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Selected Physical Properties of Eucalyptus and Pine Veneered Plywood from Mufindi, Iringa, Tanzania

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ABSTRACT

Deforestation and the increasing demand for sustainable wood alternatives have promoted the use of plywood for structural applications in Tanzania; however, little is known about how veneer species affect its performance. This study compared eucalyptus and pine veneered plywood panels bonded with phenol formaldehyde resin. Water absorption, swelling, shrinkage, and density were measured according to European Norm (EN) standards. Eucalyptus plywood performed better across all tests. It showed lower water absorption (86.18% compared with 116.44%) and thickness swelling (1.86% compared with 3.34%). Dimensional changes were also smaller, with shrinkage of 0.72% in length, 0.68% in width, and 4.63% in thickness, whereas pine exhibited larger values. Eucalyptus had a higher density (633.2 kg/m³) than pine (569.6 kg/m³), enhancing its dimensional stability. These differences were statistically significant ($p < 0.05$). Overall, eucalyptus-veneered panels demonstrated superior moisture resistance and stability, suggesting greater suitability for structural plywood in humid environments.

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1.0 Introduction

Wood is a vital forest product with widespread applications in construction, pulp and paper, packaging, furniture, wood-based composites, and shipbuilding. Rising population and industrial demand are accelerating the depletion of forest resources (Kumar and Bisht, 2025). At the same time, solid wood exhibits inherent drawbacks such as anisotropy, heterogeneity, and poor dimensional stability under fluctuating moisture. To address both the rising demand and these performance limitations, engineered wood products like plywood have become indispensable. Plywood is produced by bonding thin wood veneers with adhesive under heat and pressure (Nicole, 2021; Tatyana *et al.,* 2024). Its cross-laminated structure overcomes many of the shortcomings of solid wood, offering enhanced durability, flexibility, and dimensional stability. This versatility makes plywood suitable for construction, furniture, shipbuilding, interior design, and even aviation (Devid, 2020; Nidhi, 2023; Nitty, 2023). Quality production depends on straight, defect-free logs, and in Tanzania, eucalyptus and pine are the primary sources of raw material, reflecting the country's reliance on plantation-grown timber.

Plantation forestry in Tanzania has been promoted since the 19th century and today covers about 554,500 hectares, with eucalyptus and pine as the dominant species (Beleko, 2021; Andrew, 2022). These plantations supply raw material not only for plywood but also for construction, pulp and paper, and packaging industries (Babune *et al.,* 2021). Eucalyptus, a fast-growing hardwood, is valued for its pest resistance, adaptability to poor soils, and short rotation period of around seven years (Khan *et al.*, 2020). Its high density and natural oils improve moisture resistance, directly enhancing dimensional stability.

In contrast, pine grows well in cooler, high-rainfall regions, with relatively low pest vulnerability but high susceptibility to forest fires (Gyeltshen, 2016). Its lower density and limited natural durability make it more prone to dimensional changes when exposed to moisture (Wei *et al.*, 2019). These fundamental differences between hardwood and softwood veneers significantly influence plywood properties such as swelling, shrinkage, and stability. Additionally, performance is shaped by the type of adhesive, commonly phenol-formaldehyde or similar resins, and possible additives, all of which determine the final quality of the product.

Ultimately, plywood performance depends on its physical properties, which govern its suitability for specific applications. In construction, for example, it is valued for resistance to warping and cracking under moisture exposure, as well as its cost-effective, precise manufacturing (Vlaović *et al.*, 2024). Production of plywood involves a sequence of steps, including veneer peeling, cutting, grading, drying, bonding, pressing, and glueing (Bambang, 2017). Advances in automation and digital technologies have improved production efficiency and quality, while global demand for plywood continues to expand (Leo *et al.*, 2022).

Within this context, Tanzania's forest sector, including plywood manufacturing, contributes significantly to the national economy, accounting for 3.57% of GDP and 4.26% of gross value added (Temu *et al.*, 2024). Mufindi District in the southern highlands has become a major hub for plywood production, supported by abundant plantations and skilled labour (Christian *et al.*, 2017; Yona and Robart, 2022). Manufacturing activities in this district supply domestic markets and create jobs, support exports, and enhance national income (Mziray *et al.,* 2024).

