JOSTIR Publication 2025 | ISSN: 1118-3896

Special Issue December 2025 | 123-128

Journal of Science, Technology and Innovation Research

Volume 1 Special Issue | December 2025

An Evaluation of the Fuel Value Indices of Selected Two Wood Fuel Species Used in Nigeria

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ABSTRACT

In order to evaluate the fuel value indices of two selected wood fuel species in Nigeria, that is, hardwood *Iroko* (Milicia excelsa) and softwood *Obeche* (Triplochiton scleroxcylon). Proximate and ultimate analyses were performed on 2kg samples of sawdust (Biomass) obtained from each species of the wood to determine their moisture content, ash content, calorific value, bulk density, and the percentage quantity of composition of Carbon (C), Oxygen (O), Hydrogen (H), Nitrogen (N), and Sulfur (S), respectively. For this study, the threshold values for high fuel indices were set to be: calorific value ≥19.5 kg/m², ash content <1.5%, moisture content <25%, bulk density ≥320 kg/m³, carbon content ≤48%, sulfur ≤0.15%, nitrogen ≤0.8%, hydrogen ≥6.0%, and oxygen ≤40%. The result of the proximate analysis showed that the calorific values of *Milicia excelsa* and *Triplochiton scleroxcylon* were 94.9 and 10.9 kg/m², Ash content was 3.3% and 6.1%, with moisture contents of 6.0% and 6.7%, respectively. Bulk densities were 17.8 and 16.2 kg/m³. Similarly, the result of ultimate analysis revealed that carbon content were 33.2% and 29.6%, sulfur content of 0.08% and 0.12%, nitrogen content of 0.57% and 0.65%, hydrogen content of 3.1% and 2.78%, and oxygen content of 24.1% and 22.7%, respectively. These results infer that both hardwood and softwood species possess favorable fuel indices and they may contribute to a cleaner environment if used sustainably. The study helps in the understanding of the fitness and efficacy of these two wood fuel species in Nigeria, also, providing insights for better fuelwood management and utilization strategies. The research therefore recommended that this methodology may be used to study more wood biomass species.

Keywords: Biomass, Wood fuel, Clean Energy, Fuel value indices

Introduction

Nigeria is endowed with both renewable and non-renewable energy sources, which include hydroelectric power and natural gas. But the governments currently rely on fossil fuels such as petroleum and gas for electricity generation. These may not be enough to meet the growing energy needs of the population. Additionally, the environmental impact of fossil fuels has become a major concern in today's energy discussions. Unlike renewable sources, fossil fuels are non-recyclable and release harmful byproducts, such as carbon (IV) oxide, without reabsorption. Issues like oil spills and increase in rate of air pollution due to fossil further worsen the situation, both in reality and in theory.

The rising demand for electricity and cleaner energy, has necessitated the researchers to turn their attention to alternative energy sources, including wood waste (biomass) (Kanekezi and Kthyon, 2006). Moreover, the provision of clean and sustainable energy, as emphasized in the 7th goal of the United Nations

doi.org/10.51459/jostir.2025.1.Special-Issue.069

Sustainable Development Goals, is fundamental to other global objectives and serves as a basis for the socio-economic advancement of nations and their citizens. This interconnection has places of interest the importance of the continuous and responsible exploitation of energy resources (Menges and Pfaffenberger, 2015; Shoaib *et al*., 2016; Olabomi 2024). Biomass consists of organic, biodegradable materials derived from plants, animals, and microorganisms, including agricultural, forestry, and municipal waste Ogunsola *et al.,* (2018). Wood biomass has become a key source of renewable energy in both advanced and developing nations and has been playing a vital role in rural energy supply. A significant portion of this potential comes from wood processing byproducts, particularly wood shavings.

Wood has become a significance fuel source and this has prompted research into optimizing wood selection and combustion processes to maximize energy output (Zelinka *et al.,* 2022). Wood properties such as moisture content, calorific value, ash content, density, and specific gravity have been studied through empirical observation to determine which wood species perform best as fuels (Glass and Zelinka, (2021)). Additionally, metrics like fuel value index (FVI) and combustion efficiency, derived through numerical calculations, has been studied to rank wood species according to their suitability Evbuomwan and Okorji, (2018). The FVI accounts for multiple factors, weighing both positive and negative attributes.

