UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(1), March (2024), 573-583
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Comprehensive Analysis of Thatch Grass from Southeastern Nigeria for Sustainable Particleboard Production

Harold Chukwuemeka Godwin[1] and Hillary Ejike Chukwu[2]*

[1]Industrial/Production Engineering Department, Faculty of Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

[2]Advance Manufacturing Technology Center, Scientific Equipment Development Institute, SEDI, Okpara Mine Road, Akwuke, Awkunanaw, Enugu, Nigeria

* Email: chukwuhillaryejike@gmail.com

Abstract

This study presents an investigation into the viability of thatch grass as a sustainable raw material for particleboard production. The transition from traditional thatch to modern roofing materials has resulted in environmental challenges, including increased wildfire risks. The key objectives of the study was to investigate the suitability of hyparrhenia grass for sustainable particleboard production. Proximate analysis, following ASTM standards, was employed to assess moisture, ash, volatile matter, and fixed carbon content. Density was determined using a Pycnometer. The study encompassed samples from five Southeastern Nigerian states, employing triplicate analyses for each parameter. The study contributes to regional industrial development and aligns with sustainable development goals; while emphasizing ecological and economic benefits. The methodology involves proximate analysis and density assessment, employing standardized protocols for moisture, ash, volatile matter, and fixed carbon content determination. Moisture content falls within ASTM E871-82(2019) standards, validating suitability for particleboard production. Ash content ranges from 2.238% to 2.837%, indicating potential compatibility with particleboard production standards. Volatile matter content (75.565% to 77.761%) aligns with biomass material standards, supporting suitability. Fixed carbon content falls within the range of 16.338% to 18.305%, meeting ASTM D3172-13 (2021)e1 standards. Bulk density ranges from 0.820 g/ml to 0.848 g/ml, complying with ASTM E873-82 (2019) standards for biomass materials. Results indicate that hyparrhenia meets ASTM standards for particleboard raw materials, showcasing promising characteristics. The findings advocate for the ecological and economic benefits of hyparrhenia-based particleboard, addressing environmental threats and contributing to regional industrial development. Collectively, these findings underscore the potential of thatch grass as a promising and sustainable resource for particleboard production. The alignment with established standards in key properties, coupled with its regional abundance, positions thatch grass as a viable and environmentally friendly alternative for particleboard production. Further exploration and development in this direction could contribute to the expansion of biomass resources in the particleboard industry, fostering economic and ecological sustainability.

Keywords: Thatch Grass, Biomass, hyparrhenia, Particleboard, Sustainable development.

1. Introduction

Vast regions of land in Nigeria and various parts of Africa are abundantly covered by certain species of grasses known as hyparrhenia (Hyparrhenia, n.d., Para. 1). Historically, these grasses have been employed for thatching of building roofs, showcasing their inherent relevance to traditional construction practices (Hyparrhenia, n.d., Para. 2). However, the advent of modernization has witnessed the gradual displacement of thatch grass by contemporary roofing materials such as corrugated aluminum, zinc sheets, and asbestos (Types of roofing sheets, 2023).

Consequently, this shift has marginalized the once-prevalent thatch grass, rendering it less useful and, unfortunately, contributing to the heightened risk of wild fires (ScienceDaily, 2019).

The implications of this shift are not only environmental but extend to posing a threat to the delicate ecosystem. Bush burning, often initiated by the accumulation of neglected thatch grass, has severe repercussions on the environment, agricultural productivity, public infrastructure, and human life and livelihood. Recognizing the urgency of addressing these challenges, we propose the utilization of hyparrhenia as the preferred material for the production of particleboard—a sustainable solution aligned with the United Nations Sustainable Development Goal (UNDP, 2018).

According to Hassan (2019), as an engineered wood product, Particleboard finds extensive use in the production of furniture and various interior facilities. Notably, particleboards currently available in the market are predominantly imported into Nigeria (Abdulkareem & Adeniyi, 2016). The demand for particleboard in the country is driven by factors such as the need for a fine surface finish, lightweight properties, and cost-effectiveness compared to other engineered wood products like plywood (Types of roofing sheets, 2023).

