



Evaluating the Physical, Mechanical, and Aesthetic Properties of Wood-Plastic Composites from *Gmelina arborea*, *Khaya senegalensis*, and High-Density Polyethylene Blends

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ABSTRACT

Sawdust disposal and High-Density Polyethylene (HDPE) waste both cause significant environmental pollution through air, soil, and water contamination. Their improper management leads to harmful ecological impacts due to particulate emissions and plastic persistence. The objective of the study was to assess how varying proportions of *Gmelina arborea* and *Khaya senegalensis* sawdust blended with HDPE affect the physical and mechanical properties of wood-plastic composites (WPCs). The composites were assessed for density, shatter resistance, modulus of elasticity (MOE), modulus of rupture (MOR), compressive strength, and surface characteristics. Results indicated that composites with higher *K. senegalensis* content exhibited superior performance across most parameters. The Highest Density ($0.67 \pm 0.48 \text{ g/cm}^3$) was observed in the hybrid 60:40 *K. senegalensis* and *G. arborea* blend. Pure *K. senegalensis* composites demonstrated the lowest shatter index (5.78%) and highest shatter resistance (94.22%), surpassing pure HDPE composites. MOE and MOR values peaked at $10.43 \pm 7.62 \text{ N/mm}^2$ and $478.88 \pm 419.57 \text{ N/mm}^2$, respectively, in 100% *K. senegalensis* composites. The highest compressive strength ($232.19 \pm 89.75 \text{ N/mm}^2$) was recorded in the 60:40 *K. senegalensis* and *G. arborea* blend. Surface analysis showed that increasing *K. senegalensis* content produced smoother textures and reddish-brown hues in the composites. This contrasted with the rough, black surfaces seen in pure HDPE composites. Adding *K. senegalensis* sawdust to HDPE improved both the structural and aesthetic qualities of the WPCs. The hybrid blend of *K. senegalensis* and *G. arborea* (60:40) achieved the highest density and compressive strength. These results indicate a synergistic effect between the two wood species, making the composites suitable for demanding applications.

Keywords:

Wood-Plastic Composites, High-Density Polyethylene, *K. senegalensis*, *G. arborea*, Physical and Mechanical Properties.

INTRODUCTION

Wood-plastic composites (WPCs) are innovative materials combining wood particles or fibers with thermoplastic matrices, offering advantages such as durability, low maintenance, and environmental friendliness (Burgstaller & Renner, 2023; Renner et al., 2021). These composites find applications in construction, packaging, automotive, and furniture industries (Guo & Kethineni, 2019). WPCs can be made from various thermoplastics, with polypropylene (PP) and High-Density Polyethylene (HDPE) being common choices (Burgstaller & Renner, 2023; Kajaks et al., 2017). Wood plastic composites have been successfully manufactured using sawdust from various species mixed with plastics like HDPE and Polypropylene (PP) (Najafi et al., 2006). These composites exhibit good mechanical

properties, with PP-based composites showing higher stiffness and strength but lower impact strength compared to HDPE-based ones. Interestingly, while *Gmelina arborea* and *Khaya senegalensis* are not specifically mentioned in many studies WPC, they are both valuable timber species. *Gmelina arborea* is known for its fast growth and versatile wood applications, including potential use in agroforestry systems (Dvorak, 2004). *Khaya senegalensis*, commonly known as African mahogany, is a valuable tree species prized for both its timber and medicinal properties. The wood of *K. senegalensis* is highly valued for its aesthetic appeal and durability, making it an important commercial species (Sahu et al., 2023). HDPE is widely used in wood-plastic composites (WPCs) for various industries, including building

materials, automotive, packaging, and furniture (Guo et al., 2019). Wood-plastic composites (WPCs) made from various wood fibers and HDPE have been extensively studied for their physical, mechanical, and aesthetic properties. The mechanical properties of WPCs are significantly influenced by the wood fiber content, type of coupling agent, and processing conditions. Studies have shown that the addition of wood fibers to HDPE generally improves the tensile and flexural properties of the composites (Guo et al., 2019; Hanana et al., 2018). For instance, the addition of carbon fiber to WPC resulted in a 40% increase in tensile strength and a 253% increase in tensile modulus compared to WPC with the same fiber loading (Guo et al., 2019). The use of coupling agents, such as maleated polyethylene (MAPE), has been found to enhance the compatibility between wood fibers and the plastic matrix, leading to improved mechanical properties (Catto et al., 2014; Hanana et al., 2018). The optimal wood fiber content for mechanical properties varies among studies. While some research indicates that maximum flexural modulus is achieved at 70% fiber content (Chaharmahali et al., 2008), others suggest that 50% wood fiber content with appropriate lubricant and coupling agent concentrations yields optimal tensile and flexural properties (Adhikary et al., 2010). This variation highlights the importance of optimizing the formulation for specific wood species and applications.

