UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 6(1), March (2026), 3185-3202
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Effect of sawdust–rice husk blend ratios and adhesive type on particleboard properties

Collins Chukwuebuka Okoli[1*], Franklin Chukwueloka Uzodinma [1,] Odinaka Okonkwo [1] and Celestine Akaolisa Ezeagu [1]
[1]Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[*]Corresponding Author's E-mail: okoliojii@gmail.com

Abstract

The rising need for cheaper and more sustainable Building materials has generated interest in converting wood-processing and agricultural waste into Building Material. This study investigates the feasibility of producing particleboard from sawdust and rice husk, concentrating on the impact of adhesive type and mix ratio on board performance. Twenty-seven particleboard samples were made using seven sawdust–rice husk ratios (90:10, 80:20, 70:30, 60:40, 30:70, 0:100, and 100:0) and three binders (phenol-formaldehyde, urea-formaldehyde, and cassava starch). Key Structural and physical properties of the boards were evaluated, including density, moisture content, water absorption, thickness swelling, impact strength, compressive strength, and modulus of rupture (MOR). Results indicated that densities ranged between 495 and 639 kg/m³ and moisture contents ranged from 7.17% to 11.95%. Water absorption and thickness swelling varied from 30.25–37.47% and 9.01–15.15%, respectively. Compressive strength ranged from 0.11 to 0.492 N/mm², impact strength from 2.22 to 4.80 kg/m³, and MOR from 9.87 to 17.92 N/mm². Boards bonded with phenol-formaldehyde consistently exhibited superior mechanical strength and dimensional stability, followed by urea-formaldehyde and cassava starch. Increasing sawdust content enhanced density and mechanical performance, with the 30:70 rice husk–sawdust ratio yielding optimal overall properties. These results support the development of resource-efficient building materials and shows that sawdust-rice husk particleboards are viable, feasible and sustainable substitutes for traditional wood-based panels.

Keywords: Particleboard; Rice husk; Sawdust; Urea-formaldehyde; Phenol-formaldehyde; Cassava starch; Strength Properties; Physical Properties

1. Introduction

The production of agricultural and wood-processing waste has increased dramatically due to rapid urbanization and industrial growth, creating major environmental and waste management issues, especially in developing economies like Nigerian Economy (Akinyemi et al., 2023; Zhao et al., 2022). Rice husk and sawdust are the most common Agricultural waste that are produced in significant amounts as a result of increased rice milling and wood processing operations in Nigeria. (Akinyemi et al., 2023). Due to the bulkiness, low biodegradability, and limited disposal options. Rice husk and sawdust are frequently burned or dumped in the open, which causes air pollution and land degradation, (Adekunle et al., 2021).Converting these waste into engineered wood products like particleboard is a sustainable and value-driven approach to Sawdust and Rice husk waste management (Ikubanni et al., 2025; Jock et al., 2021; Akinyemi et al., 2016; Guo et al., 2024) (Particleboards from agricultural/agroforestry wastes, 2024).

According to Li et al., (2022); Yusoff et al., (2023); Abutu et al., (2024); Ikubanni et al., (2025); Temitope et al., (2015); Jabile et al., (2022), Particleboard Production can be defined as the bonding of Lignocellulosic particles, such as wood chips, sawdust, or agricultural residues with a resin binder, consolidated under controlled heat and pressure to create an engineered composite panel. This technology lessens reliance on solid timber while enabling the use of low-value biomass resources. (Ikubanni et al., 2025; Sánchez-Soto et al., 2024; Dukarska et al., 2025;

Laemlaksakul et al., 2014; Okedere et al., 2017). Traditionally, particleboard production has relied heavily on Timber. However, increasing deforestation rates and the rising cost of timber have intensified research into non-conventional lignocellulosic materials as partial or full replacements for the virgin wood particles (Rashid et al., 2020; Singh and Kumar, 2021). In Nigeria, Rice husk and sawdust are particularly attractive alternatives due to their abundance, low cost, and complementary material characteristics. (Ikubanni et al., 2025). According to Olupot et al., (2022) and Morimoto et al. (2023), Sawdust generally contributes to improved bonding and mechanical strength because of its fibrous structure, while rice husk offers advantages such as low density and enhanced resistance to biological degradation, albeit with challenges related to silica content and interfacial bonding. Hence combining both Rice husk and Sawdust in the production of particleboard will create board with more overall performance than when used individually. (Ezeagu et al., 2025)

According to Nuruddin et al., (2021); Zhang et al., (2024); Obam et al., (2019); Sarkar et al., (2015), the structural, durability, and physical performance of particleboard are all greatly influenced by the type of adhesive used and the choice of raw materials or particles. Nuruddin et al., (2021); Zhang et al., (2024) also concluded that synthetic adhesives like phenol-formaldehyde (PF) and urea-formaldehyde (UF) are widely used because of their strong bonding ability and proven industrial performance. Phenol-formaldehyde is renowned for its superior water resistance and durability, while Urea-formaldehyde offers cost effectiveness and quick curing (Nuruddin et al., 2021; Zhang et al., 2024; Valyova et al., 2025; Chang et al., 2024; Yu, 2024). However, interest in bio-based adhesives has increased due to growing concerns about formaldehyde emissions and environmental sustainability. (Calvez et al. 2024; Reotutar et al., 2024; Mensah et al., 2025; Mustapha and Ismail, 2022). In particular, cassava starch has drawn interest because it is renewable, readily available locally in many tropical regions like Nigeria, biodegradable, and, when properly gelatinized or modified, can form hydrogen bonds with lignocellulosic materials (Mustapha and Ismail, 2022; Huang et al., 2023).

This study's main aim is to look into how sawdust and rice husk can be used to make particleboards. The specific objectives includes to create particleboards by utilizing three different types of adhesive with different mix ratios of sawdust and rice husk; to assess the manufactured particleboards' structural and physical characteristics; and to determine the optimal ratio of rice husk to sawdust that produces the best results in terms of structural and physical properties. Although recent studies have shown how sawdust and rice husk mix ratios affect the properties of particleboard. And how structural and physical performance could be improved by optimal ratios. (Abutu et al., 2024; Ikubanni et al., 2025; Şahin et al., 2024). Adhesive selection and ideal mix ratios are still poorly understood, particularly in Nigeria. (Ikubanni et al., 2025; Aguliefo et al., 2025; Ezeagu et al., 2025). Moreover, the combined use of sawdust and rice husk in different ratios for particleboard manufacture is currently understudied despite growing interest in sustainable materials engineering worldwide. (Ezeagu et al., 2025). And the majority of studies concentrate on single raw materials for particleboard production. Furthermore, there is not enough empirical data to compare the effectiveness of bio-based adhesives (cassava starch) and synthetic adhesives (phenol-formaldehyde, UF) in relation to different ratios of rice husk to sawdust. It is imperative that these gaps be filled. This study compares the effects of phenol-formaldehyde, urea-formaldehyde, and cassava starch adhesives in relation to varying Sawdust and rice husk mix ratio on the structural and physical performance of sawdust–rice husk particleboards.

2.0 Materials and methods

2.1 Materials

Sawdust and rice husk were locally sourced from sawmills in Ifite, Awka, and Amansea, both in Anambra State, Nigeria, served as the study's main lignocellulosic raw materials. These materials were chosen because they are widely accessible, reasonably priced, and useful as agro-industrial leftovers with substantial potential for sustainable composite applications.

Figure 1: Sawdust

Figure 2: Rice Husk

2.1.1 Sourcing of Raw Materials

i. Urea formaldehyde (UF) resin under the trade name Topbond, was procured from a local Vendor at Eke Awka Market in Anambra State.

ii. Phenol formaldehyde (PF) resin, which is marketed as phenolic resin was also procured from the local supplier at Eke Awka Market in Anambra State.

iii. Cassava Starch, which is marketed as Elephant Cassava starch was obtained also from the local supplier at Eke Awka Market in Anambra State.

2.1.2 Preparation of Adhesive

Before being used, phenol formaldehyde and cassava starch, which were purchased in powered form, are first combined with water in accordance with the manufacturer's specifications.

2.1.3 Other Auxiliary Materials

Other Materials includes; Plywood sheets, which were used to build the molds for shaping the particleboard samples during the pressing stage.

