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Comparison of Mechanical Properties of Banana Pseudostem Fiberboard vs. Conventional Medium-Density Fiberboard

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Abstract

This paper investigates the possibility of adopting banana pseudostem (BPS) fibers as a sustainable medium-density fiberboard (MDF) reinforcement for the Philippine construction industry. The purposes were to evaluate and compare the mechanical properties of BPS fiber-reinforced MDF, BPSF MDF, to conventional MDF, or CMDF, in terms of internal bond (IB), modulus of elasticity (MOE), and modulus of rupture (MOR). To achieve this, quasi-experimental research design was used for testing the five fiber ratios. Results indicated that the optimal mixture of 50% BPSF and 50% wood fibers proved to possess better mechanical properties than the other mixtures and conventional MDF. Although the production cost of the Mixture 3: 50/50 mixture was a bit higher, enhanced durability and flexural strength values suggest its feasibility for applications in construction projects. The research thus recommends using the Mixture 3: 50/50 BPSF-WF mixture for producing MDF in the future due to environmental sustainability combined with better mechanical performance. Further research is also suggested to be conducted on long-term performance in order to be perfected in the method of production, which will enable the high utilization of this sustainable material.

Keywords
BPSF, MDF, Mechanical Properties, Modulus, Sustainable Construction Materials.

1. Introduction

Among fiberboard variants, Medium-Density Fiberboard (MDF) remains a preferred choice in the construction and furniture industries due to its smooth finish, machinability, and cost-effectiveness (Rodríguez et al. 2024). Composed primarily of wood fibers bonded with synthetic resins, MDF offers structural uniformity and versatility, making it widely used in applications ranging from furniture and cabinetry to flooring and interior paneling (Among fiberboard variants, medium-density fiberboard (MDF) remains a dominant material in construction and furniture manufacturing due to its affordability, machinability, and smooth finish (Rodríguez et al. 2024). The Philippine construction sector, valued at approximately Php 1.51 trillion in 2023, relies heavily on MDF for interior applications such as flooring, cabinetry, and moldings (Materials Inc. 2020). However, the declining availability of wood-based raw materials has impacted MDF production. In 2020, the Philippine Wood Producers Association (PWPA) reported a 30% drop in log production which exacerbated the material deficit (Goldhahn et al. 2021). By 2022, local lumber production reached only 344,000 cubic meters that is far below the 6 million cubic meters required to meet domestic demand (Statista 2023).

This shortfall has driven interest in alternative, sustainable reinforcements that maintain or enhance MDF's mechanical properties. One such alternative is fiberboard reinforced with Banana Pseudostem (BPS) fibers, a widely available agricultural byproduct in the Philippines. The country produces approximately 2.269 million metric tons of bananas per quarter, generating an estimated 1.35 billion kilograms of BPS annually in Mindanao alone, most of which is left to decompose (DOST 2022). Hence, rather than allowing these agricultural residues to go to waste, the utilization of BPS fibers in MDF manufacturing can potentially address material shortage and environmental concerns, as conventional MDF (CMDF) relies on wood fibers and synthetic adhesives that contribute to deforestation and formaldehyde emissions (Lubis et al. 2021).

CMDF also exhibits moderate resistance to mechanical stress but remains vulnerable to moisture absorption as it limiting its durability in humid environments such as the Philippines (Ahmed et al. 2020). Meanwhile, natural fibers like banana pseudostem offer high tensile strength, flexural rigidity, and biodegradability which makes them viable reinforcements for engineered wood products (Pugazhenthi and Anand 2020). It even has hydrophobic characteristics that may mitigate moisture absorption and address one of CMDF's primary weaknesses in tropical climates (De Souza Barnasky et al. 2020). However, the mechanical performance of BPS-reinforced MDF and its feasibility as an alternative to CMDF for structural and furniture applications has yet to be fully established. This study aims to bridge that gap by determining whether they can meet or exceed industry standards for strength, durability, and stability under load-bearing conditions. through an experimental analysis to determine whether BPS fiberboard can be a structurally viable, moisture-resistant, and environmentally sustainable alternative to CMDF.

1.1 Objectives

The main objective of the study is to evaluate the potential of BPS fiber-reinforced fiberboard as a viable alternative to CMDF for construction applications in the Philippines. The researchers will conduct a comparative analysis of mechanical properties, including Internal Bond (IB), Modulus of Elasticity (MOE), and Modulus of Rupture (MOR), to assess its structural performance if implemented in the local construction industry.

