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From Waste to Resource: Banana Plant (Musa Sapientum) Stem Fibers as a Sustainable Material for Eco-friendly Fiberboard Production

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Abstract

This study explored the potential of banana stem fibers (*Musa sapientum*) as a sustainable alternative material for eco-friendly fiberboard production. The research highlighted the applicability of banana fiberboard as a composite material for furniture and construction, leveraging the fiber's inherent strength and durability. Employing a quantitative research approach with a quasi-experimental design, the study systematically collected, organized, and analyzed data to address its objectives and research questions. Researchers utilized banana stem fibers combined with epoxy resin as a bonding agent to enhance the fiberboard's strength and structural integrity. Various configurations of banana fibers were tested, revealing that layered combinations of fine and strand fibers produced the most durable and mechanically robust material. These fiberboards exhibited significantly higher tensile strength, stiffness, and stress resistance compared to fiberboards made exclusively from fine fibers, which, although functional, demonstrated weaker mechanical properties. The findings confirmed the promising characteristics of banana fiberboard, including lightweight structure, high tensile strength, flexibility, and resistance to mechanical stress, making it suitable for sustainable applications in construction and furniture manufacturing. By utilizing agricultural waste, this study not only supported environmental sustainability but also provided a cost-effective alternative to traditional fiberboard materials. This research contributed to advancing the development of eco-friendly composite materials, reducing reliance on non-renewable resources, and addressing the growing demand for sustainable industrial solutions.

Keywords: Fiberboard, Banana Fiber, Eco-friendly

Introduction

Banana stem fiber as a sustainable alternative material in fiberboard production. Fiberboard is a widely used material in construction and manufacturing that traditionally relies on wood fibers, which contributes to deforestation and depletion of natural resources. Fibreboards are easily accessible building materials that can be used for insulation, furniture, and soundproofing, among other purposes. Fibreboard research has advanced significantly to balance the practical requirements of the building industry with the emerging environmental concerns, which support the production of panels using by-products rather than adhesives(Vitrone *et al*., 2021) [25]. Additionally, the more the world seeks to balance industrial needs with environmental stewardship, the more human interest in exploring renewable and eco-friendly alternatives grows.

Coracero *et al*. (2021) [8] claim that the nation's increasing solid waste load, improper regulations implementation, lack of properly maintained landfills, and improper disposal are all components causing problems with solid waste management. The finest response from the country is the Ecological Solid Waste Management Act of 2000, also known as RA 9003, which stresses the need for waste reduction, proper disposal, and segregation. Therefore, seeking alternative materials has never been more important as environmental issues keep getting more severe and the need for sustainable practices becomes apparent. This study is motivated by the urgent need to mitigate and address the substantial ecological consequences linked to conventional materials and processes. The present environmental crisis calls for creative ideas that cut waste and minimize the total ecological damage. In this context, developing and adopting alternative materials prioritizing sustainability and efficiency is essential for achieving a more environmentally responsible future.

The banana plant stem represents a promising yet underutilized resource. Banana cultivation generates substantial agricultural waste, particularly from the stems, often discarded or burned. According to Kavitha and G (2021) [14], Banana composition affects the quantity of biomass that goes to waste; the main sources of fiber are the sections above ground, such as the peduncle and pseudo-stem. Banana fiber is used as a raw material in manufacturing tea bags, papers, tokens, and reinforced polymer composites. Natural fiber is produced in an affordable, sustainable, and environmentally responsible manner and is utilized as a resource substitute for synthetic fibers in polymer composite materials. Natural fibers are cheaper, denser, and more durable than synthetic fibers. Nevertheless, their mechanical qualities can be enhanced through fiber treatments. These stems, however, are rich in natural fibers that possess significant potential for use in various industrial applications. Transforming these waste materials into valuable resources aligns with the principles of a circular economy, where waste is repurposed to create new, sustainable products.

Banana plant stem fibers have shown remarkable strengths, flexibility, and durability, making them an excellent candidate for producing eco-friendly fiberboards. Banana fiber, derived from the pseudo-stem of the banana plant, is a type of cellulosic fiber. A bast fiber with excellent mechanical qualities is banana fiber. Similar to glass fiber, banana fiber offers excellent explicit strength characteristics that are comparable to those of common material. At that point, the thickness of this substance decreases to glass filaments. The pseudo-stem is a clustered collection of leaf tail bases with the shape of a barrel (Kavitha & G, 2021) [14].

