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Performance evaluation of hybrid biomass briquettes produced from carbonized sawdust, guinea corn straw and *Cissus populnea* binder

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Abstract

In this study, the performance of hybrid biomass briquettes produced from carbonized sawdust and guinea corn straw using *Cissus populnea* as a natural binder was investigated. The briquettes were produced at varying blend ratios (S90G0B10, S75G15B10, S60G30B10, S45G45B10, S30G60B10, S15G75B10, S0G90B10). The produced briquettes were tested for ash content, volatile matter, carbon content, calorific value and performance indicators such as ignition time, burning time, burning rate and boiling time. The results showed that the ash content increased with higher proportions of guinea corn straw whereas the volatile matter decreased across the samples thereby influencing the ignition and combustion behaviour of the briquettes. The result of carbon content showed S45G45B10 composition reached a maximum value of 44.6%. This indicates an optimal balance in biomass blending. Similarly, the calorific value was peaked at 24.5 MJ/Kg for same composition demonstrating enhanced energy potential due to the interaction between the blending materials. The combustion performance analysis showed that briquettes with higher volatile matter ignited more easily when compared with those having higher carbon content. However, those with higher carbon content possessed more stable burning characteristics. The S45G45B10 sample showed superior overall performance (combining high energy output with efficient combustion and reduced boiling time). The study demonstrates the potential use of agricultural residues as sustainable energy sources and the effectiveness of *Cissus populnea* as an eco-friendly binder in briquette production.

Keywords: Briquettes; Guineacorn Straw; Sawdust; Biomassfuel; Combustion

1. Introduction

The increasing global demand for energy coupled with the depletion of conventional fossil fuel resources has increased the search for sustainable and renewable energy alternatives (Holechek et al., 2022). In many developing countries, a large proportion of the population relies heavily on traditional biomass fuels such as firewood and charcoal for domestic cooking and heating (Balume et al., 2025; Njenga et al., 2024). This has contributed to severe environmental challenges such as deforestation, land degradation and increased greenhouse gas emissions. The inefficient combustion of these traditional fuels often results in indoor air pollution which poses serious health risks to users (Jaiswal et al., 2024). These challenges reveal the urgent need for cleaner, more efficient and sustainable energy sources that can be locally produced and widely adopted.

Biomass briquetting has emerged as a promising technology for converting agricultural and forestry waste into clean, efficient and sustainable solid fuels (Roman and Grzegorzewska., 2024; Yunusa et al., 2024). Briquettes are produced by compressing biomass materials into uniform shapes using a binder. This improves handling, storage and combustion characteristics of the briquettes. Unlike traditional fuels such as firewood, briquettes generally exhibit higher energy density, lower moisture content and more consistent burning behaviour (Kebede et al., 2022). Recently, attention has shifted toward the development of hybrid briquettes which combine different biomass feedstocks to improve fuel properties and overall performance. This approach not only enhances combustion efficiency but also promotes effective

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waste management by using multiple agricultural residues that would otherwise be discarded or underutilized (Kebede et al., 2022).

Despite the growing interest in biomass briquetting, improving the performance of briquettes produced from diverse agricultural residues have not been fully explored. Furthermore, while numerous studies have explored single-feedstock briquettes (walozi et al., 2026; Nonsawang et al., 2026; Lichinga et al., 2025), there is still limited research on the effects of combining carbonized materials such as sawdust and guinea corn straw to enhance fuel quality. Furthermore, the choice of binder plays a critical role in determining the mechanical strength and combustion behaviour of briquettes. However, the use of natural and eco-friendly binders such as *Cissus populnea* has not been extensively investigated. Most existing studies focus primarily on either physicochemical properties or combustion characteristics with fewer studies providing an evaluation that integrates both aspects. Addressing these gaps is essential for developing high-performance, sustainable briquettes suitable for domestic energy applications.

