An Eco-Friendly Waste Management Solution for Economic Growth: A Novel Approach for Production of Rice Husk Particle Board

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An Eco-Friendly Waste Management Solution for Economic Growth: A Novel Approach for Production of Rice Husk Particle Board

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Abstract: *This study explores the development of particleboard using rice husk and gum Arabic as a natural, locally sourced binder. The aim was to evaluate their viability as sustainable alternatives to conventional particleboard materials. Three board variants were produced with gum Arabic binder contents of 40%, 50%, and 60% by weight of rice husk. Physical properties such as specific gravity and particle size distribution were characterized, while mechanical properties were assessed through compressive, flexural, and tensile strength tests. Durability was evaluated based on water absorption and thickness swelling. Results showed that mechanical strength increased with higher binder content, with the 60% gum Arabic board achieving the highest values: 6.01 N/mm² (compressive), 5.01 N/mm² (flexural), and 1.13 N/mm² (tensile). However, all samples exhibited excessive water absorption and swelling beyond acceptable standards. The findings suggest that rice husk bonded with gum Arabic is suitable for dry, interior particleboard applications, though further treatment is needed to enhance moisture resistance.*

Keywords: Rice husk; Particle Board; Waste Management;

1. INTRODUCTION

The growing demand for particleboards and wood-based panels in Nigeria has significantly reduced the forest cover, leading to the depletion of many tree species, including some lesser-known timber varieties (Kayode, 2007). Despite various conservation efforts, global demand for wood products continues to outpace the rate at which trees are being replaced [1] imbalance between consumption and sustainable supply poses serious social, economic, and environmental challenges[2].

In response to this situation, there is an increasing need to explore alternative raw materials for board and panel production. One promising material is rice husk, a byproduct generated in large quantities during the rice dehusking process [3]. Although rice is cultivated year-round in many parts of Nigeria, its husks are often underutilized. In most underdeveloped and developing countries, these husks are either discarded improperly or openly burned, leading to harmful environmental consequences. Notably, the burning of rice husk releases significant amounts of carbon dioxide, contributing to global warming.

Given its low cost and abundant availability, rice husk presents a viable alternative if handled appropriately. Utilizing rice husk for particleboard production could not only reduce environmental pollution but also provide socio-economic benefits [4]. In support of this, several studies have demonstrated the potential of rice husk in improving particleboard performance. For instance [5] reported that particleboards made from rice husk exhibit improved mechanical properties such as modulus of rupture and modulus of elasticity. Similarly, Takao Ota1 and Tomoya Okamoto (2015) emphasized the importance of selecting appropriate binder ratios to optimize the flexural strength and modulus of rice husk particle boards[6].

Gum Arabic, another natural material widely available across Nigeria, can serve as a sustainable binder in particleboard manufacturing. Its use not only supports local economies but also enhances the mechanical integrity of the boards. [7] found that incorporating gum Arabic in rice husk-based boards increases adhesive strength due to its high polysaccharide content, which promotes particle bonding. Likewise, [8] demonstrated that combining rice husk with natural binders improves the strength and stability of particleboards.

Despite these promising findings, several challenges remain. Variability in rice husk characteristics, arising from differences in geographic origin, local rice varieties, and particle sizes, necessitates the development of standardized processing techniques to ensure consistent board quality. Nevertheless, the combination of rice husk and gum Arabic offers considerable environmental and economic potential, particularly in resource-limited settings like Nigeria.

This study investigates the potential of rice husk and gum Arabic as sustainable alternatives for particleboard production. It aims to assess their mechanical performance, durability, and the effect of varying binder ratios, with the broader goal of promoting eco-friendly construction materials and reducing environmental impact.

While previous findings indicate that these boards offer promising mechanical strength, improvements in durability are necessary for broader use. Building on this, the current research explores the combination of rice husk and gum Arabic as a natural adhesive system, seeking to provide a sustainable solution for agricultural waste utilization and support economic growth through value-added product development.