Using these fibers allows one to create a sustainable material that solves the problem of agricultural waste and presents a good substitute for traditional fibreboard products. This approach can reduce reliance on wood, decrease environmental degradation, and contribute to a more sustainable future. This method offers a dual benefit: It addresses the issue of agricultural waste while providing a sustainable material that minimizes reliance on timber and helps prevent deforestation. Furthermore, utilizing banana plant stems aligns with the principles of a circular economy, where waste is reintegrated into the production cycle, thus contributing to a more sustainable and environmentally friendly industrial practice.

Background of the Study

One of the most important problems that a community has encountered that needs to be recognized and addressed seriously is the increased rate of agricultural waste. All crop portions that are not used to provide food for humans or animals are considered agricultural waste. The primary components of crop residues are stems, branches, and leaves. Due to several causes of waste affecting the community's population, agricultural waste has become more of a problem worldwide. According to Acevedo *et al*. (2021), the banana fruit is primarily grown in tropical regions of the world. Nearly 60% of the biomass in bananas is wasted after harvest. Around 114.08 million metric tonnes of banana trash are generated globally, which fuels environmental problems like too high greenhouse gas emissions. The present environmental crisis calls for creative ideas that reduce waste and minimize the general ecological impact. In this context, developing and adopting alternative materials prioritizing sustainability and efficiency is essential for achieving a more environmentally responsible future. Therefore, the extraction of bananas from these secondary metabolites may yield functional substances or materials that can be used for something else and boost the banana sector.

This study shows that using banana plant (Musa sapientum) stem fibers as a sustainable material for eco-friendly fiberboard production could have various effects and implications in various groups. Using the stems of banana plants may help lessen reliance on conventional and original wood sources, preserve forests, and reduce deforestation. It promotes the recycling of agricultural waste, leading to more sustainable practices in the production of fiberboards. Reducing the amount of banana waste can create new economic opportunities in the agricultural community. This will increase the number of local industries involved in fiberboard production.

Additionally, farmers can generate additional income by selling banana stems for fiberboard production. Consumers will gain from having access to more environmentally friendly and sustainable fiberboard options, which will influence their behavior and preferences towards more eco-friendly and greener products. Banana plants are one of the plants that have a high number of plants and produce a large amount of agricultural waste, including stems. Using banana stems for the production of fiberboard can help reduce the increasing number of these types of waste and provide a sustainable alternative to traditional materials. Traditional fiberboard is often manufactured and dependent on wood, which contributes to increasing rates of deforestation and destruction of animal habitat. Using the banana stem, the researchers aim to reduce the continued reliance on wood for fiberboard production and the environmental impact. The development of products from agricultural waste has the potential to create new local opportunities for farmers and local communities. This will provide an additional revenue stream and support the rural economy. Banana plant fibers have unique and special qualities that are suitable and can be used to produce high-quality fiberboard. Investigating its properties will develop innovative and eco-friendly products.

This study aims to evaluate the mechanical and physical characteristics and properties of banana stem fibers to see if they can meet necessary standards for fiberboard, such as fiber strength, durability, and flexibility. Through exploring these characteristics, the research seeks to determine whether banana stem fibers could give the best performance required for different uses in fiberboard, therefore perhaps presenting a sustainable substitute for traditional materials.

Objectives of the Study

This study aims to evaluate the mechanical and physical characteristics and properties of banana stem fibers to see if they can meet necessary standards for fiberboard, such as fiber strength, durability, and flexibility. Through exploring these characteristics, the research seeks to determine whether banana stem fibers could give the best performance required for different uses in fiberboard, therefore perhaps presenting a sustainable substitute for traditional materials. Our objective in investigating the possibilities of these fibers for the manufacturing of environmentally friendly fiberboards is to address the waste management and material innovation gap and therefore contribute to a more sustainable future. This research sought to (1) determine the essential components and most effective processing techniques required to produce sustainable, high-quality, eco-friendly fiberboards; (2) compare the physical and mechanical properties of fiberboards made from banana plant (Musa sapientum) stem fibers to those of conventional wood-based fiberboards in terms of Tensile Tensile Strength, Water Absorption, and Thickness Swelling; (3) identify the environmental impact of using banana plant stem fibers for fiberboard production, particularly in reducing agricultural waste and minimizing carbon emissions compared to traditional wood-based materials;