This study aims to evaluate the performance of hybrid biomass briquettes produced from carbonized sawdust and guinea corn straw using *Cissus populnea* as a natural binder. Specifically, the study seeks to determine the ash content, volatile matter, moisture content, and carbon content of the produced samples. In addition, the calorific value of the briquettes is assessed to identify their energy potential. The combustion performance is further examined through ignition time, burning rate and water boiling tests in order to evaluate their suitability for domestic cooking applications. Through this comprehensive assessment, the study aims to identify the most efficient briquette formulation and demonstrate the viability of utilizing agricultural residues as sustainable alternative energy sources.

2. Materials and methods

2.1. Materials

The materials used for this study were sawdust and guinea corn straw (see Figure 1 and 2). These were sourced locally from sawmills and agricultural fields in Rivers State. The materials were selected due to their abundance and potential for energy recovery. *Cissus populnea*, a natural plant-based binder was obtained from a local market and prepared for use as a binding agent in the briquette production (see figure 3). All materials were air-dried to reduce their moisture content prior to processing.

2.2. Preparation of Biomass Materials

Figure 1 Saw Dust

The sawdust and guinea corn straw were cleaned to remove dirt and impurities. The guinea corn straw was shredded into smaller sizes to enhance uniformity and ease of processing. Both biomass materials were carbonized using a controlled heating process in the absence of oxygen to produce char. The carbonized materials were allowed to cool after which they were ground and sieved to obtain uniform particle sizes suitable for briquetting. The *Cissus populnea* external fibre was dissolved in a 4 litres bowl of warm water to form a paste after which it was squeezed gently while warm until smooth homogeneous gelatinized solution was obtained.

2.3. Briquette Production

The prepared carbonized sawdust and guinea corn straw were mixed in varying proportions to produce different briquette samples. The carbonized char powder was mixed with the binder at varying ratios (S90G0B10, S75G15B10, S60G30B10, S45G45B10, S30G60B10, S15G75B10). The mixtures were then thoroughly homogenized before being fed into a briquetting mold. Compaction was done using a hydraulic press to form solid briquettes of uniform shape and size. The produced briquettes were removed and dried in a convection oven at 105 ^oC for 3 hours.

Figure 2 Guinea Corn Straw

2.4. Determination of Ash Content.

The ash content of the briquette samples was determined using Equation 1. Here, furnace residues from fixed carbon determination were heated at 600 ^oC for a period of 2 hours after which it was cooled and weighed.

$$Ash\ Content\ \% = \frac{final\ Weight\ of\ Ash}{Initial\ Weight\ of\ dry\ sample} \times 100 \quad (1)$$

Figure 3 *Cissus poplnea*

2.5. Determination of Volatile Matter.

The briquettes volatile matter content was determined using Lenton furnace. The residue for the dry samples from moisture content determination were preheated at 900 ^oC for 2 hours. The samples were further heated at 700 ^oC for 2 hours and cooled in desiccators (Adekunle et al., 2015). The percentage volatile matter was obtained using equation 2.

$$Volatile\ matter\ \% = \frac{Final\ Weight}{Original\ Weight} \times 100 \quad (2)$$

2.6. Determination of Carbon Content.

The carbon content which is the amount of carbon to be burnt by a primary current of air drawn through the hot bed of fuel was determined using equation 3.

$$\boldsymbol{Carbon\ Content} = 100 - MC\,\% + VM\,\% + AC\%. \quad (3)$$

Where MC is moisture content, VM is the Volatile matter and AC is Ash content.

2.7. Determination of Calorific Value

The calorific value for the briquette samples was determined through correlation with the proximate analysis findings as defined by Ayse and Serdar, (2017) (see Equation 4).

$$HHV = 167.2 - 1.449\,VM - 1.562\,FC - 1.846\,Ash. \quad (4)$$

2.8. Combustion Performance Tests

Ignition time was measured as the time required for each briquette sample to ignite under controlled conditions. Equation 5 was used to determine the ignition time.

$$Ignition\ time = t1 - t0 \quad (5)$$

Where t1 = time the briquette ignited, (min), t0 = time the burner was lighted, (min).

Burning rate was determined by measuring the rate of mass loss of the briquette over time during combustion.