2. Literature Review

2.1. Medium-Density Fiberboard

MDF is primarily composed of wood fibers bonded with synthetic resins. Zimmer and Bachmann (2023) emphasize that while MDF utilizes renewable resources, the resin content complicates recycling. Most MDF waste is incinerated due to its caloric value, but this approach is suboptimal for sustainability which is why alternative sustainable materials are being explored.

Fiberboards are also classified by density into low (<400 kg/m³), medium, and high (>800 kg/m³), with performance characteristics such as internal bonding (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) varying according to these classifications (Çamlibel and Aydin 2023). Industry standards—JIS A 5905:2003 in Japan, SNI 01 4449-2006 in Indonesia, MS 1787:2005 in Malaysia, and EN 622-5:2006 in Europe—define these parameters, while European Standard EN 622-1 and the California Air Resources Board phase II regulate formaldehyde emissions (Magalhaes 2021).

2.2. Biocomposites

Lee et al. (2020) compared several natural fibers (e.g., rice straw, kenaf, and sisal) in fiberboard production and found that sisal offered the highest Modulus of Rupture (42.9–52.3 MPa), while certain rice straw variations achieved superior Internal Bond values (up to 1.13 MPa). Fibers ranging from coconut coir and bagasse to kenaf and sisal can be integrated into fiberboard via blending, spraying, or pressing to create composites with specific mechanical and physical properties (Ali et al. 2014; Ibrahim et al. 2016). For instance, rice straw fibers are mixed to distribute urea formaldehyde evenly; kenaf fibers may be sprayed with resin in a rotating drum blender; and wheat or soybean stalks often receive wax emulsion treatments for enhanced water resistance (Ye et al. 2007; Aisyah et al. 2013). Final board dimensions vary significantly as it reflect each study's objectives and desired density (Nayeri et al. 2014; Kargarfard et al. 2011).

Yang and Rosentrater (2020) assessed the life-cycle impacts of common adhesives, reporting that although UF adhesives generate lower greenhouse gas emissions than phenol-formaldehyde (PF), they exhibit higher effects on human health and certain environmental factors. As advancements in adhesive formulations continue, biocomposites are poised to bridge functional performance with reduced ecological impacts.

2.3. Chemical Composition of Natural Fibers

Natural fibers predominantly contain cellulose, hemicellulose, and lignin, collectively termed lignocellulose (Karimah et al. 2021). Cellulose, especially its crystalline regions, contributes significantly to tensile strength, while lignin provides mechanical support and enhances UV stability. A higher lignin ratio, however, can reduce overall tensile strength because it occupies spaces between cellulose and hemicellulose (Karimah et al. 2021). Hemicellulose content correlates with moisture uptake and biodegradation; consequently, lower hemicellulose levels often mean higher cellulose crystallinity (Wan et al. 2010; Karimah et al. 2021).

Banana pseudostem fibers exemplify these principles. A fully mature banana pseudostem can contain 20–25 layers of flesh sheath whose lignocellulosic fibers are extracted manually or via decorticating machines (Badanayak et al. 2023). Banana fibers that typically comprise 55–65% cellulose, 15–25% hemicellulose, 10–15% lignin, and 3–5% pectin exhibit favorable length-to-fineness ratios and strength for various applications, from textiles to bio-based composites, although exact proportions vary by species, growing conditions, and extraction techniques (Badanayak et al. 2023). Apart from fiber applications in textiles, banana pseudostem can also be valorized as fiber-cement composites, binderless fiberboard, rope, or even as absorbents for industrial wastewater (Karimah et al. 2021). This versatility underscores the potential of BPS and other natural fibers in developing high-performance, eco-friendly composites.

3. Methods

3.1. Research Design

This study employed a quasi-experimental research design, which allows for an intervention without requiring a fully

Table 1. Summary of Variables

Variable	Description
Independent Variables	
BPS Fiber	Lignocellulosic fiber with high cellulose content (Mohuiddin et al. 2014).
Virgin Wood Fiber	Conventional MDF raw material (Selke 2016).
Urea-Formaldehyde	Common resin used for MDF bonding (Sterley et al. 2021).
BPS Fiber-Reinforced MDF	A novel fiberboard formulation incorporating banana pseudostem fibers as a reinforcing material.
Medium Density Fiberboard	Standard MDF panels, produced as a control for comparative analysis.
Dependent Variables	
Internal Bond	Measures fiber adhesion strength (El-Kassas and Mourad 2013).

