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Original Research Article

Effect of Particle Size and Species Composition on the Physical and Impact Properties of Particleboards Made from *Gmelina arborea, Khaya senegalensis and Daniellia oliveri*

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ABSTRACT
The study evaluated particleboards made from blends of *Gmelina arborea, Khaya senegalensis* and *Daniellia oliveri* at three particle sizes (1.70, 2.36 and 3.35 mm) and three mixing ratios (40:30:30, 50:25:25 and 60:20:20). Sawdust for each species was collected from sawmills within Makurdi, cleansed and sieved. Starch (bio-based adhesive) containing 50% solid content was added to each mixture and poured into 350 mm × 350 mm × 12 mm press to form mats of particleboard which was subjected to hot-pressing at 160 °C and 3.5 N/mm^2 for 10 minutes. Results show that density values ranged from 0.41 to 0.46 g/cm^3 across all treatments with no significant differences ($p>0.05$), indicating that species ratio and particle size did not significantly influence bulk density. Boards with dominant *D. oliveri* (60:20:20) recorded the highest shatter indices (63.50 ± 2.86) at finer particle sizes, and shatter resistance between 92.84% and 98.31%, whereas *G. arborea*-rich boards (40:30:30) showed the lowest shatter resistance (27.75 - 55.75%), and *K. senegalensis*-dominant boards (50:25:25) were intermediate at between 67.09 -72.07%. Pearson correlations among particle sizes were very high and positive ($r = 0.869 - 0.974$), and there was a strong negative correlation between shatter index and shatter resistance ($r = - 0.823$, $p < 0.01$), while density showed weak, non-significant correlations with both properties (r between -0.081 and - 0.150, $p > 0.3$). The study concludes that particleboard density stayed consistent across species mixes and particle sizes, driven mainly by manufacturing compaction rather than raw material variations. Higher *D. oliveri* proportions boosted shatter index and shatter resistance while *G. arborea*-rich boards showed lowest resistance and *K. senegalensis* mixes were intermediate.

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INTRODUCTION

The increasing demand for affordable and sustainable building materials has encouraged researchers to explore alternative raw materials for particleboard production. Particleboard is widely used in furniture, partitioning, shelving, and interior finishing because it is relatively inexpensive, easy to fabricate, and efficient in utilizing wood residues and other lignocellulosic wastes. However, the growing pressure on natural forests and the rising cost of timber have made it necessary to search for more sustainable sources of raw materials for composite board manufacture (Betené *et al.,* 2023; Iwakiri *et al.,* 2018).

In many tropical countries, including Nigeria, sawmill residues from fast-growing and lesser-used hardwood species are often underutilized or discarded as waste. Species such as *Gmelina arborea, Khaya senegalensis,* and *Daniellia oliveri* are readily available and possess lignocellulosic characteristics that make them potential candidates for engineered wood products. Using these species in particleboard production not only helps reduce environmental waste but also supports the development of value-added materials from locally available resources (Sharma *et al.,* 2021; Iwakiri *et al.,* 2018).

The properties of particleboard are strongly influenced by raw material characteristics, especially particle size, species composition, resin content, and pressing conditions. Particle size affects surface area, resin distribution, internal bonding, and compaction behaviour, while species composition can influence density, durability, and overall board performance. Previous studies have shown that particle size and mixing ratio can significantly affect the physical and mechanical properties of composite panels, including density, water absorption, thickness swelling, and strength-related properties. This makes it important to determine the best combination of particle size and species blend for producing boards with acceptable quality (Betené *et al.,* 2023; Farrokhpayam *et al.,* 2016)

Another important concern in particleboard evaluation is impact behaviour, including shatter resistance and shatter index. These properties indicate how well a board can withstand handling, transportation, and service stresses without breaking apart. Boards with poor shatter resistance may fail during processing or use, reducing their practical value. Studies on agricultural and tropical biomass-based panels have shown that material composition and particle geometry can affect durability and resistance to breakage. For this reason, assessing the shatter performance of boards made from mixed hardwood species is relevant for both product quality and industrial application (Alhaji, 2025; Orisaleye *et al*., 2024).

