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Development and Evaluation of Particleboard Composites Using Ipil-Ipil (*Leucaena leucocephala*) and Water Hyacinth (*Eichhornia crassipes*)

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ABSTRACT :

This study explored the potential of Ipil-Ipil (*Leucaena leucocephala*) and water hyacinth (*Eichhornia crassipes*) as alternative and sustainable raw materials for particleboard production. The study aimed to evaluate and compare the physical and mechanical properties of particleboards produced using two different inclusion ratios: 25% water hyacinth and 75% Ipil-Ipil, and 75% water hyacinth and 25% Ipil-Ipil. The particleboards were assessed in terms of moisture content, bulk density, and internal bond strength. The plant materials were collected, prepared, dried, crushed, sieved, mixed with adhesive, molded, and allowed to dry before testing. Descriptive statistics and one-way analysis of variance (ANOVA) were used to analyze the collected data and determine whether significant differences existed between the two formulations. Results showed that the particleboard containing 25% water hyacinth and 75% Ipil-Ipil performed better overall. It recorded a moisture content of 8.55%, a bulk density of 659.83 kg/m³, and an internal bond strength of 0.615 MPa. In comparison, the formulation containing 75% water hyacinth and 25% Ipil-Ipil recorded 11.55% moisture content, 539.83 kg/m³ bulk density, and 0.377 MPa internal bond strength. The differences between the two formulations were statistically significant at $p < .001$. The findings show that both plant materials can be used for particleboard production, although their proportions significantly affect the resulting board properties. Overall, the formulation with 25% water hyacinth and 75% Ipil-Ipil provided better moisture control, higher density, and stronger internal bonding under the conditions of the study

Keywords : Ipil-Ipil, water hyacinth, particleboard, sustainable materials, internal bond strength

INTRODUCTION

One of the greatest contradictions of modern production lies in the fact that forests are being depleted for raw materials while vast quantities of plant-based waste are discarded every day. As demand for wood products continue to rise, so does the pressure on natural ecosystems, stressing the urgent need to rethink how materials are sourced and utilized. The global construction and manufacturing industries rely heavily on particleboard composites as fundamental materials for furniture, housing, and interior design applications. However, the commercial production of these standard boards heavily accelerates environmental degradation through logging and unsustainable timber harvesting to meet industrial demand.

According to Food and Agriculture Organization of the United Nations (FAO), agricultural expansion drives almost 90 percent of global deforestation. Deforestation is the transformation of forests to other land uses. Despite covering 3.5 billion hectares and accounting for 27% of the world's land area in 2020, natural forests continue to face alarming rates of depletion. Data from Global Forest Watch reveal that by 2025, approximately 23 million hectares of natural forest had been lost globally. This releases an estimated 9 gigatons of CO₂ into the atmosphere every single year worldwide.

The effects of land degradation and forest loss are also evident in the Philippines. Global Forest Watch reported that the world lost approximately 23 million hectares of natural forest in 2025, generating an estimated 9 gigatons of carbon dioxide (CO₂) emissions. In the Philippines, around 32 thousand hectares of natural forest were lost during the same year, resulting in approximately 18 million metric tons of CO₂ emissions. More specifically, Bulacan, which had about 110 thousand hectares of natural forest in 2010, has experienced a loss of approximately 122 hectares of natural forest, equivalent to 62.4 kilotons of CO₂ emissions. These figures emphasize the continuing decline of forest resources and emphasize the need to explore sustainable alternatives to conventional wood-based materials.

According to Global Forest Watch data, San Miguel, Bulacan has experienced a decline in tree cover over the past two decades. From 2001 to 2024, the municipality lost a significant area of tree cover, reflecting the impacts of land-use change, agricultural expansion, infrastructure development, and other human activities. Tree cover loss reduces the capacity of ecosystems to store carbon, regulate water resources, and support biodiversity. The continuous reduction of forested and vegetated areas in San Miguel highlights the need for stronger environmental protection measures and sustainable land management practices to mitigate further degradation and preserve the municipality's remaining natural resources.

