



Physical and Mechanical Properties of Particleboards Produced from *Ficus Racemosa* Sawdust and Bone Glue

Soviwadan DROVOU^{1,2,3,5}, Kokouvi Happy N'TSOUAGLO^{1,2*}, Kossi Agbédidi ESSEY^{1,2}, Komlan Assogba KASSEGENE^{1,2}, Antony PIZZI^{5,6}, Komla SANDA^{3,4}, André DL BATAKO⁷

¹Polytechnical School of Lomé in University of Lomé (EPL – UL), 01Po. Box 1515 Lomé 01, Togo

²Laboratory of Structure and mechanic of materials (LaS2M), (EPL – UL), 01Po. Box 1515 Lomé 01, Togo

³Laboratory of Recherche on Agricultural resources and Environmental Health (LARASE), University of Lomé, 01Po. Box 20131 Lomé 01, Togo

⁴University of Kara, Kara, Togo

⁵Laboratory of Study and Recherche on Wood Materials, University of Lorraine (LERMAB – UL), Épinal, 88000, France

⁶Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia

⁷Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK

Corresponding author: kokouvi.ntsouaglo@gmail.com / kokouvi.ntsouaglo@univ-lome.tg

Abstract: The growing environmental concerns related to synthetic adhesives and wood-based composites have encouraged research into renewable and biodegradable alternatives. *Ficus racemosa* sawdust, a widely available wood residue, and bone glue, a natural protein-based adhesive, represent promising bio-sourced materials. This study aims to investigate the effect of particle size and bone glue content on the physical and mechanical properties of eco-friendly particleboards made from *Ficus racemosa* sawdust. Particleboards were manufactured using four adhesive contents (7.5%, 10%, 12.5%, and 15%) and five particle size ranges. The mixtures were hot-pressed at 160 °C under 11 bar pressure. Physical tests (density, water absorption, and thickness swelling) and mechanical tests (modulus of rupture, MOR, and modulus of elasticity, MOE) were conducted according to the ANSI A208.1–2022 standard. The results show that increasing the adhesive content raised the density (640–844 kg/m³) while reducing water absorption and swelling. The best formulation achieved an MOE of 2450 MPa and an MOR of 15.24 MPa, values close to the M-3i standard. This study demonstrates the potential of *Ficus racemosa* sawdust reinforced with bone glue for producing bio-based particleboards suitable for interior applications.

Keywords: *Ficus racemosa*, bone glue, particleboard, mechanical properties, bio-based materials

1. Introduction

The construction and furniture manufacturing sectors are increasingly challenged to reduce their environmental impact while maintaining high technical performance. The production and use of conventional materials such as plywood, particleboard, and medium-density fiberboard (MDF) contribute significantly to greenhouse gas emissions and deforestation [1], [2], [3]. In this context, the development of bio-based, renewable, and non-toxic materials has emerged as a sustainable and necessary alternative for the wood and composite industries [4], [5], [6], [7].



Composite materials produced from agricultural residues and organic binders have gained growing attention in recent years due to their biodegradability, local availability, and low production cost [8], [9], [10]. Various agricultural and forestry by-products such as rice straw [11], coconut shells [12], maize stalks, and kenaf fibers etc [13], [14], [15] have already been successfully used for the manufacture of eco-friendly particleboards and fiberboards.

The use of bone glue as a natural binder represents a promising alternative to synthetic adhesives. This animal-derived material exhibits strong adhesive properties, high biodegradability, and non-toxic behavior [16], [17]. *Ficus racemosa*, a tropical tree belonging to the Moraceae family, generates large amounts of sawdust as a by-product of woodworking activities. These residues represent a renewable and underutilized resource with potential for producing environmentally friendly composite panels. Their valorization can contribute to reducing deforestation while promoting local and sustainable production chains.

The main objective of this study is to develop and characterize particleboards made from *Ficus racemosa* sawdust using bone glue as a natural binder. The work aims to evaluate the influence of particle size distribution and binder content on the physical and mechanical properties of the resulting panels. This research aligns with a broader effort to valorize local resources and promote the development of sustainable, eco-friendly construction materials.

2. Materials and Methods

Raw Materials

The *Ficus racemosa* wood sawdust used in this study was collected from local carpentry workshops in the Badou region of Togo. *Ficus racemosa*, a species belonging to the Moraceae family, is an evergreen tree widely distributed across tropical regions of South Asia and West Africa. It is commonly exploited for timber production and traditional medicine.