2. MATERIALS AND METHODS

2.1 Materials

Rice husk: the rice husk was collected from Fursa Rice Mills, Sharada Yahaya Gusau Road, Kano State, Nigeria. The rice husk was dried, screened, ground into fine particles and sieved through the 2 mm British Standard sieves (Figure 1a and 1b).

Figure 1: (a)Dried Screened Rice Husk, (b) Sieved Rice Husk

Gum Arabic and water: This was obtained from Kurmi Market, Kano State, Nigeria (Figure 2a). Gum Arabic granules were manually crushed into powder (Figure 2b) to ease the formation of its solution. While Clean water was obtained from Civil Engineering Bayero University Kano, Nigeria laboratory water tank.

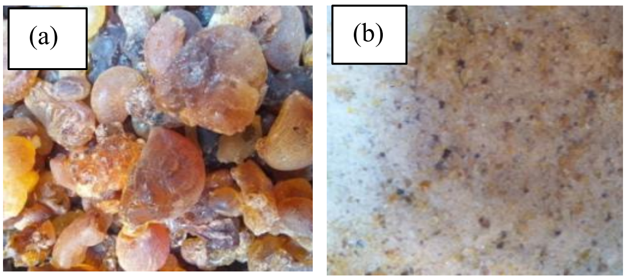

Figure 2: (a) Gum Arabic Figure (a)Crushed Gum Arabic

2.2. Method

2.2.1. Physical property Test

Specific Gravity Test of Rice Husk Particles and Gum Arabic: The specific gravity of rice husk particles and gum Arabic was determined in accordance with BS 8500 (2000)[9]. The test setup used for this procedure is illustrated in Figure 3a.

Particle Size Distribution (PSD) Test of Rice Husk Particles: The particle size distribution test was carried out exclusively on the rice husk using C430 – 08[10] sample to assess the range and proportion of particle sizes present as shown in Figure 3b.

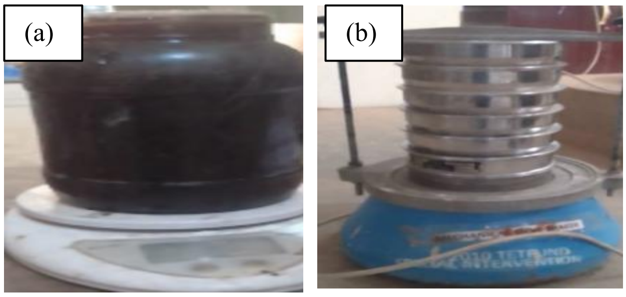

Figure 3: (a) Specific gravity (b) Particle size distribution

2.2.2. Particleboard Preparation and Production: The rice husk was accurately weighed using a digital balance to ensure precise material proportions. Gum Arabic was dissolved in water to prepare a binder solution with a concentration of 1000 g/dm³. This binder solution was then used to mix with the rice husk particles in specified ratios for the particleboard production process.

Mixing: The rice husk and gum Arabic solution were thoroughly mixed in varying proportions to produce different particleboard samples. Specifically, gum Arabic was added at 40%, 50%, and 60% by weight of rice husk. These varying binder contents were used to investigate their effect on board properties. The prepared mixtures and resulting samples are illustrated in Figures 4.

Figure 4: Mixing of Gum Arabic by weight of Rice husk.

Moulding and compressing and demoulding: The prepared mixture was placed into a rectangular mould measuring 150 mm × 150 mm × 15 mm and compressed under a load of 130 kg for 48 hours. After the pressing process and complete drying, the boards were demoulded, cut to the required sizes, and labeled for subsequent mechanical and durability testing, as shown in Figures 5.