Gmelina arborea and *K. senegalensis* sawdust waste have emerged as promising materials for wood composites due to their unique properties and environmental benefits. *Khaya senegalensis*, also known as African mahogany, has been explored for its potential as a dedicated energy crop for green energy production (Ismail et al., 2023). Makurdi, a major timber processing hub in Benue State, Nigeria, generates large volumes of wood waste daily, including sawdust from *G. arborea* and *K. senegalensis*, which pose significant environmental and health hazards if not properly managed. The environmental pollution caused by improper disposal of sawdust and HDPE waste, leading to air, soil, and water contamination (Ramesh et al., 2022). The lack of knowledge on how the different proportions of *G. arborea* and *K. senegalensis* sawdust blended with HDPE influence the physical and mechanical properties of wood-plastic composites. Converting these wastes into value-added WPCs offers a sustainable solution by reducing pollution and promoting resource efficiency. Unmanaged sawdust and plastic contribute to air and water pollution, endangering mill workers and nearby communities; integrating these materials into WPCs supports local efforts to mitigate hazardous waste and improve public health. WPCs combine the benefits of wood and plastic, resulting in durable, moisture-resistant materials suitable for various construction and interior applications. Given Nigeria's high demand for affordable and sustainable building materials, research into locally

produced WPCs can contribute to housing affordability and industry development. While some studies have explored the physical and mechanical properties of WPCs from these species, comprehensive assessments integrating both aesthetic and mechanical properties remain scarce. This study addresses that gap by providing a holistic understanding of WPC performance for diverse applications.

MATERIALS AND METHODS

Study area

This study was carried out in Makurdi. Makurdi, the capital city of Benue State in central Nigeria, is geographically positioned at approximately latitude 7.73°N and longitude 8.52°E. The city is situated in the Guinea Savannah ecological zone, characterized by a tropical wet and dry (savanna) climate (Köppen classification: Aw). Makurdi experiences average annual temperatures ranging from about 26°C (79°F) to 32°C (90°F), with the warmest months being February, March, and April, and the coolest temperatures typically occurring between July and September (Sambe et al., 2021). Annual precipitation averages between 900 and 1,350 mm, with the heaviest rainfall recorded from July to September, when monthly totals can exceed 180 mm, and the driest months are December and January, which receive less than 10 mm of rain.

Makurdi is a major hub for timber processing and trade, with several Timber Sheds located in Wurukum, North Bank and industrial layout in Anaka within the city. These Timber Sheds are strategically situated near the main markets and along major transportation routes, facilitating the flow of wood products from surrounding LGA, especially Guma, Gwer West, Makurdi, and Gwer East. Guma LGA is the largest supplier, accounting for about 42% of wood species brought to Makurdi's Timber Sheds, followed by Gwer West (25%) and Makurdi LGA itself (21%) (Ekhuemelo et al., 2024). The Timber Sheds serve as key centers for the processing and sale of a wide variety of wood species, including *Gmelina arborea*, *Khaya senegalensis*, and others, and are recognized as the highest generators of wood waste in the metropolis (Sambe et al., 2021).

Samples collection and preparation

Sawdust (SD) from the wood species *Gmelina arborea* and *Khaya senegalensis* was collected from the North Bank Timber Shed located near the old bridge in Makurdi, Benue State, Nigeria. High-Density Polyethylene samples were sourced from the Mechanic Village in Kanshio, Makurdi, Benue State. All materials were subsequently prepared for further processing and analysis. The sawdust samples were sun-dried for six days to evaporate excess moisture.

After drying, the wood sawdust was sieved using a 1–2 mm mesh to remove undesirable materials such as plastic fragments, metal particles, and oversized wood pieces, ensuring uniformity in particle size. The sieved sawdust served as both filler and reinforcement in the composite matrix, and its particle size (mm) and bulk density (g/cm³) were determined. Subsequently, a cold-setting adhesive, formalin formaldehyde resin (Top Bond), was applied to the sieved sawdust and crushed plastic samples as a binder.

Board Formation

Composite Boards were produced using a rectangular mold measuring 17 cm by 16 cm. The sample mixtures were prepared in different ratios—100%, 50:50, 70:30, 60:40, and 30:70—and thoroughly mixed with a thermosetting adhesive known as Top Bond. The mixtures were then poured into a flat mold with a thickness of 2 cm and pressed using a pressing machine (Plate 4) for approximately 5 minutes to ensure proper adhesive curing. After pressing, the boards were removed and air-dried for 30 minutes to complete the curing process before being stored.

Determination of Physical and Mechanical Properties of Composite Board

Physical and mechanical tests on the produced composite Boards were conducted in accordance with ASTM D7031 standards.