A water boiling test was conducted to evaluate the practical performance of the briquettes. A fixed volume of water was heated using each briquette sample, and the time required to reach boiling point was recorded. Equation 6 was used to determine the burning rate of the briquette samples.

$$Bs = \frac{Q1 - Q2}{T}. \quad (6)$$

Where Bs = burning rate (g/min), Q1 = initial weight of briquettes prior to burning, Q2 = final weight of briquettes after burning, g, T = total burning time, min.

3. Results

3.1. Ash Content of Briquette samples.

The Ash content of the produced briquette samples is presented in Figure 4. The values ranged from 3% to 15.7% with sample S90G0B10 exhibiting the lowest ash content whereas sample S0G90B10 shows the highest ash content (see Figure 4).

The other samples showed intermediate values of 4.9%, 5.5%, 6.4%, 7% and 7.7% respectively indicating a gradual increase in ash content with variation in biomass composition. This phenomenon can be attributed to the mineral composition of the raw materials used. Guinea corn straw is known to contain high amounts of inorganic constituents compared to saw dust which explains the increase in the ash content as the proportion of guinea corn straw increased in the briquette formation. Furthermore, the ash content value obtained from the final briquettes may have been influenced by the carbonization process which concentrates on non-combustible residues. In every fuel, ash content is one parameter that influences the fuel quality and as such, a lower ash content enhances combustion efficiency, reduces slagging tendencies and improves heat transfer during burning (Chen et al., 2021). The result is in alignment with (Luan et al., 2025) who noted that higher saw dust composition in a hybrid matrix leads to a better fuel performance and cleaner combustion characteristics.

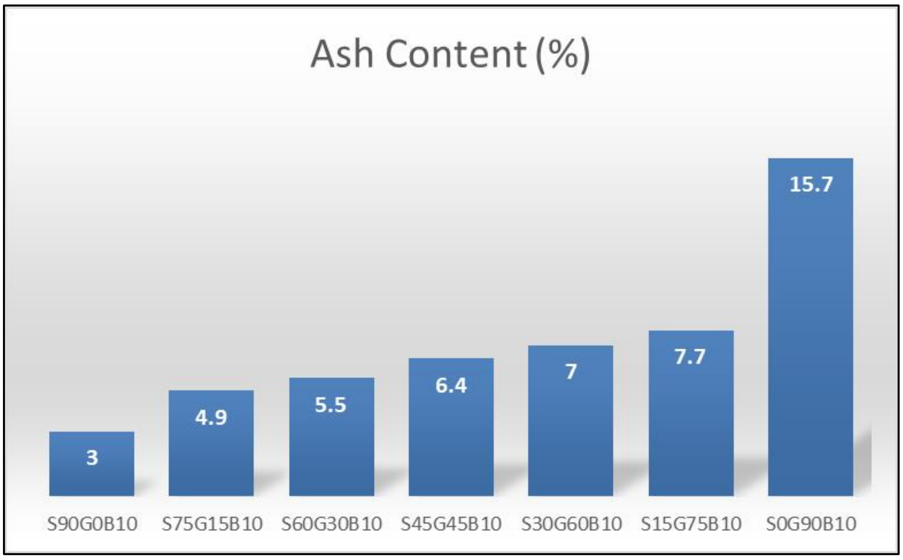

Figure 4 Results of Ash Content of Produced Briquette samples

3.2. Volatile Matter of Briquette Samples

The volatile matter content of the briquette samples is presented in Figure 5. The results showed that the volatile matter varies significantly among the samples with values ranging from 28.0% to 70.2%. The highest volatile matter content was observed in sample S90G0B10 (70.2%), followed by S75G15B10 (65.0%) and S60G30B10 (61.5%). However, the lowest value was obtained at sample S0G90B10 (28.0%). A consistent decreasing trend in volatile matter content is seen as the proportion of guinea corn straw increases in the briquette composition.