Materials and Methods

The study will use quantitative research, a methodical analysis mostly intended for statistically, mathematical, or computational methodically quantifying relationships, behaviors, and events. Its dependence on numerical data defines it since it enables academics to reach generalizable conclusions across more extensive populations. One is unable to emphasize the need for strict methodology in quantitative research since it directly affects the reliability and validity of the results (Ghanad, 2023) [10]. Therefore, the quantitative analysis of the relationships and behaviors associated with the utilization of banana plant stem fibers in fiberboard production is reliant upon this method, which entails a systematic investigation using statistical and computational methods. The dependence on numerical data guarantees that results about the strength, durability, and sustainability of the material can be expanded over more broad areas. Moreover, the strict approach usually used in quantitative research enhances the validity and dependability of results about the practicality and environmental friendliness of banana stem fibers as a substitute material. Using quantitative approaches guarantees that the findings may be generally used, supporting the potential of banana fibers in environmentally friendly production processes.

In a variety of disciplines, quasi-experimental research designs are indispensable, particularly when randomization is not feasible due to ethical or practical limitations. These designs enable researchers to maintain a degree of control over confounding variables while drawing causal inferences about the effects of interventions. Quasi-experimental studies, in contrast to randomized controlled trials (RCTs), do not randomly designate participants to treatment or control groups. This can result in difficulties in establishing causality. Nevertheless, they can still offer valuable insights, particularly in sectors such as healthcare, education, and social sciences (Baldwin *et al*., 2023) [4]. In particular, when it is impractical to randomize materials or production conditions, the quasi-experimental research design would be beneficial when examining the potential of banana stem fibers in fiberboard manufacturing. The study can still offer valuable insights into the efficiency of using banana fiber as a sustainable material, offering relevant findings for industries focused on eco-friendly production methods.

The data collection process is a systematic method that is intended to acquire, organize, and analyze necessary information to address the research questions and accomplish the study's objectives. The data collection procedure for this research consists of a series of carefully organized stages, such as the selection and preparation of raw materials, fiber extraction, production of fiberboards, and comprehensive testing of their properties. The objective of each stage is to acquire valid and dependable data that can be used to evaluate the environmental sustainability, physical characteristics, and mechanical strength of the fiberboard. A field study is also incorporated into the process to assess market feasibility and potential user interest, thereby guaranteeing that the results are both scientifically rigorous and practically pertinent. The objective of this research is to offer valuable insights into the potential of banana stem fibers as a viable and environmentally favorable alternative in the production of fiberboard through the implementation of these procedures.

In this study on the use of banana plant (musa sapientum) stem fibers as a sustainable material for eco-friendly fiberboard production, the population contains all banana plants and the stem fibers in it which is known for producing bananas in Noveleta, Cavite. This includes different cultivars of the banana plant (musa sapientum) that differ in fiber properties such as tensile strength and fiber length. By focusing on a specific area, this study can make more accurate and correct conclusions about the viability of these fibers from the banana plant for sustainable manufacturing or fiberboard production.

Purposive sampling is also called judgmental or non-probability sampling where the units are selected because of the characteristics needed in the sample. Purposive sampling is what researchers used to select banana plants based on specific criteria that are consistent with the objectives and purpose of the study. This study prioritizes varieties known for fiber quality, selecting mature banana plants that are at least 12 months old to ensure consistency in fiber properties. Additionally, plants from farms that use sustainable harvesting techniques might be chosen, increasing the findings ecological significance. By applying the criteria, the study could focus on the most promising sources of banana stem fibers.

One of the accompanying sampling methods is also the identification of suitable plantations of banana plants and the selection of plants that meet and conform to the established criteria. The stem fibers are harvested and subjected to various tests to evaluate the physical and mechanical characteristics, after being selected. This not only ensures that the study focuses only on the quality and durability of the materials but also enhances the potential for practical applications in eco-friendly fiberboard production. By using purposive sampling, this study aims to contribute valuable insights into sustainable materials derived from agricultural products, which ultimately support environmental sustainability efforts.

The chosen for this research is Quasi-experiments, in contrast to randomized controlled trials (RCTs), do not randomly designate participants to treatment or control groups. This can result in difficulties in establishing causality. Nevertheless, they can still offer valuable insights, particularly in sectors such as healthcare, education, and social sciences (Baldwin *et al*., 2023) [4].

Implementation science provides comprehensive guidance on developing, conducting, and reporting randomized trials of implementation strategies, aiming to improve the evidence base in implementation science. It consolidates established randomized trial methods with recent developments in implementation science, addressing key components such as trial aims, recruitment and retention strategies, design selection, theoretical frameworks, measurement, sample size calculations, ethical considerations, and reporting (Wolfenden *et al*., 2021) [15]. It aims to enhance how effective practices are adopted and sustained in real-world settings. It emphasizes ensuring these practices are used correctly and remain effective over time. To investigate related questions, researchers often utilize rigorous experimental designs, particularly randomized controlled trials (RCTs), which allow for a clear assessment of the effectiveness and impact of these practices in practical scenarios.