Physical Properties

i. **Density:** Calculated using $D = M/V$ (Kg/m³) (1)
M is mass and *V* is volume.

ii. **Shatter Index:** $\%WL = W1 - W2/W1$ (2)
Where: %WL = Percentage weight loss; W1= Initial weight before shattering; W2 = weight of shattering

iii. **Shatter Resistance:** Measured as $SR = 100 - SI$ (3)

Where: Shatter resistance =SR; SI = Shattered index

iv. **Compressive Strength (Parallel to Grain):** Measured using a CDI machine, calculated with $CS = (L \times 1000)/A$ (4)

Where: CS = Compressive Strength; L = Length; A= Area

Mechanical Properties

i. **Modulus of Elasticity (MOE):** Derived from the load-deflection graph using $MOE = \Delta PL^3 / 4bd^3 \Delta s$ (5)

ii. Where: MOE = modulus of elasticity (N mm⁻²); P = increment in load (N); L = the span of the sample between the machine support (mm); b = width of the sample (mm); d = thickness of the sample (mm); Δs = increment in deflection corresponding to increment in load

iii. **Modulus of Rupture (MOR):** Evaluated by applying load until failure, using $MOR = 3PL/2bd^2$ (6)

iv. Where: MOR = modulus of rupture (N mm⁻²); P = the ultimate failure load (N); L = the wood sample span between the machine support (mm); b = width of the wood sample (mm); d = thickness of the wood sample (mm).

Data Collection

Data collection involved evaluating the physical and mechanical properties of the composite boards, including density, shatter index, shatter resistance, and compressive strength. Initial measurements of sample thickness (mm), weight (g), and length (m) were recorded prior to immersion in water. Final measurements were taken after 24 hours of immersion at 20°C, with additional readings recorded at 2-hour intervals. Water absorption and related changes in physical properties were measured using an electronic weighing balance, digital caliper, micrometer screw gauge, and meter rule.

Data Analysis

Descriptive statistics (mean, frequency, percentage, standard deviation) and one-way ANOVA ($\alpha \leq 0.05$) were used to analyze the effect of wood type, mixing ratio, and immersion duration on composite board properties.

RESULTS AND DISCUSSION

Results

Table 1 presents results on the density of wood-plastic composite (WPC) boards produced by combining HDPE with sawdust from *G. arborea* and *K. senegalensis*. The density values ranged from 0.39 ± 0.19 g/cm³ to 0.67 ± 0.48 g/cm³, with significant variations observed across treatments. Composites containing 100% *K. senegalensis* (0.57 ± 0.28 g/cm³) and the HDPE and *K. senegalensis* (30:70) blend (0.57 ± 0.27 g/cm³) exhibited the highest densities, both statistically significant from other formulations ($p < 0.05$). The hybrid *K. senegalensis* and *G. arborea* (60:40) composite achieved the maximum density (0.67 ± 0.48 g/cm³), indicating synergistic interactions between the two wood species. In contrast, HDPE-dominated composites (50:50 or 70:30 ratios with *G. arborea*) showed no significant differences in density compared to pure HDPE ($0.39 - 0.42$ g/cm³).

Table 1: Density of Wood Plastic Composites Board produced from the combination of *G. arborea*, *K. senegalensis* sawdust and High-Density Polyethylene

S/No.	Treatment	Density (Mean \pm SD, g/cm ³)
1	100% HDPE	0.39 \pm 0.19 ^a
2	HDPE + <i>G. arborea</i> (50:50)	0.42 \pm 0.19 ^a
3	HDPE + <i>G. arborea</i> (70:30)	0.40 \pm 0.22 ^a
4	HDPE + <i>K. senegalensis</i> (30:70)	0.57 \pm 0.27 ^b
5	HDPE + <i>K. senegalensis</i> (70:30)	0.39 \pm 0.21 ^a
6	100% <i>K. senegalensis</i>	0.57 \pm 0.28 ^b
7	<i>K. senegalensis</i> + <i>G. arborea</i> (60:40)	0.67 \pm 0.48 ^c

Note: Means within a column sharing the same superscript letter (a, b) are not significantly different ($p > 0.05$); HDPE=High-Density Polyethylene

The results of shatter behaviour of wood-plastic composites (WPCs) fabricated from HDPE blended with sawdust from *G. arborea* and *K. senegalensis* are shown in Table 2. The shatter index (SI) and shatter resistance (SR) varied significantly across treatments, with SI ranging from 5.78% to 12.56% and SR from 87.44% to 94.22%. Composites containing 100% *K. senegalensis* exhibited the lowest SI (5.78%) and highest SR (94.22%), outperforming pure HDPE (SI: 12.56%, SR: 87.44%). Blends with higher wood content, such as HDPE and *K. senegalensis* (30:70; SI: 7.11%) and the hybrid *K. senegalensis* and *G. arborea* (60:40; SI: 6.11%), demonstrated superior mechanical integrity, with

SR values exceeding 92%. In contrast, HDPE-dominated formulations (for example, HDPE and *G. arborea* at 70:30) showed no significant improvement in SR (88.40–88.45%) compared to pure HDPE.

Statistical analysis revealed distinct groupings: wood-rich composites. Treatments (S/No.) 2, 4, 6, 7 formed a homogeneous subset (SI: 5.78–8.46%; SR: 91.54–94.22%), while HDPE-heavy blends, Treatments (S/No.) 1, 3, 5 clustered separately (SI: 11.55–12.56%; SR: 87.44–88.45%).

These results underscore the reinforcing role of lignocellulosic fillers, particularly *K. senegalensis*, in enhancing fracture resistance.