After collection, the sawdust was air-dried for seven days and then sieved to obtain five particle size classes (g): $g \leq 0.8$ mm, $0.8 < g \leq 1.6$ mm, $1.6 < g \leq 2.5$ mm, $2.5 < g \leq 5$ mm, and unsieved (raw). This classification was adopted to better evaluate the influence of particle size on the final properties of the panels, as previously demonstrated in studies on other tropical wood species [18], [19], [20], [21].

The binder used in the panel fabrication was a natural animal-based adhesive known as bone glue pearls. This adhesive is obtained from the processing of animal bone residues, primarily composed of collagen. Traditionally used in woodworking and restoration crafts, bone glue offers several advantages, including non-toxicity, biodegradability, and good compatibility with lignocellulosic fibers [17], [22]. It was selected for this study due to its local availability, strong adhesive performance, and low environmental impact, aligning with the objectives of developing bio-based and sustainable materials.

Particleboards Preparation

The particleboards were produced from a homogeneous mixture of *Ficus racemosa* sawdust and pearls bone glue. Each panel was prepared using a total dry weight of 600 g, with varying binder rates of 7.5%, 10%, 12.5%, and 15% by weight relative to the sawdust. This variation aimed to assess the influence of binder content on the internal cohesion and mechanical performance of the panels, following methodologies reported in previous studies on bio-based composites [7], [19], [23]. Water was added at 20% of the total mixture weight (i.e., 120 g for 600 g).

The mixture was thoroughly hand-mixed to ensure a uniform distribution of the bone glue over all wood particles. The resulting paste was then poured into a 30 × 30 cm metallic mold, whose inner surfaces were previously coated with a releasing agent to facilitate demolding after pressing.

Hot pressing was carried out using a **CARVER-type hydraulic press**. The operating parameters were established based on recommendations from previous studies: a pressing temperature of **160 °C**, an applied pressure of **11 bar**, and a pressing duration ranging from **30 to 36 minutes**. These conditions were selected to ensure proper plasticization of the binder, efficient impregnation into the wood particles, and adequate structural cohesion of the boards, while avoiding carbonization or thermal degradation of the fibers.

After pressing, the panels were left to cool under pressure before being carefully demolded. They were then conditioned at **room temperature (~25 °C)** and **protected from humidity** for a period of **seven days**, allowing complete binder hardening and dimensional stabilization.



This fabrication process is simple, reproducible, and accessible for local artisans and small-scale production units, making it particularly suitable for potential semi – industrial applications.

Physical Properties Determination

Density

The density of the materials was determined by calculating the ratio of the mass of each specimen to its volume, following the method described in [24]. Measurements were conducted in accordance with the **ANSI A208.1-2022** standard on ten (10) specimens taken from each of the six types of boards produced. The density was calculated using Equation (1):

$$\rho = \frac{M}{V} \quad (1)$$

where ρ is the density of the material (kg/m^3), M is the mass of the specimen (kg), and V is its volume (m^3). The mass was measured using a high-precision digital balance, while the volume was obtained from dimensional measurements of the samples after pressing.

Determination of Water Absorption and Thickness Swelling

The **water absorption test** evaluates the amount of water absorbed by a material after immersion for a defined period, while the **thickness swelling test** measures the variation in specimen thickness after immersion.

In this study, both tests were performed according to the **ANSI A208.1-2022** standard using twelve (12) specimens measuring **50 mm × 50 mm**. Before immersion, the initial mass and thickness of each specimen were carefully measured. The samples were then immersed in water, and six specimens were withdrawn after **2 hours** and the remaining six after **24 hours**. The mass and thickness were measured again. To remove surface water, the specimens were left at room temperature for **15 to 20 minutes** before the final weighing and thickness measurements.

These measurements allowed the calculation of **water absorption (WA)** and **thickness swelling (TS)**, which are key indicators of the performance of materials under humid conditions. The thickness swelling (TS) was calculated using Equation (2):

$$TS (\%) = \frac{t_i - t_0}{t_0} \times 100 \quad (2)$$

where t_0 is the initial thickness of the specimen (mm), and t_i is the thickness after immersion (mm), measured after 2 or 24 hours.

Similarly, water absorption (WA) was determined using Equation (3):

$$WA (\%) = \frac{W_i - W_0}{W_0} \times 100 \quad (3)$$

where W_0 is the initial mass of the specimen (g), and W_i is the mass after immersion (g), measured after 2 or 24 hours.

Mechanical Properties Determination

The mechanical properties of the samples were determined using a **universal testing machine** equipped with specific accessories for **three-point bending** and **tensile tests**. All tests were carried out under controlled environmental conditions, maintaining a **relative humidity of 65%** and a **temperature of 20 ± 3 °C** to ensure consistency and comparability of the results.

