ENGENHARIAS, TECNOLOGIA, GESTÃO E TURISMO
ENGINEERING, TECHNOLOGY, MANAGEMENT AND TOURISM
INGENIERÍA, TECNOLOGÍA, ADMINISTRACIÓN Y TURISMO

millenium

Millenium, 2(Edição Especial Nº23)

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RUGOSIDADE DA SUPERFÍCIE E DUREZA SHORE-D DE SEIS MADEIRAS TROPICAIS
SURFACE ROUGHNESS AND SHORE-D HARDNESS OF SIX TROPICAL HARDWOODS
RUGOSIDAD SUPERFICIAL Y DUREZA SHORE-D DE SEIS MADERAS TROPICALES

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RECEIVED: 29th May, 2025
REVIEWED: 18th March, 2026
ACCEPTED: 25th May, 2026
PUBLISHED: 23rd June, 2026

DOI: https://doi.org/10.29352/mill0223e.41753

RESUMO

Introdução: Este estudo investiga as características da dureza Shore-D e da rugosidade superficial de seis espécies de madeiras tropicais: Canelo (Nectandra spp.), Limbali (Gibertiodendron dewevrei), Difou (Morus mesozygia), Curupay (Anadenanthera macrocarpa), Ebiara (Berlinia bracteosa) e Zwarte kabbes (Diplotropis martiusii), com o intuito de avaliar sua adequação para aplicações de alto desempenho.
Objetivo: Avaliar como o tipo de madeira e o processo de lixagem influenciam as propriedades mecânicas e a qualidade da superfície das madeiras tropicais selecionadas.
Métodos: As amostras foram acondicionadas e submetidas a lixamento com lixas de diferentes granulometrias (80, 100, 120, 150 e 180). Foram avaliados os parâmetros de rugosidade superficial Ra, Rq e Rz, além da dureza Shore-D. Os dados foram analisados estatisticamente por meio de ANOVA e teste de Duncan.
Resultados: A análise estatística revelou que a granulometria da lixa influenciou significativamente a rugosidade superficial ($p < 0{,}001$), sendo que lixas mais finas resultaram em superfícies mais lisas. O tipo de madeira também teve efeito significativo sobre a rugosidade e a dureza. A lixagem apresentou o maior impacto nos parâmetros Ra, Rq e Rz. A madeira Ebiara apresentou a superfície mais lisa, enquanto a Curupay demonstrou a maior dureza (74,65).
Conclusão: A rugosidade superficial é influenciada principalmente pelo grão da lixa, enquanto a dureza é determinada pela espécie da madeira. Os resultados destacam a importância de adaptar os procedimentos de lixagem ao tipo de madeira, com o objetivo de otimizar a qualidade da superfície e o desempenho mecânico em aplicações industriais e decorativas.

Palavras-chave: madeira tropical; rugosidade superficial; dureza Shore-D; lixagem; propriedades do material

ABSTRACT

Introduction: This study investigates the Shore-D hardness and surface roughness characteristics of six tropical wood species: Canelo (Nectandra spp.), Limbali (Gibertiodendron dewevrei), Difou (Morus mesozygia), Curupay (Anadenanthera macrocarpa), Ebiara (Berlinia bracteosa), and Zwarte kabbes (Diplotropis martiusii), aiming to assess their suitability for high-performance applications.
Objective: To evaluate how wood species and sanding processes influence the mechanical properties and surface quality of selected tropical woods.
Methods: Samples were conditioned and sanded using abrasives of different grit sizes (80, 100, 120, 150, and 180). Surface roughness parameters Ra, Rq, and Rz, as well as Shore-D hardness, were measured. Statistical analyses were performed using ANOVA and Duncan's test.
Results: Statistical analysis revealed that abrasive grit size significantly affected surface roughness ($p < 0.001$), with finer grits producing smoother surfaces. Wood species also had a significant effect on both roughness and hardness. Sanding had the greatest influence on Ra, Rq, and Rz parameters. Ebiara exhibited the smoothest surface, while Curupay showed the highest hardness (74.65).
Conclusion: Surface roughness is primarily influenced by sanding grit, whereas hardness is determined by wood species. The results emphasize the importance of tailoring sanding procedures to the wood species in order to optimize surface quality and mechanical performance in industrial and decorative applications.