Modulus of Elasticity (MOE)	Assesses board stiffness (Suryono and Bhakti 2020).
Modulus of Rupture (MOR)	Determines bending strength (Faraj et al. 2022).

randomized setup (Goldfarb et al. 2022). The intervention in this case was the integration of banana pseudostem (BPS) fibers into medium-density fiberboard (MDF) production. The mechanical properties of BPS Fiber-Reinforced MDF were compared with conventional MDF in terms of Internal Bond (IB), Modulus of Elasticity (MOE), and Modulus of Rupture (MOR).

Above (Table 1) is a summary of the independent and dependent variables assessed in the study. The independent variables include key materials used in the fiberboard formulations, such as BPS fibers, virgin wood fibers, and urea-formaldehyde resin, which influence the structural composition of the MDF. It also differentiates between BPS Fiber-Reinforced MDF and conventional MDF which are the experimental and control groups, respectively. The dependent variables IB, MOE and MOR are the mechanical properties measured to evaluate the structural performance of the fiberboards. These parameters provide insights into adhesion strength, stiffness, and bending resistance that forms the basis for comparative analysis.

3.2. Instrumentation

The mechanical properties of the BPS Fiber-Reinforced MDF and conventional MDF were evaluated using a Universal Testing Machine (UTM), as supported by the methodologies established by Rodriguez et al. (2024), Nayeri et al. (2014), and Puspaningrum et al. (2020). The testing protocols adhered to the standards outlined in PNS 230:1989 for mechanical property evaluation, while computations followed the procedures set by ASTM D1037-12. *(see Table 2)*.

Table 2. Mechanical Property Computation and Standard Testing Parameters

Internal Bond $IB = \frac{P_{max}}{ab}$	**Modulus of Elasticity** $E_t = \frac{lg}{bd}\frac{\Delta P}{\Delta y}$	**Modulus of Rupture** $R_b = \frac{3P_{max}L}{2bd^2}$
a = width of the specimen measured in dry condition, in. (mm) b = length of the specimen measured in dry condition, in. (mm) Pmax = maximum load, lbf (N) IB = internal bond strength, psi (MPa)	b = width of the reduced cross-section of the specimen measured in dry condition, in. (mm) d = thickness of the specimen measured in dry condition, in. (mm) Et = modulus of elasticity in tension parallel to the surface of the panel, psi (MPa) lg = gage length or distance between the gage points of extensometer, in. (mm) DP⁄Dy = slope of the straight line portion of the load deformation curve, lbf/in. (N/mm) E = Modulus of elasticity, kg/cm²	L = length of span, in. (mm) b = width of specimen measured in dry condition, in. (mm), L = length of span, in. (mm) DP⁄Dy = slope of the straight line portion of the load deflection curve, lbf/in. (N/mm) R = Modulus of Rupture, measures force per unit area, psi (MPa)

Table 2 provides the formulas and parameters used to compute the mechanical properties of IB strength, MOE, and MOR to define the structural performance of fiberboards and compare the strength and flexibility of BPSF-reinforced MDF with conventional MDF.

4. Data Collection

The experiment was conducted at the Department of Science and Technology - Forest Products Research and Development Institute (DOST-FPRDI) within the University of the Philippines, Los Baños. This facility was selected due to its advanced equipment and controlled environment to ensure consistency in fiberboard production and mechanical testing. Five different fiberboard formulations were also prepared which incorporated varying proportions of BPS fibers and conventional wood fibers. The mechanical performance of these fiberboards was assessed through IB, MOE, and Modulus of Rupture MOR which were then compared against conventional CMDF to determine the structural feasibility of BPS fiber-reinforced MDF.

4.1. Production of BPS Fiber-Reinforced MDF

The process of preparing BPS fibers was adapted from Nayeri et al. (2014), who explored the effects of refining and resin content on fiberboards made from kenaf stems.

4.1.1. Fiber Preparation

Mature banana pseudostems (18-24 months old) were sourced from Villa Socorro Farm. The pseudostems were thoroughly cleaned to eliminate contaminants then air-dried for two weeks at room temperature to reduce moisture content. Once dried, they were cut into uniform sizes to facilitate fiber extraction using a defibrillator machine. This process mechanically refined the pseudostems into usable fiber form, which was further processed to remove hemicellulose-induced clumping which helps enhance fiber quality. The fibers were manually refined to a uniform length of 8 inches before undergoing oven drying at 105°C. Mixing was performed every 30 minutes to maintain uniform heat distribution until a moisture content of 7% was achieved to enhance adhesive compatibility.