Figure 3: Urea Formaldehyde

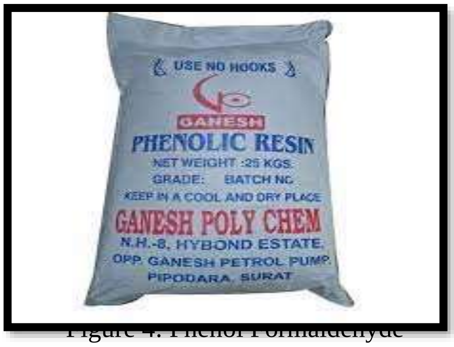

Figure 4: Phenol Formaldehyde

Figure 5: Cassava Starch

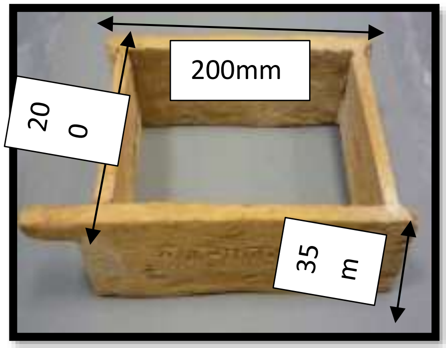

Figure 6: Wooden Mould

2.1.4 Mix ratio of Sawdust-Rice husk for different samples

Table 1: Mix ratio of Sawdust-Rice husk for different samples

Sample	Mix Ratio (Rice husk: Sawdust)	Weight of sawdust (g)	Weight of Rice husk (g)	Weight of Adhesive (g)
A	100:0	0	244	610
B	90:10	219.6	24.4	610
C	80:20	195.2	48.8	610
D	70:30	170.8	73.2	610
E	60:40	146.4	97.6	610
F	30:70	73.2	170.8	610
G	0:100	244	0	610

2.2 Methodology

2.2.1 Preparation of Sawdust and Rice Husk

Sawdust and rice husk were sourced from local mills in Anambra State and transported to the Civil Engineering Laboratory, Nnamdi Azikiwe University, Awka, Nigeria, where all experimental works were conducted. The raw materials were first oven-dried at 60 °C for 24 hours to reduce moisture content to acceptable levels. After drying, both sawdust and rice husk were sieved using British Standard (B.S.) sieves with 2.36 mm and 1.18 mm aperture sizes to eliminate oversized and undersized particles, thereby ensuring uniform particle size distribution and improving mixture homogeneity.

2.2.2 Mould Preparation

Particleboard moulds were fabricated using plywood. Each mould had internal dimensions of 200 mm × 200 mm with a depth of 35 mm. The thickness of the mould cover was 15 mm, and a thin layer of oil was applied to the interior surfaces of the mould before casting to facilitate easy demolding.

2.2.3 Production of Composite Particleboard

The following production processes were carried out in accordance with particleboard production procedures described by Abdulkareem et al., (2017):
i. Pre-established mix ratios were used to batch sawdust and rice husk.

ii. The required quantity of adhesive (urea formaldehyde, phenol formaldehyde, or cassava starch) was measured and poured into a mixing container.

iii. Half of the batched particles were added to the adhesive and manually mixed until partial uniformity was achieved.

iv. The remaining portion of the particles was then incorporated into the mixture.

v. Thorough hand mixing continued until a homogenous blend was obtained, ensuring even distribution of the adhesive throughout the particles.

vi. The procedure was repeated for all mix ratios and adhesive types to produce multiple replicates.

vii. The homogenous mixture was placed into the pre-lubricated mould, filled to a 35 mm thickness, which corresponds to 1.5 times the intended final thickness (20 mm) to allow for compression.

viii. A metal spatula was used to compact the mixture, eliminating air voids and leveling the surface.

ix. The mould cover was secured, and a metal slab was placed atop the mould to aid uniform pressure distribution during pressing.

x. The filled moulds were then transferred to a manual compression machine and compressed for 24 hours.

xi. After compression, the moulds were transferred to an oven and cured at 60 °C for 1 hour.

xii. Upon removal from the oven, the moulds were allowed to cool for 10 minutes, then exposed to ambient sun drying for 24 hours.

xiii. After sun drying, the panels were demoulded and placed on a flat surface to cure under ambient conditions.

xiv. Finally, the particleboard panels were trimmed and cut into specified dimensions for subsequent mechanical and physical testing.

Figure 7: 100% Sawdust Particleboard

Figure 8: Rice Husk Particleboard

Figure 9: Compression Setup

Figure 10: Sample Cutting for Tests

2.3 Testing of Physical and Mechanical Properties

i. Moisture Content:

The moisture content of the samples was determined using the oven-dry method in accordance with ASTM D4442 – Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials.

$$\text{Moisture content } (\%) = \frac{Wa - Wo}{Wo} \times 100\% \quad (1)$$

Wo = Oven dried weight of the particleboard, Wa = wet weight of the particleboard.

ii. Density:

The density was calculated by measuring the mass-to-volume ratio of the dried particleboard samples, following the procedures specified in ASTM D2395 – Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood-Based Materials.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \quad (2)$$

iii. Water Absorption:

Water absorption was measured after submerging the samples in distilled water for 24 hours, in accordance with ASTM D1037 – Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.

$$M (\%) = \frac{m_t - m_0}{m_0} \times 100\% \quad (3)$$

m_0 and m_t denotes the oven dry weight and wet weight after time t in water

iv. Thickness Swelling:

Thickness swelling was also determined in line with ASTM D1037, by measuring the difference in sample thickness before and after 24-hour immersion in water.

$$T\ (\%) = \frac{t_t - t_0}{t_0} \times 100\% \tag{4}$$

t_0 and t_t denotes the thickness of the oven dry sample and thickness of wet sample

v. Compressive Strength:

Compressive strength was evaluated using ASTM D695 – Standard Test Method for Compressive Properties of Rigid Plastics, to determine the maximum stress the samples could withstand under axial loading.

$$\text{Compressive strength} = \frac{\text{Ultimate Load (N)}}{\text{Cross sectional area (mm}^2\text{)}} \tag{5}$$

vi. Bending Strength / Modulus of Rupture (MOR):

The modulus of rupture was assessed using ASTM D1037, which involves a three-point bending test to determine the sample's flexural strength.

$$\text{MOR} = \frac{3P_b\text{L}}{2\text{bh}^2} \tag{6}$$

Pb is the maximum load (N),b is the width (mm), h is the thickness (mm), L is the span (mm).

vii. Impact Strength:

The boards' impact strength was evaluated using ASTM D256, Standard Test Procedures for Determining the Izod Pendulum Impact Resistance of Plastics. This test determined Impact Strength.

$$\text{Impact Strength} = {}^{E}\!/_{A} \tag{7}$$

E= Energy absorbed during Impact

A= Cross sectional Area of the sample

3.0 Result and Discussion

3.1 Density of Produced Particleboards

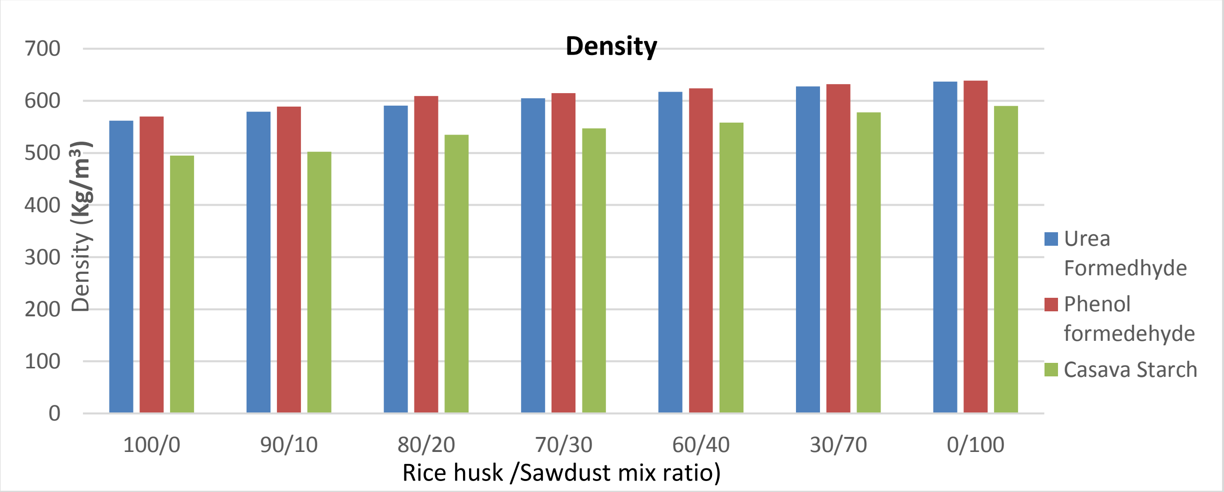

Fig 10: Showing density of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to trends noted by Akinyemi et al. (2023) and Nurhazirah et al. (2022), lignocellulosic particle properties directly affect composite compaction and mass per unit volume. The measured densities ranged from 495 kg/m³ to 639 kg/m³. The result from Figure 10 obviously concurred with the trend, as varying mix ratio of the sawdust-ricehusk particleboard generally affect the density of the particleboard.