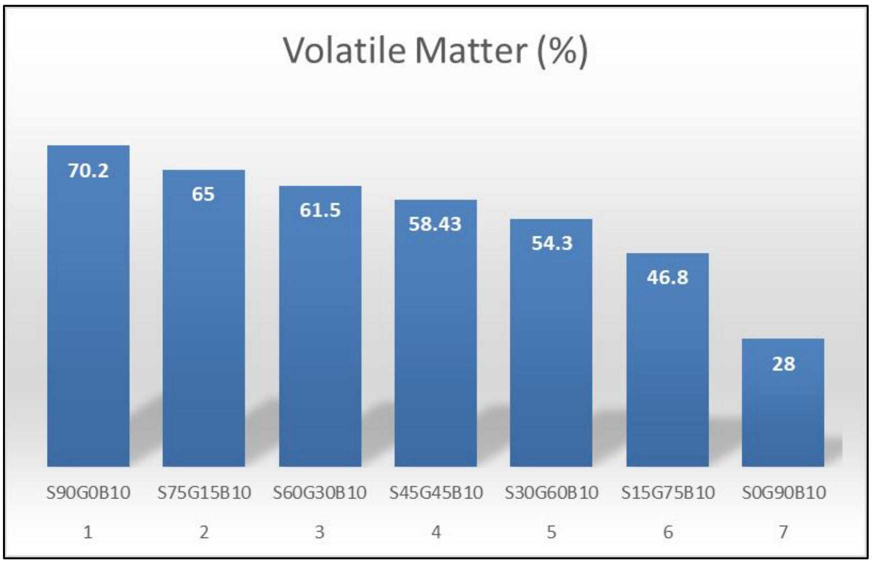

Figure 5 Result of volatile matter of various samples

This variation can be attributed to the differences in the thermal decomposition characteristics of the raw materials (ref). Sawdust typically contains higher amounts of volatile organic compounds compared to guinea corn straw, which explains the higher volatile matter content in samples with greater sawdust composition (Inegbedion, 2022). Additionally, the carbonization process causes reduction in the volatile components but the extent of this reduction depends on the original biomass composition and carbonization conditions. Volatile matter plays an important role in determining the ignition and combustion behaviour of solid fuels (Zhai et al., 2022). Higher volatile matter content generally enhances ease of ignition and promotes rapid flame development. This is because more combustible gases are released during heating. The result showed samples with higher sawdust content ignited more easily and exhibited more vigorous initial combustion. However, the lower volatile matter content observed in samples with higher guinea corn straw composition suggests a slower ignition process and more controlled combustion characteristics.

3.3. Calorific Value of Briquette Samples

The calorific values of the briquette samples are presented in Figure 6. The results showed calorific value range from 13.6 to 24.5 MJ/kg. This can be attributed to the significant variation in the energy content of the different briquette formulations. The highest calorific value was recorded for sample S45G45B10 (24.5 MJ/kg) whereas the lowest value was obtained in sample S90G0B10 (13.6 MJ/kg). Other samples exhibited intermediate values of 14.1, 14.7, 15.0, 15.6, and 16.2 MJ/kg suggesting a gradual improvement in energy content with changes in biomass composition.

