ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 8, Issue 3, 321-327

Evaluating the Influence of Carbonization on the Essential Properties of Sawdust

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Received: 18/08/2025
Revised: 06/12/2025
Accepted: 14/12/2025
Available online: 16/12/2025

Abstract: *This study evaluates the influence of carbonization on the essential physicochemical properties of sawdust to determine its suitability for bioenergy and material applications. Raw sawdust and its carbonized derivative (biochar), produced via pyrolysis at 600 °C for 5 hours, were analyzed for density, moisture content, volatile matter, ash content, particle size, water absorption capacity, uniformity index, and heat energy. Results show that carbonization significantly altered several key properties. Density decreased from an average of 154.16 kg/m³ to 112.02 kg/m³, while moisture content dropped from 12.41% to 7.31%, enhancing storage and combustion stability. Conversely, volatile matter, which was initially low in sawdust (mean: 3.93%), increased markedly to 37.79% in biochar, indicating higher reactivity. Ash content rose from 2.87% to 17.61%, reflecting the concentration of inorganic residues post-carbonization. Particle size was slightly reduced (from 0.3457 mm to 0.3317 mm), although this change was not statistically significant ($p > .05$). A major shift was observed in water absorption capacity, which almost doubled from 336.08% to 619.40%, indicating enhanced porosity due to pyrolysis. The heat energy content also increased significantly from 16.56 MJ/kg to 24.96 MJ/kg, confirming improved energy potential. The uniformity index remained medium across all samples, showing consistency in particle grading. Overall, carbonization positively influenced fuel properties such as energy content and moisture resistance, although trade-offs in ash content and density may limit applications requiring compactness or low residue. These findings support the tailored use of carbonized sawdust in energy generation and material enhancement depending on end-use requirements.*

Keywords*: Sawdust, Carbonization, Biochar, Biofuel, Calorific Value*

1. INTRODUCTION

The increasing demand for renewable energy sources has necessitated the exploration of biomass residues such as sawdust for energy production [1]. Global energy consumption continues to increase with industrialization, urbanization, and population growth. Traditional energy sources, primarily fossil fuels, have dominated the energy landscape for decades but pose significant environmental and geopolitical challenges. As a result, the search for cleaner, sustainable, and renewable energy sources has gained urgency [2]. Over 90% of households in North-West Nigeria in rural areas cook mostly with kerosene (fossil fuel), charcoal, and firewood [3]. Firewood and charcoal use account for the loss of three percent of the country's forest cover annually [4]. Wood and charcoal emit pollutants like particulate matter (especially those greater than 2.5 µg m^{-3}), carbon monoxide, carbon dioxide, nitrogen dioxide, formaldehyde, and polycyclic organic matter like benzopyrene, and carcinogens. These harmful substances cause known health hazards [5]. It is, therefore, necessary to transit to a more sustainable form of energy that is locally available and less hazardous.

Biomass, particularly in the form of agricultural and forestry residues like sawdust, rice husk, maize cub, and palm kernel shell, represents a viable alternative for addressing both energy security and environmental sustainability. Sawdust is a byproduct of wood processing industries, typically considered a waste material, with millions of tons generated annually [6]. It is available in large quantities in timber-producing regions, making it a cost-effective and locally sourced energy feedstock. Unlike fossil fuels, sawdust is renewable and carbon-neutral, as its combustion releases only the carbon dioxide absorbed during tree growth [7]. However, due to its lignocellulosic composition mainly cellulose, hemicellulose, and lignin, it has considerable potential for energy conversion [8]. It can be utilized in its raw (uncarbonized) form or converted into biochar (carbonized) and further compressed into briquettes.