It can also be observed that higher sawdust content is associated with higher particleboard density, whereas higher rice husk content is associated with lower densities. This can be explained mechanistically by packing efficiency and particle shape. Because sawdust particles are often fibrous and have more irregular forms and a higher aspect ratio, they can efficiently interlock and fill blank areas during hot pressing, improving compaction. The bulkier, more rigid, and silica-rich nature of rice husk particles, on the other hand, prevents deformation and densification under pressure. A less dense board is produced as a result of rice husk's decreased lignin concentration, which also lessens the particles' capacity to form strong bonds (Singh & Kumar, 2021).

Density was also greatly impacted by the type of glue. Cassava starch-based adhesives yielded the lowest values, whereas Phenol Formaldehyde-bonded boards showed the maximum density, followed by Urea Formaldehyde board. Variations in adhesive solid content, viscosity, and bonding efficiency are all factors that generally affect density of particleboard, as reflected in this result. Denser composites are produced when Phenol Formaldehyde resins create robust, stiff cross-linked networks that improve particle cohesion and minimize voids. Although Urea Formaldehyde adhesives are equally efficient, their decreased polymer chain stiffness results in significantly less firm bonding. Particle consolidation is limited by starch-based adhesives' lower solids and weaker interfacial bonds (Huang et al., 2023).

Sawdust's densifying effect in the composite was confirmed by the fact that the 0:100 rice husk-to-sawdust control sample had the highest density among adhesive kinds, while the 100:0 sample had the lowest. The ideal ratio of rice husk to sawdust was found to be 30:70, which produced densities of 578 kg/m³ (PF), 628 kg/m³ (UF), and 632 kg/m³ (starch). This ratio emphasizes the significance of both particle shape and interfacial bonding in reaching the ideal composite density by balancing particle packing and adhesive dispersion. Standards-wise, every board satisfies ANSI A208.1 (2009) Grade LD-1 requirements for low-density particleboard (<640 kg/m³). Furthermore, the boards surpass the minimum density criterion of 400 kg/m³ for 20–30 mm thick panels in accordance with BS EN 13353, and the generated materials are appropriate for lightweight masonry applications (<1600 kg/m³) in accordance with BS EN 13353 recommendations.

The observed density trends also highlight the fact that particle morphology, adhesive type, and interfacial bonding all influence particleboard performance in addition to raw material proportions. While silica-rich rice husk serves as a filler but resists compaction, sawdust's fibrous structure promotes interlocking and mechanical strength. These effects are further amplified by the choice of adhesive, as weaker adhesives (starch) permit more micro-porosity, which lowers density, whereas stronger, cross-linked adhesives like Phenol Formaldehyde improve particle cohesion and decrease voids.

3.2 Water Absorption of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to Water Absorption test results, the water absorption percent of produced particleboard samples at 24-hour, ranges from 30.25% to 37.47%. From the test result it can also be observed that, higher rice husk concentration leads to greater moisture uptake, while increasing sawdust content decreases water absorption. This tendency is mechanistically related to the raw materials' porosity and particle shape. Under pressure and heat, sawdust fibers efficiently interlock to form a dense, low-void matrix that prevents water from penetrating. The thicker, stiffer, and silica-rich rice husk, on the other hand, prevents compact packing and decreases interfacial bonding, creating micro voids that allow water to enter (Rashid et al., 2020; Nurhazirah et al., 2022). Water resistance was also greatly affected by the type of glue. Cassava starch-bonded boards had the maximum water uptake, whereas Phenol Formaldehyde-bonded boards had the lowest, followed by Urea Formaldehyde-bonded boards. This is consistent with other research (Akinyemi et al., 2023; Abdulkareem et al., 2017), although further analysis mechanistic perspective is necessary.

Phenol Formaldehyde resins provide a hydrophobic barrier against water by reducing free volume and forming a dense, highly cross-linked polymer network that firmly binds particles. Urea Formaldehyde resins on the other hand, provide intermediate water resistance due to their moderate hydrophobicity and cross-linking. Cassava starch being a naturally occurring polysaccharide is naturally hydrophilic, that is it easily takes in water. The high water intake is caused by the hydroxyl groups in its polymer chains, which easily form hydrogen bonds with water. Its poorer interfacial interaction with lignocellulosic particles and lower molecular weight also lessen matrix cohesion, making it easier for water to pass through. This explains why even sawdust-rich boards bound with starch showed better absorption as shown in the test results.

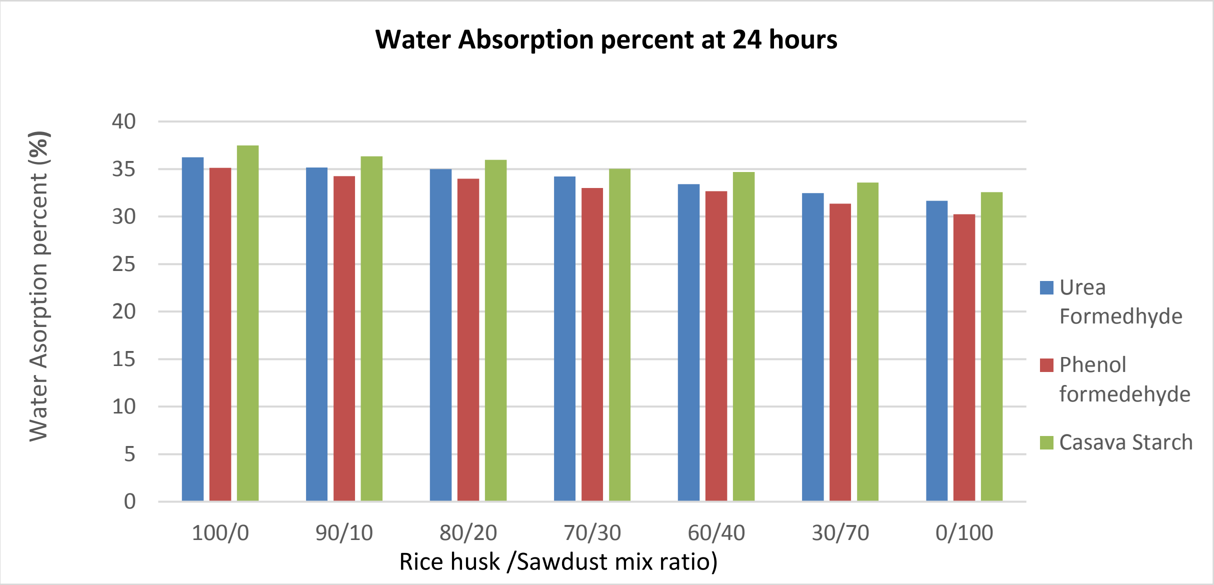

Fig. 11: Water Absorption of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

The control samples demonstrate how adhesive performance and particle type interact. The 100:0 rice husk board exhibited the largest water absorption, because rice husk is bulkier and less compactable. On the other hand, the 0:100 sawdust board exhibited the least amount of water absorption, confirming that fibrous sawdust has a densifying influence on dimensional stability. With water absorption rates of 31.35% (Phenol Formaldehyde), 32.46% (Urea formaldehyde), and 33.57% (starch), the 30:70 rice husk-to-sawdust combination proved to be the best, balancing particle packing and adhesive coverage. From the water absorption test results, it can also be deduced that water ingress is directly impacted by packing efficiency and void content, which are determined by particle morphology. Also, Interfacial bonding is influenced by the type of adhesive, as hydrophilic adhesives (starch) increase water penetration and micro voids, whereas stronger, hydrophobic adhesives (Phenol Formaldehyde and Urea formaldehyde) decrease them.

