litter. When poorly managed, this leaf litter constitutes a significant waste management challenge in urban and institutional settings (Food and Agriculture Organization of the United Nations [FAO] 2017; United Nations Environment Programme [UNEP] 2021).

Despite the abundance of *Terminalia catappa* leaf litter, its utilization for energy generation remains limited. Most fallen leaves are either left to decay naturally or disposed of through open burning, practices that contribute to environmental pollution and the wastage of potentially useful biomass resources. This situation highlights the need to explore sustainable methods for managing leaf biomass while simultaneously addressing growing energy demands. Converting leaf biomass into briquettes represents a viable approach that integrates effective waste management with renewable energy production, thereby promoting environmental sustainability and resource efficiency (Food and Agriculture Organization of the United Nations [FAO] 2020; International Energy Agency [IEA] 2019).

By investigating the processing and combustion characteristics of briquettes produced from *Terminalia catappa* leaf biomass, this study seeks to contribute to sustainable waste management practices, reduce dependence on traditional fuels, and support environmentally responsible energy solutions.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out at the Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria. The institute is characterized by a large population of forest tree species, including *Terminalia catappa*, which sheds substantial quantities of leaf litter annually, particularly during the dry season. This makes the institute suitable for studies related to biomass waste management and renewable energy.

Collection and Preparation of Raw Materials

Dry fallen leaves of *Terminalia catappa* were collected from selected locations within the Forestry Research Institute of Nigeria (FRIN). The leaves were sun-dried to reduce moisture content and then grinded into powdered form. The powdered biomass was sieved using a 2 mm mesh sieve to obtain uniform particle size suitable for briquette production.

Cassava starch was prepared by boiling measured quantities with boiled water and mixing to form a gelatinized binder.

Briquette Production

Briquettes were produced by mixing *Terminalia catappa* leaf biomass with cassava starch binder at ratios 1:1=S, 1:2=SS, 1:3=ST, and 1:4=SF (binder to biomass by weight). One hundred milliliters (100 ml) of hot water were used to prepare the starch (binder). The mixtures were thoroughly homogenized and compressed using a briquetting moulding at a pressure of 10.4 kg/cm². Each treatment was replicated five (5) times, resulting in a total of twenty (20) briquette samples. The produced briquettes were air-dried under controlled conditions (temperature, humidity, airflow, exposure time was regulated to ensure consistency) for 2 days before proper drying in the oven in preparation for analysis (Fig. 1).



Fig. 1.
a and b - Samples of produced briquettes.

Sampling Method

Simple random sampling was used to select briquette samples for laboratory analysis. This ensured equal representation of samples for the determination of physical and energetic value. Tables 1 and 2 present the Standard methods used in determining the various parameter tests.

Determination of Strength Properties and Energy value of briquette

The standard methods and steps involved in determining physical properties (Density and Shatter index) and energy value (volatile matter, ash content, fixed carbon and calorific value) are presented in Table 1.

Table 1

Standard for determining physical properties and energetic value of briquettes

Parameters	Procedure
Density (g/cm ³)	ASTM Standard D2395-17 (2017)
Shatter index (%)	ASTM Standard D440-86 (2002).
%Volatile Matter	ASTM Standard D3174-12 (2018)
%Ash Content	ASTM Standard D3175-20 (2018)
%Fixed Carbon	ASTM Standard D3172-13 (2021)
Calorific value (MJ/kg ¹)	ASTM Standard D5865-19 (2013)

Statistical Analysis

Data obtained were analyzed using Analysis of Variance (ANOVA). Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences) at a 95% confidence level.

RESULTS AND DISCUSSION

Physical Properties

Density

The result presented in Fig. 2 shows that the density of the briquette samples ranged from 0.63 to 1.06g/cm³. Among the samples, ST recorded the highest density (1.06g/cm³), while SF recorded the lowest density (0.63g/cm³). The other samples S and SS recorded density values of 0.69g/cm³ and 0.74g/cm³, respectively. The ANOVA presented in Table 2 shows that there was no significant difference ($p > 0.05$) in the density of the briquettes produced from the different formulations.

Density is an important physical property of briquettes because it influences their strength, durability, storage characteristics and combustion behavior. Briquettes with higher density tend to burn more slowly and steadily due to reduced internal porosity which limits the rate of oxygen penetration during combustion. The result obtained in this study agrees with the findings of Kpalo *et al.* (2020) and Nurek *et al.* (2021) who reported density ranges of 0.6-1.2 g/cm³ for biomass briquettes produced using organic binders.