Three-Point Bending Test

The specimens used for the bending tests had dimensions of **150 mm × 100 mm**. The tests were performed in accordance with the standards **EN 312-2:2004** and **EN 310** [25], [26]. The calculation of the mechanical properties, namely the **Modulus of Elasticity (MOE)** and the **Modulus of Rupture (MOR)**, followed the procedures described in **NF B51-124:1993** and **NBN EN 310:1999** [27], [28].

The **Modulus of Elasticity (MOE)** was determined using Equation (4):

$$MOE = \frac{F.l^3}{4be^3y} \quad (4)$$

With $F = (F_2 - F_1)$ and $y = (y_2 - y_1)$, leading to the expression:

$$MOE = \frac{(F_2 - F_1).l^3}{4be^3(y_2 - y_1)} \quad (5)$$

The modulus of rupture (MOR) was calculated using Equation 6:

$$MOR = \frac{3Fl}{2be^2} \quad (6)$$



In these equations, l represents the distance between the supports (mm), e is the thickness of the specimen (mm), and b is its width (mm). F denotes the maximum load at failure (N), while F_1 and F_2 correspond to 10% and 40% of the maximum load, respectively. The parameters y_1 and y_2 represent the deflections corresponding to F_1 and F_2 , respectively

3. Results and Discussion

This section presents the experimental results obtained from the physico-mechanical tests performed on particleboards made from *Ficus racemosa* sawdust bonded with bone glue pearls. The parameters investigated include, on one hand, the physical properties such as density, water absorption (WA), and thickness swelling (TS) after 2 and 24 hours of water immersion, and on the other hand, the mechanical properties, including the tensile strength (MOT), modulus of elasticity (MOE), modulus of rupture (MOR), and Young's modulus (E).

The results related to physical properties provide insight into the dimensional stability and moisture resistance of the panels, while the mechanical results offer an evaluation of their stiffness, strength, and suitability for structural or semi-structural applications.

For the presentation and comparison of results, the panels were classified into five categories based on particle size distribution: G1 ($g \leq 0.8$ mm), G2 ($0.8 < g \leq 1.6$ mm), G3 ($1.6 < g \leq 2.5$ mm), G4 ($2.5 < g \leq 5$ mm), and G5 corresponding to unsieved: raw particles.

Density

The density results of the *Ficus racemosa* particleboards as a function of binder content and particle size are presented in Figure 1. Overall, the density increases with higher binder content across all particle sizes. Panels made from finer particles (G1, $g \leq 0.8$ mm) exhibit the highest densities, reaching 844.05 kg/m^3 at 15% binder content, indicating better compaction and internal cohesion. In contrast, panels from groups G2 to G5 show lower and relatively similar density values.

All panels display densities ranging from 640 to 800 kg/m^3 , except those made with fine particles and higher binder levels (12.5–15%), which exceed 800 kg/m^3 . According to ANSI A208.1-2022, most panels fall within the medium-density fiberboard (MDF) category, while the densest ones can be classified as high-density fiberboards (HDF).

These findings align with previous studies by Kadja [29], who developed bone glue-bonded panels from cotton and kenaf fibers, and by Drovou et al. [19], who used tannin-based binders from *Parkia biglobosa* pods and *Pithecellobium dulce* bark to produce eco-friendly panels. Generally, higher binder contents promote stronger fiber adhesion and fewer voids, resulting in increased density, consistent with trends reported in the literature [12], [19].

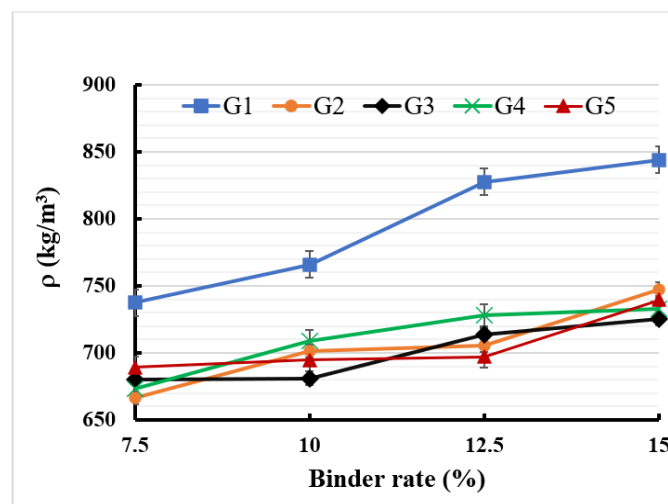


Figure 1: Variation of density according to granulometry and binder rate

Thickness Swelling and water absorption

Figure 2 shows the variation in thickness swelling of the particleboards after 2 and 24 hours of water immersion as a function of bone glue content. In general, thickness swelling decreases progressively with increasing binder



content. For instance, in G1, swelling drops from 65.78% at 7.5% binder to 38.42% at 15%, representing a reduction of about 42% after 2 hours of immersion. Similar trends are observed across other formulations.