These challenges accentuate the need for sustainable alternatives that can reduce dependence on virgin wood materials while promoting the beneficial

use of biomass. Concurrently, aquatic ecosystems are severely threatened by the rampant proliferation of water hyacinth (*Eichhornia crassipes*), an invasive alien species that thrives in polluted bodies of water. Local government and environmental records that water hyacinths rapidly multiply, with a single plant capable of producing 3,000 more in just 50 days, resulting in massive mats that choke waterways like the Pasig River and Laguna de Bay, causing devastating floods, disrupting marine transport, and destroying local fishing livelihoods.

Because of these negative impacts, there is a growing need to develop sustainable ways of utilizing water hyacinth instead of simply disposing of it. One potential solution is to use the plant as a raw material for particleboard production. Converting water hyacinth into particleboards may help reduce environmental problems caused by its overgrowth while providing an alternative and eco-friendly material for various applications. Therefore, this study aims to explore the potential of water hyacinth as a resource for particleboard production and contribute to more sustainable waste management practices.

The rapid growth of the Philippine construction industry is on urgent need for eco-friendly Sustainable Building Materials (SBMs). While current literature explores the individual potential of invasive plants like Water Hyacinth and Ipil-Ipil, no research exists on a hybrid particleboard combining both. Alternative composites are typically manually fabricated, they lack comparative data against factory-made, chemically treated commercial boards regarding critical structural and physical properties

The world face large quantities of agricultural and aquatic plant wastes that are often discarded or left unmanaged, leading to environmental concerns such as land pollution, greenhouse gas emissions from decomposition, and inefficient resource utilizations. Therefore, this study evaluates a novel, eco-friendly solution by engineering alternative particleboard composites utilizing *Leucaena leucocephala* (Ipil-Ipil) and water hyacinth inclusions. Ultimately, this research directly advances the United Nations Sustainable Development Goals (SDGs), specifically contributing to SDG 12 (Responsible Consumption and Production) by reducing reliance on forest timber, and SDG 15 (Life on Land) by actively managing and utilizing an invasive species to protect terrestrial and aquatic biodiversity.

The growing amount of unused plant materials and invasive species has become an environmental concern, making it important to explore ways of turning these resources into useful products. This study supports Sustainable Development Goal 12 (Responsible Consumption and Production). By using Ipil-Ipil and water hyacinth as alternative materials for particleboard production, the study promotes the proper utilization of plant-based resources that are often left unmanaged or treated as waste. It also encourages the development of more sustainable materials that may help lessen the reliance on conventional wood-based resources. The continuous spread of invasive plant species can negatively affect ecosystems and biodiversity when left unmanaged.

This study supports Sustainable Development Goal 15 (Life on Land) by exploring the potential use of Ipil-Ipil and water hyacinth in producing particleboard composites. Water hyacinth, in particular, can rapidly spread and affect aquatic environments, while the uncontrolled growth of invasive plants may disrupt native ecosystems. By converting these plants into useful materials, this study presents a possible way of managing their abundance while giving them a practical purpose. Through this approach, the research promotes the responsible use of natural resources and supports efforts to reduce the environmental impact of invasive species.

METHODOLOGY

This chapter explains the methods and procedures used in the study. It covers how the materials were collected, prepared, made into particleboards, and tested. Two particleboards with different amounts of Ipil-Ipil and Water Hyacinth were produced and evaluated based on their strength, durability, and thickness swelling. The results were then analyzed using statistical methods to compare the performance of the experimental particleboards.

2.1 Collection of Materials

The Ipil-Ipil were collected from the local neighborhoods, and the Water Hyacinth plants were carefully collected at Magumbali, Camdaba, Pamapanga. The Urea Formaldehyde Resin was bought from an international online shop due to it not being available in the Philippines.

2.2 Preparation of Materials

Before the experiment began, the researchers prepared the safety wear and necessary lab apparatuses. After collecting the plants, the petioles were separated from the rest of the plant and were washed to remove any impurities. Then, it was placed separately in an oven at 30° and left to dry until 95% of the weight is reduced.

2.3 Crushing and Sieving of Dried Plants

Using a blender, the plants were separately crushed and sieved at a 10-mesh sieve then crushed and sieved again at a 35-mesh sieve until it is fine but not pulverized. After that, both plants were placed in a bowl individually.