Table 2: Shattered Index and Shattered Resistance of wood plastic composites produced from the combination of *G. arborea*, *K. senegalensis* sawdust and HDPE

S/No.	Treatment	Shattered Index (%)	Shattered Resistance (%)
1	100% HDPE	12.56 ^b	87.44 ^a
2	HDPE + <i>G. arborea</i> (50:50)	8.46 ^a	91.54 ^b
3	HDPE + <i>G. arborea</i> (70:30)	11.60 ^b	88.40 ^a
4	HDPE + <i>K. senegalensis</i> (30:70)	7.11 ^a	92.89 ^b
5	HDPE + <i>K. senegalensis</i> (70:30)	11.55 ^b	88.45 ^a
6	100% <i>K. senegalensis</i>	5.78 ^a	94.22 ^b
7	<i>K. senegalensis</i> + <i>G. arborea</i> (60:40)	6.11 ^a	93.89 ^b

Note: Means within a column sharing the same superscript letter (a, b) are not significantly different ($p > 0.05$); HDPE=High-Density Polyethylene

The Modulus of Elasticity (MOE) of WPCs produced by combining HDPE with sawdust from *G. arborea* and *K. senegalensis* ranged from 2.68 \pm 2.43 N/mm² to 10.43 \pm 7.62 N/mm², with the highest values observed in composites containing 100% *K. senegalensis* (10.43 \pm 7.62 N/mm²) and the hybrid *K. senegalensis* and *G. arborea* (60:40) (8.66 \pm 7.00 N/mm²). The Modulus of Rupture (MOR) exhibited a much broader range, from

57.04 \pm 25.71 N/mm² (100% HDPE) to 478.88 \pm 419.57 N/mm² (100% *K. senegalensis*), with *K. senegalensis*-rich blends (Treatments 4, 6, 7) showing substantially higher values compared to HDPE-dominated or *G. arborea*-rich formulations. Statistical analysis revealed significant differences among treatments, with wood-rich composites (especially those based on *K. senegalensis*) demonstrating superior stiffness and flexural strength.

Table 3: Modulus of Elasticity and Modulus of Rapture of wood-plastic composites produced from the combination of *Gmelina arborea*, *Khaya senegalensis* sawdust and HDPE

S/No.	Treatment	Modulus of Elasticity (Mean \pm SD, N/mm ²)	Modulus of Rupture (Mean \pm SD, N/mm ²)
1	100% HDPE	3.90 \pm 2.14 ^a	57.04 \pm 25.71 ^a

2	HDPE + <i>G. arborea</i> (50:50)	2.87±2.14 ^a	72.85±24.19 ^b
3	HDPE + <i>G. arborea</i> (70:30)	3.80±1.44 ^a	73.51±6.43 ^b
4	HDPE + <i>K. senegalensis</i> (30:70)	6.41±4.51 ^b	445.56±500.82 ^c
5	HDPE + <i>K. senegalensis</i> (70:30)	2.68±2.43 ^a	74.21±20.47 ^b
6	100% <i>K. senegalensis</i>	10.43±7.62 ^c	478.88±419.57 ^d
7	<i>K. senegalensis</i> + <i>G. arborea</i> (60:40)	8.66±7.00 ^b	419.80±444.67 ^c

Note: Means within each column sharing the same superscript letter (a, b, c, d) are not significantly different ($p > 0.05$); HDPE=High-Density Polyethylene

The compressive strength of WPCs produced from combinations of *Gmelina arborea*, *Khaya senegalensis* sawdust and HDPE varied significantly across the different composite formulations, ranging from 138.06 ± 78.32 N/mm² in the HDPE and *G. arborea* (70:30) blend to a maximum of 232.19 ± 89.75 N/mm² in the hybrid *K. senegalensis* and *G. arborea* (60:40) composite (Table 4). The results indicate that the incorporation of *K. senegalensis* sawdust, either alone or in combination with *G. arborea*, consistently yielded higher compressive strength values compared to composites with higher HDPE content or those dominated by *G. arborea*.

Statistical analysis revealed three distinct groupings: the lowest compressive strength was observed in the HDPE and *G. arborea* (70:30) blend (138.06 N/mm²), which was significantly lower than the other treatments. Composites containing 100% HDPE, HDPE and *G. arborea* (50:50), and HDPE and *K. senegalensis* (70:30) exhibited intermediate compressive strengths ($156.25 - 158.90$ N/mm²), forming a statistically homogenous group. The highest compressive strengths were achieved in composites with significant proportions of *K. senegalensis*, particularly the HDPE and *K. senegalensis* (30:70) blend (223.73 N/mm²), 100% *K. senegalensis* (203.66 N/mm²), and the *K. senegalensis* and *G. arborea* (60:40) blend (232.19 N/mm²).