The G3 formulation behaves differently, showing higher swelling values (113.05% at 7.5% and 75.89% at 15%) despite an overall decrease with increased binder content. This suggests higher water sensitivity, possibly due to internal porosity or uneven binder distribution, though density results do not fully support this hypothesis [30], [31].

As expected, after 24 hours of immersion, all panels exhibit higher swelling values than after 2 hours, confirming continuous water absorption over time. Nevertheless, the decreasing trend with increasing binder content persists, with a noticeable slowdown in swelling between 2 and 24 hours, suggesting stabilization of water uptake.

According to the ANSI A208.1-2022 standard, acceptable thickness swelling limits are 20% for flooring panels, 8% for roofing panels (after 2 hours), and 50% for general-purpose panels (after 24 hours). The values obtained in this study exceed these limits and also remain above the stricter EN 317 standard [32], highlighting the panels' high moisture sensitivity and the need for further improvement, such as binder modification or surface treatment to enhance dimensional stability.

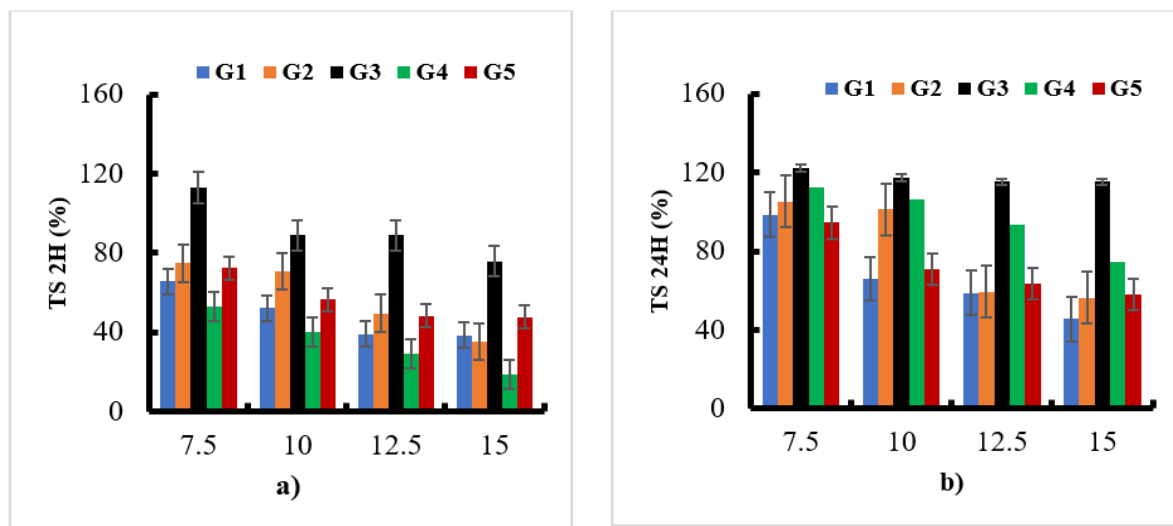


Figure 2: Thickness swelling variation according to the granulometry and binder a) after 2 hours b) after 24 hours immersion

Figure 3 shows the variation in water absorption of the panels as a function of bone glue content after 2 and 24 hours of immersion. Overall, water absorption decreases progressively with increasing binder content, following the same trend observed for thickness swelling. For example, in G1, absorption drops from 114.84% to 49% after 2 hours and from 171.13% to 68.73% after 24 hours as the glue content increases from 7.5% to 15%.

After 2 hours, G2 and G3 exhibit the highest absorption values (185.7% and 154.23%, respectively), while G4 shows the lowest (71.36% at 7.5% binder). The same pattern persists after 24 hours, with all panels showing increased absorption over time, indicating continuous water uptake. Panels with higher binder content (15%) consistently display the lowest absorption values, confirming that increasing the glue ratio enhances water resistance. However, G2 and G3 remain more sensitive, likely due to internal structural differences or less uniform binder distribution.

The water absorption values obtained are comparable to those reported by Diop et al. [33] (120–160%) for fiberboards made from thermomechanical pulp and lignocellulosic nanofibrils. However, they are much higher than those reported by Rodríguez et al. [34] (18–60%) and Boran and Torun [35] (20–25%) for MDF-based and cellulose–antimony trioxide composite panels, respectively.