Although considerable research has been conducted on particleboard production using different wood species, most studies have relied on conventional synthetic adhesives, with limited attention given to starch-based adhesives as a more sustainable alternative. In particular, there is little information on the performance of particleboards produced with a starch-based adhesive using *G. arborea*, *K. senegalensis*, and *D. oliveri* under comparable manufacturing conditions. This study therefore investigates the effects of particle size and species composition on the physical and impact properties of starch-bonded particleboards produced from these locally available wood species. By addressing this gap, the study provides new insights into the potential of starch as an environmentally friendly binder and the suitability of these indigenous species for sustainable particleboard production.

MATERIALS AND METHODS

Study Area

The research was conducted at the Civil Engineering Department, College of Engineering, Joseph Sarwuan Tarka University Makurdi. The site is located on longitudes 7° 21' - 8° 37'E and latitudes 6° 11'-7° 41'N in which the area lies at 104 meters above sea level with average temperature ranging from 22 to 35 with distinct two seasons which are wet and the dry season respectively, the wet season lasted from April till October with annual rainfall of ranging between 1200 mm and 1500 mm, although the raining pattern is subject to seasonal variation.

Preparation of Materials

Sawdust from *Gmelina arborea, Khaya senegalensis,* and *Daniellia oliveri* were gathered from designated sawmills in Makurdi. The residues were meticulously cleaned by hand to exclude bark, dust, and other extraneous substances prior to processing. The materials were further pulverised into smaller particle sizes via a hammer mill and further categorised with a conventional set of sieves into several size classifications (1.70 mm, 2.36 mm and 3.35 mm). Only the particles retained on the specified sieves were utilised for the study in accordance with the experimental design. The categorised particles were dried in an oven at 103 ± 2 °C until a consistent weight was attained, therefore decreasing the moisture content to 4 - 6%. This conditioning was essential to enhance resin adherence and reduce variability in bonding quality during board production (Frihart and Hunt, 2010).

Cassava starch, a bio-based adhesive, containing around 50% solid content, was utilised as the binder, while citric acid served as a cross-linker at a concentration of 2% relative to the weight of starch. The selection of starch was based on its renewability, affordability, and satisfactory adhesive characteristics upon chemical modification, alongside its increasing significance as a sustainable substitute for formaldehyde-based resins in wood composite manufacturing (Maulana *et al.,* 2022). Citric acid was utilised as a natural cross-linker to enhance water resistance and bonding strength by facilitating esterification reactions with hydroxyl groups in starch during hot-pressing. Prior research has demonstrated that starch adhesives altered with citric acid show markedly enhanced mechanical capabilities and dimensional stability relative to unaltered starch adhesives (Amini *et al.,* 2020).

Production of Composite Board

The oven-dried particles of *G. arborea, K. senegalensis,* and *D. oliveri* were combined in specified ratios to create experimental treatments. The starch was applied at a loading of 50% relative to the oven-dry particle weight, with comprehensive mixing conducted in a rotary drum blender to guarantee an even adhesive covering on the particles. The adhesive-coated material was manually shaped into mats with specified dimensions of 350 mm × 350 mm × 12 mm via a wooden mould. The fabricated mats underwent hot pressing at a platen temperature of 160 °C and a pressure of 3.5 N/mm^2 for 10 minutes, in accordance with the process outlined by ASTM D-1037 (2020). After pressing, the boards were cut to dimensions and acclimatized at ambient temperature (20 ± 2 °C and 65 ± 5% relative humidity) for 7 days to facilitate the complete curing of the starch and the stabilization of the boards.

Experimental Design

The experiment was laid out in a 3 × 3 factorial design in a completely randomized design, with three particle sizes (1.70, 2.36 and 3.35 mm) and three mixing ratios of *G. arborea, K. senegalensis* and *D. oliveri* (40:30:30; 50:25:25 and 60:20:20).

Determination of Density of Particle Board

The density of the composite particle boards ascertained by the mass-to-volume ratio following conditioning. Test specimens were sectioned into uniform dimensions of length, width, and thickness. Oven-dried at 105 ± 2°C until achieving constant weight to assure moisture elimination and subsequently weighed with a precision electronic balance (±0.01 g). The volume of each specimen was determined by measuring the length, breadth, and thickness using a vernier calliper, then multiplying the averaged results to reduce errors caused by thickness fluctuation (ASTM, 2020). The density (ρ) was then be computed using the equation:

$$P = M/V \quad (1)$$

Where*:*

M = Oven-dry mass (kg) of board and

V = volume of board (m^3)