Thatch grass, with its unique characteristics, presents an opportunity for a paradigm shift in the particleboard industry (Thatching, n.d.). Unlike wood waste, thatch grass is less dense and offers higher renewable value. Therefore, the proposed production of particleboard from thatch grass holds the potential for several advantages, including improved product quality with an enhanced strength-to-weight ratio, reduced dependence on wood waste, and a consequent reduction in the overall cost of raw materials and finished products (Hassan, 2019).

This paper advocates for the utilization of hyparrhenia grass in particleboard production as a sustainable alternative solution to wood based particleboards to counteract the diminishing significance of traditional thatch grass in construction practices. Conduct a thorough analysis of hyparrhenia grass, examining its moisture, ash, volatile matter, fixed carbon content, and density to determine its feasibility for particleboard production. Ensure that the proposed solution aligns with United Nations Sustainable Development Goals, specifically targeting environmental concerns related to the neglect of traditional thatch grass, while contributing to sustainable economic practices.

The proposed solution of particleboard production from hyparrhenia grass aims to address this dual challenge. By repurposing hyparrhenia, which has historical relevance in traditional construction, as a raw material for particleboard, the study seeks to revitalize the importance of this grass in a contemporary context. This approach not only mitigates environmental threats associated with neglected thatch grass but also aligns with sustainable development goals by introducing an economically viable and ecologically sound alternative to conventional construction materials. Particleboard production from hyparrhenia grass emerges as a holistic solution that bridges the gap between cultural heritage, environmental preservation, and economic development in the region.

2.0 Material and Methods

In conducting proximate analysis, standard methods protocols were adhered to, ensuring methodological consistency (Onyeonagu & Eze, 2013).

2.1 Precautions, Safety and Accuracy

Using a muffler furnace at high temperatures, such as 900 degrees Celsius, requires careful attention to safety to prevent accidents and ensure a secure working environment. Here are some safety precautions observed: wearing of Personal Protective Equipment (PPE), ensure training and knowledge of equipment used, ensure ventilation within work environment, provision of fire safety equipment, communicate emergency procedures to all involved, monitoring set out temperatures, equipment inspection and maintenance, isolation and lockout/tagout procedures during maintenance, ensure proper material handling, clear communication, protective barriers and provision and equipping of first aid box.

However, to ensure accuracy in the measurements for Proximate Analysis and for density, a representative and homogenous sample were prepared. The use of the right analytical techniques for proximate analysis, such as moisture content, ash content, volatile matter, and fixed carbon were employed. Instruments were calibrated regularly and validated using certified reference materials. Quality control samples were included in each batch of analyses. Temperature and humidity were controlled and monitored during sample preparation and analysis, as these factors can influence the moisture content and other proximate components. Duplicate analyses on a subset of samples were performed to assess precision and consistency. Appropriate method for density measurement were chosen which is pycnometry. Density measurement instruments was calibrated regularly using standard known density. The temperature was control and monitor during density measurements. Samples were handled carefully to avoid introducing air bubbles or other artifacts that could affect density measurements. The stability of the density measurement instrument was checked and verified before each use. Calibration certificates for the density measurement equipment was maintained and referenced during measurement. Data obtained were clearly reported.

2.2.1 Determination Moisture Content

The ASTM E871 standard test method is employed for determining the moisture content in the thatch grass. The procedure involves using specific equipment like a crucible, analytical balance, muffler furnace, and desiccator (Abdul et al., 2012). The process includes sample preparation by grinding, weighing the crucible, $\mathbf{W_1}$ then weighing the crucible and about 2g of the initial sample together, $\mathbf{W_2}$, then drying in a muffler furnace at 107°C in intervals of time until a constant weight is achieved, cooling in a desiccator, and then re-weighing the crucible and sample to obtain $\mathbf{W_3}$ to calculate the moisture content using a specified formula as stated below:

$$\text{Moisture Content, QML } (\%) = \frac{W_2 - W_3}{W_2 - W_1} \text{ x } 100 \qquad (1)$$

Equipment and Materials used are Crucible, Analytical Balance, Muffler Furnace, Desiccator (for cooling) and Sample of thatch grass.