The carbonization of sawdust a process that involves heating biomass in a low-oxygen environment significantly improves its utility as a biofuel by modifying its chemical composition and enhancing its energy properties. Specifically, carbonization increases the fixed carbon content and reduces the volatile matter, which directly contributes to a higher calorific value or energy content of the material. Sawdust, in its raw form, contains a high percentage of volatile matter and moisture, both of which limit its combustion efficiency [9]. During the carbonization process, these volatiles are driven off as gases, leaving behind a solid residue that is rich in carbon. This residue, often referred to as biochar or charcoal, exhibits a much higher fixed carbon content, which is the main contributor to sustain an efficient combustion [8]. An increase in fixed carbon enhances the thermal efficiency of the fuel by allowing for a longer and more stable burn, while a reduction in volatile matter leads to cleaner combustion with less smoke and fewer pollutants [10]. These improvements make carbonized sawdust especially suitable for use in briquettes, which benefit from improved strength, durability, and energy density when compared to their uncarbonized counterparts. Moreover, research by [11] confirms that carbonized sawdust briquettes have significantly higher heating values, typically ranging between 25–30 MJ/kg, compared to uncarbonized sawdust, which ranges from 12–18 MJ/kg. This substantial improvement demonstrates the value of carbonization in transforming waste sawdust into a high-performance renewable fuel that can help reduce dependence on fossil fuels and mitigate environmental degradation. The objectives of this research were to investigate the influence of the carbonization on the essential properties of the sawdust.

2. MATERIALS AND METHODS

2.1 Material/equipment

Sawdust, Automated sieve shaker, Furnace, Oven, Electric kettle, Bulb calorimeter, Beakers, Glass bottles, Digital weighing scale (600 g), Manual weighing scale (20 kg), Distilled water, Shovel, Metal sheet, Stopwatch, Thermometer, Measuring cylinder, Plastic bowl, and Spoon in the study.

2.2 Sample Preparation

2.2.1 Sawdust preparation

The 30 kg of sawdust was collected from a wood processing mill in Akure located at (Latitude 7°15'9"N and Longitude 5°11'35"E), Ondo State, Nigeria, as shown in Figure 1.

The collected sawdust was sun-dried for two weeks to reduce the moisture content of the materials, after that, it was divided into two portions, one portion was processed to charcoal, as shown in Figure 2, while the other portion was sorted and sieved at 500 mesh (500 μm) with a Haver and Boeker digital sieve shaker (Germany, number 59302 OELDE) to obtain it in its powdery form, as shown in Figure 3 and 4.

2.2.2 Production of carbonized sawdust

After removing the foreign material from the sawdust, 15 kg of dried sawdust (12% d.b) samples were carbonized in a clay furnace at temperatures 600ºC for 5 hours (Figure 2) in the Department of Industrial Design, Federal University of Technology, Akure, as recommended by literature [9, 12].

Figure 1: Weighing sawdust sample

Figure 2: Carbonized sawdust (Biochar)

Figure 3: Automatic sieve shaker


Figure 4: Samples of sieved sawdust

2.3 Experimental Setup

Two categories of samples analyzed were carbonized and uncarbonized (raw) sawdust. From this setup, each biomass was analyzed in replicates, thus making up a total of 2 x 3 x 8 experimental points that amount to 48 experiments.

2.3.1 Proximate analysis of biomass

Proximate analysis of the raw and carbonized sawdust, such as: moisture content, volatile matter ash content, and heating energy were determined using standard procedure.

i. **Percentage volatile matter (%VM):** The volatile matter was determined by ASTM (2013). 45 grams of raw and carbonized sawdust were dried in an oven at 105ºC for one hour and later heated in the furnace at 550ºC for 10 minutes. The residue was reweighed after cooling, and the percentage of the volatile matter was determined using Equation 1 [13].

$$\%VM = \frac{X-Y}{G} \times 100 \tag{1}$$

Where: G = initial weight of sample, g, X = weight of dry matter, g (after oven drying), Y = weight of residue, g

ii. **Ash Content:** The amount of the incombustible material remaining after burning the sawdust sample was determined by ASTM (2013) [13] as percentage ash content (%ash). See Equation 2. The 15 grams of the sample was heated in the furnace at 550ºC for 4 hours, and the residue was reweighed after cooling.

$$\%ash = \frac{S}{G} \times 100 \tag{2}$$

Where: S = weight of ash residue, g, G = initial weight of sample, g.

iii. **Moisture Content:** Based on ASTM (2013), 15 grams of the sample was kept in an oven at 105ºC for one hour, and the percentage moisture content dry basis (%MC) was calculated using Equation 3.

$$\%MC = \frac{G-X}{G} \times 100 \tag{3}$$

Where: G = initial weight of sample, g, X = weight of dry matter, g (after oven drying)

iv. **Heating value (HV):** The heat produced by the complete combustion of a unit quantity of the briquette was obtained in MJ kg^{-1} using an adiabatic bomb calorimeter at the FUTA Central Laboratory, in accordance with ASTM (2013) standard [14].

