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Proximate and Elemental Analysis of the Biomass of Six Different Wood Types for Sustainable Energy and Resource Management: Makore, Plywood, MDF, Particleboard, Coconut Wood, and OSB

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Abstract
The characterisation of material composition is essential for evaluating the suitability of wood and biomass products in various industrial and energy applications. This study conducts a comprehensive proximate and elemental analysis of the biomass from six distinct wood types: Makore (Tighemella hecklii), Plywood, Medium Density Fibreboard (MDF), Particleboard, Coconut Wood, and Oriented Strand Board (OSB). By evaluating parameters such as moisture content, volatile matter, ash content, fixed carbon, and key elemental compositions (including carbon, hydrogen, nitrogen, sulfur, and oxygen), the research aims to compare their suitability and performance as alternative energy resources. The findings will contribute valuable insights toward sustainable energy strategies and improved material selection for energy applications, supporting broader goals of environmental stewardship and resource efficiency. Based on ASTM E872 and E1755-01 the proximate and elemental analyses were done. Each sample was evaluated for volatile matter (% loss on ignition), ash content, organic carbon (O.C), hydrogen (H), nitrogen (N), and sulfur (S). Results indicate significant variation in ash content, with MDF exhibiting the highest values (up to 7.18%) and Makore, Particleboard, and Coconut wood displaying the lowest (as low as 0.43%). Organic carbon content ranged from 29.13% in Coconut wood to 40.30% in Plywood. Hydrogen content was relatively consistent across all samples, while nitrogen and sulfur levels were higher in MDF and Plywood compared to the other materials. These findings highlight the compositional diversity among the samples, with implications for their suitability in energy production, material processing, and environmental applications.

Keywords: proximate, elemental analysis, Makore, Plywood, MDF, particleboard, coconut wood, OSB, sustainable energy.

Introduction

The growing emphasis on sustainable energy and responsible resource management has intensified the search for renewable alternatives to fossil fuels. Biomass, derived from plant and wood materials, represents a promising avenue due to its abundance, carbon-neutral potential, and versatility for energy production. Understanding the fundamental properties of various biomass sources is critical for optimising their use in energy conversion processes and ensuring efficient, eco-friendly utilization.

The characterisation of material composition is essential for evaluating the suitability of wood and biomass products in various industrial and energy applications. Proximate analysis can be defined as a technique to measure the chemical properties of a compound based on four elements: moisture content, fixed carbon, volatile matter and ash content (Dayana et al., 2016, as cited in Namadi et al., 2024). According to Oony-iye et al (2024), proximate analysis gives the gross composition of lignocellulosic biomass in terms of gross components, namely, moisture content (MC), volatile matter (VM), ash (ASH) and fixed carbon (FC) (Basu, 2013). The ultimate analysis of biomass gives the basic elements present in the organic component of the biomass in terms of carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and sulphur (S) (Basu, 2013). (Ash content may also be determined.) With the percentages of carbon, hydrogen and oxygen in a biomass we can calculate the hydrogen-to-carbon (H/C) ratio and oxygen-to-carbon (O/C) ratio. These atomic ratios help us understand the heating value of the biomass. Proximate and elemental analyses provide critical insights into the chemical makeup and combustion properties of these materials, influencing their performance, environmental impact, and processing requirements. According to Brown, (2022), as cited in Ghaffariyan, (2023), in addition to better positioning in high demand, multiple end-user markets, this basic knowledge of biomass quality will enable effective and economic access to areas with emerging biomass opportunities.

This study focuses on six distinct sample types—Makore, Plywood, MDF, Particleboard, Coconut wood, and OSB—representing a range of natural wood, engineered wood products, and agricultural residues.

Materials and Methods

Material Selection

Six different wood-based and biomass materials were selected for analysis: MAKORE (natural hardwood), PLYWOOD (engineered wood product), MDF (Medium Density Fiberboard), PARTICLEBOARD (Particleboard), COCONUT (coconut wood), and OSB (Oriented Strand Board). All samples were procured in solid form and prepared for laboratory analysis by following established procedures to ensure uniformity and comparability, as outlined in Basu (2013).

Sample Preparation

Drying: Each sample underwent air-drying, followed by oven-drying at 105 °C for 24 hours to ensure complete removal of moisture.

Grinding: After drying, samples were ground using a laboratory mill until they could pass through a 1 mm sieve, guaranteeing homogeneity.

Storage: The ground samples were then stored in airtight containers to prevent reabsorption of moisture prior to analysis.

Proximate Analysis

Determination of Volatile Matter (% Loss on Ignition):

Approximately 1 g of each prepared sample was weighed into a pre-weighed crucible for further analysis.