Table 4: Compressive Strength Parallel Grain of wood plastic composites produced from the combination of *G. arborea*, *K. senegalensis* sawdust and HDPE

S/No.	Sample Combination	Compressive Strength (Mean ± SD, N/mm ²)
1	100% HDPE	158.90±99.23 ^b
2	HDPE and <i>G. arborea</i> (50:50)	157.71±96.32 ^b
3	HDPE and <i>G. arborea</i> (70:30)	138.06±78.32 ^a
4	HDPE and <i>K. senegalensis</i> (30:70)	223.73±87.08 ^c
5	HDPE and <i>K. senegalensis</i> (70:30)	156.25±95.79 ^b
6	<i>K. senegalensis</i> (100%)	203.66±71.15 ^c
7	<i>K. senegalensis</i> and <i>G. arborea</i> (60:40)	232.19±89.75 ^c

Note: Means within the column sharing the same superscript letter (a, b, c) are not significantly different ($p > 0.05$); HDPE=High-Density Polyethylene

The results of WPCs produced by combining HDPE with sawdust from *G. arborea* and *K. senegalensis* revealed variations in both colour and surface texture, depending on the wood species and their blending ratios with HDPE. Pure HDPE composites were uniformly black and exhibited a very rough surface, while the introduction of *G. arborea* sawdust resulted in cream-black or black

hues and maintained a rough surface texture. In contrast, composites containing higher proportions of *K. senegalensis* sawdust displayed reddish or reddish-brown colors and notably smoother surfaces, with the smoothest surfaces observed in 100% *K. senegalensis* and the hybrid *K. senegalensis* and *G. arborea* (60:40) composites (Table 5).

Table 5: Color and Surface Appearance of Wood-Plastic Composites Produced from the Combination of *G. arborea*, *K. senegalensis* Sawdust, and HDPE

S/No.	Sample Combination	Colour	Surface Appearance
1	100% HDPE	Black	Very Rough
2	HDPE and <i>G. arborea</i> (50:50)	Cream Black	Rough
3	HDPE and <i>G. arborea</i> (70:30)	Black	Rough
4	HDPE and <i>K. senegalensis</i> (70:30)	Reddish Black	Rough
5	HDPE and <i>K. senegalensis</i> (30:70)	Reddish Black	Smooth
6	<i>K. senegalensis</i> (100%)	Reddish	Very Smooth
7	<i>K. senegalensis</i> and <i>G. arborea</i> (60:40)	Reddish Brown	Very Smooth

Note: HDPE=High-Density Polyethylene

Discussion

The density values of WPCs in this study showed significant variations observed across treatments. Composites containing 100% *K. senegalensis* and the HDPE and *K. senegalensis* (30:70) blend exhibited the highest densities, both statistically significant from other formulations ($p < 0.05$). These results highlight the critical role of wood species selection and compositional ratios in determining WPC density, with *K. senegalensis*-enriched formulations demonstrating superior densification. The findings suggest that optimizing HDPE-wood ratios and species combinations can enhance material properties for applications requiring specific density profiles. In prior research, the density of WPCs was shown to vary based on the type of polymer matrix and wood filler content. For instance, a study by Ratanawilai *et al.* (2023) examining WPCs made with various plastics reported that density decreased with increasing plastic content, with PVC-based composites reaching up to 1.231 g/cm³ and PP-based composites as low as 0.913 g/cm³. Another study by Amirta *et al.* (2024) focusing on red meranti (*Shorea spp.*) sawdust combined with polyethylene and polypropylene found density values ranging from 0.63 to 0.73 g/cm³.

The findings align with studies emphasizing wood-polymer compatibility and particle dispersion as critical factors in WPC durability (Samyn, 2024; Hejn *et al.*, 2020). Optimizing HDPE-wood ratios and leveraging species-specific properties (e.g., *K. senegalensis*'s dense fiber structure) can yield composites tailored for high-impact applications, such as construction and automotive components, while promoting sustainable material reuse. The shatter index and shatter resistance of test boards in the study varied significantly across treatments, with SI ranging. Composites containing 100% *K. senegalensis* exhibited the lowest SI and highest SR, outperforming pure HDPE. Blends with higher wood content, such as HDPE and *K. senegalensis* and the hybrid *K. senegalensis* and *G. arborea*. These results align with prior research emphasizing the influence of fiber content and dispersion on the impact resistance of natural fiber-reinforced polymer composites. For instance, a study on WPCs produced from *G. arborea* and *K. senegalensis* sawdust combined with polyethylene terephthalate (PET) reported SI values ranging from 5.00% to 6.99% and SR values between 93.01% and 95.00%, with the highest resistance observed in the *G. arborea* and *K. senegalensis* (60:40) blend (Varun *et al.*, 2024; Ekhuemelo *et al.*, 2024). Moreover, the impact resistance of natural fiber composites is known to be affected by factors such as fiber-matrix adhesion and fiber dispersion within the polymer matrix. Studies by Thomason *et al.*, (2018) has shown that increasing fiber content up to an optimal point enhances impact strength due to better energy absorption, but excessive fiber loading can lead to agglomeration and stress

concentration, reducing impact performance. The superior performance of composites with higher *K. senegalensis* content suggests that this wood species contributes positively to the impact resistance of WPCs. The findings underscore the importance of optimizing fiber content and ensuring uniform dispersion to achieve desirable mechanical properties in WPCs.