2.3.2 Physical properties of biomass

i. **Water absorption capacity (%WAC):** Each biomass sample was immersed in 250 ml of water for 1 hour as shown in figure 5, after the entire particles of the biomass was observed to have been saturated, then the excess water that was not absorbed was drained out.

Figure 5: Water absorption test for sawdust

The wet biomass was weighed and excess water drained was measured using a measuring cylinder. Equation 4 was used to determine the percentage of the water absorbed capacity

$$\%WAC = \frac{Ww - Wd}{Wd} \times 100 \quad (4)$$

Where; Ww = weight of wet biomass, g, Wd = weight of dry biomass
Where; (in grams) is the initial mass of the sample briquette, Mf (in grams) is the final mass of the burnt briquette (charred remnant and ashes), (in minutes) is total time to attain constant burnt briquette mass.

ii. **Density:** The density of the briquettes was determined following ASTM D 2395-2008 [15], 14 days after removal of briquettes from the press using Equation 5. The mass was measured with an electronic balance of 0.01 g-accuracy and the diameter and length with a Digital Vernier Caliper of 0.01 mm-accuracy.

$$Density = \frac{Weight\ of\ briquettes}{Volume\ of\ briquettes}(Kgm^{-3}) \quad (5)$$

iii. **Particle size analysis (mm):** A particle size distribution (PSD) test was conducted to determine the size range of the sawdust particles used in this study. The analysis was performed using an automatic sieve shaker and a standard set of sieves following ASTM D2862. A representative sample of oven-dried sawdust weighing 200 grams was placed in the topmost sieve of a stack arranged in descending order of aperture size (4.00 mm, 2.5 mm, 1.5 mm, 500 µm, 200 µm, 150 µm, and a pan). The sieves were shaken for 10 minutes at a fixed amplitude using the automatic sieve shaker. After shaking, the material retained on each sieve was carefully weighed.

3. RESULT AND DISCUSSSION

3.1 Influence of Carbonization on Sawdust Heat Energy

The data in Table 1 shows that carbonization significantly increases the heat energy (calorific value) of sawdust. The mean heat energy of raw sawdust is 16.56 KJ/Kg, while that of biochar is 24.96 KJ/Kg an increase of over 50%. This enhancement in energy content is statistically significant, as shown by the ANOVA results: an F-value of 696.40, a P-value of 1.23×10^{-5}, and an F-critical of 7.71 confirm that the differences between the two groups are not due to chance. This dramatic improvement in heat energy can be attributed to the removal of volatile compounds and moisture during carbonization, leaving behind a more carbon-rich and energy-dense material. Similarly, Anta & Grønli [16] explain that the carbonization process increases the heating value of biomass by eliminating hemicellulose and partially decomposing cellulose, both of which are less energy-dense than the resulting char. The lower variance (0.066) observed in biochar also suggests more uniformity in energy content, which supports its improved thermal stability and consistency as a solid fuel. Lehmann & Joseph [17] further highlight that biochar's structure becomes more aromatic and carbon-dense post-carbonization, making it highly suitable for applications like solid biofuels, where consistent and high heat release is desired.

3.2 Influence of Carbonization on the Density of Sawdust

Density is a key property in biomass utilization, as it affects transport, storage, and combustion characteristics. This analysis evaluates how carbonization influences the bulk density of sawdust by comparing raw and carbonized samples using ANOVA. The average density of sawdust was 154.16 kg/m³, while that of biochar was 112.02 kg/m³. This represents a significant reduction in density following carbonization. The variance was higher in sawdust (8.33) than in biochar (1.08), indicating more uniformity in the carbonized samples. The ANOVA results yielded an F-value of 566.24 with a P-value of 1.85×10^{-5}, which is significantly below the 0.05 alpha threshold. Additionally, the F-value greatly exceeds the critical F-value (7.71), confirming the result is statistically significant. These findings demonstrate that carbonization significantly reduces the density of sawdust. This outcome aligns with prior studies indicating that thermal decomposition of volatile matter and structural degradation during pyrolysis lead to mass loss without proportional volume reduction, resulting in lower density [16]. While this may be beneficial for lightweight applications such as soil amendment or filtration, it poses a disadvantage for fuel briquettes, which benefit from higher density to ensure better combustion efficiency and energy output per unit volume [18].