The performance constraints of cassava starch are also intrinsic to its chemical makeup, however they may be lessened by chemical modification (such as acetylation or crosslinking with glutaraldehyde or citric acid) to increase water resistance while preserving biodegradability. (Rashid et al., 2020). Although cassava starch provides a biodegradable substitute, its weaker binding and poor water resistance limit its use on its own in high-moisture environments, emphasizing the necessity for modification or blending with synthetic resins to obtain useful performance. (Nurhazirah et al., 2022).

3.3 Thickness Swelling of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

On the other hand, 0:100 sawdust board showed little swelling, indicating the strengthening role of fibrous sawdust, whereas the 100:0 rice husk board had the highest Thickness swelling across all adhesives due to inadequate packing and weak bonding. With Thickness swelling percent values of 10.89% (Phenol formaldehyde), 9.95% (Urea formaldehyde), and 12.08% (starch), the 30:70 rice husk-to-sawdust blend produced the best balance across mixed formulations. This also further strengthened the conclusions of Ezeagu et al., (2025) and Aguliefo et al., (2025) on how mix ratio affects adhesive penetration, increases particle interaction, and lowers void content, all of which contribute to increased dimensional stability. It can also be deduced from the Thickness swelling test results that, Density and Thickness swelling have an inverse relationship. Higher-density boards have better glue bonding efficiency and more particle contact, which reduces water absorption and swelling. This finding supports the findings of Akinyemi (2016), which emphasize the importance of densification and adhesive efficacy in determining dimensional stability. The hydrophilicity, low molecular weight, and poor penetration into particle surfaces, characteristics of Cassava starch, increases the likelihood of thickness swelling in starch-bonded boards, particularly in panels with a high rice husk content. To increase water resistance while preserving biodegradability, improvements could involve chemical modification (such as acetylation or crosslinking with citric acid) or combining with synthetic resins as reported by Sahin et al., (2024).

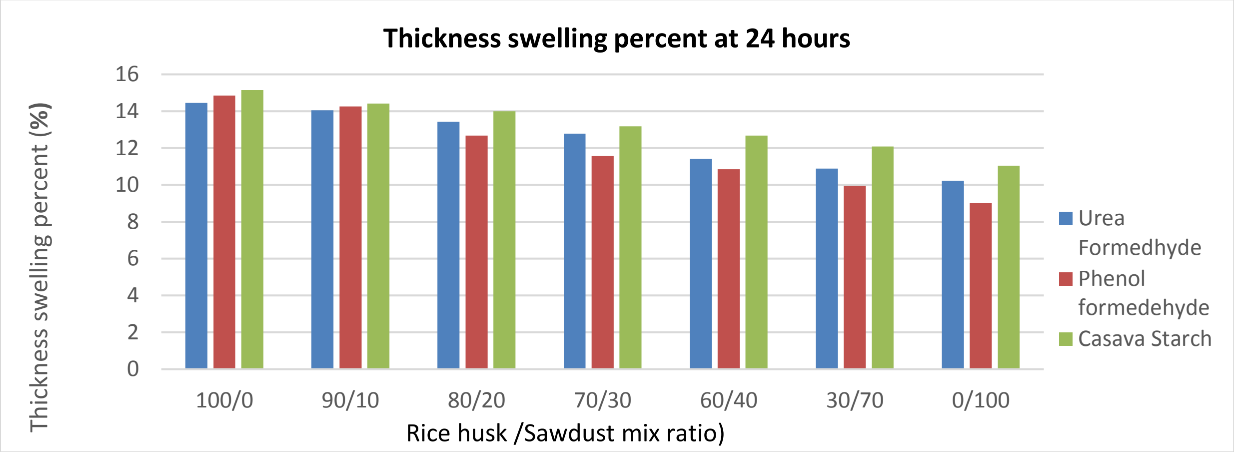

Fig. 12: Thickness Swelling of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to EN 312-3 (2003), Non-load bearing particleboards meant for humid settings are not allowed to have more than 14% Thickness swelling after 24 hours. And from our test results, Boards with rice husk-to-sawdust ratios of 100:0 and 90:10 in this investigation surpassed this limit for all adhesives, making them inappropriate for outdoor or humid applications. The 30:70 blend, especially when using Phenol formaldehyde or Urea formaldehyde adhesives, came within allowable bounds, proving that the best adhesive selection and particle composition are crucial for moisture-resistant particleboard products.

3.4 Moisture Content of Particleboard Samples with Different Ratios of Sawdust to Rice Husk

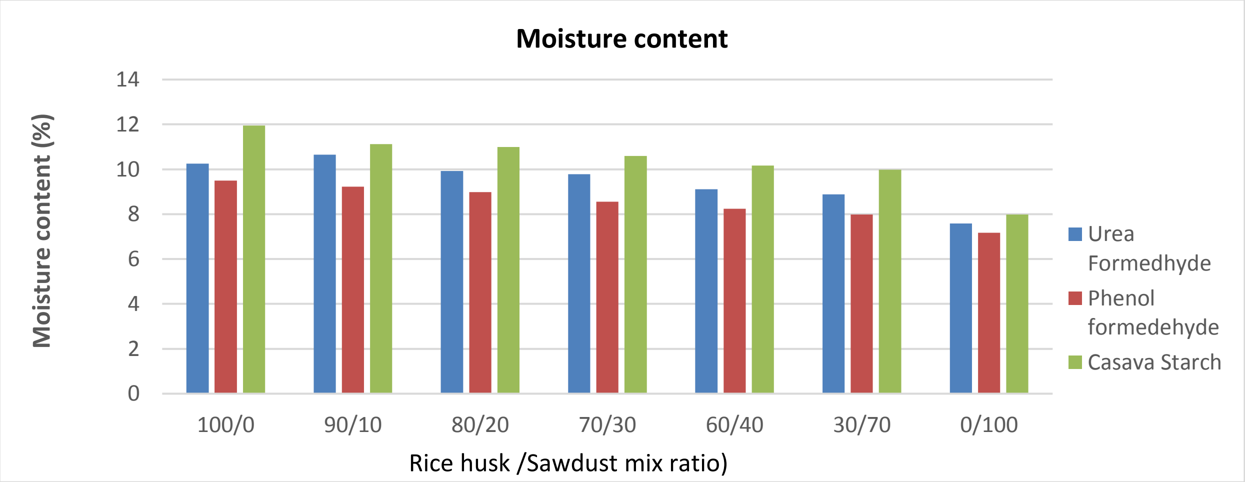

Fig. 13: Moisture Content of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to Moisture content test results (Figure 13), the moisture content of produced particleboard samples, varied from 7.17% to 11.95%. From the test result it can also be observed that, while a higher proportion of rice husk results in a higher moisture content, a higher sawdust content decreases moisture uptake. From the mechanistic perspective, The Particle shape, porosity, and hygroscopicity are responsible for this trend. The reason is because sawdust fibers are denser, they enable tighter particle packing during hot pressing, which reduces the number of gaps that could retain water. Whereas, the increased porosity and hydrophilicity of rice husk particles, which are bulkier, more stiff, and rich in silica, increases moisture absorption and weakens interfacial interaction (Rashid et al., 2020; Nurhazirah et al., 2022).

It has also been shown from the test results, that Moisture content are also greatly affected by the type of adhesive. Starch-based boards had the greatest moisture content readings, whereas Phenol formaldehyde -bonded boards consistently showed the lowest, followed by Urea formaldehyde bonded boards. This results from variations in hydrophobicity and bonding efficiency of adhesives used during production. It be further explained mechanistically, that water entry into the particleboard is restricted by the dense, highly cross-linked network that Phenol formaldehyde resin creates. Whereas, Intermediate moisture levels are produced by Urea formaldehyde resin's partial hydrophobicity and moderate bonding. Cassava starch on the other hand, is hydrophilic, it absorbs water easily and creates weaker connections between particles, which raises the moisture content overall. Water retention is made worse by its high hydroxyl content and poor interfacial adhesion, especially in boards that contain a lot of rice husk. This draws attention to a significant drawback of starch adhesives, despite being environmentally benign and biodegradable, they sacrifice dimensional stability and moisture resistance (Abdulkareem et al., 2017; Akinyemi et al., 2023).