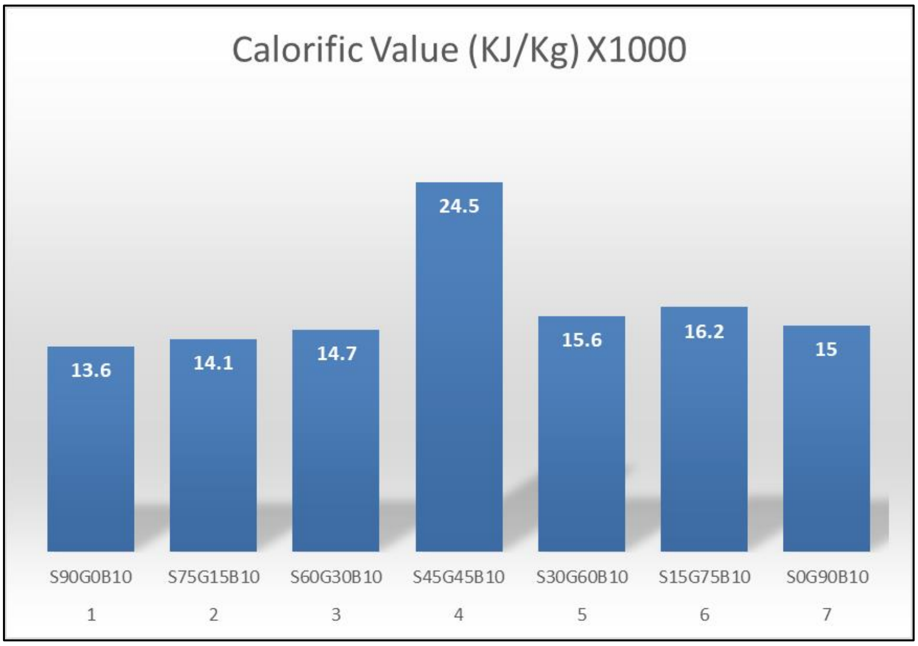

Figure 6 Result of Calorific value of various samples

The trend showed that the combining sawdust and guinea corn straw has a significant influence on the energy potential of the briquettes. The peak calorific value obtained at the equal blend ratio (45:45) suggests a synergistic interaction between the two biomass materials leading to improved fuel characteristics. This enhancement may be attributed to an optimal balance between fixed carbon and volatile matter, which promotes efficient combustion and higher heat release (Qing et al., 2025). Furthermore, the relatively lower calorific values were seen in samples with higher proportions of either sawdust or guinea corn straw alone. This shows that single-biomass briquettes may not achieve optimal energy performance. The results therefore highlight the advantage of hybrid briquette production over single-feedstock briquettes.

Generally, the calorific values obtained in this study are comparable to those of conventional biomass fuels such as firewood and approaches the lower range of charcoal values (Olabisi et al., 2023). The high calorific value recorded for sample S45G45B10 demonstrates its suitability as an efficient domestic fuel which is capable of delivering higher heat output and improved cooking performance.

3.4. Carbon Content of Briquette Samples

Figure 7 shows the results of the carbon content of the briquettes made from Saw dust and Guinea corn straw. Sample S45G45B10 showed the highest Carbon content of 44.60% and S90G0B10 recorded the lowest with 2.80%. The result shows that guinea corn straw has high carbon content while Sawdust has low carbon content. Samples S75G15B10 and S60G30B10 showed a significant decrease in 10.20% and 14.20% respectively. These values are lower than the values obtained from samples S30G60B10 and S15G75B10 whose carbon content increased. The carbon contents are lower than 32.3% - 57.46% recorded by (Ogbuagu *et al.,* 2013) in their production of coal and rice husk briquettes.