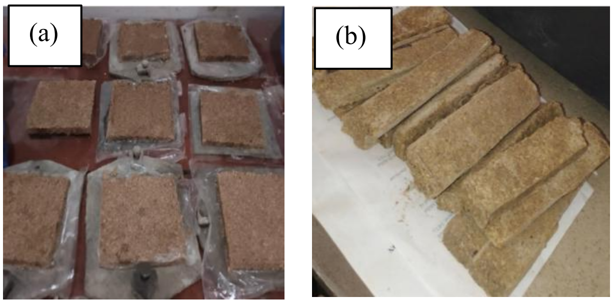

Figure 5: (a) moulded Rice husk Ash, (b): Gum Arabic particle board

2.2.3. Mechanical Property Tests

Compressive Strength: Test is conducted in accordance with ASTM D1037 (1978) [11]procedure and calculated using equation 1:

$$Compessive\ Strength = \frac{Load}{Area} == \frac{Wc}{lb} \qquad (1)$$

Where

Wc = failure load (N)
b = breadth of the sample (mm)
l = length of the sample (mm).

Flexural strength: The flexural strength of the particleboard samples was tested in accordance with the BS EN 310 (1993) standard procedure[12]. The flexural strength was calculated using the equation 2:

$$Flexural\ strength = \frac{3WL\ (N)}{2bt^2 (mm^2)} \qquad (2)$$

Where.
W = failure load (N),
l = span length (mm),
b = breadth (mm),
t = thickness (mm)

Tensile strength: The tensile strength test was conducted in accordance with the BS EN 319 (1993) [13] standard. This test measures the internal bond strength of the particleboard using equation 3:

$$\delta t = \frac{Wt}{b\,x\,t} \quad (3)$$

Where;
W= failure load (N),
b = breadth (mm),
t = thickness (mm).

2.2.4. Durability Property Tests.

Water absorption capacity (WA): The water absorption test was carried out using a modified procedure based on ASTM D1037 (1999) [11]. Specimens were soaked in water at a temperature range of 20–30°C for 2 hours. The water absorption percentage was calculated using equation 4:

$$\text{Water absorption (\%)} = \left(\frac{wf - Wi}{Wi}\right) x\ 100 \quad (4)$$

Where:
Wf = Final weight
Wi = Initial weight

Thickness Swelling (TS): The thickness swelling test was conducted following a modified procedure based on ASTM D1037 (1999)[11]. Specimens were soaked in water at a temperature range of 20–30°C for 2 hours. The percentage of thickness swelling was calculated using equation 5:

$$\text{Thickness swelling (\%)} = \left(\frac{Tf - Ti}{Ti}\right) x\ 100 \quad (5)$$

Where:
Ti = Initial thickness (mm),
Tf = Final thickness (mm)

3.0. Results and Discussion

3.1 Particle Size Distribution of Rice Husk:
The particle size distribution chart Figure 6; reveals that the rice husk sample is well-graded, containing an appropriate balance of fine and medium-sized particles. This type of distribution is advantageous for particleboard production, as it promotes efficient packing, reduces void spaces, and enhances inter-particle bonding. As noted by Ashori and Nourbakhsh (2010), the presence of medium-sized particles contributes to improved board uniformity and strengthens the mechanical performance of the final product[5].

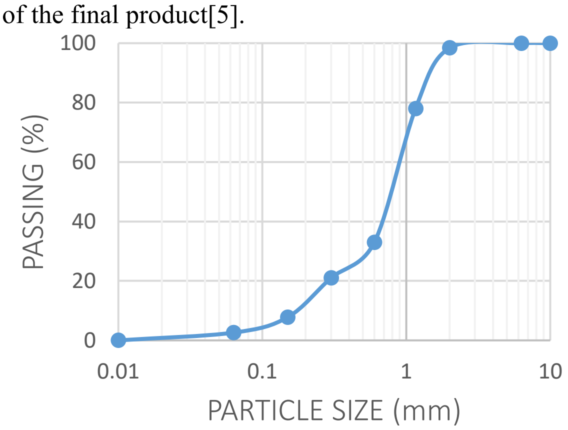

Figure 6: Particle Size Distribution Curve of Rice Husk

3.2 Specific Gravity Test: The specific gravity of rice husk and gum Arabic was found to be 1.57 and 1.47, respectively. These values are in line with the research of [14] on specific gravity values for gum Arabic, while [5] documented comparable results for rice husk. These findings confirm the consistency and suitability of both materials for particleboard production.