It can also be deduced from the Moisture content test results that the 0:100 sawdust board had the lowest moisture content among all adhesives and the 100:0 rice husk board had the highest. With moisture concentrations of 8.89% (Phenol formaldehyde), 7.98% (Urea formaldehyde), and 9.98% (starch), the 30:70 rice husk-to-sawdust blend outperformed the sawdust-only board across mixed ratios. This illustrates how optimal particle mixing reduces moisture absorption by increasing packing density and adhesive coverage. Dimensional stability, thickness swelling, mechanical strength, and susceptibility to biological degradation are all adversely affected by excessive moisture in particleboards (Elehinafe et al., 2019)

ANSI A208.1 (2009) states that particleboard's mean moisture content should not be higher than 10% (oven-dry basis). In accordance with this standard, Every Phenol formaldehyde -bonded board complied with the specifications. The criterion was exceeded by Urea formaldehyde -bonded boards with rice husk/sawdust ratios of 90:10 and 100:0. Additionally, starch-bonded boards at 60:40, 70:30, 80:20, 90:10, and 100:0 all failed to meet this criterion. These findings highlight the limits of cassava starch adhesives in regulating moisture content, particularly in composites that contain a lot of rice husk. Chemical modification of starch (such as acetylation or crosslinking), combining with more hydrophobic resins, or maximizing particle-adhesive contacts to decrease water uptake are some possible methods to enhance performance. (Nurhazirah et al., 2022).From the test results, Adhesive coverage, surface chemistry, and particle porosity all affect moisture content, as Water can enter gaps and weakly bonded interfaces on rice husk-rich boards with hydrophilic adhesives. Whereas, Sawdust fibers decrease free volume for water infiltration by enhancing particle packing and interfacial adhesion. Starch-based resins on the other hand, are constrained by their hydrophilic nature and lower bonding effectiveness, PF resins improve water resistance because of their robust, hydrophobic cross-linked networks.

3.5 Compressive Strength of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to Compression test results, the compressive strength of produced particleboard samples, varied from 0.110 N/mm² to 0.492 N/mm², as shown in Figure 14. From the test results a discerning pattern was noted with increase in rice husk content decreasing compressive strength, while increase in sawdust content in the rice husk/sawdust combination increases compressive strength. Particle shape, packing density, and interfacial bonding are major factors influencing this behavior. Because sawdust fibers are long and flexible, the composite can have stronger cohesive forces, improved resin penetration, and tighter particle interlocking. More so, because rice husk is brittle and inflexible, it reduces effective bonding area, increases void content, and restricts particle-to-particle contact, all of which lessen compressive resistance (Rashid et al., 2020; Nurhazirah et al., 2022). From the compressive test results It was also discovered that Compressive strength was greatly impacted by adhesive type. Phenol formaldehyde -bonded boards attained the highest compressive strength, because of their strong particle adhesion and high cross-linking density, which strengthen the composite structure under compressive load. Also, Urea formaldehyde-bonded boards provided a modest level of strength, because of their significantly lower adhesive penetration and weaker cross-linking. Cassava starch bonded boards had the lowest compressive strength. This is explained by the fact that starch is hydrophilic, has a smaller molecular weight, and has less interfacial bonding, all of which diminish the efficiency of load transfer between particles (Abdulkareem et al., 2017; Akinyemi et al., 2023).

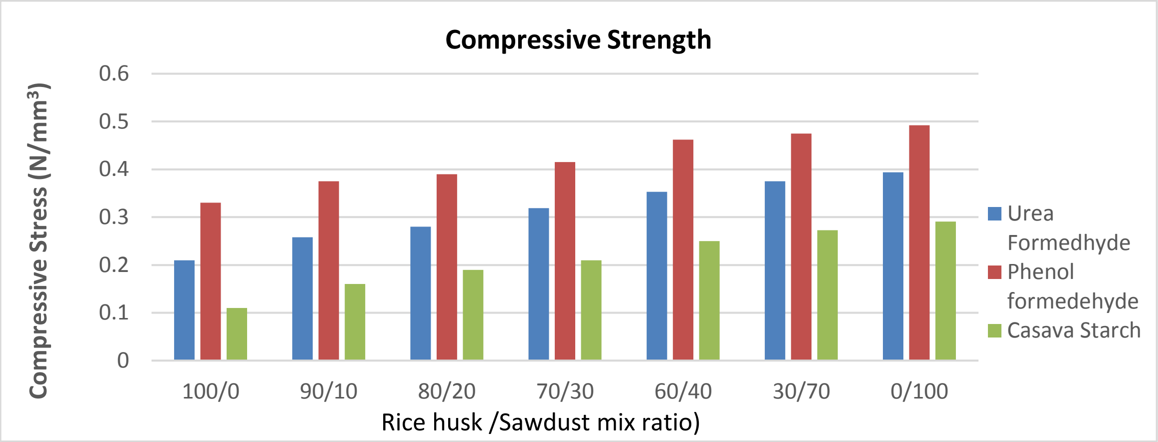

Fig. 14: Compressive strength of samples with varying rice husk/sawdust mix ratios

On the other hand, 0:100 sawdust board had the highest compressive strength, while the 100:0 rice husk board consistently had the lowest compressive strength. The 30:70 rice husk-to-sawdust mix provided the best balance among the mixed ratios, producing 0.475 N/mm² (Phenol formaldehyde), 0.375 N/mm² (Urea formaldehyde), and 0.291 N/mm² (starch). This result can be explained possible densification of Rice husk particles without significantly impairing interfacial bonding when it is included in moderation. Also From the mechanistic perspective of the test results, it has been shown that Particle packing, interfacial bonding, and adhesive type all affect compressive strength of particleboards. As stronger adhesive networks in denser particleboard help to withstand compression better. Cassava starch's poor performance emphasizes its no suitability as a stand-alone adhesive for structural applications, even though its biodegradability is still a benefit. Chemical alteration or combining with synthetic resins to increase bonding efficiency are two possible enhancement options. (Nurhazirah et al., 2022).

Finally, these produced particleboards are not appropriate for building load-bearing walls because the reported compressive strength values are significantly lower than the 2.5 N/mm² minimum requirement for sandcrete blocks (NIS 87:2000). Reinforcement methods include lamination with plastic films or further mechanical compaction could increase strength for applications needing higher structural performance (Sahin et al., 2024)

3.6 Modulus of Rupture of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

From the Static Bending Test Result, The Bending Modulus of Rupture of the particleboard samples varied from 9.87 N/mm² to 17.92 N/mm², as shown in Figure 15. From the test results, distinct patterns pertaining to adhesive type and particle composition was observed. Higher rice husk content led to decrease in bending Modulus of Rupture, while increasing the percentage of sawdust in the rice husk/sawdust mixture consistently improved Modulus of Rupture. This trends can be attributed to Particle shape and interfacial bonding which are responsible for this behavior. Since Sawdust fibers are more pliable, fibrous, and capable of efficiently interlocking, the internal network for load transfer are strengthened. While Rice husk particles, on the other hand, are brittle, stiff, and less able to create continuous load-bearing pathways, which restricts the distribution of stress and lowers bending resistance (Sekaluvu et al., 2018; Rashid et al., 2020).