Several characteristics such as flame type and duration, coal formation, smoke emission, ignition ease, flavor imparted to food, and ash residue influence the choice of wood for fuel. Researchers have used statistical tools such as Pearson's correlation coefficient, Spearman's rank correlation, and one-way ANOVA to analyze relationships between these properties. These analyses, were conducted manually or with application software like SPSS, and have proven highly effective even for byproducts like sawdust.

Wood fuel is abundant and locally accessible and may be a reliable energy source when harvested sustainably. Wood originates from diverse sources such as forests, woodlands, processing byproducts, recycled wood, and processed biofuels. Communities across socio-economic levels often revert to wood energy during economic crises, natural disasters, conflicts, or fossil fuel shortages.

Wood is categorized by density into hardwood (0.6–1.2 g/cm³) and softwood (0.3–0.6 g/cm³) Lengowski *et al.,*(2020). It is essential to evaluate the FVI for the determination of biofuel efficiency, as it reflects the bioenergy potential of different species. Studies have shown that some woods exhibit higher FVIs due to their chemical and physical properties. This study therefore assesses two commonly used wood fuel species in Nigerian communities, analyzing their FVIs based on fundamental properties.

Materials and Methods

Source and Classification of Wood Samples

The hardwood (Iroko, *Milicia excelsa*) and softwood (Obeche, *Triplochiton scleroxcylon*) used in this study were sourced from the plank market (Iso Pako) in Bodija Market, Ibadan. These species were selected based on their density classifications. Softwoods are defined as having a density of 0.3–0.6 g/cm³ and hardwoods ≥1.2 g/cm³.Wood density and specific gravity indicate the amount of solid wood material per unit volume. The standard method for determining density involves calculating the ratio of dry wood weight to its green volume, known as basic density Tsoumis, (1991). While density can be expressed in various units (g/cm³, kg/m³, or lb/ft³), specific gravity is dimensionless (e.g., 0.45 rather than 0.45 g/ml) since it compares wood density to water (1 g = 1 mL). It is important to note that density values may vary significantly depending on whether measurements are based on dry weight/dry volume, green weight/green volume, or other methods.

Sample Preparation and Analysis

From each wood type, 2 kg of sun-dried shavings (sawdust) were produced. The hardwood (Iroko) sawdust was labeled Sample A, while the softwood (Obeche) sawdust was labeled Sample B. These samples were then subjected to proximate and ultimate analyses at the Multipurpose Laboratory of the Federal College of Animal Health and Production Technology, Ibadan, Nigeria.

Proximate Analysis

In this study, proximate analysis was used to evaluate the key parameters in assessing biomass fuel quality. These parameters include (i) moisture Content (%), which affects combustion efficiency lower moisture (<20%) improves ignition and heat output. (ii) Ash Content (%) indicates inorganic residue; high ash (>5%) reduces fuel quality by causing boiler clogging and heat loss. It is worthy to note that lower values of Moisture and Ash improve combustion (iii) Calorific Value (MJ/kg) that measures energy content; the higher calorific values show enhancement of Fuel Value Index (FVI). (Hardwoods: 18–22 MJ/kg; softwoods: 16–20 MJ/kg) enhance Fuel Value Index (FVI). And (iv) Bulk Density (kg/m³) that determines the fuel compactness; the denser fuels burn longer and are more energy-efficient for storage/transport. Higher values of both Calorific Value and Bulk Density increase energy output and practicality. (Vasileiadou, 2021). These properties influence the Fuel Value Index (FVI).

Ultimate Analysis

The ultimate analysis was employed to determine the elemental composition of Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulfur (S) of the biomass produced from the samples, which indirectly impacts fuel quality (Baqir *et al*., 2019; Racero-Galaraga *et al*., 2024). Although not part of the standard FVI formula but elemental composition influences combustion behavior: The FVI integrates these properties to rank biomass fuel efficiency as shown in equation (1) (Sadiku *et al*., 2016; Islam *et al*., 2019).

$$\text{FVI} = \frac{\text{Calorific Value} \times \text{Bulk Density}}{\text{Moisture Content} \times \text{Ash Content}} \quad (1)$$