2.4 Mixing

The plants were soaked in water separately for a minute to let it mix to avoid chunks. Then the Urea Formaldehyde and wood glue were added with a ratio of 60% plant inclusions and 40% Urea Formaldehyde Resin and wood glue. Lastly, it was mixed until it turned dark brown in color.

2.5 Molding and Curing

First, a teflon sheet was placed on the bottom of the mold. Then, the mixture was poured into a 30 x 20 x 10 cm wooden frame mold using a trowel, and then another Teflon sheet was placed on top. After that, a 10-pound weight was used to flatten the board to a thickness of 10 cm. The packed mold was placed outside to sun dry. When the particle board is completely dry, it was removed from the mold and then the researcher proceeded to the next step.

2.6 Testing

Evaluated the completed particleboards for strength, durability, and thickness swelling.

Tensile Strength

Tensile strength was used to determine the maximum amount of stress a material, or a product was able to resist before it breaks due to force. In particular for the particle board, this had indicated the durability of when used in industrial purposes.

Variables:

σ = tensile strength (MPa or N/mm²)

F = maximum load at failure

A = cross-sectional area (mm²)

Equation:

$$\sigma = \frac{F}{A} \quad (1)$$

Internal Bonding (IB)

Internal Bonding was used to measure the strength of the boards that was perpendicular to the surface. It was used to determine the compatibility of the bonded materials in the boards.

Variables:

IB = internal bond strength (MPa)

F = maximum load at failure

A = bonding area of the specimen (mm²)

Equation:

$$IB = \frac{F}{A} \quad (2)$$

Thickness Swelling

Thickness swelling was tested after 24 hours of being immersed in water, to determine the stability of the boards. Through this, it was helpful to assess its resistance to moisture.

Variables:

TS = thickness swelling (%)

T_i = initial thickness before soaking (mm)

T_f = final thickness after soaking (mm)

Equation:

$$TS(\%) = \frac{T_f - T_i}{T_i} \times 100 \quad (3)$$

2.7 Waste Disposal

Following the experimental procedures, unused *Leucaena leucocephala* (Ipil-Ipil) and *Eichhornia crassipes* (Water Hyacinth) leaf specimens were collected, air-dried, and stored in sealed, airtight containers prior to disposal through designated composting facilities. To avoid ecological risks, particularly the uncontrolled proliferation of invasive flora, none of the plant material was discharged into open bodies of water. Chemical management, excess urea-formaldehyde resin was allowed to undergo complete curing and hardening before removal. Once fully solidified, the resin was safely gathered and processed as solid chemical waste, strictly following to the standard institutional and laboratory waste disposal protocols.

2.8 Data Analysis

The performance of the two particleboards was looked at based on the data that was collected. The tests were done two times due to having two setups with varying ratios. The results were put in order based on the standard deviation. An analysis of variance was used to see the differences in the results. The tests conducted were tensile strength, internal bonding, and thickness swelling. The tensile strength of the particleboards was used to see how stress they could take before breaking due to force. The two different setups were looked at using the equation for tensile strength, which helped the researcher figure out how strong the particleboards were. This helped the researcher see how durable the particleboards were.

The strength of the particleboards was also looked at from the side to see how strong the bonds between the particles were. The formula was used again

in three setups for this test. This helped the researcher see how strong the bonds were between the particles. Lastly, the particleboards were put in water for 24 hours. Then the thickness swelling test was done to see how stable they were. The formula, for thickness swelling was used, which helped the researcher see how well the particleboards could resist moisture. The performance of the four particleboards, including the commercial particleboard was analyzed in all these tests.

RESULTS

The results describe the physical and mechanical properties of the two particleboard formulations and determine whether their differences were statistically significant. Moisture content, bulk density, and internal bond strength were compared using descriptive and inferential statistical analyses.

3.1 Physical and Mechanical Properties of the Particleboards

Table 1. Physical and Mechanical Properties of the Two Particleboard Formulations

Particleboard Formulation	Moisture Content (%)	Bulk Density (kg/m ³)	Internal Bond Strength (MPa)
25% Water Hyacinth + 75% Ipil-Ipil	8.55 ± 0.24 ^b	659.83 ± 7.73 ^a	0.615 ± 0.024 ^a
75% Water Hyacinth + 25% Ipil-Ipil	11.55 ± 0.29 ^a	539.83 ± 7.73 ^b	0.377 ± 0.022 ^b

Note. Values are mean ± SD. Different superscript letters within a property indicate a significant difference at $\alpha = .05$.