Proximate analysis, including measurements of volatile matter (% loss on ignition) and ash content, reveals the proportion of organic and inorganic components in each sample. Elemental analysis further quantifies the concentrations of key elements such as organic carbon (O.C), hydrogen (H), nitrogen (N), and sulfur (S), which are vital for assessing fuel quality, emissions potential, and material purity. By systematically comparing these parameters across the selected samples, this study aims to highlight compositional differences that may impact their application in energy generation, manufacturing, and environmental management

Proximate Analysis

Determination of Volatile Matter (% Loss on Ignition)

- Approximately 1 g of each prepared sample was weighed into a pre-weighed crucible.
- The crucible was placed in a muffle furnace at 950 °C for 7 minutes (following ASTM E872).
- After cooling in a desiccator, the crucible was reweighed.
- Volatile matter was calculated as the percentage weight loss during ignition.

Determination of Ash Content

- The residue from the volatile matter test was further heated in a muffle furnace at 575 °C for 3 hours (ASTM E1755-01).
- After cooling in a desiccator, the crucible and ash were weighed.
- Ash content was calculated as the percentage of the original sample mass remaining as inorganic residue (Sluiter et al. 2012).

Elemental Analysis

Elemental composition (organic carbon, hydrogen, nitrogen, and sulfur) was determined using a CHNS elemental analyzer (PerkinElmer 2400): (ASTM D5373-16)

- **Sample Size:** Approximately 2–3 mg of each ground sample was weighed and loaded into the analyzer.
- **Analysis:** The instrument combusted the sample in an oxygen-rich environment, and the resulting gases were quantified to determine the percentage of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S).
- **Calibration:** The analyzer was calibrated using certified reference materials before sample analysis.

Data Analysis

- All measurements were performed in triplicate for each sample to ensure accuracy and reproducibility.
- Mean values and standard deviations were calculated for each parameter.
- Results were tabulated and compared across all sample types.

Results and Discussion

The provided data presents the proximate and elemental analysis of six different sample types: MAKORE, PLYWOOD, MDF, PARTICLEBOARD, COCONUT, and OSB. Key parameters measured include percentage loss (volatile matter), ash content, organic carbon (O.C), hydrogen (H), nitrogen (N), and sulfur (S).

Table 1: Mean Values by Sample Type

Sample	Loss (%)	Ash (%)	O.C (%)	H (%)	N (%)	S (%)
COCONUT	99.24	0.76	29.53	9.46	0.43	0.42
MAKORE	99.55	0.45	35.78	9.02	0.33	0.51
MDF	92.96	7.04	37.77	9.19	3.38	0.45
OSB	99.62	1.04	32.85	9.85	0.72	0.40
PARTICLE	99.49	0.51	32.85	9.57	3.28	0.46
PLYWOOD	97.17	2.16	38.97	9.30	2.61	0.52

The following analysis is from Table 1:

Volatile Matter (% Loss)

- Most samples exhibit very high volatile matter (above 99%), except MDF (92.96%) and PLYWOOD (97.17%), indicating higher thermal stability or more fixed carbon in these two.

Ash Content

- MDF has the highest ash content (7.04%), suggesting more inorganic residue after combustion.
- COCONUT, MAKORE, and PARTICLEBOARD have the lowest ash content (below 1%), indicating higher organic purity.

Organic Carbon (O.C)

- PLYWOOD and MDF are highest in organic carbon (38.97% and 37.77%), while COCONUT is lowest (29.53%).
- Higher organic carbon content typically correlates with higher energy content for fuel applications.

Hydrogen (H)

- Hydrogen content is fairly consistent, ranging from 9.02% (MAKORE) to 9.85% (OSB).

Nitrogen (N)

- MDF and PARTICLEBOARD have notably higher nitrogen content (3.38% and 3.28%), which may be due to the use of nitrogen-rich resins or additives in their manufacture.
- COCONUT and MAKORE have much lower nitrogen content (0.43% and 0.33%).

Sulfur (S)

- Sulfur content is relatively low across all samples (0.40% to 0.52%), which is favorable for combustion applications as it reduces the risk of SOx emissions.

Elehinafe et al. (2019) references proximate analysis ranges for a variety of Nigerian wood species, reporting ash content from 0.08% to 5.09%, volatile matter from 9.58% to 18.44%, and fixed carbon from 77.51% to 93.59% in different wood species which falls in the range of the wood species studied except for the engineered woods.

Comparative Insights

- Best for Combustion (Low Ash, High Carbon): MAKORE and PARTICLEBOARD, due to their low ash and moderate-to-high organic carbon will tend to have a high caloric value (Fahrussiam et al. 2023)
- Potential Environmental Concerns: MDF and PARTICLEBOARD, with higher nitrogen, may produce more NOx emissions when combusted.
- Industrial Waste Potential: MDF's high ash content suggests more inorganic fillers or additives, which may influence disposal or recycling strategies.