The MOE of WPCs produced by combining HDPE with sawdust from *G. arborea* and *K. senegalensis* had highest value observed in composites containing 100% *K. senegalensis* and the hybrid *K. senegalensis* and *G. arborea*. The MOR exhibited a much broader range, from 100% HDPE to 100% *K. senegalensis*, with *K. senegalensis*-rich blends showing substantially higher values compared to HDPE-dominated or *G. arborea*-rich formulations. These findings align with previous research by Ekhuemelo *et al.*, (2024) indicating that the incorporation of wood fibers into polymer matrices can enhance mechanical properties such as MOE and MOR. For instance, a study on WPCs made from *G. arborea* and *K. senegalensis* sawdust with polyethylene terephthalate (PET) reported MOE values ranging from 1.88 to 8.16 N/mm² and MOR values from 2.68 to 10.43 N/mm², with the highest values observed in composites containing 100% *G. arborea* (Ekhuemelo *et al.*, 2024). Another study investigating WPCs produced from various indigenous trees in Nigeria found that the type of wood and the mixing ratio significantly affected the mechanical properties. Composites with higher wood content generally exhibited increased MOE and MOR values (Ayo *et al.*, 2018). Furthermore, research on WPCs from teak wood sawdust and HDPE by Bootkul *et al.* (2017) demonstrated that increasing the sawdust content led to higher tensile and flexural modulus, indicating improved stiffness and strength. The current study's results suggest that *K. senegalensis* contributes more significantly to enhancing the mechanical properties of WPCs compared to *G. arborea*. The higher MOE and MOR values in *K. senegalensis*-rich composites imply better stiffness and load-bearing capacity, making them more suitable for structural applications. These findings underscore the importance of selecting appropriate wood species and optimizing the wood-to-plastic ratio to achieve desired mechanical properties in WPCs.

The compressive strength of WPCs produced from combinations of *Gmelina arborea*, *Khaya senegalensis* sawdust and HDPE varied significantly across the different composite formulations, ranging from HDPE and *G. arborea* (70:30) blend to a maximum in the hybrid *K. senegalensis* and *G. arborea* (60:40) composite (Table 4). The results indicate that the incorporation of *K.*

senegalensis sawdust, either alone or in combination with *G. arborea*, consistently yielded higher compressive strength values compared to composites with higher HDPE content or those dominated by *G. arborea*. Previous research has demonstrated that the type of wood species and the mixing ratio significantly influence the mechanical properties of WPCs. For instance, a study on WPCs produced from *G. arborea* and *K. senegalensis* sawdust with polyethylene terephthalate by Ekhuemelo *et al.* (2024) reported compressive strength values ranging from 135.63 N/mm² to 153.19 N/mm², with the highest value observed in the PET and *G. arborea* (70:30) blend. In contrast, the current study achieved higher compressive strength values, particularly in composites with greater *K. senegalensis* content. Research by Oladimeji *et al.* (2022) on biopolymer composites made from various Nigerian-grown wood species indicated that increasing the proportion of certain wood species, such as *Cordia milleni*, in the composite formulation enhanced the load-bearing capacity. This aligns with the present findings, where higher *K. senegalensis* content correlates with improved compressive strength. The superior compressive strength observed in *K. senegalensis*-rich composites underscores the importance of wood species selection in WPC manufacturing. The inherent properties of *K. senegalensis*, such as higher density and better interfacial bonding with HDPE, likely contribute to enhanced mechanical performance. These findings suggest that optimizing the wood-to-plastic ratio, particularly by incorporating *K. senegalensis*, can produce WPCs with superior structural integrity, making them suitable for applications requiring high compressive strength. These findings align with previous research indicating that the color and surface quality of WPCs are influenced by the type and amount of wood filler, as well as the processing conditions. For instance, studies by Clemons (2002) and Stark & Rowlands (2003) have demonstrated that the incorporation of hardwood species such as *K. senegalensis* can impart distinct reddish-brown tones and improve surface smoothness due to their fine particle size and good compatibility with the polymer matrix. Conversely, higher HDPE content or the use of certain softwoods may result in darker, rougher surfaces, as observed in the present study. The observed colour and surface characteristics are important for both aesthetic and functional applications of WPCs. Smooth, uniformly colored surfaces are desirable for indoor furniture, decorative panels, and other applications where visual appeal is paramount. The results suggest that optimizing the wood species and blending ratios can be used to tailor the appearance and texture of WPCs to meet specific market demands or application requirements. These insights are supported by the literature, which highlights the role of wood filler characteristics in determining the final properties of WPCs (Clemons, 2002; Stark & Rowlands, 2003; Ashori, 2008).