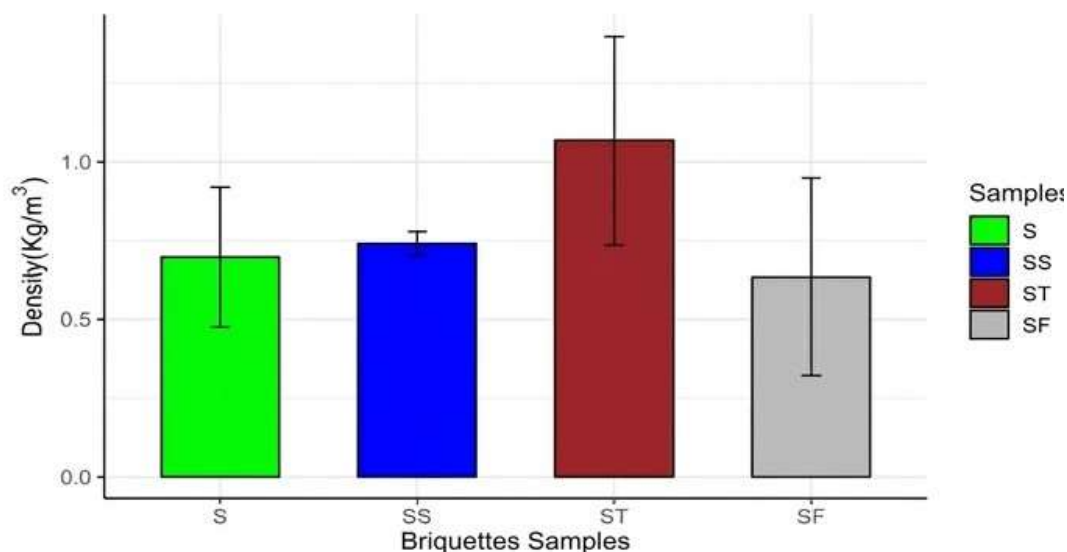


Fig. 2.
Density of briquette samples.

Table 2

ANOVA for physical and energetic properties of briquettes			
Variables	DF	F-value	P-vaalue
Density	3	2.855	0.109ns
Shatter index (%)	3	84.047	<0.05
Volatile matter (%)	3	22.2114	< 0.001
Ash content (%)	3	53.575	< 0.001
Fixed carbon (%)	3	101.2	< 0.001
Calorific value (MJ/kg)	3	5.1129	< 0.001
Error	16		
Total	19		

Table 3

Post-hoc Analysis for Physical Properties Using Least Significant Difference (LSD)

Briquettes samples	Density (%)	Shatter index ((%)
S	ns	95.84 ^{ab}
SS	ns	92.63 ^b
ST	ns	95.84 ^a
SF	ns	97.91 ^a

Shatter Index

The result presented in Fig. 3 shows that the shatter index of the briquette samples ranged from 92.64 to 97.91%. Among the samples, SF recorded the highest shatter index (97.91%), while SS recorded the lowest value (92.64%). The other samples S and ST recorded shatter index values of 95.08% and 95.64%, respectively. Table 2 presented the ANOVA, it shows that the shatter index of the briquettes was significantly influenced ($p < 0.05$) by the different formulations used in the briquette production. The post-hoc analysis using LSD is presented in Table 3 further shows that SF differed significantly from SS, while S and ST showed intermediate values.

Shatter index is an important mechanical property of briquettes because it indicates the ability of the briquettes to resist breakage during handling, transportation and storage. Briquettes with higher shatter index values are generally considered to possess better mechanical strength and durability. The result obtained in this study agrees with the findings of Yusuf *et al.* (2025) and Onukak *et al.* (2017) who reported that good

quality biomass briquettes generally possess shatter index values above 90%, indicating high resistance to breakage during handling and transportation.