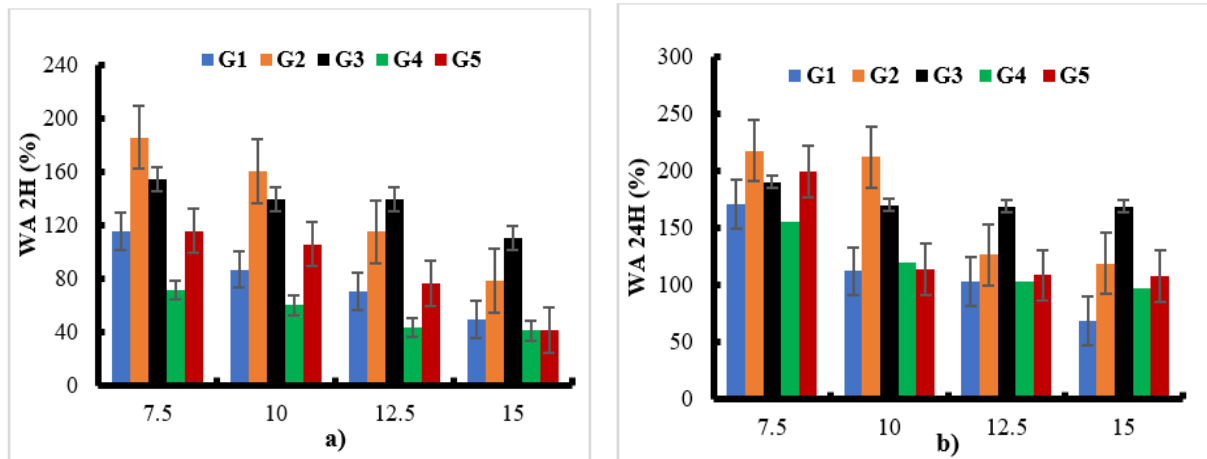


Figure 3: Water absorption (WA) variation according granulometry and binder a) after 2 hours and b) 24 hours immersion.

Three-point bending test properties

Moduli of elasticity (MOE)

Figure 4 shows the variation of the modulus of elasticity (MOE) of *Ficus racemosa* particleboards as a function of bone glue content for the different formulations (G1–G5). Overall, MOE increases with higher binder content, indicating improved stiffness. For instance, in G1, MOE rises from 1627.06 MPa at 7.5% binder to 2450.07 MPa at 15%, a significant enhancement. Similar trends are observed for all formulations.

G1 exhibits the highest MOE values (above 2000 MPa at 15%), consistent with its higher density, while G3 shows the lowest initial values (948.95 MPa) but improves to 1671.9 MPa at 15%, reflecting strong dependence on binder content. This confirms that increasing glue content enhances internal bonding and mechanical rigidity. However, none of the panels meet the ANSI A208.1 requirement for grade M-3i (MOE $\geq$ 2500 MPa), indicating a need for optimization in formulation or processing (e.g., higher density, improved binder distribution, or surface treatment). These findings are consistent with previous studies on bio-based panels from agricultural residues, where MOE values generally remain below industrial standards due to material heterogeneity and lower internal cohesion [33].

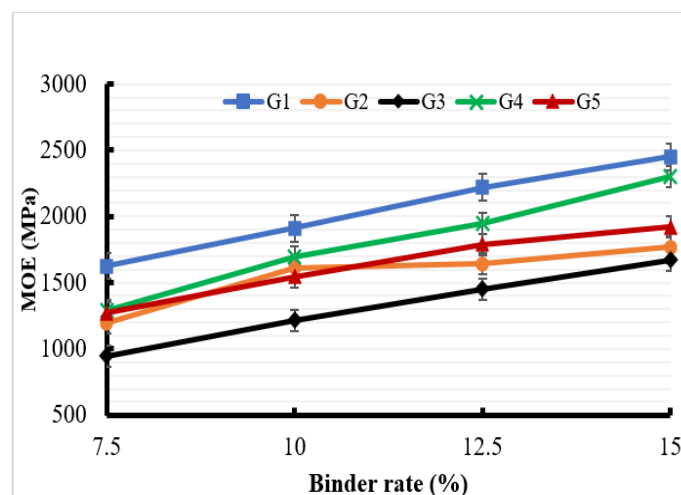


Figure 4: Variation of modulus of Elasticity (MOE) according to binder content and particle size.