Also From the test results, the type of adhesive had a big impact on Bending Modulus of Rupture performance. Phenol formaldehyde-bonded boards had the highest Modulus of Rupture values Because of its thick, cross-linked network, which improves particle adhesion and load transfer. Urea Formaldehyde -bonded boards had mild Bending Modulus of Rupture performance, indicating a minor decrease in particle adhesion and weaker cross-linking. Cassava starch-bonded boards had the lowest Bending Modulus of Rupture performance, Because of its hydrophilic character, low molecular weight, and weak interfacial bonding with the lignocellulosic particles, (Abdulkareem et al., 2017; Akinyemi et al., 2023). The argument according to Nurhazirah et al., (2022) that bio-based adhesives has Limitations in providing structural strength, particularly under bending stresses, are further strengthened by the poor performance of starch-bonded boards from the test results. Chemical modification of starch (crosslinking or combining with Phenol formaldehyde / Urea Formaldehyde) to improve bonding and water resistance is one possible enhancement. (Nurhazirah et al., 2022)

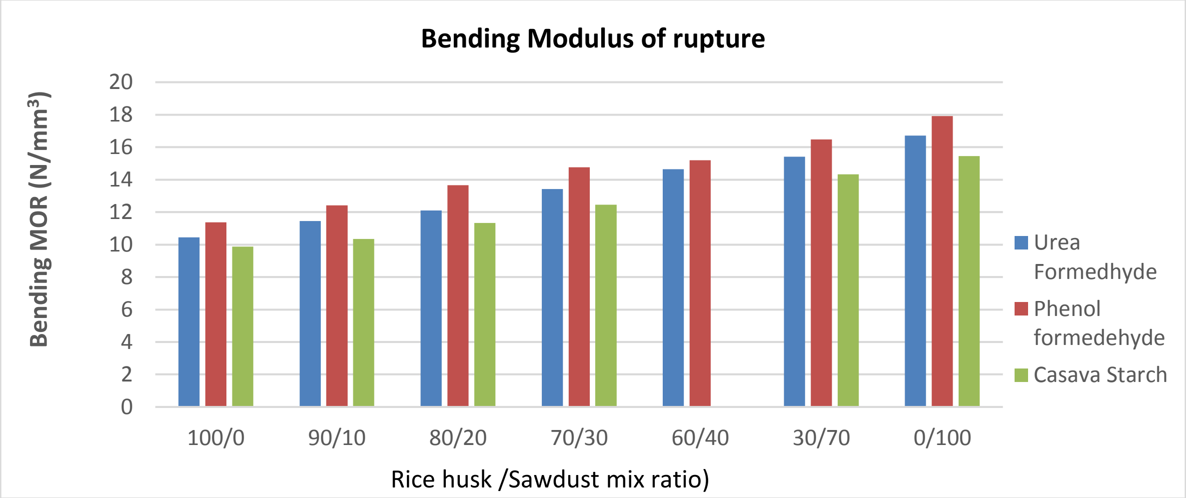

Fig. 15: Bending Modulus of Rupture of samples with varying rice husk/sawdust mix ratios

Furthermore, the 0/100 sawdust board had the greatest bending Modulus of Rupture. While the 100/0 rice husk board consistently had the lowest bending Modulus of Rupture. With bending Modulus of Rupture values of 14.32 N/mm² (Phenol formaldehyde), 15.41 N/mm² (Urea Formaldehyde), and 14.32 N/mm² (starch). The 30/70 rice husk-to-sawdust ratio proved to be the best among mixed formulations for bending Modulus of Rupture performance. This suggests that addition of rice husk in moderation to the blend can preserve sufficient packing density and particle spacing, striking a balance between mechanical performance and the sustainable use of agricultural waste.
According to ANSI A208.1 (2009), it states that structural particleboards must have a minimum Bending MOR of 11 N/mm². Since all Phenol formaldehyde -bonded boards surpassed this limit, they can be used in mild structural applications. At intermediate ratios (0/100 to 90/10), boards bonded with Urea Formaldehyde or starch satisfied the minimum criterion; however, at 100/0 rice husk content, they did not meet the criteria. Only Phenol formaldehyde - bonded 30/70 boards are eligible for high-density particleboards (MOR ≥ 16.5 N/mm²), whereas Urea Formaldehyde - and starch-bonded boards are classified as medium-density. Low-density boards (MOR < 11 N/mm²) can only be used for non-structural interior applications including wall cladding, ceiling panels, and furniture.

Finally form Mechanistic perspective, Particle interlocking, adhesive coverage, and particle-adhesive compatibility all affect Bending Modulus of Rupture. Boards that include a lot of Sawdust has higher bending resistance, Because of the fibrous nature of sawdust which helps in improving load distribution. Boards that include a lot of rice husk are more fragile and likely to collapse quickly when bent. While Starch bonded boards generally has very weak Bending Modulus of Rupture, since starch adhesives are constrained by hydrophilicity and weak bond formation, unlike Phenol formaldehyde / Urea Formaldehyde adhesives that enhances bending MOR through high cross-linking density.

3.7 Impact Strength of Particleboard Samples with Varying Rice Husk/Sawdust Ratios

According to Impact strength test results, the impact strength response of produced particleboard samples made with different adhesive techniques and rice husk–sawdust blend ratios, varied from 2.22 to 4.80 kg/m³, as shown in Figure 16. From the test results, the measured impact strength values consistently increases as the sawdust content in rice husk–sawdust blend ratios increases. On the other hand, higher rice husk content led to decreased impact resistance. This behavior is closely associated with variations in the two lignocellulosic materials' interfacial bonding effectiveness and particle shape. This can be attributed to Sawdust particles having a stronger fibrous structure, a higher lignin content, and better surface roughness than Rice husk Particles. During abrupt impact loading, these features improve mechanical interlocking and facilitate efficient stress transmission across the particle–adhesive contact. Rice husk, on the other hand, has a smoother, more brittle surface morphology and a comparatively high silica concentration, which reduces interfacial adhesion and encourages fracture initiation under impact stresses. Because of this, boards with more rice husk have a lesser ability to absorb energy and are less resistant to rapid fracture.

Furthermore, it can be observed from the test results that Impact performance is significantly influenced by the type of adhesive used. Panels bonded with phenol formaldehyde (PF) and urea formaldehyde (UF) consistently showed the maximum impact strength, while boards bonded with cassava starch showed the lowest Impact performance. Variations in bonding durability and cross-link density can account for this hierarchy. Phenol formaldehyde adhesive creates a thermoset, highly cross-linked network that efficiently connects neighboring particles and disperses impact energy throughout the matrix. Urea formaldehyde adhesive has a moderate bonding strength, is more prone to micro cracking during dynamic stress or Impact. Cassava starch adhesives, on the other hand, are less able to prevent fracture propagation after impact because they are intrinsically hydrophilic and provide weaker hydrogen-bond-dominated surfaces.

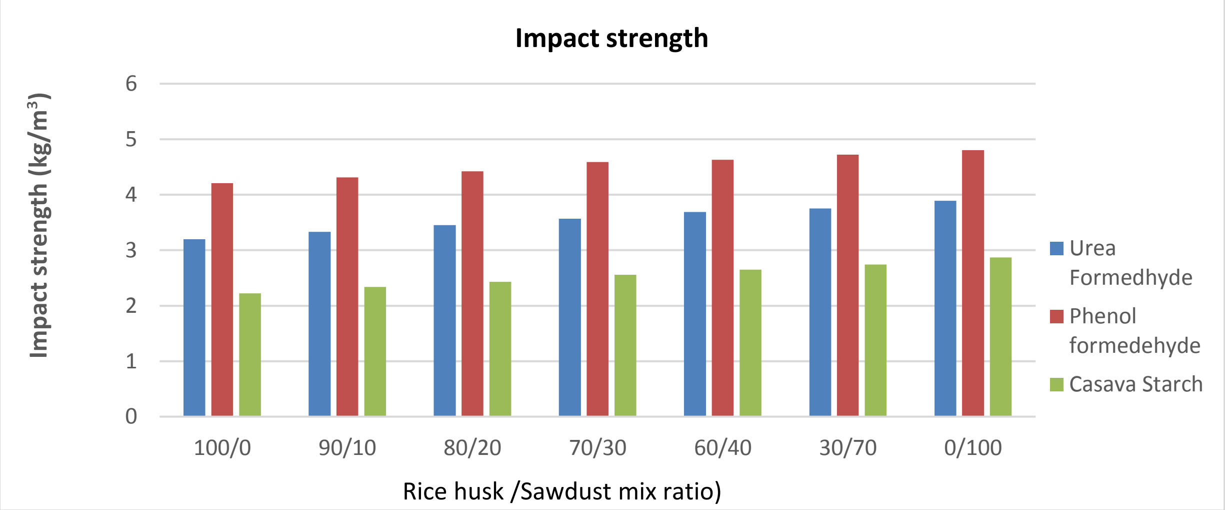

Fig. 16: Impact strength of samples with varying rice husk/sawdust mix ratios

More so, 100/0 rice husk/sawdust showed the lowest impact strength across all adhesive systems. 0/100 rice husk/sawdust On the other hand, had the maximum impact strength due to better particle packing, stronger interfacial bonding, and more effective stress redistribution after abrupt loading. Finally, the 30/70 rice husk/sawdust ratio proved to be the optimal Mix ratio for best Impact Performance among the blended formulations, with impact strengths of 4.59, 3.57, and 2.56 kg/m³ for Phenol formaldehyde- bonded boards, Urea formaldehyde-bonded boards, and starch-bonded boards, respectively. This implies that as long as there is enough sawdust present to preserve structural integrity and good bonding, a little amount of rice husk inclusion can be accepted without significantly reducing impact resistance. According to Sahin et al., (2024), he stated that Post-manufacturing surface treatments like plastic film lamination enhances impact performance, by limiting crack formation at the surface and enhancing stress distribution under Impact. These modifications could increase the boards' applicability, especially in situations where impact resistance is a crucial performance requirement.