CONCLUSION

This study aimed to evaluate the influence of *K. senegalensis* and *G. arborea* on the performance of HDPE-based WPCs. The study demonstrated that incorporating *K. senegalensis* sawdust into high-density polyethylene (HDPE) matrices significantly enhances the physical and mechanical properties of wood-plastic composites (WPCs). Composites with higher *K. senegalensis* content exhibited increased density, improved shatter resistance, and superior mechanical strength, including higher modulus of elasticity (MOE), modulus of rupture (MOR), and compressive strength. The hybrid blend of *K. senegalensis* and *G. arborea* (60:40) achieved the highest density and compressive strength, indicating synergistic interactions between the two wood species. Surface analysis revealed that increasing *K. senegalensis* content resulted in smoother textures and reddish-brown hues, contrasting with the rough, black surfaces of pure HDPE composites. These findings suggest that *K. senegalensis* not only enhances structural integrity but also improves the aesthetic qualities of WPCs. The study underscores the potential of *K. senegalensis* as a valuable lignocellulosic filler in WPC production, offering a sustainable approach to utilizing wood waste. The study is limited to evaluating specific sawdust-HDPE blends under controlled conditions without examining long-term durability or real-world performance. Future research should explore the long-term durability and environmental performance of these composites to further validate their applicability in construction and related industries.

REFERENCE

- Adefisan, O. O. (2012). Production and testing of wood-plastic composites boards from mixed particles of *Gmelina arborea* and *Khaya ivorensis*. *Journal of Tropical Forest Resources*, 28: 1 – 6.
- Adhikary, K. B., Rizvi, G. M., Islam, M. R., and Park, C. B. (2010). Effects of Lubricant Content on Extrusion Processing and Mechanical Properties of Wood Flour-High-density Polyethylene Composites. *Journal of Thermoplastic Composite Materials*, 24(2), 155–171. <https://doi.org/10.1177/0892705710388590>
- Amirta J. R., Suwinarti W., Kusuma I.W. and Wardhani I.Y. (2024), The physical properties of wood-plastic composite produced from red meranti (*Shorea spp.*) sawdust, polyethylene and polypropylene; JBES, V25, N3, September, P121-128
- Ashori, A. (2008). Wood-plastic composites as promising green-composites for automotive

industries! *Bioresource Technology*, 99(11), 4661-4667.

Ayo A.W., Olukunle O. J., Oyerinde A.S. and Olutayo L. (2018). Physico-Mechanical Characterisation of Wood Plastic Composites Produced from Indigenous Trees in Nigeria. *International Journal of Research - Granthaalayah*, 6(2), 182–196. <https://doi.org/10.29121/granthaalayah.v6.i2.2018.156>

Bootkul, D., Butkul, T., and Intarasiri, S. (2017). Physical and Mechanical Properties of Wood Plastic Composites from Teak Wood Sawdust and High-Density Polyethylene (HDPE). *Key Engineering Materials*, 751, 277–282.

Burgstaller, C., and Renner, K. (2023). Recycling of Wood-Plastic Composites—A Reprocessing Study. *Macromol*, 3(4), 754–765. <https://doi.org/10.3390/macromol3040043Kajaks, J.>

Catto, A. L., Santana, R. M. C., Stefani, B. V., and Ribeiro, V. F. (2014). Influence of coupling agent in compatibility of post-consumer HDPE in thermoplastic composites reinforced with eucalyptus fiber. *Materials Research*, 17(Suppl 1), 203–209. <https://doi.org/10.1590/s1516-14392014005000036>

Chaharmahali, M., Tajvidi, M., Najafi, S. K., Mirbagheri, J., and Mirbagheri, Y. (2008). Mechanical and Physical Properties of Wood-Plastic Composite Panels. *Journal of Reinforced Plastics and Composites*, 29(2), 310–319. <https://doi.org/10.1177/0731684408093877>

Clemons, C. (2002). Wood-plastic composites in the United States: The interfacing of two industries. *Forest Products Journal*, 52(6), 10-18.

Dvorak, W. S. (2004). The world view of Gmelina arborea: opportunities and challenges. *New Forests*, 28(2/3), 111–126. <https://doi.org/10.1023/b:nefo.0000040940.32574.22>

Ekhuemelo D. O. Onah A. A. and Tembe E.T. (2024). Physical and mechanical properties of wood plastic composite particle boards produced from the combination of Gmelina arborea and Khaya senegalensis sawdust and polyethylene terephthalate. *Journal of Research in Forestry, Wildlife and Environment*, 16(1): 49 – 61.

Ekhuemelo, D. O., Tembe, E. T. and Aondoaver, M. T. (2021). Assessment of Physical and Mechanical Properties of three Hardwood Species from Timber Sheds in Makurdi, Benue State, Nigeria. *Proceedings of the 7th Biennial Conference of Forests and Forest Products Society, Held at University of Uyo, Uyo, Nigeria. 26th - 30th April 2021*

Guo, G., and Kethineni, C. (2019). Direct injection molding of hybrid polypropylene/wood-fiber composites reinforced with glass fiber and carbon fiber. *The International Journal of Advanced Manufacturing Technology*, 106(1–2), 201–209. <https://doi.org/10.1007/s00170-019-04572-7>

Guo, G., Finkenstadt, V. L., and Nimmagadda, Y. (2019). Mechanical properties and water absorption behavior of injection-molded wood fiber/carbon fiber high-density polyethylene hybrid composites. *Advanced Composites and Hybrid Materials*, 2(4), 690–700. <https://doi.org/10.1007/s42114-019-00116-5>