3.3. Compressive Strength: Compressive strength shown in figure 7; indicate an increased in strength with higher gum Arabic content. The particleboard containing 40% gum Arabic recorded an average strength of 2.09 N/mm², which rose to 3.49 N/mm² at 50%, and reached 6.01 N/mm² at 60%. This improvement is attributed to enhanced adhesive distribution and stronger inter-particle cohesion. When mixed with water, gum Arabic forms a sticky layer that promotes effective bonding between rice husk particles. Similar performance trends were reported by [15], [16] and [17] in agro-based boards using gum Arabic as a binder in particleboards.

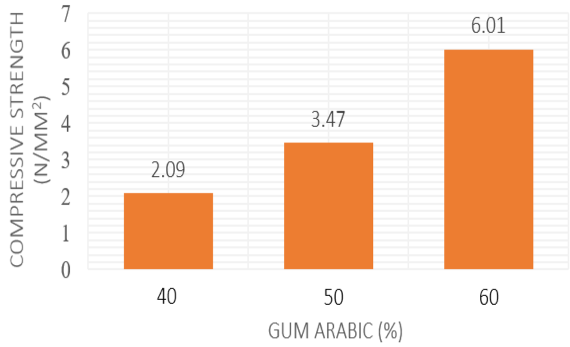

Figure 7: Compressive Strength of Rice Husk and Gum Arabic Particle Board

In terms of standards, only the 60% gum Arabic board met the 5.0 N/mm² benchmark specified for non-load-bearing particleboards (Type P3). The 50% formulation met the 2.5–3.45 N/mm² compressive strength range outlined in NIS 87:2007 for non-loadbearing and load bearing wall respectively as stated by [18]. These findings are consistent with results reported by Sanusi et al. (2023), who emphasized the significant role of binder ratios in determining the compressive strength of natural-fiber-based boards.

3.4 Flexural Strength: Flexural strength increased with higher gum Arabic content as illustrated in Figure 8; Boards with 40%, 50%, and 60% gum Arabic recorded flexural strengths of 0.97 N/mm², 2.37 N/mm², and 5.01 N/mm², respectively. This improvement is attributed to enhanced bonding between particles as the binder content increases. At lower binder levels, insufficient adhesion likely led to premature failure under bending loads.
Despite the upward trend, all recorded values remain below the BS EN 310 standard for general-purpose particleboards, which specifies flexural strength values between 11–15 N/mm². This indicates that the boards may only be suitable for light-duty applications, such as ceiling panels and interior partitions. These findings are consistent with those of [14], who reported that while natural adhesives like gum Arabic offer moderate flexural strength, they generally fall short compared to synthetic resin binders.

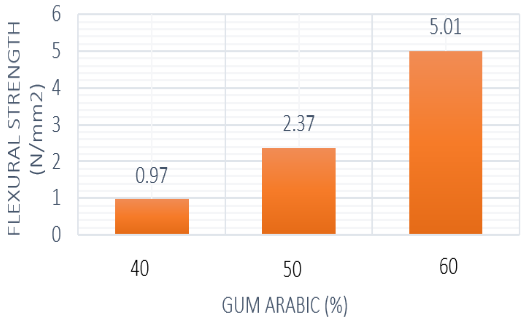

Figure 8: Flexural Strength of Rice Husk and Gum Arabic Particle Board

3.5. Tensile Strength: Tensile strength test result in figure 9; showed a consistent increase with higher gum Arabic content. The particleboards recorded tensile strengths of 0.11 N/mm² at 40%, 0.42 N/mm² at 50%, and 1.13 N/mm² at 60% binder content. This improvement is attributed to more effective bonding as the binder uniformly coats the particles, reducing weak bonding zones. At lower binder levels, inadequate coverage likely resulted in poor inter-particle adhesion and lower tensile performance.