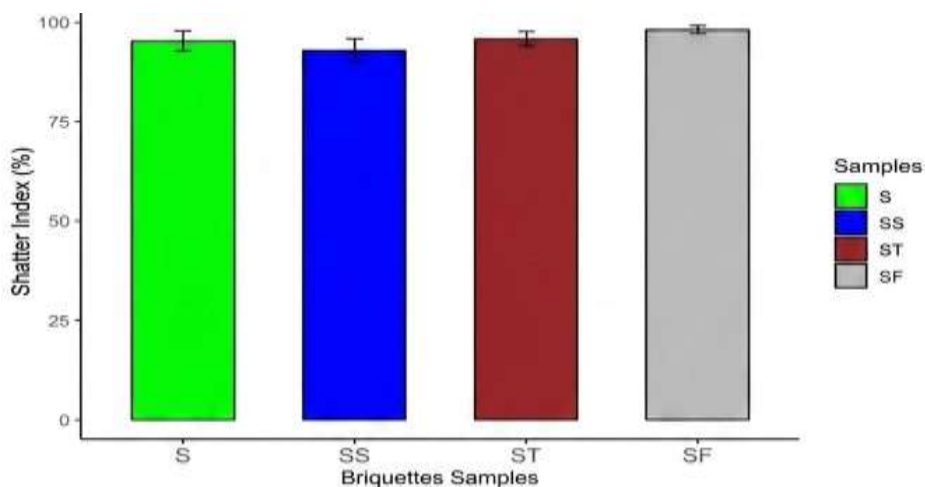


Fig. 3.
Shatter index of briquette samples.

Energy Value of Briquettes

Volatile matter (%)

The result presented in Fig. 4 shows that the volatile matter content of the briquette samples ranged from 72.00% to 83.90%. Among the samples, SF recorded the highest volatile matter content (83.90%), while SS recorded the lowest value (72.00%). The other samples S and ST recorded volatile matter contents of 73.90% and 72.30%, respectively. The ANOVA in Table 2 shows that the volatile matter content of the briquettes was significantly influenced ($p < 0.001$) by the different formulations used in the briquette production. Post-hoc analysis was presented in Table 4.

Volatile matter is an important combustion property of briquettes because it influences ignition and flame stability during burning. Briquettes with higher volatile matter content tend to ignite more easily and burn with a longer flame, while lower volatile matter content may result in slower ignition. The result obtained in this study agrees with the findings of Tze-Zhang Ang *et al.* 2022 and Kpalo *et al.* (2020) who reported that biomass briquettes typically contain high volatile matter content, which enhances ignition characteristics and supports efficient combustion.

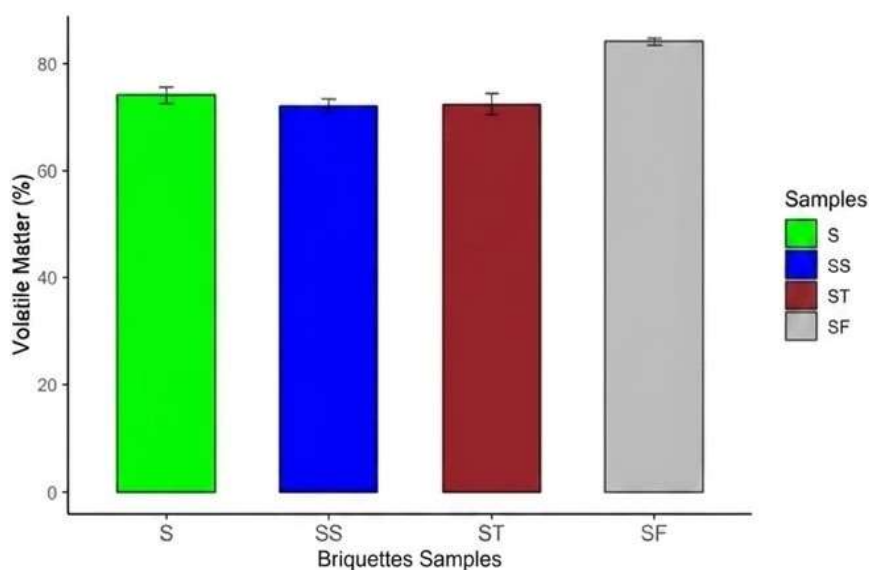


Fig. 4.
Volatile matter of briquette samples.