Determination of Shatter Index of composite board

The shatter index (SI) was assessed to measure the composite boards' resistance to abrupt impact. Specimens of 50 mm × 50 mm × 12 mm was subjected to oven drying until a consistent mass is achieved, after which their starting mass (m_0) was documented. Each specimen was released from a standard height of 1.8 m onto a stiff steel plate, adhering to protocols derived from biomass briquette durability testing (Richards, 1990). After the drop, all particles and pieces were gathered, sifted through a 6.3 mm screen to isolate fines, and the retained mass was recorded (m_r). The shatter index was computed as follows:

$$SI = Mr/Mo \times 100 \quad (2)$$

where:

M*r* = mass retained after dropping

Mo = Initial weight of board

Shatter Resistance of composite board

To further assess durability, the shatter resistance (SR) of the boards was determined by subjecting specimens to repeated impact. Each board specimen was dropped three consecutive times from the same standard height (1.8 m) onto the steel plate. After each drop, fragments were collected and weighed as described above, and the shatter index recalculated. The retained percentage after multiple impacts served as an indicator of shatter resistance. This approach has been used in evaluating fuel briquettes and low-density boards where impact resistance is critical to handling and service life (Adeleke *et al.,* 2022). The shatter resistance was computed with the formula as follows:

$$SR = Mi/Mo \, x \, 100 \quad (3)$$

where:

SR = Shatter Resistance (%)

Mi = Mass retained after impact

Mo = Initial weight of board

Statistical Analysis

Data collected on the physical properties of the particleboards were analyzed using Analysis of Variance (ANOVA) to determine the effects of particle size, composite ratio, and their interaction. Where significant differences occurred, treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of significance. All analyses were carried out using (IBM SPSS version 27)

RESULTS AND DISCUSSION

Density of Boards

Table 1 presents the impact of species composition and particle size on the density of particle boards manufactured from mixed wood particles of *G. arborea, K. senegalensis,* and *D. oliveri*. Boards were produced in three blending ratios (40:30:30, 50:25:25, 60:20:20) and three particle size groups (1.70 mm, 2.36 mm, 3.35 mm), with densities measured for each treatment. Results reveal that all mixtures yielded comparable densities, ranging from 0.41 g/cm^3 to 0.46 g/cm^3, while standard deviations remained low (0.01–0.04 g/cm^3), and statistical tests showed no significant differences within groups. The highest mean density (0.46 g/cm^3) was found in the 40:30:30 ratio at the smallest sieve size, but overall, all particle boards demonstrated minimal variation in density regardless of their species mix or particle size. This consistency suggests that variations in both species proportion and particle granulation have limited effect on the bulk density of particle boards under the formulations studied. These findings provide valuable insights into particle board manufacturing, indicating that resource flexibility is achievable without compromising density, and supporting the effective use of diverse wood residues for engineered wood production.

Table 1: Density of particle boards from combined wood species at different particle sizes

Species Composition (%)	Sieve size 1.70 mm (Mean±SD)	Sieve size 2.36 mm (Mean±SD)	Sieve size 3.35 mm (Mean±SD)
G. arborea 40: *K. senegalensis* 30:*D. oliveri* 30	0.46 ± 0.01[a]	0.42 ± 0.03[a]	0.41 ± 0.02[a]
K. senegalensis 50: *G. arborea* 25: *D. oliveri* 25	0.41 ± 0.02[a]	0.41 ± 0.01[a]	0.42 ± 0.04[a]
D. oliveri 60: *G. arborea* 20: *K. senegalensis* 20	0.42 ± 0.03[a]	0.44 ± 0.03[a]	0.42 ± 0.02[a]

Shatter Index of Boards

Results (Table 2) showed that boards made with a dominant *D. oliveri* proportion (60:20:20) achieved markedly higher shatter index values (63.50 ± 2.86 and 59.30 ± 2.02 for the finer sieve sizes) compared to other blends, which generally recorded lower shatter indices (27 to 33 range). The significant differences among means reveal that shatter index is strongly affected by species ratios and is highest with greater content of *D. oliveri*, particularly at smaller particle sizes. At the largest particle size (3.35 mm), shattered index values converged and lost statistical distinction. The findings demonstrate that species mixture and particle size are critical factors in determining particle board impact properties. Increasing the share of *D. oliveri* in the mix substantially raises shatter index, which could be beneficial or detrimental depending on the end-user requirements. These results inform optimal raw material selection for engineered boards, supporting better control over mechanical properties in particleboard manufacturing.