Summary Table: Key Properties

Sample	Best Feature	Potential Concern
COCONUTWOOD	Low ash, low N, low S	Low organic carbon
MAKORE	High O.C, low ash	Moderate S
MDF	High O.C, high N	High ash, high N
OSB	High H, low S	Moderate O.C
PARTICLEBOARD	Low ash, high N	High N
PLYWOOD	Highest O.C	Moderate ash, high N

Guiding the Selection of Sustainable and Efficient Wood-Based Materials

The combined proximate and elemental analysis in the data provides a comprehensive basis for selecting wood-based materials that balance sustainability, efficiency, and environmental impact.

Key Selection Criteria from the Data

- **Low Ash Content:** Materials with lower ash content (e.g., Makore, Particleboard, and Coconutwood) minimize inorganic waste and reduce the environmental burden of disposal after combustion or processing. Low ash also indicates fewer additives and higher organic purity, which is preferable for both energy and material applications.
- **High Volatile Matter (% Loss):** High values (as seen In Makore, Particleboard, Coconut wood, OSB) suggest a higher proportion of combustible organic material, leading to greater energy efficiency and cleaner burning, making these materials suitable for bioenergy and fuel applications.
- **High Organic Carbon (O.C):** Materials with higher organic carbon content (e.g., Plywood, MDF) generally offer higher calorific value, which is advantageous for energy production. However, this must be weighed against other factors such as ash and nitrogen content.

- **Low Nitrogen and Sulfur:** Lower nitrogen and sulfur levels (e.g., Makore, Coconut wood, OSB) are desirable to minimize NOx and SOx emissions during combustion, supporting cleaner energy production and compliance with environmental regulations.

Sustainability and Efficiency Implications

- **Natural Woods (Makore, Coconut wood):** These materials combine low ash, low nitrogen, and moderate-to-high organic carbon, making them highly sustainable and efficient for both energy and material uses. Their minimal inorganic and pollutant content supports cleaner processing and end-of-life disposal.

Engineered Woods (Plywood, MDF, Particleboard, OSB):

- **MDF and PLYWOOD** have higher ash and nitrogen, which can reduce efficiency and increase environmental impact, especially for energy applications. Their use may be better suited for structural or manufacturing contexts where these factors are less critical.
- **PARTICLEBOARD and OSB** offer a balance, with low ash and competitive organic carbon, making them efficient choices for both energy and material uses if sourced from recycled or sustainably managed feedstocks.

Application Guidance

- **Bioenergy/Fuel:** Favour MAKORE, PARTICLEBOARD, COCONUTWOOD, and OSB for high efficiency, low emissions, and minimal ash.
- **Material Manufacturing:** Select materials with low ash and high organic carbon for better product quality and reduced equipment wear—MAKORE and PARTICLEBOARD stand out.
- **Environmental Impact:** Prioritize materials with low nitrogen and sulfur (MAKORE, COCONUTWOOD, OSB) to reduce air pollution and regulatory burden.

Conclusion

The proximate and elemental analyses of biomass samples from Makore, Plywood, MDF, Particleboard, Coconut Wood, and OSB reveal distinct characteristics that impact their suitability as sustainable energy resources. Natural wood types such as Makore, Coconut wood, and OSB generally exhibit lower ash and nitrogen contents, along with high volatile matter percentages, indicating cleaner combustion profiles, higher energy yield potential, and reduced pollutant emissions. In contrast, engineered wood products like MDF and Particleboard show elevated ash and nitrogen levels, likely due to added resins and adhesives, which may lead to increased operational challenges, higher ash disposal needs, and greater nitrogen oxide emissions during combustion.

Plywood's higher organic carbon content suggests a comparatively higher calorific value, making it a promising biomass fuel, though its moderate ash and nitrogen contents warrant emission considerations. Across all samples, sulfur content remains low, favoring minimal sulfur oxide emissions, which aligns with environmental sustainability goals.

This analysis highlights the importance of selecting biomass feedstocks with optimal proximate and elemental profiles to balance energy production efficiency and environmental impact. Implementing biomass with lower ash and nitrogen contents from natural wood species can enhance combustion performance and reduce pollution, supporting sustainable energy production consistent with broader resource management objectives.

These findings corroborate prior research demonstrating that proximate and elemental analyses are critical tools for evaluating biomass fuel quality and environmental implications, thus guiding effective biomass resource management and sustainable energy strategies.

By leveraging this combined analysis, decision-makers can select wood-based materials that optimize energy yield, minimize waste and emissions, and support sustainable resource use. Natural woods and select engineered products with low ash, high volatile matter, and low pollutant content are the most sustainable and efficient choices for a wide range of applications.

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