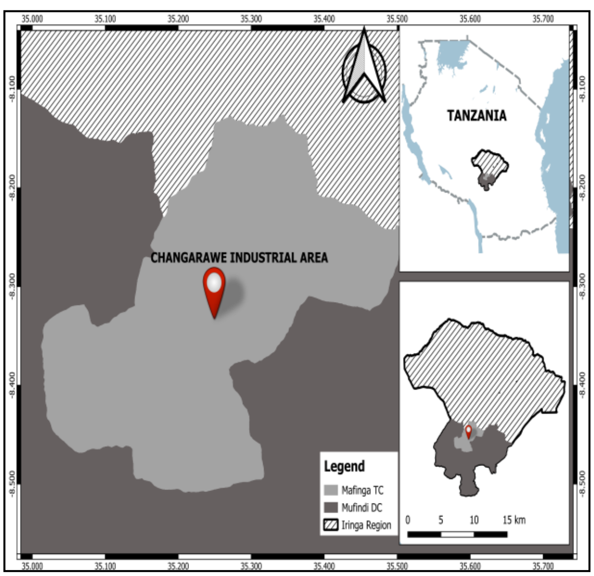
Despite these contributions, the plywood industry faces persistent challenges, particularly in ensuring raw material quality, improving product consistency, adopting modern technologies, and competing in global markets (Tatues, 2023). A notable gap remains in comparative studies of eucalyptus and pine-based plywood, especially in relation to physical properties such as water resistance, density, shrinkage, and swelling. Addressing this gap, the present study evaluates the physical characteristics of plywood produced from these two species to inform improvements in manufacturing, strengthen product quality, and enhance the sector's long-term sustainability and competitiveness.

2.0 Materials and Methods

2.1 Description of the Study Area

This study was conducted in the Iringa and Morogoro regions of Tanzania, focusing on three main sites. Plywood panels were collected from Mufindi District in Iringa (Figure 1), a major hub for wood-based industries supported by both small-scale growers and large forest plantations. Mufindi District, comprising Mufindi District Council and Mafinga Town Council, lies between latitudes 8°0′ and 9°0′ South of the Equator and longitudes 30°0′ and 36°0′ East of Greenwich (Beleko, 2021). It is bordered to the north by Kilolo and Iringa Districts, to the south by Njombe Region, to the east by Morogoro Region, and to the west by Mbeya Region (Mziray *et al.,* 2024). Specimen preparation was conducted at the Vuyisile Mini Furniture Factory, and laboratory analyses were performed at the Wood Science Laboratory of Sokoine University of Agriculture.

Figure 1
Study Area



2.2 Sampling and Experimental Design

This study focused on four physical properties – water resistance, shrinkage, swelling, and density – because these are critical indicators of plywood performance under varying service conditions. For comparative analysis, six plywood panels, three each from eucalyptus and pine, were randomly selected and tested under identical conditions to ensure consistent and reliable data across both material types. The physical properties of the plywood were assessed using a combined qualitative and quantitative approach under controlled laboratory conditions, with temperature maintained at 23 ± 2°C and relative humidity at 65 ± 2%. A total of 48 specimens were then prepared in strict accordance with the EN 636 standard, with samples taken at least 50 mm from the panel edges to avoid edge effects and cut to a uniform size of 50 × 50 mm.

2.3 Data Collection

Accurate measurements were obtained using an electronic balance for mass and a digital vernier calliper for dimensional parameters, following standardised procedures. Data collected included initial and final thickness for swelling evaluation, weights before and after water immersion to determine water absorption, and basic dimensions (length, width, thickness, and mass) for density calculations. Observations also included responses to moisture changes such as swelling, shrinkage, and any signs of delamination.