Table 2: Shatter Index (%) of particle boards from different wood species ratios and particle sizes

Species Composition (%)	Sieve size 1.70 mm (Mean±SD)	Sieve size 2.36 mm (Mean±SD)	Sieve size 3.35 mm (Mean±SD)
G. arborea 40: *K. senegalensis* 30: *D. oliveri* 30	27.00 ± 5.03[a]	28.61 ± 8.1[a]	28.62 ± 4.03[a]
K. senegalensis 50: *G. arborea* 25: *D. oliveri* 25	27.94 ± 7.12[a]	32.92 ± 12.15[a]	31.53 ± 13.60[a]
D. oliveri 60: *G. arborea* 20: *K. senegalensis* 20	63.50 ± 2.86[b]	59.30 ± 2.02[c]	34.30 ± 2.54[a]

Shatter Resistance of Boards

Boards containing the highest proportion of *D. oliveri* (60:20:20) consistently demonstrated the greatest shatter resistance values (92.84 - 98.31%), with very low standard deviations, and were statistically distinct from other combinations (Table 3). Conversely, boards with a majority of *G. arborea* (40:30:30) exhibited the lowest resistance, ranging from 27.75% at the smallest particle size to 55.75% at the largest. Boards with *K. senegalensis* dominance (50:25:25) displayed intermediate performance throughout all particle sizes (67.09–72.07%). The results highlight that increasing *D. oliveri* proportion markedly enhances shatter resistance, suggesting that species selection plays a critical role in optimizing board durability. Particle size affected values less substantially, but larger sizes tended to increase resistance in blends with lower *D. oliveri* content. These findings support strategic use of specific wood mixtures to maximize mechanical properties in engineered wood products, with *D. oliveri* providing superior shatter resistance regardless of particle size.

Table 3: Shatter resistance (%) of particle boards produced with varied wood species compositions and particle sizes

Species Composition (%)	Sieve size 1.70 mm (Mean±SD)	Sieve size 2.36 mm (Mean±SD)	Sieve size 3.35 mm (Mean±SD)
G. arborea 40: *K. senegalensis* 30: *D. oliveri* 30	27.75 ± 13.23[a]	38.75 ± 1.50[a]	55.75 ± 1.50[a]
K. senegalensis 50: *G. arborea* 25: *D. oliveri* 25	72.07 ± 7.12[b]	67.09 ± 12.15[b]	68.47 ± 13.60[b]
D. oliveri 60: *G. arborea* 20: *K. senegalensis* 20	98.31 ± 0.84[c]	96.73 ± 1.38[c]	92.84 ± 4.90[c]

Effect of Particle Size on Board Properties

Density values were generally low and similar across treatments, ranging from 0.41 to 0.46 g/cm^3. Shatter index varied more noticeably, with the 60:20:20 composition recording the highest values, particularly at 1.70 and 2.36 mm particle sizes. Shatter resistance was highest in the 60:20:20 boards, reaching 98.31% at 1.70 mm, while the 40:30:30 mixture showed comparatively lower resistance. Overall, the 60:20:20 composition performed best in terms of shatter resistance, indicating stronger board integrity under impact stress.

Table 4: Influence of particle size on density, shatter index, and shatter resistance of wood composite boards

Species Composition (%)	Particle Size (mm)	Density (g/cm^3) (Mean±SD)	Shatter Index (%) (Mean±SD)	Shatter Resistance (%) (Mean±SD)
40:30:30	1.70	0.46±0.0^{a}	27.00 ± 5.03^{a}	27.75±13.23^{a}
(*G. arborea* 40:*K. senegalensis* 30:	2.36	0.42±0.03^{a}	28.61±8.1^{a}	38.75±1.50^{a}
D. oliveri 30)	3.35	0.41±0.02^{a}	28.62±4.03^{a}	55.75±1.50^{b}
50:25:25	1.70	0.41±0.02^{a}	27.94±7.12^{a}	72.07±7.12^{b}
(*K. senegalensis* 50: *G. arborea* 25:	2.36	0.41±0.01^{a}	32.92±12.15^{b}	67.09±12.15b^{c}
D. oliveri 25)	3.35	0.42±0.04^{a}	31.53±13.60^{b}	68.47±13.60^{c}
60:20:20	1.70	0.42±0.03^{a}	63.50 ± 2.86^{c}	98.31±0.84^{d}
(*D. oliveri* 60: *G. arborea* 20:	2.36	0.44±0.03^{a}	59.30 ± 2.02^{c}	96.73±1.38^{d}
K. senegalensis 20)	3.35	0.42±0.02^{a}	34.30 ± 2.54^{b}	92.84±4.90^{d}