2.2.2 Determination of Ash Content

To determine the ash content of thatch grass intended for particleboard production, a laboratory procedure involving specific materials and equipment was employed. The procedure includes weighing a clean, dry crucible **(W_1)** and adding about 2g of the sample. Heating the crucible with the sample to remove moisture and weighing it again **(W_2)**. Placing the crucible with the dried sample in a muffle furnace, gradually increasing the temperature to 600 degrees Celsius to ash the sample completely. Allowing the crucible with the ashed sample to cool in a desiccator and weighing it **(W_3)**. The ash content is determined using a specific formula. The procedure ensures accurate analysis of the ash content in preparation for particleboard production.

$$\text{Ash Content} = \frac{W_3 - W_1}{W_2 - W_1} \text{ x } 100 \qquad (2)$$

Equipment and Materials used are Crucible, Analytical Balance, Muffler Furnace, Desiccator (for cooling) and Sample of thatch grass.

2.2.3 Determining the Volatile Matter Content

To determine the volatile matter content in Thatch Grass for particleboard production, a proximate analysis was conducted, breaking down the material into its components (Volatile matter values, n.d.). The procedure involves. Weighing a clean, dry crucible **(W_1)** and adding about 2g of the sample. Heating the crucible with the sample to remove moisture and weighing it again **(W_2)**. Placing the crucible with the dried sample in a muffle furnace, gradually heating to 900 degrees Celsius for four hours to volatilize volatile matter. The remaining material is allowed to cool in a desiccator. Weighing the crucible with the residue after volatilization **(W_3)**. Determining the volatile matter content using a specific formula. This process ensures accurate analysis for particleboard production.

$$\text{Volatile Matter} = \frac{W_2 - W_3}{W_2 - W_1} \text{x } 100 \qquad (3)$$

Equipment and Materials used are Crucible, Crucible Cover, Analytical Balance, Muffler Furnace, Desiccator (for cooling) and Sample of thatch grass.

2.2.4 Determination of Fixed Carbon Content

The fixed carbon content of a thatch grass material was determined by subtracting the sum of moisture content (M), volatile matter (VM), and ash content from 100%. The fixed carbon represents the carbonaceous residue remaining after removing moisture, volatile matter, and ash. The calculation is done using the formula:

$$\text{Fixed Carbon (\%)} = 100\% - (\text{Moisture (\%)} + \text{Ash (\%)} + \text{Volatile Matter (\%)}) \qquad (4)$$

Plugging in the values obtained for moisture content, volatile matter, and ash content allowed for the calculation of the fixed carbon content of the thatch grass material. The result is presented below.

2.2.5 Determination of Density

The specific density was determined through these procedure; thoroughly wash a 50ml pycnometer bottle with detergent water, and petroleum ether, and dry in the oven at temperature 105^{0}C then Fill the bottle with the thatch grass sample and weigh

$$\text{Density} = \frac{\text{Weight of sample (g)}}{\text{Volume of pycnometer (ml)}} \text{x } 1000 = \frac{\text{kg}}{\text{m}^3} \qquad (5)$$

Equipment and Materials used are pycnometer bottle, detergent, water, petroleum ether, dry in the Muffler furnace and thatch grass sample and Analytical Balance.

2.3 Limitations

While conducting tests on hyparrhenia grass for particleboard production, there are several limitations encountered:

1. Sample Variability: The properties of hyparrhenia grass can vary significantly depending on factors such as location, climate, and soil conditions. This limitations were surmounted by ensuring that multiple samples were collected from various locations and seasons to capture the natural variability.

2. Seasonal Variation: The composition and characteristics of hyparrhenia grass may vary seasonally, impacting its suitability for particleboard production. Test were conducted over multiple seasons to account for variations in the composition of hyparrhenia grass.

3. Standardization Challenges: The absence of standardized testing protocols specific to hyparrhenia grass may pose challenges. Standardized testing protocols specific to wood resource were employed.

3.0 Results and Discussions

The result was derived by calculating the mean value from tests conducted on three thatch grass samples collected from five different locations within each of the five Southeastern States in Nigeria. In other words, a total of 15 thatch grass samples were collected from each state. The mean value was then calculated to provide a representative and averaged outcome for the given parameter or property being measured. This approach helps in reducing the impact of potential variations across different locations and ensures a more comprehensive understanding of the overall characteristics of the Thatch Grass across the entire region (Khan et al., 2017).

Table 1: Moisture content of Thatch Grasses from Five Southeastern States of Nigeria

Crucible	Quantity of Moisture Left, QML (%)				
	AB	AN	EB	EN	IM
A	4.104	4.078	4.093	3.834	4.078
B	3.805	3.785	4.049	4.096	3.659
C	4.132	3.873	4.012	4.028	3.868
D	3.974	3.934	3.769	4.113	4.161
E	3.799	4.015	3.907	3.766	3.793

Table 1 presents findings related to the moisture content of samples of thatch grass. The moisture content measurements were specifically conducted at a temperature of 107 degrees.