Table 4

<i>Follow-up Test for Energetic value Using Least Significant Difference (LSD)</i>					
Briquette samples	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (MJ/kg)	
S	73.7 ^b	11.9 ^b	14.9 ^b	26.32 ^b	
SS	72.0 ^b	7.90 ^c	19.7 ^a	26.29 ^b	
ST	72.3 ^b	15.6 ^a	12.0 ^c	25.54 ^c	
SF	83.9 ^a	11.5 ^b	4.50 ^d	28.74 ^a	

Ash Content (%)

The result presented in Fig. 5 shows that the ash content of the briquette samples ranged from 8.50 to 15.70%. Among the samples, ST recorded the highest ash content (15.70%), while SS recorded the lowest ash content (8.50%). The other samples S and SF recorded ash content values of 11.20% and 11.60%, respectively. The analysis of variance (ANOVA) presented in Table 2 shows that the ash content of the briquettes was significantly influenced ($p < 0.001$) by the different formulations used in the briquette production. The result obtained in this study agrees with the findings of Kpalo *et al.* (2020) who reported that ash content in biomass briquettes varies depending on the mineral composition (such as Potassium, Zinc, Iron, Manganese, Sodium etc.) of the raw materials used in their production. The high ash content in this study could be due to the abundant amount of mineral elements present in the plant.

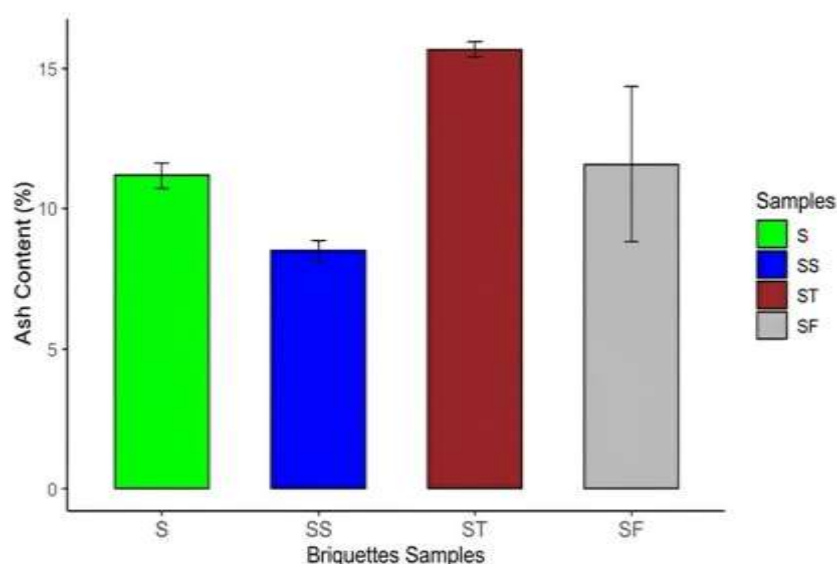


Fig. 5.
Ash content of briquette samples.

Fixed Carbon (%)

Fig. 6 shows that the fixed carbon content of the briquette ranged from 4.50 to 19.70%. Among the samples, SS recorded the highest fixed carbon content (19.70%), while SF recorded the lowest value (4.50%). The other samples S and ST recorded fixed carbon contents of 14.90 and 12.00%, respectively. The ANOVA shows that the fixed carbon content of the briquettes was significantly influenced ($p < 0.001$) by the different formulations used in the briquette production (Table 2). While Table 4 shows the post-hoc analysis using LSD. Fixed carbon is an important parameter in determining the combustion characteristics of briquettes, as it represents the solid combustible material that remains after volatile components have been released during combustion and exclude the ash. Briquettes with higher fixed carbon content tend to burn for a longer period and produce sustained heat during combustion. The result obtained in this study agrees with the findings of Nurek *et al.* (2021) and Kpalo *et al.* (2020) who reported that fixed carbon plays an important role in determining the burning duration and heat generation capacity of biomass briquettes.