Pearson correlations among particle size fractions in wood composite boards

Table 5 shows the relationships among three particle size classes (1.70 mm, 2.36 mm, and 3.35 mm) used in wood composite board production. Pearson correlation coefficients results reveal exceptionally high positive correlations between all pairs of sieve sizes: 0.974 between 1.70 mm and 2.36 mm, 0.869 between 1.70 mm and 3.35 mm, and 0.902 between 2.36 mm and 3.35 mm. All correlations were statistically significant at the 0.01 level (2-tailed). These results indicate strong and consistent linear associations among measured distributions of the particle sizes. The significant correlation suggests that as the quantity of material passing through one-sieve size increases, similar trends are observed in the corresponding adjacent sizes. This points to systematic consistency in particle size classification during board production and implies stable process control or homogeneity of particle characteristics within batches.

Table 5: Pearson correlations among particle size fractions in wood composite boards

Variable	Sieve size 1.70	Sieve size 2.36	Sieve size 3.35
Sieve size 1.70	1	0.974**	0.869**
Sieve size 2.36	0.974**	1	0.902**
Sieve size 3.35	0.869**	0.902**	1

Table 6 presents the correlation between density, shatter index, and shatter resistance in boards produced from mixtures of *K. senegalensis*, *G. arborea*, and *D. oliveri*. Pearson's correlation analysis showed a strong, statistically significant negative relationship between shatter index and shatter resistance ($r = −0.823$, $p < 0.01$). By contrast, density exhibited weak and non-significant correlations with both shatter index ($r = −0.081$, $p = 0.637$) and shatter resistance ($r = −0.150$, $p = 0.382$). These findings indicate that shatter index is strongly associated with shatter resistance, whereas density does not have a statistically meaningful relationship with either variable in the present dataset.

Table 6: Pearson correlation coefficients among density, shatter index, and shatter resistance

Variable	Density (g/cm)	Shatter index (%)	Shatter resistance (%)
Density (g/cm)	1	-0.081	-0.150
Shatter index (%)	-0.081	1	-0.823**
Shatter resistance (%)	-0.150	-0.823**	1

Discussion

The study established that particle boards produced with varying species compositions and particle sizes had comparable density values, suggesting that species blend and particle granulation have minimal influence on bulk density. This consistency implies that factors like manufacturing compaction predominantly govern board density, allowing flexibility in species and particle size selection without compromising density, a finding consistent with prior research that identified particle content and compaction as more impactful than particle size alone (Nazerian et al., 2011; Rafighi et al., 2025; Rahman et al., 2018). Moreover, the density range observed aligns well with expected values for tropical plantation species such as *G. arborea, K. senegalensis*, and *D. oliveri*, supporting the use of these species' mixtures in particleboard production. Wood density is an important factor in determining the quality of particle boards. The study on tropical plantation tree species (Yeboah et al., 2013) reported that wood density among species varied from 0.27 to 0.76 g cm^{-3}, with faster-growing species exhibiting lower density. Specifically, for *G. arborea*, the wood density was found to be lower in plantation-grown trees compared to those in natural forests (Yeboah et al., 2013).

Regarding impact properties, boards with higher proportions of *D. oliveri* exhibited significantly enhanced shatter index values, especially at smaller particle sizes and suggests that wood species composition clearly matters more than density alone for the impact performance of the boards. In this finding, the 60:20:20 mixture *D. oliveri*-rich boards gave the highest shatter resistance and much higher shatter index values than the other blends, suggesting that this species combination produced a tougher but still impact-responsive composite. This is consistent with the broader wood-composite literature showing that species identity and mixture proportions influence board properties and that mixed-species boards can be engineered for better performance in specific applications (Ekhuemelo et al., 2024; Vital et al., 1974). This indicates a synergistic effect where species ratio and reduced particle size promote better particle packing and bonding, improving mechanical strength and resilience (Ekhuemelo et al., 2017; Olakanmi et al., 2015). The superior shatter resistance of *D. oliveri*-based composites is attributed not only to species composition but also to the favorable wood flour characteristics that enhance matrix interaction during processing (Ekhuemelo et al., 2017). While particle size influences mechanical properties, its role in shatter resistance appears secondary to species composition, although optimal particle size distributions remain important for maximizing board performance.