2.4 Data Analysis

Before the statistical analysis, water absorption, thickness, swelling, shrinkage, swelling, and density were computed according to Islam *et al.* (2012):

$$WA\ (\%) = \frac{M2-M1}{M1}\times 100$$

Where: WA is the water absorption, M1 is the weight of the sample before the test, and M2 is the weight of the sample after the test.

$$TS\ (\%) = \frac{A2-A1}{A1}\times 100$$

Where: TS is the Thickness swelling, A1 is the thickness before the test, and A2 is the thickness (mm) after the test.

$$\text{Shrinkage} = \frac{change\ in\ dimension\ from\ swollen\ size}{swollen\ dimension}\times 100$$

$$\text{Swelling} = \frac{change\ in\ dimension\ from\ dry\ size}{dry\ dimension}\times 100$$

$$D = \frac{M}{V}$$

Where: D is the density, M is the mass, and V is the volume of the plywood sample.

Descriptive statistics, including the mean, standard deviation, standard error, minimum and maximum, were used to analyse the data. The significance of results was tested using an independent sample t-test at (α = 0.05), and all statistical analyses were carried out using JASP statistical software.

3.0 Results and Discussion

3.1 *Water Resistance*

The results of water resistance are presented in Table 1. The results from the independent sample t-test indicated that there is a significant difference (*p<0.05*) in mean water resistance between eucalyptus and pine veneer plywood.

Table 1
Water Resistance of Eucalyptus and Pine Veneered Plywood

Species	Moisture Performance Characteristic	Mean (%)	Standard deviation (%)	Standard error (%)	Maximum (%)	Minimum (%)
Eucalyptus	Water absorption	86.181	4.301	0.785	95.575	77.863
Pine		116.438	14.248	2.601	162.433	95.679

The findings in Table 1 indicate that eucalyptus-veneered plywood demonstrates superior water resistance compared to pine plywood. This is attributed to eucalyptus's denser and more fibrous structure, which restricts moisture penetration and reduces overall water absorption (Azevedo *et al.*, 2020), whereas pine's more open cellular structure facilitates higher uptake and compromises its resistance to moisture (Hacke *et al.*, 2015). Consistent with these results, Islam *et al.* (2012) reported that eucalyptus plywood exhibited a water absorption rate of 36.9%, markedly lower than the 55.54% recorded for pine. Similarly, Esen *et al.* (2022) observed weaker water resistance in pine, further confirming its vulnerability to moisture. More recent investigations by Ranjan *et al.* (2022) and Bednarczuk *et al.* (2024) reinforce this trend, showing that eucalyptus plywood consistently achieves lower water absorption values and stronger resistance than pine and other alternative panel materials. Variations across studies are likely linked to differences in soaking duration and test conditions; in the present study, for instance, specimens were immersed in cold water until full saturation, which occurred after 28 days. Importantly, the results align with the requirements outlined in EN 314-2 and EN 317 standards, which emphasise bond durability and limit excessive thickness swelling and water absorption in plywood and related wood-based panels.

3.2 Shrinkage and Swelling

The results of shrinkage and swelling in three different directions of plywood are presented in Table 2. The results from the independent sample t-test indicate that there is a significant difference (p<0.05) in mean shrinkage and swelling between eucalyptus and pine veneer plywood.

Table 2
Dimensional Stability Properties

Species	Dimensional Stability	Mean (%)	SD (%)	SE (%)	Max (%)	Min (%)
Eucalyptus	Length shrinkage	0.72	0.156	0.028	0.929	0.415
Eucalyptus	Length swelling	1.691	0.25	0.046	1.977	1.065
Eucalyptus	Thickness shrinkage	4.633	0.635	0.116	5.521	3.03
Eucalyptus	Thickness swelling	13.455	3.036	0.554	20.122	8.671
Eucalyptus	Width shrinkage	0.68	0.169	0.031	0.926	0.222
Eucalyptus	Width swelling	2.548	0.4	0.073	3.87	2.065
Pine	Length shrinkage	1.392	0.259	0.047	1.913	1.093

Species	Dimensional Stability	Mean (%)	SD (%)	SE (%)	Max (%)	Min (%)
Pine	Length swelling	2.451	0.401	0.073	3.35	1.773
Pine	Thickness shrinkage	6.678	0.865	0.158	7.935	4.887
Pine	Thickness swelling	18.469	3.478	0.635	25.166	13.291
Pine	Width shrinkage	1.447	0.281	0.051	1.893	1.093
Pine	Width swelling	4.261	0.661	0.121	3.004	3.004

SD – Standard deviation, SE – Standard error, Max – Maximum and Min – Minimum

The findings in Table 2 show that eucalyptus plywood exhibited superior dimensional stability compared to pine plywood, as reflected in its consistently lower shrinkage and swelling across all measured directions. In contrast, pine plywood demonstrated greater dimensional variation, indicating a higher susceptibility to moisture-induced changes.