Table 2: Ash Content Thatch Grasses from Five Southeastern States of Nigeria

Crucible	Quantity of Ash, QA (%)				
	AB	AN	EB	EN	IM
A	2.274	2.557	2.462	2.502	2.508
B	2.755	2.670	2.376	2.657	2.717
C	2.573	2.619	2.752	2.442	2.837
D	2.720	2.449	2.704	2.678	2.510
E	2.494	2.556	2.737	2.749	2.238

Table 2 presents findings related to the ash content of samples of thatch grass. The ash content measurements were conducted through a specific process involving two temperature stages: first at 107 degrees Celsius until constant weight, and then at 600 degrees Celsius for four hours.

Table 3: Volatile Matter Content Thatch Grasses from Five Southeastern States of Nigeria

Crucible	Quantity of Volatile Matter, QVM (%)				
	AB	AN	EB	EN	IM
A	77.635	77.756	77.761	77.390	77.580
B	75.987	75.853	75.922	75.983	76.032
C	76.705	76.737	76.898	77.000	76.819
D	75.883	75.997	76.087	75.981	75.842
E	75.565	75.741	75.862	75.651	75.664

Table 3 presents findings related to the volatile matter content of samples of thatch grass. The volatile matter content measurements were conducted within the ASTM D5832-98 (2021) through a specific process involving two temperature stages: first at 107 degrees Celsius until constant weight, and then at 900 degrees Celsius for four hours.

Table 4: Fixed Carbon Content of Thatch Grasses from Five Southeastern States of Nigeria

Sample	Fixed Carbon Content in Samples, 100% - (Moisture Content (%) + Ash (%) + Volatile Matter Content (%))				
	AB	AN	EB	EN	IM
A	15.988	15.609	15.683	16.273	15.834
B	17.453	17.691	17.653	17.265	17.592

C	16.590	16.771	16.338	16.530	16.476
D	17.423	17.621	17.441	17.227	17.488
E	18.142	17.689	17.494	17.835	18.305

Table 4 provides data related to the fixed carbon content of samples of thatch grass.

Table 5: Density Measurement of Thatch Grasses from Five Southeastern States of Nigeria

	Density (g/ml) = Mass of Sample (g)/Volume (ml)				
Sample	**AB**	**AN**	**EB**	**EN**	**IM**
A	0.837	0.837	0.839	0.845	0.823
B	0.824	0.848	0.845	0.820	0.838
C	0.830	0.829	0.843	0.839	0.822
D	0.843	0.841	0.843	0.842	0.847
E	0.833	0.827	0.828	0.823	0.827

Table 5 provides data or findings related to the density of samples of thatch grass obtained in line with the specifications of the ASTM E873-82 (2019) for determination of bulk density of biomass materials. The density tests were conducted using a specific apparatus called a Pycnometer, and in this case, the Pycnometer used has a volume capacity of 50 milliliters.