Table 1 shows that increasing the water hyacinth proportion from 25% to 75% increased moisture content but decreased bulk density and internal bond strength. The 25% water hyacinth + 75% Ipil-Ipil formulation produced the drier, denser, and more strongly bonded particleboard.

3.2 Moisture Content

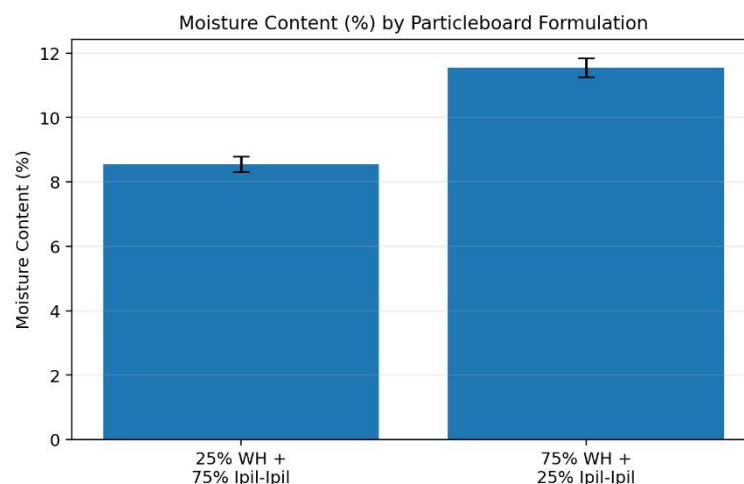
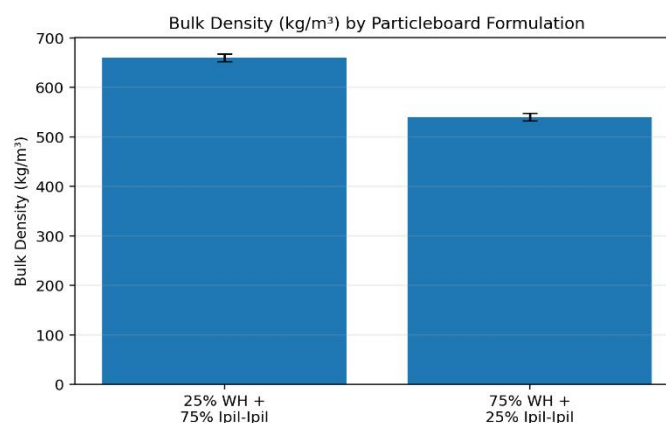


Figure 1. Mean Moisture Content of the Two Particleboard Formulations

The 25% water hyacinth + 75% Ipil-Ipil formulation had a lower moisture content (8.55 ± 0.24%) than the 75% water hyacinth + 25% Ipil-Ipil formulation (11.55 ± 0.29%). Increasing the water hyacinth proportion resulted in a 3.00-percentage-point (35.1%) increase in moisture content.

3.3 Bulk Density

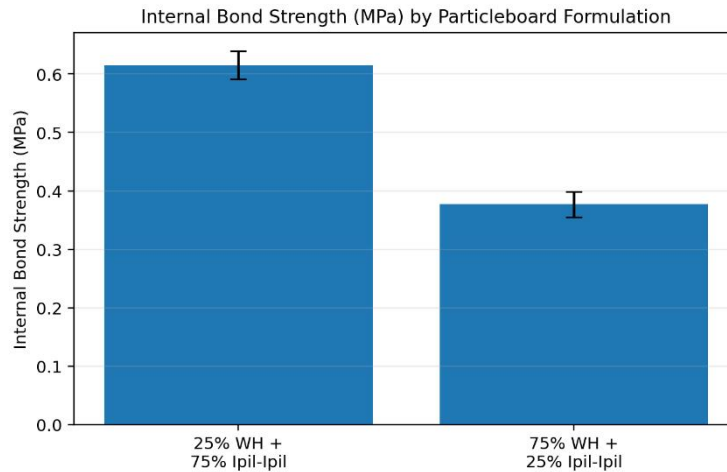
Figure 2. Mean Bulk Density of the Two Particleboard Formulations



Bulk density was higher in the 25% water hyacinth + 75% Ipil-Ipil formulation ($659.83 \pm 7.73 \text{ kg/m}^3$) than in the 75% water hyacinth + 25% Ipil-Ipil formulation ($539.83 \pm 7.73 \text{ kg/m}^3$). This represents a 120.00 kg/m^3 or 18.2% decrease as the water hyacinth proportion increased.