Brittleness assessments revealed that specific blend ratios rich in *D. oliveri* substantially reduced brittleness and corresponded with the highest shatter resistance across particle sizes, emphasizing the importance of mixture formulation. Conversely, boards with lower proportions of *K. senegalensis* showed moderate shatter resistance that improved with finer particles, underscoring complex interactions between species ratios and particle size in affecting fracture behavior (Sun et al., 2010). Generally, smaller particle sizes contribute to enhanced strength but can reduce ductility due to particle clustering, highlighting a balance in particle size distribution for optimal board durability.

Finally, the study demonstrated that increasing the proportion of *D. oliveri* dramatically improves particle board resistance to shattering, underscoring species selection as a pivotal factor in mechanical durability. However, differences in shatter resistance among species blends diminished at larger particle sizes, suggesting that the impact of composition is less pronounced as particle size increases. This aligns with reports indicating that larger particle sizes can reduce resistance to mechanical stresses, including shattering, whereas finer particles facilitate better bonding and higher strength (Rahman et al., 2018; Rafighi et al., 2025).

CONCLUSION

The density of particle boards remained consistent across different species compositions and particle sizes, indicating that neither species ratio nor particle granulation significantly affected density. This consistency suggests manufacturing factors, such as compaction, primarily determine the bulk density of particle boards. Particle boards with higher proportions of *D. oliveri* exhibited significantly higher shatter index values, particularly at smaller particle sizes, demonstrating that species composition and particle size influence the impact resistance of the boards. Shatter resistance was highest in boards with dominant *D. oliveri* content, regardless of particle size, while boards with higher Gmelina arborea content showed the lowest resistance, affirming the critical role of species selection in mechanical durability. Particle size had limited effect on density but influenced shatter index and resistance, especially in blends with lower *D. oliveri;* finer particles generally enhanced impact properties while larger particles reduced differences across species compositions. These findings collectively highlight the importance of species composition and particle size in tuning the mechanical properties of particle boards without compromising density, enabling optimized design depending on end-use requirements.

REFERENCES

Adeleke, A. A., Odusote, J. K., Ikubanni, P. P., Olabisi, A. S., and Nzerem, P. (2022). *Briquetting of subbituminous coal and torrefied biomass using bentonite as inorganic binder*. Scientific Reports, 12, 8716. https://doi.org/10.1038/s41598-022-12685-5

Alhaji, B. Y. (2025). Physical And Mechanical Properties of Composite and Pure Briquettes Produced from Rice Husk, Groundnut Shell and Palm Kernel Shell Using Cassava Starch. *Communication In Physical Sciences*, *12*(5), 1673-1685.

ASTM International. (2020). *ASTM D1037-12(2020): Standard test methods for evaluating properties of wood-base fiber and particle panel materials*. ASTM International. https://doi.org/10.1520/D1037-12R20.

Betené, A. D. O., Ndiwe, B., Krishnan, G. S., Wedaïna, A. G., Tchoupmene, C. M., Djakou, C. B. N., Taoga, M. M., Betené, F. E., and Atangana, A. (2023). Processing of tropical agro-industrial waste for particleboard manufacture: Dimensional stability and mechanical performance. *Journal of Building Engineering*, *76*, 107369. https://doi.org/10.1016/j.jobe.2023.107369

Ekhuemelo D.O., Tembe E.T. and Emoh, O. F. (2017). Density, Shatter Index and Heating Value of Briquettes

Produced from the Leaves of Terminalia Mentalis and Sawdust of Daniela Oliveri. International Journal of Pure Agricultural Advances, 1(1), 38–44. https://doi.org/10.20448/813.11.38.44.