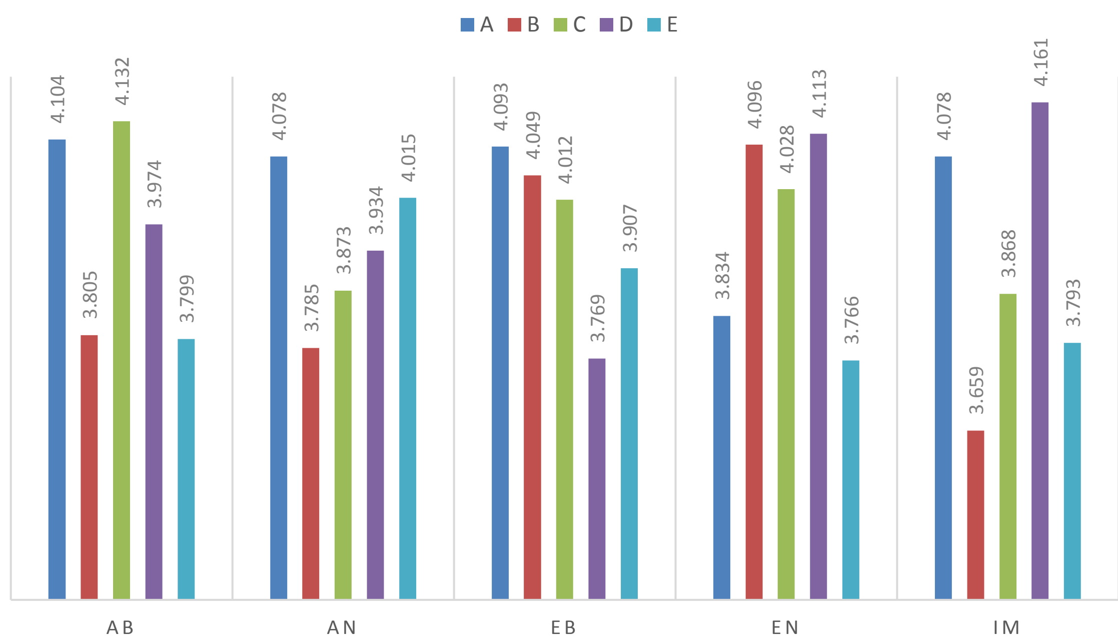

Figure 1: Moisture Content Analysis of Thatch Grasses from Five Southeastern States of Nigeria

Figure 1 illustrates the Quantity of Moisture that Left (QML, %) in thatch grass samples collected from Abia (AB), Anambra (AN), Ebonyi (EB), Enugu (EN), and Imo (IM) States. Each bar represents a different crucible labeled A, B, C, D, or E. The empirical data reveals that the moisture content of the aforementioned thatch grass falls specifically between 3.659 and 4.161. The moisture content analysis was conducted following ASTM E871-82(2019) standards, with an emphasis on pre-formed mat production for particleboard. According to the standard, an acceptable moisture content range of 0 to 5% is crucial for ensuring optimal conditions in the production process. Key observations from the graph include variations in moisture content across states and crucibles. This data is significant for biomass applications, especially in the production of particleboard, where moisture content directly impacts product quality. Understanding regional differences highlighted in this analysis is essential for tailoring production strategies to local conditions, ultimately contributing to more efficient and sustainable biomass utilization practices for particleboard production in the Southeastern States of Nigeria.