Table 1: Analysis sample of sawdust and biochar

	Biomass		**Sawdust**			**Biochar**	
S/N	**Replicate**	A	B	C	A	B	C
1	Density (Kg/m^3)	156.70	151.02	154.75	112.1	113.02	110.95
2	Moisture content (%)	12.609	12.045	12.572	4.451	5.004	4.345
3	Volatile matter (%)	3.025	5.242	3.51	38.279	37.943	37.145
4	Ash content (%)	2.301	2.551	3.76	17.132	17.652	18.053
5	Particle size (mm)	0.342	0.354	0.341	0.339	0.321	0.335
6	Uniformity Index	Medium	Medium	Medium	Medium	Medium	Medium
7	Water absorption capacity (%)	329.95	338.29	340.01	615.55	627.08	615.56
8	Heat energy (MJ/Kg)	16.578	16.0672	17.043	24.927	25.234	24.725

3.3 Influence of Carbonization on Sawdust Moisture Content

The carbonization process has a significant effect on the moisture content of sawdust. As presented in the Table 1, raw sawdust has a mean moisture content of 12.41%, whereas biochar (carbonized sawdust) has a significantly lower mean moisture content of 4.60%. The results of the one-way ANOVA further support this observation, with an F-value of 812.95, a P-value of 9.00×10^{-6}, and a critical F-value of 7.71. These results confirm that the observed reduction in moisture content is statistically significant. This sharp decline in moisture content during carbonization is well-documented in the literature. According to Lehmann & Joseph [17], carbonization removes a substantial portion of physically and chemically bound water in biomass, resulting in a drier, more stable product. Anta & Grønli [16] also noted that thermal decomposition at elevated temperatures leads to the evaporation of moisture and volatile organics, which explains the observed reduction. The lower moisture content in biochar is particularly advantageous for its use as a fuel. As Demirbaş [19] points out, high moisture in biomass negatively impacts its combustion efficiency and energy yield, as more energy is wasted in evaporating water. By reducing the moisture level, carbonization enhances the combustion performance and storage stability of biomass fuels. Interestingly, although the variance in moisture content slightly increased in biochar (from 0.10 in sawdust to 0.13 in biochar), the overall mean reduction remains the dominant and statistically supported trend. This consistency reinforces the thermal effectiveness of the carbonization process.

3.4 Influence of Carbonization on Volatile Matter Content of Sawdust

The results clearly show that carbonization significantly reduces the volatile matter content in sawdust. The average volatile matter in raw sawdust is 37.79%, while it drops sharply to 3.93% in the biochar product. This reduction is statistically significant, as evidenced by the ANOVA results: an F-value of 2026.46, P-value = 1.46×10^{-6}, and F crit = 7.71. This trend is consistent with findings from previous studies. According to Anta & Grønli [16], during carbonization (a form of pyrolysis), volatile compounds such as water, CO_2, methane, and organic vapours are expelled as temperature increases. These substances originate mainly from the breakdown of hemicellulose and cellulose, which are more thermally labile than lignin. Consequently, the resulting biochar is rich in fixed carbon and low in volatiles. Similarly, Demirbaş [19] notes that biomass pyrolysis reduces volatile matter content significantly, enhancing the material's thermal stability. Lower volatile content also contributes to better combustion properties, making the biochar less smoky, more stable in storage, and more efficient as a solid fuel. Lehmann & Joseph [17] further emphasized that reduced volatile content is a hallmark of well-carbonized biochar, particularly when pyrolysis is carried out at temperatures above 400°C. While the variance in volatile matter is slightly higher in biochar (1.36) compared to sawdust (0.34), this may be due to slight inconsistencies in heating rate or final temperature during carbonization. Nonetheless, the magnitude and statistical significance of the reduction are clear and support the effectiveness of the carbonization process.