Results and Discussion

This chapter introduces the data analysis phase of the study, which evaluates banana plant stem fibers as a sustainable material for fiberboard production. This section examines the fibers' tensile strength, water absorption, and thickness swelling, comparing these properties with traditional fiberboard materials to assess the potential for eco-friendly applications.

Different types of banana stems produce fibers with varying characteristics, which influence the final fiberboard's processing methods and quality. The efficacy of these fibers as reinforcement materials is closely tied to their morphological properties. According to Bedru *et al*. (2023), the mechanical advantages of banana fibers are primarily due to their long fiber lengths and narrow cell wall thicknesses. These characteristics play a crucial role in enhancing durability and quality, making banana stem fibers highly suitable for applications requiring solid and sustainable reinforcements.

Table 1A: Sample Data Table for Tensile Strength Test

Fiberboard type	Initial Length (mm)	Applied Weight (kg)	Force Applied (N)	Displacement (mm)	Final Length (mm)	Stress (N/mm²)	Strain (mm/mm)	Elastic Modulus (N/mm²)
Fine Banana Fibers	85 mm	2-3 kg	29.4 N	85 mm	85 mm	0.0058 N/mm²	1.0000	0.0058
Strands Banana Fiber	104 mm	7-8 kg	78.4 N	104 mm	104 mm	0.0168 N/mm²	1.0000	0.0168
Layered Banana Fiber (Fine and Strand)	127 mm	15-20 kg	196 N	128 mm	128 mm	0.0383 N/mm²	1.0079	0.0380

Table 1B: Sample Data Table for Tensile Strength Test

Fiberboard type	Thickness (mm)	Width (mm)	Cross - Sectional Area (mm²)	Tensile Strength (MPa)	Test Condition	Rank
Fine Banana Fibers	9 mm	60 mm	5100 mm²	5.8 MPa	Room Temperature	3
Strands Banana Fiber	10 mm	45 mm	4680 mm²	16.8 MPa	Room Temperature	2
Layered Banana Fiber (Fine and Strand)	13 mm	40 mm	5120 mm²	38.3 MPa	Room Temperature	1

The table A and B shows the tensile strength tests for three types of banana fiberboards—fine banana fibers, strand banana fibers, and a combination of fine and strand fibers—revealed key differences in their mechanical properties. The fine banana fiberboard had the shortest starting length (85 mm) and a thickness of 9 mm, while the layered fiberboard had the longest length (127 mm) and a greater thickness of 13 mm. The widths of the boards also varied, with fine fibers having the widest (60 mm) and the layered fibers having the narrowest (40 mm). The cross-sectional areas showed slight differences, with the layered fiberboard having the largest area (5120 mm²), compared to fine fibers (5100 mm²). Regarding applied weight and force, fine banana fibers experienced 2-3 kg of applied weight (29.4 N), strand fibers received 7-8 kg (78.4 N), and layered fibers had the highest applied weight (15-20 kg, 196 N). Despite these variations, the displacement under load was minimal for all samples. The fine and strand fiberboards maintained their original lengths, while the layered fiberboard expanded slightly from 127 mm to 128 mm. Comparing the other prototypes of the fiberboards, the layered one ranked 1 in terms of having the greater load-bearing capacity along with minimal deformation.

Furthermore, the layered fiberboard exhibited the highest tensile stress (0.0383 N/mm²), tensile strength (38.3 MPa), and elastic modulus (0.0380 N/mm²), indicating superior resistance to deformation and maximum load capacity. In comparison, the strand fiberboard followed with moderate values for tensile stress (0.0168 N/mm²), tensile strength (16.8 MPa), and elastic modulus (0.0168 N/mm²), while the fine fiberboard showed the lowest performance in these areas, with a tensile stress of 0.0058 N/mm², tensile strength of 5.8 MPa, and elastic modulus of 0.0058 N/mm². Notably, the strain, representing relative deformation, was nearly identical across all types, reflecting minimal expansion under stress.