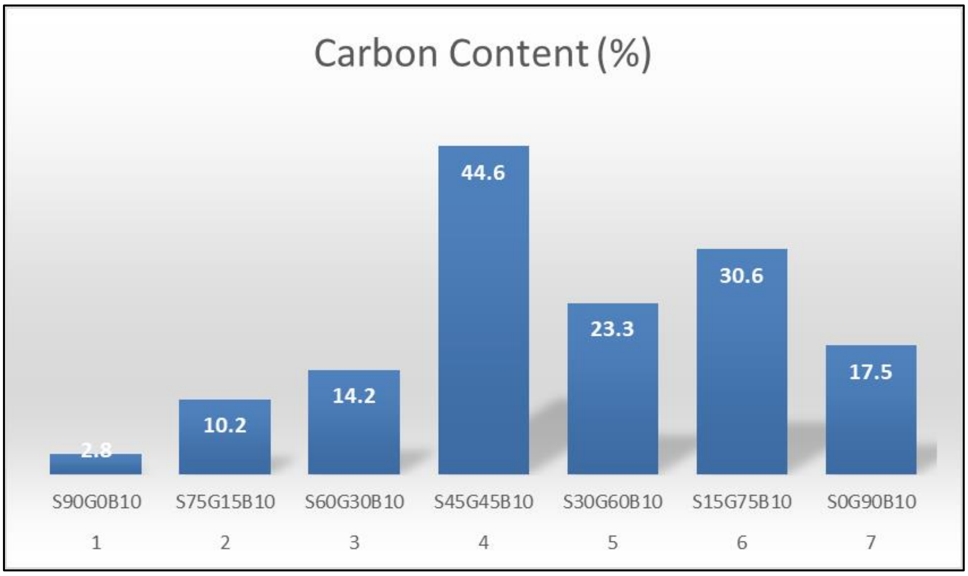

Figure 7 Result of carbon content value of various samples

The carbon content of the briquette samples is presented in Figure X. The results show a wide variation in carbon content across the different formulations, ranging from 2.8% to 44.6%. The lowest carbon content was observed in S90G0B10 (2.8%), while the highest value was recorded for S45G45B10 (44.6%). Other samples exhibited intermediate values of 10.2%, 14.2%, 23.3%, 30.6%, and 17.5%, indicating a non-linear relationship between biomass composition and carbon yield. The variation in carbon content values obtained can be attributed to the combined effects of biomass composition and the carbonization process (Shen et al., 2025). Carbonization enhances the carbon content of biomass by driving off volatile components. However, the extent of carbon retention depends on the intrinsic properties of the raw materials. Furthermore, higher carbon content (see sample S45G45B10) suggests an optimal balance in the hybrid composition which favors carbon enrichment during thermal treatment (Shen et al., 2025).

Generally, carbon content is an important parameter in the determination of the fuel quality of briquettes. This influences the energy output that is higher carbon content corresponds to higher calorific value and improved combustion efficiency. This relationship is clearly seen in this study, where the sample with the highest carbon content (S45G45B10) also exhibited the highest calorific value confirming its superior fuel characteristics. Furthermore, the result showed combining sawdust with guinea corn straw using *Cissus populnea* as a binder influences the carbon content of produced briquettes.

3.5. Combustion Test

The performance evaluation of the briquette samples was conducted for burning time, ignition time, burning rate and boiling time (see Figure 9). The results showed Ignition time ranged from 57.8 s (S90G0B10) to 23.9 s (S0G90B10). Similarly, burning time varied between 18.0 min (S0G90B10) and 36.4 min (S45G45B10), burning rate increased steadily from 1.2 g/min (S90G0B10) to 7.1 g/min (S0G90B10) and boiling time decreases from 30.5 min (S75G15B10) to 16.5 min (S0G90B10).