Modulus of Rupture (MOR)

Figure 5 shows the variation of the modulus of rupture (MOR) with bone glue content for the different formulations (G1–G5). A general increase in MOR is observed as binder content rises, indicating improved



bending strength. For example, in G1, MOR increases from 10.1 MPa at 7.5% binder to 15.24 MPa at 15%, demonstrating significant strengthening. G1 panels exhibit the highest MOR values, meeting the ANSI A208.1 requirement for grade M-3i ($MOR \geq 15$ MPa). G4 and G5 show intermediate performance, close to the M-2 grade threshold ($MOR \geq 13$ MPa), while G3 remains the weakest (6.29–10.28 MPa), likely due to structural heterogeneity.

These results confirm that higher binder content enhances internal bonding and flexural strength, while particle size distribution also significantly affects mechanical behavior. Similar trends have been reported in studies on bio-based particleboards from agricultural residues, where performance strongly depends on fiber type and binder composition [36], [37].

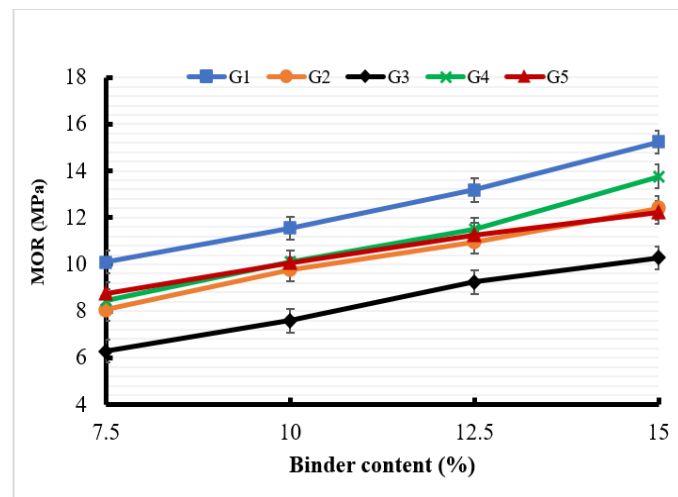


Figure 5: Variation of modulus rupture (MOR) according to binder content and particle size.

4. Conclusion

This study aimed to develop and characterize particleboards made from *Ficus racemosa* sawdust using bone glue as a natural binder. The results demonstrated that both particle size and binder content significantly influence the physical and mechanical properties of the panels.

The density ranged from 640 to 844 kg/m³, classifying most panels as medium-density fiberboards (MDF) according to ANSI A208.1-2022. Finer particles and higher binder content (12.5–15%) produced denser, more cohesive panels. However, water absorption and thickness swelling tests revealed high sensitivity to moisture, exceeding ANSI and EN 317 standards, indicating a need to improve dimensional stability—possibly through binder modification or surface treatments.

Mechanically, increasing binder content enhanced stiffness and strength. The best-performing formulation (G1, 15% binder) achieved a modulus of elasticity (MOE) of 2450 MPa and a modulus of rupture (MOR) of 15.24 MPa, approaching the ANSI M-3i grade requirements ($MOE \geq 2500$ MPa, $MOR \geq 15$ MPa). Coarser particles, however, yielded weaker panels.

Overall, the study confirms the technical feasibility of producing eco-friendly *Ficus racemosa* particleboards using bone glue. While mechanically promising, further optimization is needed to improve water resistance and durability for broader industrial application.

References

- [1]. R. Sathre et J. O'Connor, « Meta-analysis of greenhouse gas displacement factors of wood product substitution », *Environmental Science & Policy*, vol. 13, no 2, p. 104-114, avr. 2010, doi: 10.1016/j.envsci.2009.12.005.
- [2]. F. Pomponi et A. Moncaster, « Circular economy for the built environment: A research framework », *Journal of Cleaner Production*, vol. 143, p. 710-718, févr. 2017, doi: 10.1016/j.jclepro.2016.12.055.