4.1.2. Adhesive Preparation and Fiber Blending

Urea-formaldehyde (UF) adhesive was used in powdered form and mixed with water at a 1:1 ratio. A total of 500g of adhesive mixture was allocated per MDF board, with fiber-to-adhesive proportions adjusted based on composition. Table 3 summarizes the fiber-to-adhesive distribution for each formulation.

Table 3. Fiber-to-Adhesive Ratio

BPS Fiber/Wood Fiber (%)	UF Mixed with BPSF (g)	UF Mixed with WF (g)
0/100	0	500
25/75	126	374
50/50	250	250
75/25	374	126
100/0	500	0

As seen in Table 3, if the proportion of BPSF increases, the corresponding UF allocation shifts accordingly, which ensures consistent adhesion and structural integrity across all formulation.After adhesive mixing, fibers were blended manually to ensure even distribution. The fiber-adhesive mixture was then formed into a 400mm x 400mm mat using a wooden frame. A sandwich method was applied by layering BPS fibers between wood fibers for optimal structural integrity.

4.1.3. Hot Pressing and Curing

In obtaining the optimal Reinforced BPS Fiber Medium-Density Fiberboard, different parameters of BPS Fiber and wood ratios were tested with 3 samples each. The mixtures done are given in table 4. The fiber mats were subjected to hot pressing at 150°C and 30 kg/cm² until a final thickness of 12mm was achieved. After pressing, the MDF boards underwent a cooling phase for two weeks to relieve internal stresses developed during the hot pressing process. To stabilize the boards and alleviate residual internal stresses, they were left to cool and condition at room temperature for at least two weeks. This resting period ensured the boards reached appropriate moisture content and internal stresses were minimized before mechanical testing. For each BPS-to-wood fiber ratio, three boards were produced to enable statistically valid comparisons of mechanical performance.

Table 4. BPS Fiber and Wood Fiber Composition in MDF Samples

BPS Fiber (%)	Wood Fiber (%)
0	100
25	75
50	50
75	25
100	0

4.2. Mechanical Testing Procedures

Figure 1 illustrates the complete testing methodology, which can be explained in four systematic steps to compare the performance of BPS fiber–reinforced boards with conventional MDF. The testing procedures focused on two primary mechanical assessments: the Internal Bonding (IB) Test and Static Bending Test, using a Universal Testing Machine (UTM) (Rodriguez et al. 2024).

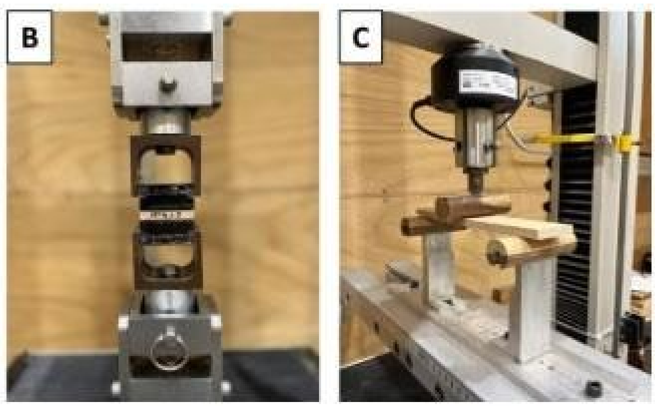

Figure 1. (B) Static Bending Test; (C) IB Testing (Rodriguez et al. 2024)

Step 1: The prepared samples were placed in the UTM for mechanical evaluation. The two tests conducted included the Internal Bond (IB) Test, which assessed the internal adhesive strength of the board, and the Static Bending Test, which measured flexural strength, specifically MOE and MOR (see Figure 1).

Step 2: For the IB test, the UTM applied perpendicular tensile force to the board's surface until failure, measuring the force required for the internal bond to break. This test determined the strength of adhesion between fibers within the MDF structure. The Static Bending Test was then performed, where a controlled load was applied at three points along the specimen. The board's deformation under load was recorded to assess its flexibility and structural integrity.Step 3: Data collected from the IB test was used to compute internal bond strength using the standard formula for tensile failure stress. For the Static Bending Test, the load-deflection data was analyzed to derive the MOE and MOR values, which quantified the material's stiffness and bending resistance.