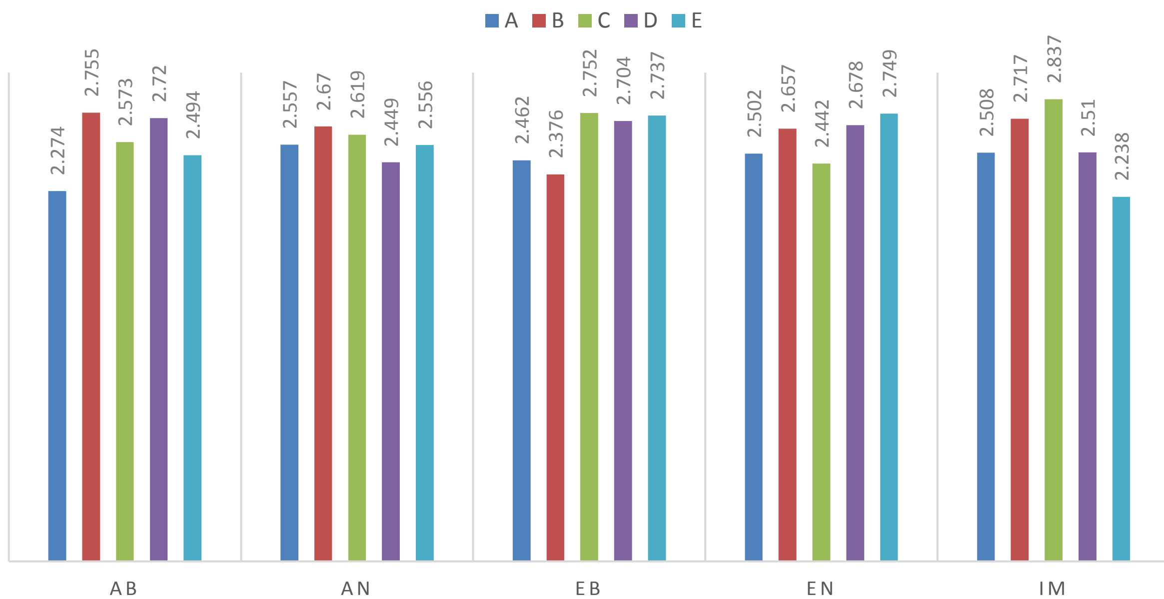

Figure 2: Ash Content Analysis of Thatch Grasses from Five Southeastern States

Figure 2 presents the Quantity of Ash (QA, %) in thatch grass samples collected from Abia (AB), Anambra (AN), Ebonyi (EB), Enugu (EN), and Imo (IM) States. Different crucibles labeled A, B, C, D, and E represent distinct samples at the same conditions. The crucible and content were heated to 107 degrees Celsius until Constant Weight, followed by further heating to 600 degrees Celsius for four hours. The ash content obtained from our analysis ranging from 2.238% as minimum to 2.837% as maximum. The analysis was conducted to align with ASTM D1102 standards, specifying permissible ash content for biomass materials subjected to 600 degrees Celsius. Notably, this standard is crucial in industries like particleboard production, where wood pellets typically exhibit an ash content of approximately 0.5%, cardoon with 17.4% and reeds with 6.1%. Understanding the ash content of biomass materials is essential for optimizing manufacturing processes and product quality. The graph illustrates variations in ash content across different states and crucibles, emphasizing the diverse composition of thatch grasses in the Southeastern region. For instance, the presented ash content ranges provide insights into potential biomass utilization, with successful particleboard production achieved using grasses with varying ash content, such as cardoon with 17.4% and reeds with 6.1%. These findings underscore the importance of regional considerations for sustainable biomass utilization and the potential adaptability of Southeastern grasses in particleboard production processes.

Figure 3: Volatile Matter Content of Thatch Grasses from Five Southeastern States of Nigeria: Measurements (%) in Crucibles A-E

Figure 3 visually represents the volatile matter content of thatch grass from Abia (AB), Anambra (AN), Ebonyi (EB), Enugu (EN), and Imo (IM) states in Southeastern Nigeria. Crucibles A to E denote different samples within each state. Volatile matter measurements were conducted using ASTM D5832-98 (2021) standards, involving a two-stage heating process to 107°C until Constant Weight, then to 900°C for four hours. The study found that volatile matter content in thatch grass falls within the typical range for lignocellulosic biomass (65-85%) (https://rsdjournal.org/index.php/rsd/article/download/20476/18598/252683 on February 3, 2024). The results, ranging from a minimum of 75.57% to a maximum of 77.76%, align with this standard. This compliance is crucial, as it ensures that the volatile matter content in the thatch grass meets the specifications for biomass materials, highlighting its suitability for sustainable applications, such as particleboard production, in line with global environmental goals.

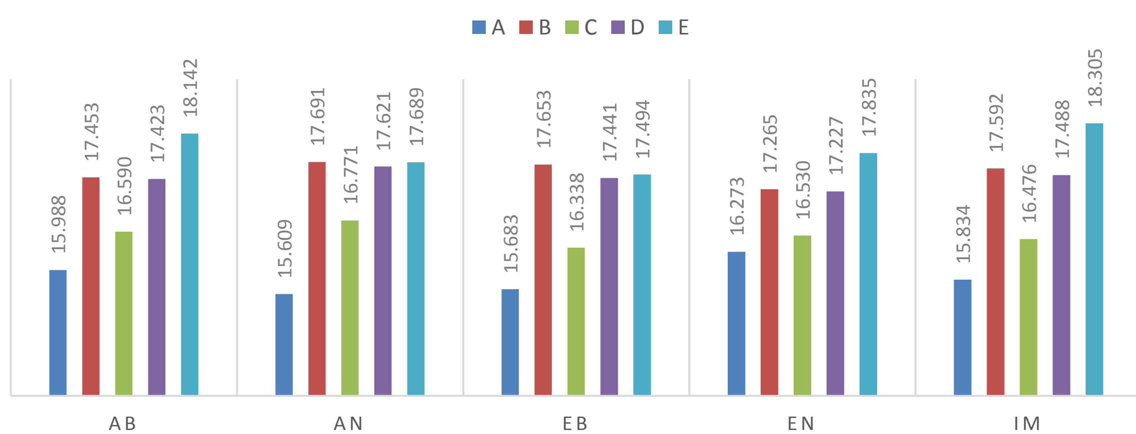

Figure 4: Fixed Carbon Content of Thatch Grasses from Southeastern Nigeria: Variability Across Samples A-E and States AB, AN, EB, EN, IM (%)