- [3]. Sangmesh B. et al., « Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review », *Construction and Building Materials*, vol. 368, p. 130457, mars 2023, doi: 10.1016/j.conbuildmat.2023.130457.
- [4]. M. Nasir et al., « Recent development in binderless fiber-board fabrication from agricultural residues: A review », *Construction and Building Materials*, vol. 211, p. 502-516, juin 2019, doi: 10.1016/j.conbuildmat.2019.03.279.
- [5]. W.-L. Lao et L. Chang, « Comparative life cycle assessment of medium density fiberboard and particleboard: A case study in China », *Industrial Crops and Products*, vol. 205, p. 117443, déc. 2023, doi: 10.1016/j.indcrop.2023.117443.
- [6]. T. C. Lee, N. A. S. Mohd Pu'ad, M. A. Selimin, N. Manap, H. Z. Abdullah, et M. I. Idris, « An overview on development of environmental friendly medium density fibreboard », *Materials Today: Proceedings*, vol. 29, p. 52-57, janv. 2020, doi: 10.1016/j.matpr.2020.05.679.
- [7]. S. Drovou, K. Attipou, K. Kadja, K. A. Kassegne, et K. Sanda, « Characterization of particleboards of African mahogany sawdust made with tannic powders of *Bridelia* and African locust bean pods », *Eur. J. Wood Prod.*, vol. 80, no 5, p. 1175-1183, oct. 2022, doi: 10.1007/s00107-022-01825-3.
- [8]. P. Kaur et H. Kaur, « Current Status of Utilization of Agricultural Waste and Prospects in Biocomposites », in *Value-Added Biocomposites*, CRC Press, 2021.
- [9]. K. Manickaraj et al., « Value-added utilization of agricultural wastes in biocomposite production: Characteristics and applications », *Annals of the New York Academy of Sciences*, vol. 1549, no 1, p. 72-91, 2025, doi: 10.1111/nyas.15368.
- [10]. S. B. et al., « Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review », *Construction and Building Materials*, vol. 368, p. 130457, mars 2023, doi: 10.1016/j.conbuildmat.2023.130457.
- [11]. N. Fitri, Mursal, et I. Ismail, « Physical and chemical properties of particleboard made of rice straw and plastic waste », *J. Phys.: Conf. Ser.*, vol. 1460, no 1, p. 012146, févr. 2020, doi: 10.1088/1742-6596/1460/1/012146.
- [12]. I. O. Ohijeagbon et al., « Physico-mechanical properties of cement bonded ceiling board developed from teak and African locust bean tree wood residue », *Materials Today: Proceedings*, vol. 44, p. 2865-2873, janv. 2021, doi: 10.1016/j.matpr.2020.12.1170.
- [13]. J. X. Lim et al., « Development of Particleboard from Green Coconut Waste », *J. Phys.: Conf. Ser.*, vol. 2120, no 1, p. 012034, déc. 2021, doi: 10.1088/1742-6596/2120/1/012034.
- [14]. A. A. Jimmim, Md. T. A. Khan, et Md. A. Rahman, « Fabrication and characterization of low density particle boards from pseudo-stem of banana plant », *AIP Conference Proceedings*, vol. 1980, no 1, p. 030031, juill. 2018, doi: 10.1063/1.5044310.
- [15]. V. B. Cabalo, « Utilization of Coconut Coir and Abaca Stripping Waste Fibers for Cement Bonded Board », *SLSU Journal of Science, Engineering and Technology (SLSU JSET)*, vol. 3, no 1, p. 183-188, déc. 2015, doi: 10.61569/v07aae53.
- [16]. M. Dunky, « Applications and Industrial Implementations of Naturally-Based Adhesives », in *Biobased Adhesives*, John Wiley & Sons, Ltd, 2023, p. 659-704. doi: 10.1002/9781394175406.ch22.
- [17]. K. Kobetičová, M. Böhm, M. Jerman, J. Dušek, et R. Černý, « Ecotoxicity and Biodegradation of Sustainable Environment-Friendly Bone-Glue-Based Adhesive Suitable for Insulation Materials », *Polymers*, vol. 14, no 11, p. 2209, janv. 2022, doi: 10.3390/polym14112209.
- [18]. N. Engehausen, J. T. Benthien, et J. Lütke, « Influence of Particle Size on the Mechanical Properties of Single-Layer Particleboards », *Fibers*, vol. 12, no 4, p. 32, avr. 2024, doi: 10.3390/fib12040032.
- [19]. S. Drovou, K. A. Kassegne, K. Kadja, Y. Koutsawa, et K. Sanda, « Effect of granulometry and binder rate on the physical, thermal and mechanical properties of Africa antiaris (*Antiaris africana*) sawdust particleboard made with the tannic powder of African locust bean pod husk (*Parkia biglobosa*) and the India tamarind (*Pithecellobium dulce*) peel », *J Indian Acad Wood Sci*, vol. 16, no 2, p. 94-102, déc. 2019, doi: 10.1007/s13196-019-00241-0.