According to ASTM D1037 (1999), the minimum internal bond strength for general-purpose boards is 0.35 N/mm². Both the 50% and 60% samples exceeded this standard, indicating their potential suitability for interior non-structural applications. These findings align with those of [15], who observed that increasing gum Arabic content enhanced tensile strength in lignocellulosic composites.

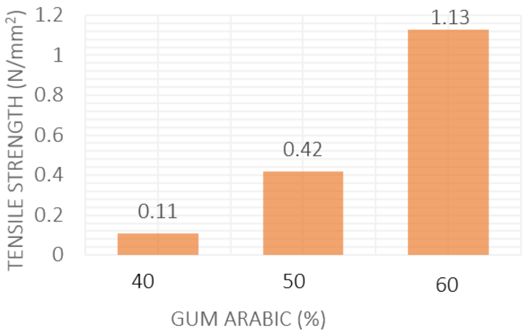

Figure 9: Tensile Strength of Rice Husk and Gum Arabic Particle Board

3.6 Thickness Swelling: Swelling increased with both soaking time and binder content, primarily due to the hydrophilic nature of gum Arabic and the inherent porosity of rice husk. The 60% gum Arabic board exceeded the BS EN 317 (1993) limit of 14% swelling after 24 hours, reaching 14.29% in just 60 minutes and 21.43% at 120 minutes Figure 10a. The 50% board remained below the limit only during the first 15 minutes but failed thereafter. The 40% board exhibited early failure, indicating poor resistance to moisture-induced expansion **as** illustrated in Figure 10b.

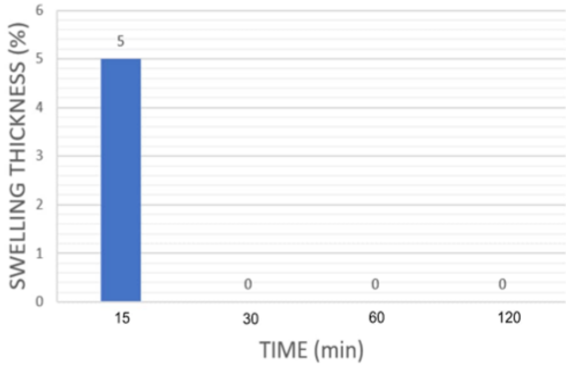

Figure 10(a): Swelling thickness for 50% Gum Arabic

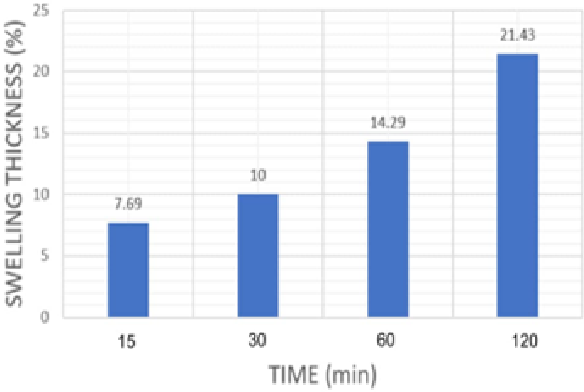

Figure 10(b): Swelling thickness for 60% Gum Arabic

These results are consistent with findings from [17], who reported that gum-based adhesives readily absorb water, negatively impacting the dimensional stability of boards. Without modification or surface sealing, such binders may limit the boards' suitability to dry interior applications only.