Analytical Methodology

Proximate and ultimate analyses were performed on 2 kg sawdust samples from each selected wood species to evaluate their fuel properties. The proximate analysis determined moisture content, ash content, calorific value, and bulk density, while the ultimate analysis quantified the elemental composition (Carbon [C], Oxygen [O], Hydrogen [H], Nitrogen [N], and Sulfur [S]). Although elemental composition is not directly included in standard Fuel Value Index (FVI) calculations, it is inevitability since it provides critical insights into why certain fuels perform better than the other. (Leach *et al.,* 2022). Moreover, the combination of proximate and ultimate analyses gives comprehensive fuel characterization, this is because elemental composition indirectly affects combustion efficiency, emissions, and energy output (Baqir *et al.,* 2019; Racero-Galaraga *et al.,* 2024). For this study, the threshold values for optimal fuel performance were set as: Calorific value ≥19.5 MJ/kg content <1.5% Moisture content <25% Bulk density ≥320 kg/m³ Carbon ≤48%, Sulfur ≤0.15%, Nitrogen ≤0.8% Hydrogen ≥6.0%, Oxygen ≤40%

Analytical Methods

Moisture Content of the Tested Sample

%Moisture was calculated using equations (2-4)

$$\%DM = \frac{w_3 - w_o}{W_1 - w_o} \times 100\ \% \quad (2)$$

$$\%Moisture = \frac{w_3 - w_o}{W_1 - w_o} \times 100\ \% \quad (3)$$

Therefore

$$\%Moisture = 100 - DM \quad (4)$$

Where

w_o is the weight of empty crucible w_1 + weight of empty crucible + sample

w_3 is the weight of empty crucible +oven dried sample DM+ dried sample

Ash Content of the Tested Sample

$$Ash\ Content = \frac{weight\ of\ \ oven\ dried\ Ash}{initial\ weight\ of\ Ash} \times 100\% \qquad (5)$$

The calorific value of the tested sample was determined by measuring the temperature rise produced by the sample and comparing it to the known temperature rise generated by standard benzoic acid. Similariy, the Bulk density of the tested samples was calculated by dividing the oven-dried weight of the sample by its original (pre-drying) volume

Ultimate Analysis of the Tested Samples

The Carbon and Hydrogen contents of the tested sample were determined by measuring the amounts of CO_2 and H_2O absorbed during analysis as shown in (Eqn. 6–7).

$$\%Carbon = \frac{a\times 0.2727}{weight\ of\ sample} \times 100\% \qquad (6)$$

$$\%Hydrogen = \frac{b\times 0.1117}{weight\ of\ sample} \times 100\% \qquad (7)$$

Where a and b are quantities of CO_2 and H_2O respectively

Nitrogen was analyzed via the Micro-Kjeldahl method (Ates and Kaya, 2021).

Results and Discussion

The findings presented in this section compare the fuel properties of Iroko and Obeche sawdust based on the above analyses. Figures 1 and 2 represent the bar chart plot of proximate and ultimate analysis of the tested samples, respectively. The proximate analysis revealed that the calorific values of *Milicia excelsa* and *Triplochiton scleroxcylon* were 94.9 and 10.9 kg/m², respectively. The ash content of the tested samples was 3.3% and 6.1%, and the moisture contents were 6.0% and 6.7%, respectively. The obtained results with high calorific values of Milicia excelsa, greater than the threshold value, with the ash content within the values, implies that the hardwood may enhance FVI (Vasileiadou, 2021). Bulk densities were 17.8 and 16.2 kg/m³. These may be an indicator for good quality of fuel. The ultimate analysis also revealed the carbon content of the tested samples to be 33.2% and 29.6%, sulfur content of 0.08% and 0.12%, nitrogen content of 0.57% and 0.65%, hydrogen content of 3.1% and 2.78%, and oxygen content of 24.1% and 22.7%, respectively. These results indicate that both the selected hardwood and softwood species may possess favorable fuel indices, suggesting they can contribute to a cleaner environment if used sustainably.