The graph visually displays the fixed carbon content of thatch grass samples from Abia (AB), Anambra (AN), Ebonyi (EB), Enugu (EN), and Imo (IM) states in Southeastern Nigeria. Samples A to E represent different specimens within each state, showcasing the range of fixed carbon content observed. The fixed carbon content was calculated following the ASTM D3172-13 (2021)e1 standard, where it is determined as the remaining percentage after deducting the percentages of moisture, ash, and volatile matter from 100%. The results highlight variations in fixed carbon content, ranging from a minimum of 16.338% to a maximum of 18.305%.

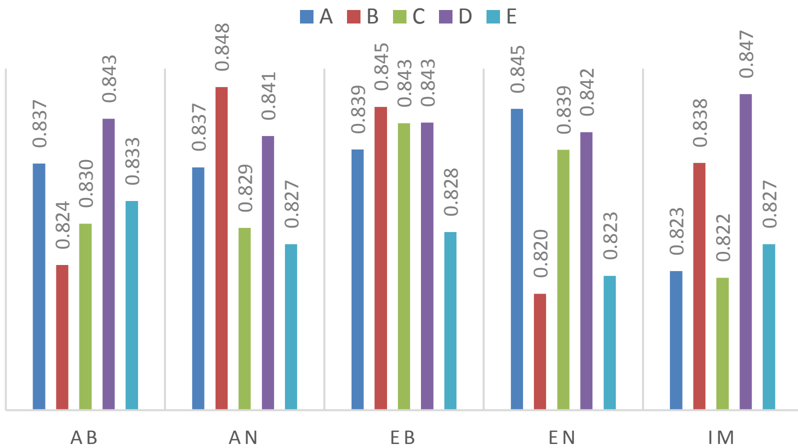

Figure 5: Density Measurement of Thatch Grasses from Southeastern Nigeria: Variation across Samples A-E and States AB, AN, EB, EN, IM (g/ml)

The graph visually illustrates the density measurements of thatch grass samples collected from Abia (AB), Anambra (AN), Ebonyi (EB), Enugu (EN), and Imo (IM) states in Southeastern Nigeria. Samples A to E represent different specimens within each state, displaying the range of density values observed. Density was calculated using the formula Density (g/ml) = Mass of Sample (g)/Volume (ml), following the specifications of ASTM E873-82 (2019) for determining the bulk density of biomass materials. The bulk density is a critical parameter in assessing the suitability of biomass materials for various applications.

The density measurements provide insights into the physical characteristics of thatch grass, aiding in determining its suitability for biomass applications such as energy generation, particleboard production, or other industrial uses. The density measurements align with the ASTM E873-82 (2019) standard, ensuring that the testing methodology follows established protocols for accurate and reliable results. This compliance is crucial for maintaining consistency in biomass testing practices. The observed density range (0.820 g/ml to 0.848 g/ml) falls within the typical bulk density range for biomass materials (approximately 400 to 850 kg/m^3). This suggests that the thatch grass from the Southeastern region holds promise for biomass utilization, aligning with sustainable development goals related to renewable energy and responsible resource management. The variations in density across different samples and states highlight the regional differences in the physical properties of thatch grass. This information can be valuable for local industries and initiatives focused on biomass utilization.

Thatch grass, emerging as a proven and sustainable source for particleboard production, holds substantial potential to contribute to several key Sustainable Development Goals (SDGs). Firstly, its utilization aligns with SDG 12 on Responsible Consumption and Production, as this renewable resource diminishes reliance on traditional wood sources, promoting sustainable practices in the manufacturing of particleboards. Secondly, the cultivation and harvesting of thatch grass, if approached sustainably, contribute to SDG 15 - Life on Land. By reducing the demand for logging and minimizing impacts on natural ecosystems, thatch grass supports the overarching goal of protecting and restoring terrestrial ecosystems, thereby fostering biodiversity conservation. Thatch grass's role extends to SDG 13 - Climate Action, as it potentially possesses carbon sequestration properties. When integrated into particleboard production sustainably, it becomes a climate-friendly alternative, aiding in the mitigation of carbon footprints associated with conventional wood-based products. Furthermore, it addresses SDG 1 and SDG 8 by providing an additional income source for communities that will be engaged in its cultivation and harvesting. This dual impact contributes to poverty alleviation and supports economic growth, particularly in rural areas where thatch grass is prevalent. The integration of thatch grass into particleboard production also aligns with SDG 9 - Industry, Innovation, and Infrastructure. Research and development into alternative materials for particleboard showcase industry innovation. This not only signifies resilience in infrastructure but also promotes sustainable industrialization, aligning with the broader goals of sustainable development. In conclusion, the adoption of thatch grass for particleboard production emerges as a multifaceted solution, addressing various Sustainable Development Goals. Its potential to foster responsible consumption, preserve biodiversity, mitigate climate impact, alleviate poverty, drive innovation, and promote sustainable resource management collectively positions thatch grass as a valuable contributor to the global sustainability agenda.