These results align with those of Bal and Bektap (2014), who reported that eucalyptus plywood exhibits greater resistance to moisture-induced dimensional changes than pine plywood, and are further supported by Zdravković *et al.* (2025), who confirmed this trend in more recent studies.

From a practical perspective, the superior dimensional stability of eucalyptus plywood makes it more suitable for humid or outdoor applications where exposure to moisture is a concern, whereas pine plywood may be less durable under such conditions.

The results also comply with international standards. According to the EN 317 (1993) standard, the maximum allowable thickness swelling for wood-based panels is 12%, which is well above the values observed in this study for both Eucalyptus (1.86%) and Pine (3.34%) plywood. These findings confirm that both species fall within the required limits, though eucalyptus plywood exhibits notably better dimensional performance.

3.3 Density

The results of the dry sample density are presented in Table 3. The results from the independent sample t-test indicate that there is a significant difference (*p<0.05*) in mean dry sample density between eucalyptus and pine veneer plywood.

Table 3

Density of Eucalyptus and Pine Plywood

Descriptive statistics (kg/m^3)	Eucalyptus	Pine
Mean	632.2	569.58
Standard deviation	22.832	37.485
Standard error	4.169	6.844
Maximum	700.212	636.794
Minimum	588.472	494.631

The findings highlight that density is a key factor influencing plywood performance, particularly its dimensional stability and durability. In this study, eucalyptus plywood recorded an average density of 633.2 kg/m^3, whereas pine plywood averaged 569.6 kg/m^3. These values are consistent with previous findings. For example, Islam *et al.* (2012) reported that standard plywood densities typically range between 430 and 794 kg/m^3.

The higher density of eucalyptus plywood can be attributed to eucalyptus's anatomical structure, which includes thicker cell walls and a greater proportion of dense fibres and lignin, resulting in more wood substance per unit volume and fewer void spaces (De Souza *et al.,* 2025). This dense structure confers advantages such as reduced water uptake and enhanced dimensional stability (Mohd Ghani and Lee, 2021). By contrast, pine's lighter and more open cellular structure contributes to its lower density and comparatively reduced dimensional stability (Żmuda and Roman, 2025).

From a practical perspective, plywood manufacturers must therefore carefully consider species selection, balancing the benefits of higher density with potential processing challenges, such as machining and adhesive penetration. The density results also conform to international standards. According to the EN 323 (1993) standard, the acceptable density range for wood-based panels is 400–800 kg/m^3, a range within which both eucalyptus (633.2 kg/m^3) and pine (569.6 kg/m^3) plywood fall.

Similarly, ASTM (2017) specifies a comparable density range of 430–794 kg/m³ for standard plywood. These results confirm that the plywood samples investigated in this study meet internationally recognised density requirements, with Eucalyptus demonstrating superior performance potential due to its higher density.

4.0 Conclusion

This study demonstrated that veneer species significantly influence the physical properties of plywood. Eucalyptus plywood exhibited superior performance over pine in all tested parameters, with notably lower water absorption, thickness swelling, and shrinkage, alongside higher density. These characteristics enhance its dimensional stability and suitability for applications where moisture resistance and durability are critical. The results provide evidence-based guidance for manufacturers and policymakers in selecting raw materials that improve product quality and competitiveness in Tanzania's plywood industry.

5.0 Recommendations

Eucalyptus veneer should be prioritised in plywood manufacturing to enhance moisture resistance, dimensional stability, and durability. Policymakers should support sustainable eucalyptus plantations and establish standards reflecting species-specific performance. Further research is recommended to evaluate long-term field performance and the economic feasibility of scaling Eucalyptus plywood production for industrial applications.

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8.0 Conflict of Interest

The authors declare no conflict of interest.

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