4.0. Conclusion

This study confirms that it is very possible to produce particleboard with reasonable Structural and Physical Properties using Rice husk and Sawdust. Which will serve as cheaper and Environmental Friendly Alternative to traditional solid wood resources. Beyond mere Feasibility, the results of these study also shed more light on how adhesive chemistry, mix ratios, and material properties interact to regulate board performance and offer recommendations for the best particleboard formulation employing agro-industrial leftovers. Particle morphology generally Affect the properties of Particleboard. Sawdust-based particleboards perform better than rice husk-based boards. Interfacial bonding and more effective stress transfer within the composite were encouraged by sawdust particles, which had a greater lignin concentration, better fiber continuity, and increased compactability. On the other hand, rice husk's high silica content and brittle structure hindered mechanical strength and dimensional stability by limiting compaction efficiency and weakening particle–adhesive interaction. The type of adhesive generally affect the properties of Particleboard with cross-link density and hydrophobic properties being a major Influencing Factor. Phenol formaldehyde (PF) regularly generated particleboards with exceptional mechanical strength, moisture resistance, and dimensional stability. Cassava starch adhesive had lowest strength and moisture resistance, mostly because of its hydrophilic nature and restricted bonding endurance, whereas urea formaldehyde (UF) provided moderate performance. These findings demonstrate that although bio-based adhesives are environmentally appealing, their current formulations need to be modified in order to compete with traditional synthetic resins.

Waste usage and board performance were balanced at the ideal rice husk–sawdust blend ratio of 30:70. At this ratio, sawdust's reinforcing action made up for rice husk's structural shortcomings, leading to increased strength, decreased water absorption, and improved dimensional stability. Furthermore, better performance was significantly connected with higher board density, highlighting the significance of particle packing and compaction efficiency in agro-waste-based particleboard. Increasing the proportion of sawdust in the rice husk–sawdust blend resulted in enhanced compressive strength, impact resistance, and bending modulus of rupture. Concurrently, reductions were observed in moisture content, water absorption, and thickness swelling. Particleboards made at ideal mix ratios, especially those bonded with Phenol formaldehyde and urea formaldehyde, are appropriate for non-load-bearing, mild moisture exposure applications including interior wall cladding, ceiling boards, furniture cores, and partition panels, according to the achieved properties. Cassava starch-bonded boards, although they are safe for the environment, are currently better suited for low-moisture, non-structural indoor applications unless they are further modified. The findings also imply that these boards' functional range could be further increased by post-production processes like surface lamination or resin modification. Although this work shows that rice husk–sawdust particleboards are technically feasible, there are a few areas that need more research. Future studies ought to concentrate on the following:

1. Modification of Cassava starch adhesives chemically or physically to increase water resistance and bonding strength (e.g., by blending with bio-resins, adding hydrophobic additives, or cross-linking).
2. The statistically validation of impact of mix ratios, adhesive content, and pressing settings using statistical optimization and modeling (e.g., ANOVA, response surface approach).
3. Evaluation of service-life performance, long-term moisture cycling, biological resistance, and thermal aging of rice husk–sawdust particleboards.
4. Analysis on Energy and life-cycle of rice husk–sawdust particleboards to measure the environmental advantages of agro-waste particleboards over traditional wood-based panels.

References

Agulefoh, C. U, Ezeagu, C. A., Adinna, B. O., Ezema, N. M., Ugboaja, C., Uzodimma, F. C., Ubani, O. U. & Chidolue, C. U., 2025. Modelling of structural properties of rice husk and sawdust in timber panel laminates using SolidWorks. World Journal of Engineering Research and Technology (WJERT), 11(3), 1–13.

Akinyemi, A.B., Olutoge, F.A. and Agbede, O.A., 2016. Development of wood–cement composites using wood sawdust and rice husk. Construction and Building Materials, 120, pp.328–333. https://doi.org/10.1016/j.conbuildmat.2016.05.097

Akinyemi, A.B., Afolayan, J.O., Alade, A.T., 2023. Properties of particleboard produced from agricultural residues using natural adhesives. Journal of Building Materials and Structures, 10(1), 45–52. https://doi.org/10.1016/j.jbms.2023.01.005

Abdulkareem, S.A., Raji, S.A., & Adeniyi, A.G., 2017. Development of particleboard from waste Styrofoam and sawdust. *Nigerian Journal of Technological Development*, 14(1), 18–22. https://doi.org/10.4314/njtd.v14i1.3

Akinyemi, A.B., Afolayan, J.O., Alade, A.T., 2023. Properties of particleboard produced from agricultural residues using natural adhesives. Journal of Building Materials and Structures, 10(1), 45–52. https://doi.org/10.1016/j.jbms.2023.01.005

Adekunle, A.A., Olorunnisola, A.O., & Ajayi, B., 2021. Disposal challenges of rice husk and sawdust in Nigeria: A review. Waste Management & Research, 39(5), pp.567–576.

ASTM D4442 – ASTM International., 2020. ASTM D4442-20: Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D4442-20

ASTM D2395 – ASTM International., 2017. ASTM D2395-17: Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D2395-17

ASTM D695 – ASTM International., 2021. ASTM D695-15: Standard Test Method for Compressive Properties of Rigid Plastics. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D0695-15R21

ASTM D256 – ASTM International., 2018. ASTM D256-10: Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D0256-10R18

ASTM International. 2023., ASTM D1037-22: Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. West Conshohocken, PA. https://doi.org/10.1520/D1037-22

ANSI A208.1., 2009. American National Standard for Particleboard. Composite Panel Association, Gaithersburg, MD.

Abutu, J., Tsoji, T. R., Stephen, A., Araye, A. D., Lawal, S. A., & Rimamtaatang, A. K., 2024. Performance assessment of particle board developed from organic wastes using polymer matrix. Materials Technology Reports, 2(1), 1603. https://doi.org/10.59400/mtr.v2i1.1603

BS EN 13353., 2011. Panel products — Characteristics, evaluation of conformity and marking. British Standards Institution.

Chang, M., Shen, P., Wang, L., Ma, Q., Jia, Z., Hu, C., & Zhang, X., 2024. *Research progress of eco-friendly plant-derived biomass-based wood adhesives: a review.* Industrial Crops and Products, 222, 120093

Calvez, I., Garcia, R., Koubaa, A., Landry, V., & Cloutier, A., 2024. Recent advances in bio-based adhesives and formaldehyde-free technologies for wood-based panel manufacturing. *Current Forestry Reports*, 10, 386–400. https://doi.org/10.1007/s40725-024-00227-3

Dukarska, D., Kawalerczyk, J., Sedliačik, J., Antov, P. & Unisa, M., 2025. *Alternative wood raw material sources in particleboard and OSB production—challenges and perspectives.* Polymers, 17(13), 1760. https://doi.org/10.3390/polym17131760

EN 312-3., 2003. Particleboards – Specifications – Part 3: Requirements for boards for use in humid conditions.European Committee for Standardization, Brussels.

Elehinafe, F.B., Okeniyi, J.O., Bankole, M.T., 2019. Evaluation of agro-waste reinforced particleboards for sustainable construction applications. *Environmental Technology & Innovation*, 14, 100335. https://doi.org/10.1016/j.eti.2019.100335

Ezeagu CA., Okoli C.C, Egbebuike M., 2025 "Investigation on the Physical Properties of Particleboard Produced from Biodegradeable Waste and Plastics". Medicon Engineering Themes 9.1 : 11-21.