4.0 Conclusion

This study underscores the dual significance of hyparrhenia grass, or thatch grass, in Nigeria and other parts of Africa, emphasizing its environmental and cultural importance in traditional construction practices. The research advocates for the sustainable utilization of thatch grass in particleboard production, aligning with the United Nations Sustainable Development Goals (SDGs). A comprehensive proximate analysis of thatch grass is conducted, evaluating its moisture content, ash content, volatile matter content, fixed carbon content, and density, providing essential data for its potential applications. The potential applications of thatch grass in particleboard production are outlined, including the promise of improved product quality with an enhanced strength-to-weight ratio, reduced dependence on wood waste, and the potential for cost reduction in raw materials and finished products compared to conventional wood-based particleboards.

5.0 Recommendation

Recommendations for future research and practical applications focus on integrating the cultural heritage aspect of thatch grass into contemporary construction practices, optimizing production processes for efficiency and quality improvement, exploring its carbon sequestration properties, and fostering local industry collaboration to establish a domestic market for thatch grass-based particleboards, thereby supporting economic growth and sustainable practices.

Nomenclature

SDGs = Sustainable Development Goals.
ASTM = ASTM International (formerly American Society for Testing and Materials)
W_1 = Weight of empty crucible
W_2 = Weight of crucible with dried sample
W_3 = Weight of crucible with Residue
A = Sample A
B = Sample B
C = Sample C
D = Sample D
E = Sample E
AB = Abia State
AN = Anambra State
EB = Ebonyi State
EN = Enugu State
IM = Imo State

References

Abdul Khalil, H. P. S., Bhat, A. H., & Ireana Yusra, A. F. 2012. Green composites from sustainable cellulose nanofibrils: A review. Carbohydrate Polymers, 87(2), 963–979. https://doi.org/10.1016/j.carbpol.2011.08.078

Abdulkareem, S. A., & Adeniyi, A. G. 2016. Production of Particleboards using polystyrene and Bamboo wastes.

Hassan, B. B. 2019. Production and characterization of Particleboards from common agro wastes in Nigeria.

Hyparrhenia. Wikipedia, the Free Encyclopedia. Accessed January, 28, 2024, from https://en.wikipedia.org/wiki/Hyparrhenia.

Khan, R., Khan, M. N., Ullah, H., Basit, A., Razzaq, A., Ahmad, M., Zafar, M., Kilic, O., & Ozdemir, F. A. 2017. A comparative assessment of proximate and elemental composition six weedy grasses for their potential use as fodder.

Onyeonagu, C. C., & Eze, S. M. 2013. Proximate compositions of some forage grasses and legumes as influenced by season of harvest.

Thatching. Wikipedia, the Free Encyclopedia. Retrieved January, 28, 2024, from https://en.wikipedia.org/wiki/Thatching.

Types of roofing sheets in Nigeria & their prices 2023. Nigerian Price. Accessed January, 28, 2024, from https://nigerianprice.com/types-of-roofing-sheets-in-nigeria/.

United Nations Development Programme (UNDP). 2018. Goal 7: Affordable and clean Energy. https://sdgs.un.org/goals/goal7.

US national-scale study shows that invasive grasses promote wildfire. ScienceDaily. Accessed January, 28, 2024, from https://www.sciencedaily.com/releases/2019/11/191104155649.htm.

Volatile matter values change according to the standard utilized. Accessed February, 03, 2024, from https://rsdjournal.org/index.php/rsd/article/download/20476/18598/252683.