Step 4: A One-Way ANOVA was performed to evaluate the significance of varying BPS fiber ratios on IB, MOE, and MOR. The statistical results indicated whether the reinforcement of MDF with BPS fiber had a notable impact on mechanical performance. Triplicate samples were analyzed to ensure data consistency and reliability.

4.3. Ethical Considerations

Researchers obtained necessary permissions to use DOST-FPRDI equipment and laboratory facilities to ensure that material processing and testing were conducted in a controlled and ethical manner. The collection of banana pseudostems was alo done sustainably, with minimal environmental disruption. Moreover, the study prioritized safety in experimentation so that all testing procedures followed standard operating protocols to prevent harm. Data integrity was maintained through unbiased testing procedures, validated research methodologies, and accurate citation of related literature. All sources were referenced in accordance with proper citation guidelines to uphold research credibility.

5. Results and Discussion

5.1. Numerical Results

Internal bond (IB) strength measures the tensile strength of MDF by evaluating its ability to resist separation between layers, following ASTM D1037 standards. A higher IB value indicates greater cohesion within the fiberboard structure, which is critical for load-bearing applications (Zhang et al. 2020).

Table 5. Results of Internal Bond Test

Specimen No.	Length (a)	Width (b)	Thickness	Weight	Load ($Pmax$)	IB (MPa)
0/100	5.11	5.1	1.23	18.1	13	0.5
0/100	5.11	5.11	1.23	17.9	18	0.69
0/100	5.09	5.12	1.22	17.6	13	0.5
Avg	**5.1**	**5.11**	**1.23**	**17.87**	**14.67**	**0.56**
25/75	5.1	5.11	1.28	24.1	4	0.15
25/75	5.1	5.09	1.3	20.3	1	0.04
25/75	5.12	5.11	1.26	18.6	5	0.19
Avg	**5.11**	**5.1**	**1.28**	**21**	**3.33**	**0.13**
50/50	5.09	5.12	1.19	24.2	41	1.57
50/50	5.08	5.1	1.18	21.1	19	0.73
50/50	5.09	5.1	1.15	17.4	18	0.69
Avg	**5.09**	**5.11**	**1.17**	**20.9**	**26**	**1**
75/25	5.1	5.08	1.22	12.6	18	0.69
75/25	5.1	5.1	1.21	14.3	6	0.23
75/25	5.09	5.08	1.16	14.4	5	0.19
Avg	**5.1**	**5.09**	**1.2**	**13.77**	**9.67**	**0.37**
100/0	5.11	5.1	1.26	21.8	11	0.42
100/0	5.12	5.09	1.22	26.6	31	1.19
100/0	5.1	5.06	1.19	26.5	30	1.16
Avg	**5.11**	**5.08**	**1.22**	**24.97**	**24**	**0.92**

The results, summarized in Table 5, reveal that fiberboards reinforced with 50% banana pseudostem fiber (BPSF) demonstrated the highest IB strength, averaging 1.00 MPa. This suggests optimal fiber-matrix interaction at this ratio. On the contrary, the lowest IB strength was recorded at the 25% BPSF concentration, averaging only 0.13 MPa, indicating weaker adhesion and structural instability. Saleh et al. (2017) stated that when the fiber content gets too high, the adhesive may struggle to coat the fibers effectively. This shows the poor compatibility between the fibers and adhesive if the mixture is not right. Additionally, Lejano & Pineda (2018) found that the right fiber combinations enhance the mechanical properties. Pure MDF (0% BPSF) exhibited an average IB strength of 0.56 MPa, while the 100% BPSF sample reached 0.92 MPa. These findings suggest that incorporating BPSF enhances IB strength but only up to a threshold (50% BPSF), beyond which the bonding efficiency declines.Meanwhile, the modulus of elasticity (MOE) quantifies the stiffness of fiberboard by measuring resistance to deformation under applied stress. It was calculated based on Equation 2, which relates stress to strain within the elastic limit.