Guo, J., Zhang, Y., Fang, J., Ma, Z., Li, C., Yan, M., Qiao, N., Liu, Y., & Bian, M., 2024. *Reduction and reuse of forestry and agricultural bio-waste through innovative green utilization approaches: A review. Forests*, 15(8), 1372. https://doi.org/10.3390/f15081372

Huang, J., Li, Q., & Wang, S., 2023. Bio-based adhesives for particleboard production: Recent developments and challenges. International Journal of Adhesion and Adhesives, 117, 103187.

Huang, Y., Wang, C., Xu, J., 2023. Comparative study on synthetic and natural adhesives in particleboard production. Industrial Crops and Products, 196, 116532. https://doi.org/10.1016/j.indcrop.2023.116532

Ikubanni, P. P., Adeleke, A. A., Adekanye, T. A., Aladegboye, O. J., Agboola, O. O., & Ogunsemi, B. T., 2025. Particleboard from biomass wastes: A review of production techniques, properties, and future trends. Research on Engineering Structures & Materials, 11(2), 713–740.

Jabile, J.P., Caparino, O.A. and Mejia, C.L., 2022. Recycling of agro-industrial residues for particleboard production: A review. Waste Management, 138, pp.47–57. https://doi.org/10.1016/j.wasman.2021.12.011

Jock, T., Umar, H.S. and Ibrahim, A., 2021. Review on waste wood management strategies: Implications for sustainable development. Environmental Technology & Innovation, 23, 101698. https://doi.org/10.1016/j.eti.2021.101698

Laemlaksakul, W., Sutthiruangwong, S. and Phromsorn, P., 2014. Utilization of rice husk and sawdust for particleboard production. Procedia Engineering, 97, pp.703–708. https://doi.org/10.1016/j.proeng.2014.12.307

Li, Y., Zhang, X., & Chen, L., 2022. Advances in particleboard production using lignocellulosic particles. Wood Science and Technology, 56(3), pp.789–804.

Mustapha, K. and Ismail, N., 2022. Comparative analysis of bio-based and synthetic adhesives in wood composite production. Materials Today: Proceedings, 60, pp.1442–1448. https://doi.org/10.1016/j.matpr.2021.12.085

Mensah, P., de Melo, R. R., de Oliveira Paula, E. A., Pimenta, A. S., de Moura, J., & Rusch, F., 2025. Eco-friendly particleboards produced with banana tree (Musa paradisiaca) pseudostem fibers bonded with cassava starch and urea-formaldehyde adhesives. Journal of Renewable Materials, 13(7), 1475–1489. https://doi.org/10.32604/jrm.2025.02025-0047

Morimoto, K., Tsuda, K., & Mizuno, D., 2023. Literature review on the utilization of rice husks: Focus on application of materials for digital fabrication. Materials, 16(16), 5597. https://doi.org/10.3390/ma16165597

Nuruddin, M.F., Abdullah, M., & Ismail, H., 2021. Incorporation of agricultural by-products into particleboard: Effects on physical and mechanical properties. BioResources, 16(2), pp.3456–3470.

Nurhazirah, S., Hassan, M.Z., Azman, N.F., 2022**.** Mechanical performance of rice husk-sawdust composite panels using bio-resin adhesives. *Construction and Building Materials*, 314, 125668. https://doi.org/10.1016/j.conbuildmat.2021.125668

Nigerian Industrial Standards (NIS) 87:2000., 2000 Specification for sandcrete blocks. *Standards Organisation of Nigeria*, Lagos, Nigeria.

Obam, S.S., Ezeh, J.C. and Adebayo, O.S., 2019. Mechanical performance of particleboards produced from agro-waste materials. BioResources, 14(2), pp.3025–3041. https://doi.org/10.15376/biores.14.2.3025-3041

Okedere, O.B., Akinyemi, A.B. and Adebayo, O.A., 2017. Environmental impact of sawmill waste disposal and utilization: A case study in Nigeria. Environmental Challenges, 1, 100005. https://doi.org/10.1016/j.envc.2020.100005

Olupot, P. W., Menya, E., Lubwama, F., Ssekaluvu, L., Nabuuma, B., & Wakatuntu, J.,2022. *Effects of sawdust and adhesive type on the properties of rice husk particleboards. Results in Engineering*, 16, 100775. https://doi.org/10.1016/j.rineng.2022.100775

Particleboards based on agricultural and agroforestry wastes glued with vegetal polyurethane adhesive: an efficient and eco-friendly alternative., 2024. *Industrial Crops and Products*, 214, 118540. https://doi.org/10.1016/j.indcrop.2024.1185402

Reotutar, A. M. R., Mamuad, R. Y., & Sy Choi, A. E., 2024. *Production of chemically modified bio-based wood adhesive from camote and cassava peels.* Polymers, 16(4), 523. https://doi.org/10.3390/polym16040523

Rashid, M.A., Islam, M.S., Ahmed, K.S., Hossain, M.K., 2020. Evaluation of rice husk-based particleboard using different adhesives. *Construction and Building Materials*, 254, 119204. https://doi.org/10.1016/j.conbuildmat.2020.119204

Rashid, M., Ahmed, S., & Khan, M.A., 2020. Utilization of rice husk and sawdust in particleboard production: A sustainable approach. Materials Today: Proceedings, 33, pp.1234–1239.

Sahin, H.T, Beglen, E., Ozkan, U., 2024. Properties of particleboards laminated with different Grammage Décor Papers. Journal of Engineering Research and Reports, 26(7)

Şahin, F. & Kaymakcı, A., 2024. Evaluation of the mechanical and physical properties of particleboards manufactured from rice husk. Artvin Çoruh University Journal of Forestry Faculty, *25*(1), 81-85. https://doi.org/10.17474/artvinofd.1356256

Sarkar, B., Adhikari, B. and Ghosh, S.K., 2015. Rice husk-based composite particleboard: Characterization and evaluation. Composite Interfaces, 22(8), pp.739–753. https://doi.org/10.1080/09276440.2015.1063131

Suleiman, B.M., Ibrahim, H.D. and Alao, J.B., 2013. Performance evaluation of particleboard made from agricultural residues and wood wastes. Nigerian Journal of Technology, 32(3), pp.411–417. https://doi.org/10.4314/njt.v32i3.9

Sánchez-Soto, P.J., Mendoza-Vega, J.G. & Torres-Barrera, R.M., 2024. Sustainable utilization of agro-industrial residues in wood-based composites: environmental impact and performance. Journal of Cleaner Production, 423**,** 138129. https://doi.org/10.1016/j.jclepro.2023.138129

Singh, R., Kumar, R., 2021. Recycling agricultural residues in engineered wood composites: A review. Resources, Conservation and Recycling, 170, 105575.https://doi.org/10.1016/j.resconrec.2021.105575

Singh, R., & Kumar, P., 2021. Non-conventional raw materials for particleboard: A review. Journal of Cleaner Production, 278, 123456.

Sekaluvu, L., Tumutegyereize, P. & Kiggundu, N., 2018. Investigating the influence of binder type and mixing ratio on mechanical properties of agricultural waste-based particleboards. Construction and Building Materials, 168, pp.376–384. https://doi.org/10.1016/j.conbuildmat.2018.02.151

Temitope, A.T., Adekunle, A.O. and Ayinde, A.O., 2015. Production of particleboard from rice husk waste. International Journal of Engineering Research and Applications, 5(12), pp.105–110.

Valyova, M. & Koynov, D., 2025. *Synthetic adhesives in production of engineered wood products: a review.* Drvna Industrija, 76(3), 343–356. https://doi.org/10.5552/drvind.2025.0260

Yu, C., 2024. A narrative review: modification of bio-based wood adhesives with comparison to traditional synthetic resins. Coatings, 14(9), 1153. https://doi.org/10.3390/coatings14091153

Yusoff, M.S., Hassan, M.A., & Rahman, M.A., 2023. Engineered wood products: A review of particleboard manufacturing. Journal of Wood Science, 69(1), 45.

Zhang, L., Liu, Y., & Chen, Y., 2024. Enhancing particleboard properties using agricultural residues: A review. Industrial Crops and Products, 180, 114765.

Zhao, Y., Li, X., & Wang, J., 2022. Agricultural and wood processing waste management: Challenges and opportunities. Journal of Environmental Management, 305, 114315.