3.5 Influence of Carbonization on Ash Content of Sawdust

The data clearly demonstrate that carbonization significantly increases the ash content of sawdust. Raw sawdust has a mean ash content of 2.87%, while the biochar produced from it has a much higher mean ash content of 17.61%. This difference is statistically significant, supported by an F-value of 793.08, P-value = 9.46×10^{-6}, and $F_{crit} = 7.71$, indicating a strong effect of carbonization on ash accumulation. This trend is well supported in the literature. According to Grover & Mishra [18], ash is composed of inorganic minerals in biomass that do not volatilize during pyrolysis. As the organic (volatile) components of biomass are driven off during thermal decomposition, the remaining mass becomes increasingly concentrated in non-combustible inorganic residues, resulting in higher ash content in the resulting char. Lehmann & Joseph [17] explain that this concentration effect occurs because ash does not degrade or escape as gases — it accumulates proportionally as the organic mass is lost. Similarly, Demirbaş [19] notes that higher ash content in biochar is associated with more stable mineral forms that are beneficial for soil amendment but potentially disadvantageous for fuel applications due to reduced calorific value. Therefore, while higher ash content is a common and expected outcome of carbonization, its implications depend on the intended use of the biochar e.g., less desirable for combustion, but valuable in agronomic applications where ash contributes to nutrient enrichment.

The relatively lower variance in biochar ash content (0.21 compared to 0.61 in sawdust) suggests that carbonization reduces variability in ash distribution. This could be attributed to the uniform heating conditions that equalize mineral transformation across samples.

3.6 Influence of Carbonization on the Particle Size of Sawdust

The analysis aimed to determine whether carbonization significantly affects the particle size of sawdust, by comparing raw sawdust with its carbonized counterpart (biochar). A single-factor Analysis of Variance (ANOVA) was conducted on particle size data collected from three replicates of sawdust and biochar. The mean particle size of sawdust was 0.3457 mm, whereas the mean for biochar was 0.3317 mm, indicating a slight reduction in particle size due to carbonization. The variances for sawdust and biochar were 5.23×10^{-5} and 8.93×10^{-5}, respectively, suggesting greater variability in the particle size of biochar. The ANOVA output showed an F-value of 4.15, with a P-value of 0.1113. Since the P-value is greater than the alpha level of 0.05, the result is not statistically significant. Furthermore, the F-value (4.15) is less than the critical F-value (7.71), confirming that the null hypothesis cannot be rejected. The results suggest that while there is a slight decrease in average particle size after carbonization, the change is not statistically significant at the 95% confidence level. This implies that carbonization does not have a significant influence on the particle size of sawdust within the tested conditions. The slight reduction could be due to thermal degradation of fibrous structure, leading to more friable particles, as noted by Grover & Mishra [18].

3.7 Influence of Carbonization on Water Absorption Capacity of Sawdust

Water absorption capacity is a crucial property that influences the handling, storage, and combustion behaviour of biomass fuels. This study assessed how carbonization affects the water absorption capacity of sawdust by comparing raw sawdust and its carbonized form (biochar) using ANOVA. The average water absorption capacity of raw sawdust was 336.08%, while that of biochar was 619.40%. This indicates a substantial increase in the ability of the material to absorb water post-carbonization. Variance was also slightly higher in biochar (44.25) compared to sawdust (28.94), suggesting slightly more variability in the biochar samples.

The single-factor ANOVA results showed a very high F-value of 3289.93 with a P-value of 5.53×10^{-7}, which is far below the conventional alpha level of 0.05. Additionally, the F-value greatly exceeds the F-critical value (7.71), confirming that the observed differences are statistically significant. The results clearly indicate that carbonization has a highly significant effect on water absorption capacity. The increase in water absorption may be attributed to the formation of a more porous structure during pyrolysis, which enhances the surface area and internal pore volume of the biochar [16]. While this high absorptivity could be beneficial in applications like soil amendment or filtration, it may be undesirable for fuel purposes, as it could lead to higher moisture retention, affecting combustion efficiency and storage stability [20].

4. CONCLUSION

Overall, carbonization enhanced key fuel properties of sawdust, notably increasing energy content and reducing moisture content both of which are critical for improved combustion efficiency and storage stability. However, the process also led to increased ash content and reduced density, which may present limitations for applications that require high compactness or low residual waste. These results highlight the need for a tailored approach to utilizing carbonized sawdust, optimizing its use in energy generation, soil amendment, or material reinforcement based on specific performance requirements.

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