Hanana, F. E., Rodrigue, D., and Chimeni, D. Y. (2018). Morphology and Mechanical Properties of Maple Reinforced LLDPE Produced by Rotational Moulding: Effect of Fibre Content and Surface Treatment. *Polymers and Polymer Composites*, 26(4), 299–308. <https://doi.org/10.1177/096739111802600404>

Hejna, A., Przybysz-Romatowska, M., Kosmela, P., Zedler, Ł., Korol, J., and Formela, K. (2020). Recent advances in compatibilization strategies of wood-polymer composites by isocyanates. *Wood Science and Technology*, 54(5), 1091–1119. <https://doi.org/10.1007/s00226-020-01203-3> <https://doi.org/10.4028/www.scientific.net/kem.751.277>

Ismail, R. I., Khor, C. Y., and Mohamed, A. R. (2023). Pelletization Temperature and Pressure Effects on the Mechanical Properties of Khaya senegalensis Biomass Energy Pellets. *Sustainability*, 15(9), 7501. <https://doi.org/10.3390/su15097501>

Kalnins, K., and Naburgs, R. (2017). Wood plastic composites (WPC) based on high-density polyethylene and birch wood plywood production residues. *International Wood Products Journal*, 9(1), 15–21. <https://doi.org/10.1080/20426445.2017.1410997>

Mothilal, T., Ragothaman, G., Manuel, D. J., Socrates, S., and Mathavan, S. (2020). Analysis on mechanical properties of plastic wood composite. *AIP Conference Proceedings*, 2283, 020037. <https://doi.org/10.1063/5.0024893>

Najafi, S. K., Hamidinia, E., and Tajvidi, M. (2006). Mechanical properties of composites from sawdust and recycled plastics. *Journal of Applied Polymer Science*, 100(5), 3641–3645. <https://doi.org/10.1002/app.23159>

- Oladimeji, A. O., Agboola, F. Z., Oguntayo, D. O., and Aina, K. S. (2022). Dimensional stability and mechanical properties of extruded-compression biopolymer composites made from selected Nigerian grown wood species at varying proportions. *Scientific reports*, 12(1), 10545. <https://doi.org/10.1038/s41598-022-14691-z>
- Ramesh, M., Rajeshkumar, L., Sasikala, G., Balaji, D., Saravanakumar, A., Bhuvaneshwari, V., and Bhoopathi, R. (2022). A Critical Review on Wood-Based Polymer Composites: Processing, Properties, and Prospects. *Polymers*, 14(3), 589. <https://doi.org/10.3390/polym14030589>
- Ratanawilai, T., Taneerat, K., and Khamtree, S. (2023). Effects of polymeric matrix on properties of wood-plastic composites with rubberwood flour as filler. *Iranian Polymer Journal*, 33(2), 131–140. <https://doi.org/10.1007/s13726-023-01242-0>
- Renner, J. S., Jiang, L., Mensah, R. A., Berto, F., Das, O., and Xu, Q. (2021). Fire Behavior of Wood-Based Composite Materials. *Polymers*, 13(24), 4352. <https://doi.org/10.3390/polym13244352>
- Sahu, S. K., Liu, M., Wang, G., Chen, Y., Li, R., Fang, D., Sahu, D. N., Mu, W., Wei, J., Liu, J., Zhao, Y., Zhang, S., Lisby, M., Liu, X., Xu, X., Li, L., Wang, S., Liu, H., and He, C. (2023). Chromosome-scale genomes of commercially important mahoganies, *Swietenia macrophylla* and *Khaya senegalensis*. *Scientific Data*, 10(1). <https://doi.org/10.1038/s41597-023-02707-w>
- Sambe, L.N., Origbo, B. Gbande, S., and Ande P.U. (2021). Assessment of Wood Waste Generation and Utilization in Makurdi Metropolis: Implication for Sustainable Management of Forest Resources. *Journal of Research in Forestry, Wildlife and Environment*, 13(1): 188 – 196.
- Samyn, P. (2024). Challenges for Wood-Plastic Composites: Increasing Wood Content and Internal Compatibility. *Environmental and Earth Sciences Proceedings*, 31(1), 1.
- Stark, N. M., and Rowlands, R. E. (2003). Effects of wood fiber characteristics on mechanical properties of wood/polypropylene composites. *Wood and Fiber Science*, 35(2), 167-174.
- Thomason, J. L., and Rudeiros-Fernández, J. L. (2018). A review of the impact performance of natural Fiber Thermoplastic composites. *Frontiers in Materials*, 5. <https://doi.org/10.3389/fmats.2018.00060>
- Varun K.S., Swamy S.R., and Darshan C. (2024). Comparative analysis of mechanical properties of Natural Fiber-Reinforced Polymer composites. *International Journal for Research in Applied Science and Engineering Technology*, 12(11), 735 - 745. <https://doi.org/10.22214/ijraset.2024.65153>