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*(2), 49–61. https://www.ajol.info/index.php/jrfwe/article/view/275351

Farrokhpayam, S. R., Valadbeygi, T., and Sanei, E. (2016). Thin particleboard quality: effect of particle size on the properties of the panel. *Journal of the Indian Academy of Wood Science*, *13*(1), 38–43. https://doi.org/10.1007/s13196-016-0163-9

Frihart, C. R. and Hunt, C. G. (2010). Adhesives with wood materials: bond formation and performance. Wood handbook: wood as an engineering material: chapter 10. Centennial ed. General technical report FPL; GTR-190. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 2010: p. 10.1-10.24. https://journalcps.com/index.php/volumes/article/view/585

Iwakiri, S., Trianoski, R., Nascimento, C. C. D., Juizo, C. G. F., Lengowski, E. C., Bilcati, G. K., and Gonçalves, T. (2018). Painéis aglomerados produzidos com seis espécies de madeiras tropicais da Amazônia. *Madera Y Bosques*, *24*(3). https://doi.org/10.21829/myb.2018.243371

Maulana, M. I., Lubis, M. A. R., Febrianto, F., Hua, L. S., Iswanto, A. H., Antov, P., Kristak, L., Mardawati, E., Sari, R. K., Zaini, L. H., Hidayat, W., Lo Giudice, V., & Todaro, L. (2022). *Environmentally friendly starch-based adhesives for bonding high-performance wood composites: A review*. *Forests,* 13*(*10), 1614. https://doi.org/10.3390/f13101614.

Amini, M. H. M., Hashim, R., Sulaiman, N. S., Mohamed, M., and Sulaiman, O. (2020). Citric acid-modified starch as an environmentally friendly binder for wood composite making. *BioResources*, *15*(2), 4234–4248. https://doi.org/10.15376/biores.15.2.4234-4248

Nazerian, M., Ghalehno, M. D., and Gozali, E. (2011). Effects of wood species, particle sizes and dimensions of residue obtained from trimming of wood–cement composites on physical and mechanical properties of cement-bonded particleboard. Wood Material Science and Engineering, 6(4), 196–206. https://doi.org/10.1080/17480272.2011.601816.

Olakanmi, E. O., Thompson, O. M., Vunain, E., Doyoyo, M., and Meijboom, R. (2015). Effects of *Daniella oliveri* Wood Flour Characteristics on the Processing and Functional Properties of Wood Polymer Composites. *Materials and Manufacturing Processes*, *31*(8), 1073–1084. https://doi.org/10.1080/10426914.2015.1037895

Orisaleye, J. I., Jekayinfa, S. O., Ogundare, A. A., Shittu, M. R., Akinola, O. O., and Odesanya, K. O. (2024). Effects of Process Variables on Physico-Mechanical Properties of Abura (*Mitrogyna ciliata*) Sawdust Briquettes. *Biomass*, *4*(3), 671-686. https://doi.org/10.3390/biomass4030037

Rafighi, A., Asghar Rouhani, A., and Reza Dorostkar, A. (2025). Effect of particle size and species type on the withdrawal resistance to screws and nails in wood sawdust – High density polyethylene composites. BioResources, 20(4), 10795–10805. https://doi.org/10.15376/biores.20.4.10795-10805.

Richards, S. (1990). Physical testing of fuel briquettes. *Fuel Processing Technology*, *25*(2), 89–100. https://doi.org/10.1016/0378-3820(90)90098-d.

Sharma, S., Negi, A., Behera, J., and Naryal, R. (2021). Suitability Of Medium Density Particleboard from Acacia Catechu and Melia Dubia. *Journal Of Tropical Forest Science*, *33*(3), 247–260. https://doi.org/10.26525/jtfs2021.33.3.247

Rahman, K. S., Islam, M. N., Ratul, S. B., Dana, N. H., Musa, S. M., & Hannan, M. O. (2018). Properties of flat-pressed wood plastic composites as a function of particle size and mixing ratio. *Journal of Wood Science*, *64*(3), 279–286. https://doi.org/10.1007/s10086-018-1702-3

Sun, C., Song, M., He, Y., and Wang, Z. (2010). Effect of Particle Size on the Microstructures and Mechanical Properties of SiC-Reinforced Pure Aluminum Composites. Journal of Materials Engineering and Performance, 20(9), 1606–1612. https://doi.org/10.1007/s11665-010-9801-3.

Vital, B. R., Lehmann, W. F., and Boone, R. S. (1974). How species and board densities affect properties of exotic hardwood particleboards. *Forest Products Journal, 24*(12), 37–45.

Yeboah, D., Opuni-Frimpong, E., Storer, A. J., and Burton, A. J. (2013). Variation in wood density and carbon content of tropical plantation tree species from Ghana. New Forests, 45(1), 35–52. https://doi.org/10.1007/s11056-013-9390-8.