- [20]. J. Fehrmann, B. Belleville, B. Ozarska, W. (Voytek) S. Gutowski, et D. Wilson, « Influence of particle granulometry and panel composition on the physico-mechanical properties of ultra-low-density hemp hurd particleboard », *Polymer Composites*, vol. 44, no 11, p. 7363-7383, 2023, doi: 10.1002/pc.27631.
- [21]. N. Ndulue, N. Esiere, A. Omole, et P. Ndulaka, « Effect of Particle Sizes on the Physio-Mechanical Properties of Bamboo Particleboard », *Asian Journal of Research in Agriculture and Forestry*, vol. 9, p. 224-232, août 2023, doi: 10.9734/AJRAF/2023/v9i3227.
- [22]. M. N. Islam et al., « Formulation and Characterization of Formaldehyde-Free Chemically Modified Bone-Based Adhesive for Lignocellulosic Composite Products », *Global Challenges*, vol. 5, no 9, p. 2100002, 2021, doi: 10.1002/gch2.202100002.
- [23]. K. Kadja, S. Drovou, K. A. Kassegne, A. Pizzi, K. Sanda, et A. D. L. Batako, « Development and Investigation into Properties of composite Particleboard of Iroko and African Locust Bean Pod », *Procedia Manufacturing*, vol. 30, p. 188-193, janv. 2019, doi: 10.1016/j.promfg.2019.02.027.
- [24]. M. Aliyu, I. S. Mohammed, M. Usman, S. M. Dauda, et J. I. Igbetua, « Production of composite briquettes (orange peels and corn cobs) and determination of its fuel properties », *Agricultural Engineering International: CIGR Journal*, vol. 22 (2), p. 133-144, juin 2020.
- [25]. CEN – European Committee for Standardization, « EN 312-2: Particleboards — Specifications — Part 2: Requirements for boards for interior fitments (including furniture) for use in dry conditions. » Brussels: CEN., 2003.
- [26]. CEN – European Committee for Standardization, « EN 310: Wood-based panels — Determination of modulus of elasticity in bending and of bending strength. » Brussels: CEN, 1993.
- [27]. NBN – Bureau de Normalisation, « NBN EN 310:1999 — Wood-based panels — Determination of modulus of elasticity in bending and of bending strength ». Brussels: NBN., 1999.
- [28]. AFNOR – Association Française de Normalisation, « NF B51-124:1993 — Panneaux à base de bois — Détermination de la résistance à la traction perpendiculairement au plan du panneau (essai d'arrachement). » Paris: AFNOR, 1993.
- [29]. K. KADJA, *Elaboration et caractérisation mécanique et thermique des panneaux de particules de Kénaf (Hibiscus Cannabinus L.) et de cotonnier (Gossypium Hirsutum.L.)*. Lomé: Université de Lomé, 2012.
- [30]. F. A. Aisien, A. N. Amenaghawon, et K. C. Bienose, « Particle boards produced from cassava stalks: Evaluation of physical and mechanical properties », *South African Journal of Science*, vol. 111, no 5-6, p. 1-4, juin 2015, doi: 10.17159/sajs.2015/20140042.
- [31]. S. Panyakaew et S. Fotios, « New thermal insulation boards made from coconut husk and bagasse », *Energy and Buildings*, vol. 43, no 7, p. 1732-1739, juill. 2011, doi: 10.1016/j.enbuild.2011.03.015.
- [32]. CEN – European Committee for Standardization, « EN 317: Particleboards and fibreboards — Determination of swelling in thickness after immersion in water. », Brussels: CEN.
- [33]. C. I. K. Diop, M. Tajvidi, Michael. A. Bilodeau, D. W. Bousfield, et J. F. Hunt, « Evaluation of the incorporation of lignocellulose nanofibrils as sustainable adhesive replacement in medium density fiberboards », *Industrial Crops and Products*, vol. 109, p. 27-36, déc. 2017, doi: 10.1016/j.indcrop.2017.08.004.
- [34]. G. E. Rodríguez, C. Bustos Ávila, et A. Cloutier, « Physical and Mechanical Properties of Fiberboard Made of MDF Residues and Phase Change Materials », *Forests*, vol. 15, no 5, Art. no 5, mai 2024, doi: 10.3390/f15050802.
- [35]. S. Boran Torun, « Investigation of the properties of fiberboards made from microcrystalline cellulose and antimony trioxide added melamine formaldehyde adhesive », *International Journal of Adhesion and Adhesives*, vol. 113, p. 103084, mars 2022, doi: 10.1016/j.ijadhadh.2021.103084.
- [36]. « Comparing properties of North American manufactured particleboard and medium density fiberboard – Part I: Particleboard:: BioResources ». Consulté le: 15 octobre 2025. [En ligne]. Disponible sur: <https://bioresources.cnr.ncsu.edu/>
- [37]. P. G. Surdi, G. Bortoletto Júnior, V. R. de Castro, F. M. S. Brito, M. da S. Berger, et J. C. Zanuncio, « PARTICLEBOARD PRODUCTION WITH RESIDUES FROM MECHANICAL PROCESSING OF AMAZONIAN WOODS », *Rev. Árvore*, vol. 43, p. e430102, 2019, doi: <https://doi.org/10.1590/1806-90882019000100002>.