3.7. Water Absorption: Water absorption increased with both soaking time and binder content. In figure 11a, 50% gum Arabic board absorbed 36.04% water within the first 15 minutes before collapsing, while the 40% board failed immediately after initial immersion. In contrast, the 60% board Figure 11b; remained structurally intact throughout the 120-minute test period, although it still absorbed 26.98% water.

This behaviour is characteristic of boards bonded with natural adhesives, which tend to be porous and moisture sensitive. Although gum Arabic enhances inter-particle bonding, it offers limited resistance to water. These findings are consistent with those of [5] and [7],who reported that particle board generally absorbs water and the quantity of gum Arabic added increases the percentage of water absorptivity. This necessitates the need for surface treatments or modifications to improve their moisture performance.

None of the tested boards met industrial water resistance standards, which typically specify 8–12% absorption for indoor particleboards. Even the best-performing 60% board exceeded this range, highlighting the need for incorporating hydrophobic additives or protective surface coatings in future formulations to enhance durability in moist environments.

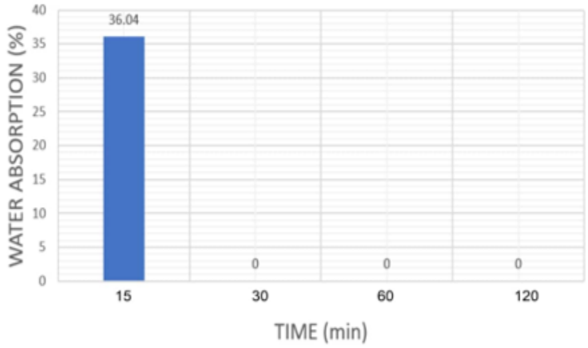

Figure 11: (a) Water absorption for 50% Gum Arabic

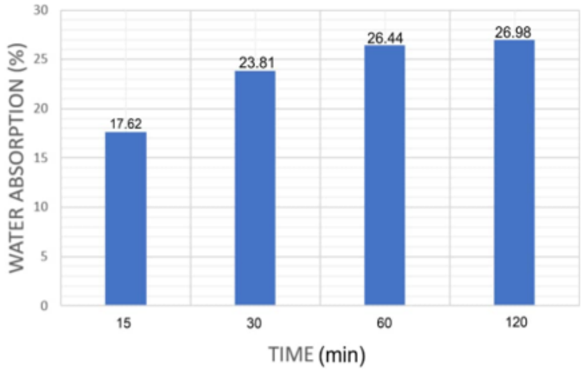

Figure 11: (b) Water absorption for 60% Gum Arabic

4.0 Conclusion

Based on the findings of this study, the following conclusions can be drawn:

1. The properties of rice husk and gum Arabic confirm their suitability as raw materials for particleboard production.
2. A 60% gum Arabic content was identified as the optimum binder ratio for rice husk-based particleboards.
3. The particleboard with 60% binder achieved mechanical strength values that meet or exceed the minimum requirements for certain non-structural applications.
4. However, the durability tests revealed poor moisture resistance across all samples. The boards absorbed water readily and exhibited significant swelling, indicating that they are unsuitable for use in humid or wet conditions without further treatment.

5.0. Recommendation

To enhance the strength, durability, and practical applicability of particleboards made from rice husk and gum Arabic, the following recommendations are proposed:

1. Use a minimum binder content of 60% to achieve acceptable mechanical performance, particularly for indoor applications.
2. Apply surface finishing materials such as laminates, varnishes, or resins to improve moisture resistance and enhance the aesthetic appearance of the boards.
3. Blend gum Arabic with other adhesives or chemically modify it to improve its water resistance while maintaining its bonding effectiveness.
4. Optimize pressing parameters including temperature, pressure, and pressing duration to increase board density and improve mechanical properties.
5. Investigate the use of other agricultural residues (e.g., sawdust, corncob fiber, coconut shell) in combination with rice husk to enhance material properties and sustainability.
6. Assess the economic feasibility and local availability of rice husk, gum Arabic, and potential additives to support scaling up for commercial production.

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