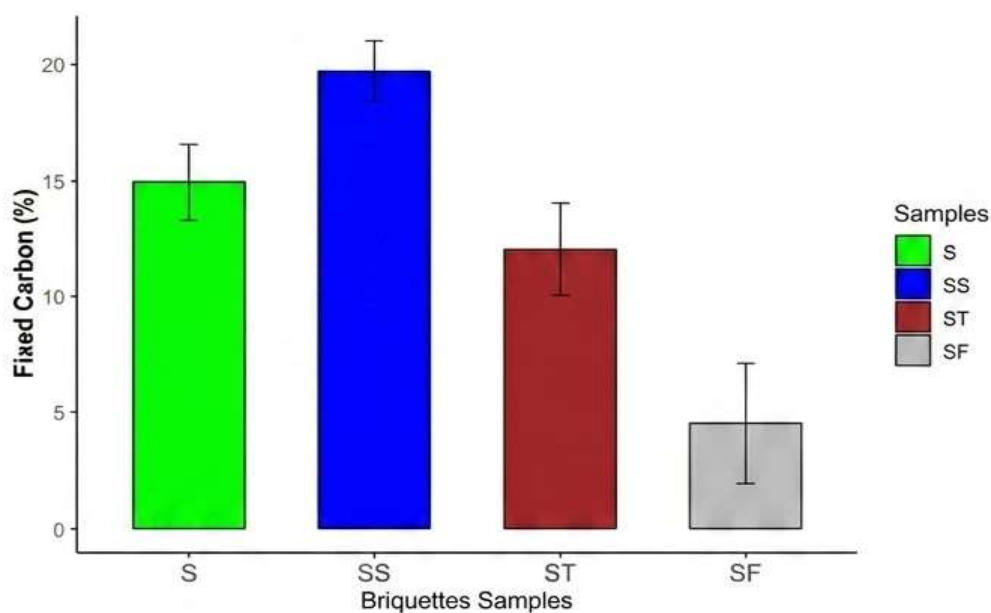


Fig. 6.
Fixed carbon of briquette samples.

Calorific Value

The result presented in Fig. 7 shows that the calorific value of the briquette samples ranged from 25.54 to 28.73 MJ/kg. Among the samples, SF recorded the highest calorific value (28.73 MJ/kg), while ST recorded the lowest value (25.54 MJ/kg). The analysis of variance (ANOVA) presented in Table 2 shows that the calorific value of the briquettes was significantly influenced ($p < 0.001$) by the different formulations used in the briquette production.

Calorific value is an important parameter used to determine the energy content of fuel materials. Briquettes with higher calorific value are capable of producing more heat energy during combustion, making them more suitable for domestic and industrial heating applications. The result obtained in this study agrees with the findings of Saidur *et al.* (2007) and Anguruwa *et al.* (2024) who reported that biomass briquettes generally possess appreciable calorific values capable of producing sufficient heat energy for domestic and small-scale industrial applications. The high calorific value of this briquette could be attributed to significant amount of volatile matter and carbon which release energy efficiently during combustion.

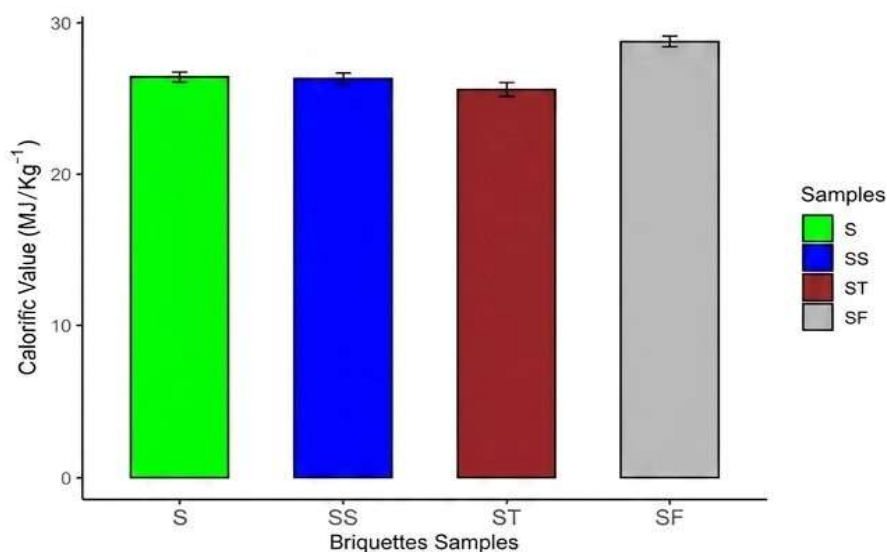


Fig. 7.
Calorific value of briquette samples.

Conclusion

This study has demonstrated that *Terminalia catappa* leaf biomass possesses significant potential as a feedstock for briquette production using cassava starch as a binding agent. The briquettes produced exhibited commendable mechanical strength, indicating their suitability for handling, storage, and transportation. In terms of energy performance, the briquettes showed favorable burning characteristics, suggesting their effectiveness as a domestic fuel source. The energy output further reinforces their potential to serve as a viable alternative to conventional biomass fuels, thereby contributing to sustainable energy development. Based on the results obtained in this study, it can be concluded that at SS and SF binding ratio *Terminalia catappa* leaf biomass is a viable raw material for briquette production.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. Studies should be conducted on the long-term storage stability and durability of the briquettes under varying environmental conditions.
2. The production of briquettes from *Terminalia catappa* leaf biomass should be encouraged as an effective method of waste management and renewable energy generation.

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