As shown in Table 6, the 50:50 BPSF-MDF composite demonstrated the highest MOE at 655.24 kg/cm², which outperforms all other configurations, including conventional MDF (317.18 kg/cm²). The incorporation of BPSF at this ratio significantly improved stiffness, likely due to effective fiber interlocking and load distribution. The 100% BPSF

Fiberboard improved MOR but had inconsistent IB and MOE. Unlike the fine-textured wood fibers, the manually cut BPS fibers were inconsistent, untreated, uneven, and larger which may have affected the bonding and formation. Sangalang (2021) & Gao et al (2018) stated that fiber length, fiber size and distribution can significantly impact mechanical properties such as strength in thermoset composites.

Table 6. Results of the Modulus of Elasticity Test

Specimen No.	LPL (kg)	Span (kg)	Width (cm)	Thickness₂ (cm)	CdPL (cm)	MOE (kg/cm²)
0/100	2.00	29.00	7.62	1.22	2.04	432.02
0/100	1.50	29.00	7.63	1.20	2.87	241.70
0/100	1.50	29.00	7.62	1.20	2.50	277.83
Avg	**1.67**	**29.00**	**7.62**	**1.21**	**2.47**	**317.18**
25/75	3.75	29.00	7.65	1.23	6.06	265.04
25/75	2.00	29.00	7.60	1.27	3.99	196.32
25/75	2.00	29.00	7.65	1.27	3.88	200.57
Avg	**2.58**	**29.00**	**7.63**	**1.26**	**4.64**	**220.64**
50/50	7.00	29.00	7.63	1.24	5.81	504.97
50/50	11.00	29.00	7.63	1.18	8.73	612.83
50/50	18.00	29.00	7.62	1.20	9.83	847.92
Avg	**12.00**	**29.00**	**7.63**	**1.21**	**8.12**	**655.24**
75/25	1.50	29.00	7.63	1.24	3.13	200.86
75/25	3.00	29.00	7.58	1.18	5.75	255.43
75/25	1.50	29.00	7.60	1.22	1.97	336.41
Avg	**2.00**	**29.00**	**7.60**	**1.21**	**3.62**	**264.23**
100/0	13.00	29.00	7.62	1.23	14.32	390.36
100/0	7.00	29.00	7.63	1.27	7.77	351.46
100/0	3.00	29.00	7.63	1.24	4.84	259.79
Avg	**7.67**	**29.00**	**7.63**	**1.25**	**8.98**	**333.87**

The trend in MOE mirrors the IB results about how a 50:50 ratio optimally balances fiber reinforcement and resin bonding. While increasing BPSF content enhances structural integrity up to a certain point, excessive replacement diminishes stiffness due to reduced fiber-matrix adhesion (Rener et al. 2020).

Table 7. Results of Modulus of Rupture Test

Specimen No.	Length	Width (b)	Thickness avg (h)	Weight	Span (L)	Load (Pmax)	MOR (R)
0/100	34	7.62	1.23	178.14	29	3	11.41
0/100	34	7.63	1.24	180.79	29	3	11.21
0/100	34	7.62	1.22	177.06	29	2	7.73
Avg	**34**	**7.62**	**1.23**	**178.66**	**29**	**2.67**	**10.12**
25/75	34	7.65	1.24	188.19	29	13.5	49.93
25/75	34	7.6	1.27	186.14	29	7	24.84
25/75	34	7.65	1.27	182.35	29	8	28.43
Avg	**34**	**7.63**	**1.26**	**185.56**	**29**	**9.5**	**34.4**
50/50	34	7.63	1.22	249.49	29	9	34.47
50/50	34	7.63	1.17	197.39	29	13	54.61
50/50	34	7.62	1.17	207.98	29	20	84.12
Avg	**34**	**7.63**	**1.18**	**218.29**	**29**	**14**	**57.73**

75/25	34	7.63	1.25	168.5	29	5	18.24
75/25	34	7.58	1.18	151.85	29	7	28.85
75/25	34	7.6	1.2	146.33	29	4	16.03
Avg	**34**	**7.6**	**1.21**	**155.56**	**29**	**5.33**	**20.9**
100/0	34	7.62	1.23	238.66	29	21	79.89
100/0	34	7.63	1.25	239.24	29	15	54.73
100/0	34	7.63	1.24	204.51	29	6	22.25
Avg	**34**	**7.63**	**1.24**	**227.47**	**29**	**14**	**52.07**