3.4 Internal Bond Strength

Figure 3. Mean Internal Bond Strength of the Two Particleboard Formulations



The 25% water hyacinth + 75% Ipil-Ipil formulation recorded a higher internal bond strength ($0.615 \pm 0.024 \text{ MPa}$) than the 75% water hyacinth + 25% Ipil-Ipil formulation ($0.377 \pm 0.022 \text{ MPa}$). Increasing the water hyacinth proportion reduced internal bond strength by 0.238 MPa or 38.7%.

3.5 Significant Differences Between the Two Particleboard Formulations

Table 2. One-Way ANOVA for the Physical and Mechanical Properties

Property	SS Between	SS Within	F(1,10)	p-value	η^2	Decision
Moisture content	27.000	0.710	380.28	< .001	0.974	Reject H_0
Bulk density	43,200.000	597.667	722.81	< .001	0.986	Reject H_0
Internal bond strength	0.170	0.005	322.54	< .001	0.970	Reject H_0

Note. All tests used $\alpha = .05$.

The one-way ANOVA showed significant differences between the two formulations for all three properties ($p < .001$). The very large η^2 values indicate that formulation accounted for 97.4%, 98.6%, and 97.0% of the observed variance in moisture content, bulk density, and internal bond strength, respectively.

Table 3. Tukey HSD Pairwise Comparison Between the Two Formulations

Property	Mean Difference	95% Confidence Interval	p-value	Interpretation
Moisture content	+3.00 percentage points	2.66 to 3.34	< .001	Higher with 75% water hyacinth
Bulk density	-120.00 kg/m^3	-129.95 to -110.05	< .001	Lower with 75% water hyacinth
Internal bond strength	-0.238 MPa	-0.268 to -0.209	< .001	Lower with 75% water hyacinth

Note. Mean difference = 75% water hyacinth formulation - 25% water hyacinth formulation.

The Tukey HSD results confirmed significant differences for all three properties ($p < .001$). Increasing water hyacinth from 25% to 75% increased moisture content by 3.00 percentage points while decreasing bulk density by 120.00 kg/m^3 and internal bond strength by 0.238 MPa.

3.6 Overall Synthesis of Findings

Overall, the 25% water hyacinth + 75% Ipil-Ipil formulation showed better performance across all measured properties. Compared with this formulation, the 75% water hyacinth formulation had 3.00 percentage points higher moisture content, 120.00 kg/m³ lower bulk density, and 0.238 MPa lower internal bond strength, with all differences statistically significant at $p < .001$.

4. Conclusion

This study concluded that the inclusion ratio of water hyacinth and Ipil-Ipil significantly affected the physical and mechanical properties of the particleboards produced. Among the two formulations, the particleboard containing 25% water hyacinth and 75% Ipil-Ipil showed better overall performance, with a lower moisture content of 8.55%, higher bulk density of 659.83 kg/m³, and greater internal bond strength of 0.615 MPa. In comparison, the particleboard containing 75% water hyacinth and 25% Ipil-Ipil had higher moisture content and lower bulk density and internal bond strength. Statistical analysis further confirmed that the differences between the two formulations were significant for all three properties at $p < .001$. Therefore, the null hypothesis was rejected, indicating that the proportion of water hyacinth and Ipil-Ipil has a significant effect on particleboard performance. The findings demonstrate that water hyacinth can be used as a raw material for particleboard production, but increasing its proportion to 75% may reduce the board's overall physical and mechanical performance. Thus, under the conditions of this study, the 25% water hyacinth and 75% Ipil-Ipil formulation is the more suitable composition for producing particleboards with better moisture control, density, and internal bonding.

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