Table 2: Sample Data Table for Water Absorption Test

Fiberboard type	Initial Weight (g)	Weight After Immersion (g)	Water Absorption (%)	Immersion Time (hrs)	Test Condition	Rank
Fine Banana Fibers	52 g	54 g	0.038 %	12 hrs	Room Temperature	3
Strands Banana Fiber	33 g	33 g	0 %	12 hrs	Room Temperature	1
Layered Banana Fiber (Fine and Strand)	78 g	79 g	0.013 %	12 hrs	Room Temperature	2

The table shows the results of a water absorption test in three different types of fiberboard using banana plant stem material. Fine banana fibers, Strand banana fibers, and a Layered combination of fine and strand banana fibers. Fine banana fibers have an initial weight (g) of 52g, Strand banana fibers are 33g, and 78g for a layered combination of fine and strand banana fibers. This is the weight of a sample after being immersed in water for a certain amount of time 54g for fine banana fibers, 33 for strand banana fibers, and 79 for layered combinations of fine and strand banana fibers. For water absorption the value tells how much water the material has absorbed as a percentage. For 54g its 0.038% of water absorption, for 33g its 0% water absorption (no weight gain, no absorption, and for 79g its 0.013% of water absorption. For immersion time each sample was immersed for 12 hours. All the test conditions were done at room temperature. The result shows that the Layered Banana Fiber has the best water resistance (0.013% absorption),which makes it perfect for applications requiring resistance to moisture, such as furniture materials.

Table 3: Sample Data Table for Thickness Swelling Test

Fiberboard type	Initial Thickness (mm)	Thickness After Immersion (mm)	Thickness Swelling (%)	Immersion Time (hrs)	Test Condition	Rank
Fine Banana Fibers	10 mm	11 mm	0.1 %	12 hrs	Room Temperature	3
Strands Banana Fiber	10 mm	10 mm	0 %	12 hrs	Room Temperature	1
Layered Banana Fiber (Fine and Strand)	12 mm	12 mm	0 %	12 hrs	Room Temperature	2

A table displaying the findings of a thickness swelling test on three different kinds of banana fiberboard Fine Banana Fibers, Strands Banana Fiber, and Layered Combination of Fine and Strand Banana Fiber. The Initial thickness of Fine Banana Fiber is 10, same as the Strand Banana Fibers, and 12 for Layered Combination of Fine and Strand Banana Fibers. The thickness after immersion of Fine Banana Fibers are 11, 10 for Strand Banana Fibers, and 12 for Layered Combination of Fine and Strand Banana Fibers. For thickness swelling it tells how much the material thickened and swollen. For 11mm it's 0.1%, 0% for 10mm, and 0% for 12mm. For Immersion Time each sample was immersed for 12 hours. All the tests were done at Room Temperature.

The ranking of banana fibers based on the water absorption and thickness swelling of it is as follows: Layered banana fiber demonstrated the highest water absorption among the tested materials, resulting in a substantial 40% increase in thickness. This indicates its high capacity for moisture retention and structural swelling when exposed to water. Fine banana fibers absorbed less water compared to layered banana fibers, resulting in a moderate 20% increase in thickness. This indicates that fine banana fibers have a lower capacity for moisture absorption and swelling. Strands Banana Fiber (0%): This fiber shows no thickness swelling, suggesting it is highly resistant to water absorption. The lack of swelling indicates that its structure is either very dense or has properties that repel water. This type would be ideal for applications where water resistance is critical, as it maintains its shape and structure without taking in moisture.

The mechanical and physical properties of banana fiberboards demonstrate notable advantages over conventional wood-based fiberboards. Layered banana fiberboards exhibit tensile strengths of up to 38.3 MPa, surpassing medium-density fiberboards (MDF), which typically range between 10 and 25 MPa, depending on their composition and manufacturing processes (Syduzzaman *et al*., 2024; Sathish *et al*., 2024) [24, 20]. While banana fiberboards have a lower elastic modulus (up to 0.0380 N/mm²) than MDF, which averages around 3,500 N/mm², their lightweight nature makes them suitable for specific applications (Sathish *et al*., 2024) [20].

In terms of water resistance, strand banana fiberboards display no water absorption or thickness swelling after 12 hours of immersion. This contrasts with wood-based fiberboards, which often absorb 2-5% water and swell significantly under similar conditions. This resilience makes banana fiberboards ideal for humid or water-exposed environments (Syduzzaman *et al*., 2024; Sathish *et al*., 2024) [24, 20]. These findings underscore the potential of banana fiberboards as sustainable alternatives to conventional wood-based boards, offering superior tensile strength and water resistance while maintaining eco-friendly attributes.

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