The Modulus of Rupture (MOR), or flexural strength, measures a material's resistance to bending forces. It quantifies the maximum load a fiberboard can withstand before structural failure occurs. The results in Table 7 reveal that the 50:50 BPSF-MDF sample exhibited the highest MOR at 57.73 kg/cm², followed by the 100% BPSF sample at 52.07 kg/cm² that outperforms conventional MDF (10.12 kg/cm²). These findings suggest that incorporating banana pseudostem fibers does enhance flexural strength due to increased fiber interlocking and stress distribution. However, excessive BPSF content beyond 50% led to inconsistent bonding, as observed in the 75:25 configuration, which showed a sharp decline to 20.90 kg/cm². The sandwich method — layering wood fiber on the surface and banana pseudostem fibers in the core — notably influenced the decrease in MOE and IB performance whilst strengthening the MOR performance. A study by Sultan et al. (2021) found that strategic layering significantly influences mechanical properties, supporting the findings of this study.

5.2 Graphical Results

The ANOVA results, presented in Figures 2, 3, and 4, indicate that fiberboard composition significantly impacts mechanical strength, as all three properties yielded p-values below 0.05.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Specimen	4	1.620	0.4051	3.80	0.039
Error	10	1.065	0.1065		
Total	14	2.685			

Figure 2. One Way Anova for IB

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Specimen	4	354721	88680	8.59	0.003
Error	10	103187	10319		
Total	14	457907			

Figure 3. One Way Anova for MOE

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Specimen	4	4890	1222.6	3.61	0.045
Error	10	3388	338.8		
Total	14	8278			

Figure 4. One Way Anova for MOR

The F-values, which measure the ratio of variance between groups to variance within groups, were highest for MOE (8.59, Figure 3), followed by MOR (3.63, Figure 4) and IB (3.80, Figure 2). This indicates that MOE exhibited the greatest variation between different mixture ratios, reinforcing its sensitivity to fiber content adjustments. For internal bond strength (IB) (Figure 2), the significant p-value (0.039) suggests that fiber content has a considerable effect on

MDF cohesion. However, the relatively lower F-value compared to MOE indicates less drastic fluctuations across the different compositions. Its effect is not as pronounced as it is for elasticity or rupture, even if fiber reinforcement alters IB.

In contrast, Figure 3 demonstrated the most substantial statistical difference ($p = 0.003$), with an F-value of 8.59 for MOE which signifies a strong dependence on fiber ratio. The stiffness is highly influenced by fiber composition, with certain ratios significantly outperforming others. The higher the F-value for MOE compared to IB implies that structural rigidity is more affected by fiber variations than bonding strength. For MOR (Figure 4), the p-value of 0.045 indicates a statistically significant impact, though with a slightly lower F-value (3.63) compared to MOE. The differences among the mixture ratios may be less extreme than in elasticity but bending resistance eventually improves with fiber content.

5.3 Proposed Improvements

Since the 50:50 mixture ratio demonstrated the most optimal mechanical properties, manufacturers in the fiberboard industry should consider this as an alternative to conventional fiberboards. Future research could also refine this composition by investigating fiber treatment methods to enhance adhesion and structural performance even more. Resin modifications must be studied further to improve bonding strength and mitigate fiber dispersion issues in compositions exceeding 50% BPSF. At the same time, the long-term durability of BPSF-MDF should be evaluated under varying environmental conditions, particularly in humid climates, to assess moisture resistance and dimensional stability. Even more so, full-scale manufacturing trials should be conducted to assess the economic feasibility, supply chain integration, and scalability of BPSF-MDF in commercial fiberboard production.

6. Conclusion

There are slight variations in performance across fiber ratios, but the 50:50 mixture ratio consistently demonstrated superior mechanical properties which makes it the most viable alternative to conventional MDF. The researchers find that incorporating banana pseudostem fibers actually enhances internal bond strength, stiffness, and flexural resistance, but only up to a certain threshold. Beyond 50% BPSF content, the structural integrity declines due to fiber dispersion inconsistencies and reduced resin adhesion. Although conventional MDF remains widely used, this study proves that natural fiber reinforcements can match or even exceed its mechanical performance. The significance of this finding extends beyond material science because it challenges the reliance on purely wood-based MDF by offering a sustainable and locally sourced alternative. However, achieving full-scale adoption requires further optimization in fiber treatment and adhesive compatibility to maximize durability and manufacturing efficiency. There is also a need for long-term environmental exposure tests to assess moisture resistance and thermal stability under real-world conditions. But nonetheless, the adoption of BPSF-MDF could revolutionize the industry by helping us shift toward sustainable and high-performance composites.

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