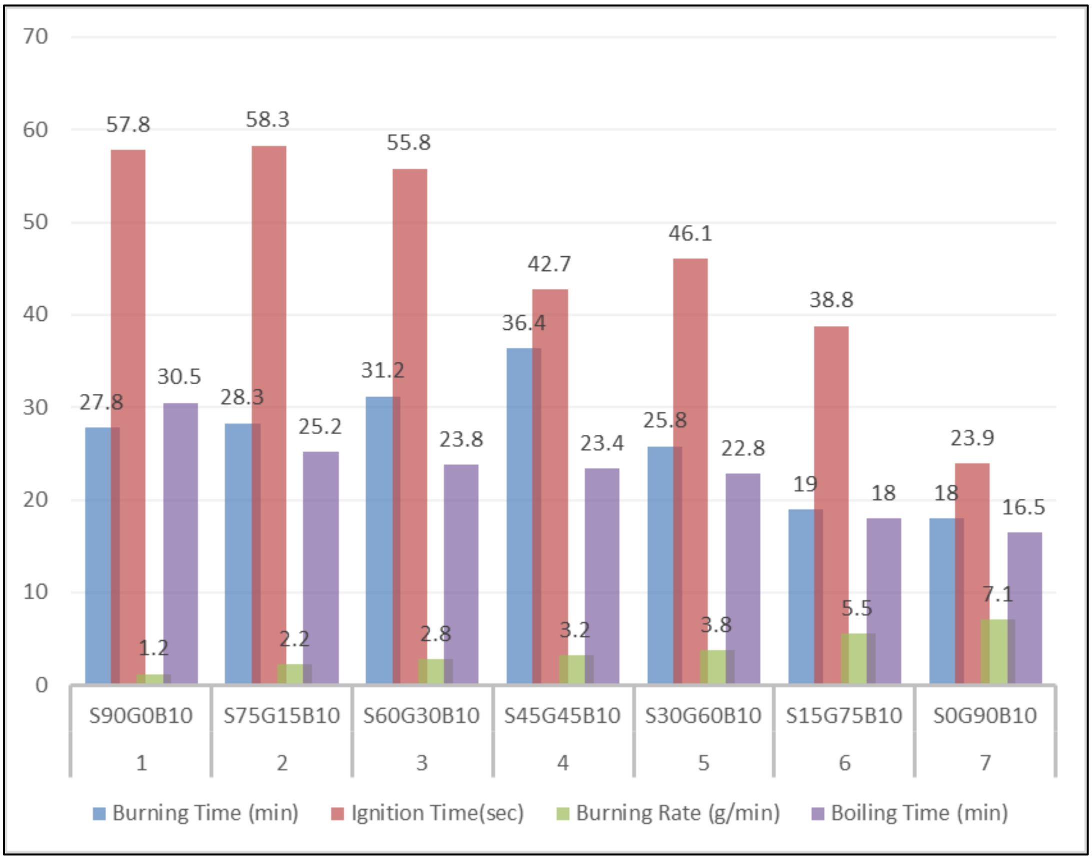

Figure 8 Carbonized Briquette with Respect to Burning Time, Ignition Time, Burning Rate, and Boiling Time

The Ignition time decreased consistently with increase in the proportion of guinea corn straw. The highest ignition time recorded for S75G15B10 (58.3 s) and S90G0B10 (57.8 s) showed that briquettes rich in sawdust require more time to ignite. This behaviour can be attributed to the higher density and compactness of sawdust-based briquettes as well as the lower volatile matter content which delays flame initiation. Similarly, the lowest ignition time was obtained on sample S0G90B10 (23.9 s) which suggests that guinea corn straw enhances flammability. This is because guinea corn straw possesses higher volatile matter and porous structure (Abubakar and Saeed, 2024). The burning time increased initially with varied formulations and reached a maximum value at S45G45B10 (36.4 min) after which it declined sharply with further increase in guinea corn straw content. The improved burning duration at intermediate compositions showed better structural integrity and energy retention. Furthermore, the reduction at higher guinea corn straw content is due to rapid combustion and lower carbon content (ref). The trend showed that a balanced formulation (45:45) optimizes the briquettes combustion stability.

A steady increase in burning rate is seen with increasing guinea corn straw proportion (from 1.2 g/min for sample S90G0B10 to 7.1 g/min for sample S0G90B10). This phenomenon can be attributed to the fact that briquettes with higher guinea corn straw content burn more rapidly due to their increased porosity which allows for better oxygen diffusion. However, higher burning rates leads to shorter fuel lifespan which reduces the efficiency in long-duration applications. The boiling time decreased as the proportion of guinea corn straw increased. The highest boiling time was exhibited by sample S75G15B10 (30.5 min) and the lowest boiling time was obtained from sample S0G90B10 (16.5 min). The relationship between the burning rate and the boiling time shows that faster burning briquettes produce higher heat intensity which results in quicker heat transfer (Jiang et al., 2025).

4. Conclusion

This study evaluated the performance of hybrid biomass briquettes produced from carbonized sawdust and guinea corn straw using *Cissus populnea* as a natural binder. The results showed that the briquettes are significantly influenced by the blending ratio of the constituent biomass materials. The ash content analysis showed that briquettes with higher sawdust composition exhibited lower ash content whereas those with higher guinea corn straw showed higher ash contents indicating better combustion efficiency and reduced residue formation. Volatile matter content decreased with increasing guinea corn straw proportion. This suggests a transition from easy ignition to more controlled combustion behaviour across the samples.

The carbon content varied among the samples with sample S45G45B10 having the highest value. This high carbon content related directly with the highest calorific value of 24.5 MJ/kg confirming the strong relationship between carbon enrichment and energy output. The findings showed that sample S45G45B10 exhibited the best fuel characteristics. The study highlights the effectiveness of biomass hybridization and carbonization in improving briquette performance and demonstrates the potential of agricultural residues as sustainable and efficient alternative energy sources for domestic applications.

Compliance with ethical standards

No conflict of interest to be disclosed.

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