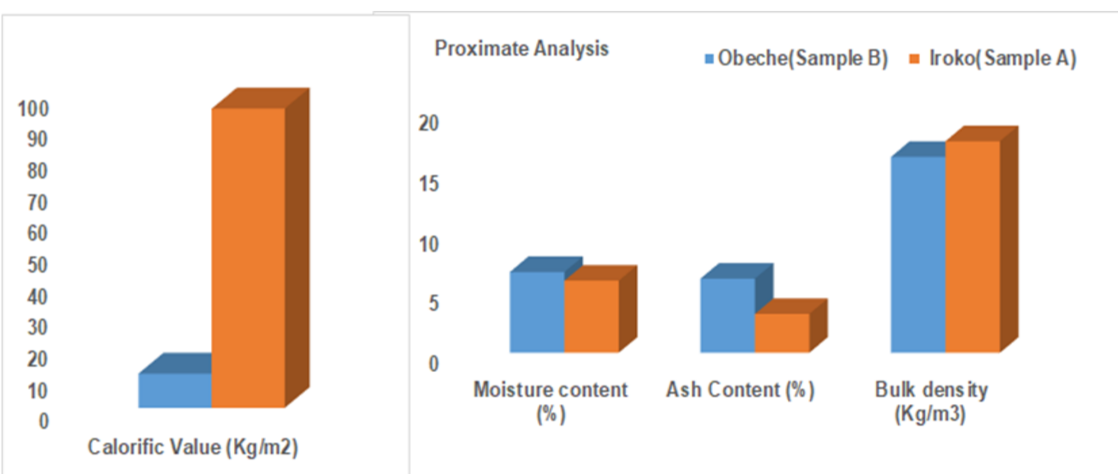

Figure 1. The Proximate Analysis of both iroko and Obeche

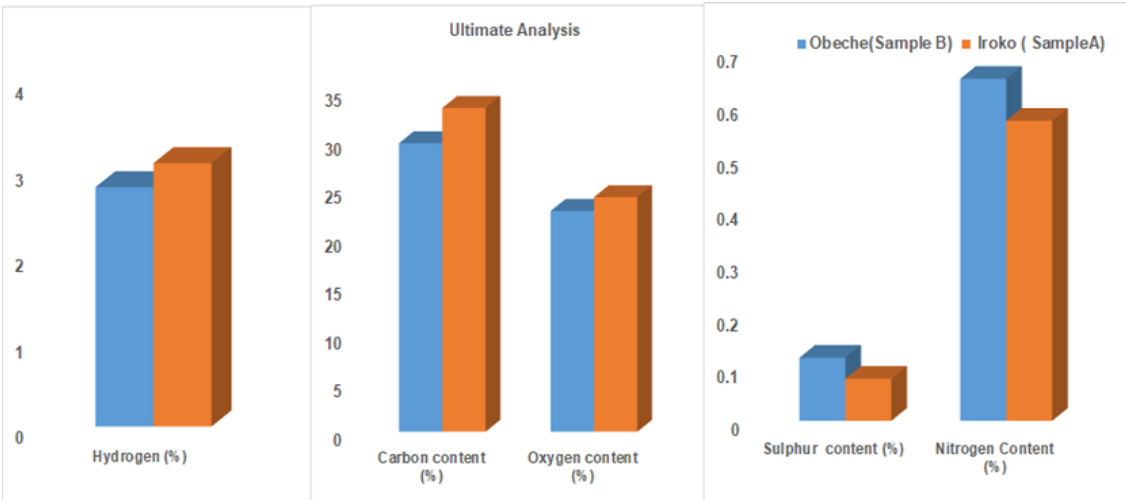

Figure2. The ultimate analysis of both iroko and Obeche

Conclusion

This study evaluates the fuel value indices (FVI) of selected wood fuel species in Nigeria, focusing on the hardwood *Iroko* (Milicia excelsa) and softwood *Obeche* (Triplochiton scleroxcylon). Proximate and ultimate analyses were conducted on 2kg samples of sawdust (Biomass) from each species to determine their moisture content, ash content, and calorific value, bulk density, the percentage quantity of composition of Carbon (C), Oxygen (O), Hydrogen (H), Nitrogen (N) and Sulphur (S) respectively. These results indicate that both hardwood and softwood species possess favorable fuel indices, suggesting they can contribute to a cleaner environment if used sustainably. The study helps enhance understanding of the suitability and efficiency of different wood fuel species in Nigeria, providing insights for better fuelwood management and utilization strategies. The research recommends using this methodology to study more wood biomass species.

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