Keywords: tropical wood; surface roughness; Shore-D hardness; sanding; material properties

RESUMEN

Introducción: Este estudio investiga las características de la dureza Shore-D y la rugosidad superficial de seis especies de maderas tropicales: Canelo (Nectandra spp.), Limbali (Gibertiodendron dewevrei), Difou (Morus mesozygia), Curupay (Anadenanthera macrocarpa), Ebiara (Berlinia bracteosa) y Zwarte kabbes (Diplotropis martiusii), con el objetivo de evaluar su idoneidad para aplicaciones de alto rendimiento.
Objetivo: Evaluar cómo la especie de madera y el proceso de lijado influyen en las propiedades mecánicas y la calidad superficial de las maderas tropicales seleccionadas.
Métodos: Las muestras fueron acondicionadas y lijadas utilizando abrasivos de diferentes granulometrías (80, 100, 120, 150 y 180). Se evaluaron los parámetros de rugosidad superficial Ra, Rq y Rz, así como la dureza Shore-D. Los datos se analizaron estadísticamente mediante ANOVA y la prueba de Duncan.
Resultados: El análisis estadístico reveló que el tamaño del grano del abrasivo influyó significativamente en la rugosidad superficial ($p < 0{,}001$), siendo las lijas más finas las que produjeron superficies más lisas. La especie de madera también tuvo un efecto significativo tanto en la rugosidad como en la dureza. El lijado tuvo el mayor impacto en los parámetros Ra, Rq y Rz. Ebiara presentó la superficie más lisa, mientras que Curupay mostró la mayor dureza (74,65).
Conclusión: La rugosidad superficial está influenciada principalmente por la granulometría del lijado, mientras que la dureza está determinada por la especie de madera. Los resultados destacan la importancia de adaptar los procedimientos de lijado al tipo de madera para optimizar la calidad superficial y el rendimiento mecánico en aplicaciones industriales y decorativas.

Palabras clave: madera tropical; rugosidad de la superfície; dureza Shore-D; lijado, propiedades del material

INTRODUCTION

Among the diverse hardwood species found across tropical regions, several stand out for their unique ecological roles, cultural significance, and potential relevance in international timber trade, including markets like Turkey. Canelo, a name commonly used for various species within the Nectandra genus, originates from Central and South America and is valued for its aromatic wood and traditional medicinal uses. Although not native to Turkey, it is a commonly used wood. Limbali (*Gibertiodendron dewevrei*) comes from the tropical forests of Central and West Africa, where this tree is recognized for its durable timber. Similarly, Difou, known scientifically as *Morus mesozygia*, is another African species, notable for its edible fruit and quality wood. From South America, Curupay (*Anadenanthera macrocarpa*) offers a strikingly hard wood and has historical importance in indigenous traditions, particularly for its psychoactive seeds. Another African species, Ebiara (*Berlinia bracteosa*), is distinguished by its vibrant, rosewood-like appearance and is often used in high-end veneers and furniture, while Zwarte Kabbes, the Dutch name for *Diplotropis martiusii*, is a dense South American hardwood used in construction and occasionally exported under various trade names. While these species are not native to Turkey, their wood or related genera are commonly used in Turkish carpentry and veneer production, reflecting the country's growing role in global trade and interest in diverse timber resources.

Tropical hardwood species exhibit substantial variation in wood density, which is strongly linked to mechanical performance, particularly surface hardness, and is therefore a key trait in evaluating timber quality and structural behavior. In Central African monodominant forests, Limbali has an average wood density of approximately 0.65 g cm^{-3} (Reyes, 1992) and is associated with moderate-to-high mechanical resistance typical of dominant canopy-forming hardwoods. Difou shows higher mechanical performance, with wood density values ranging from 0.65 to 1.05 g cm^{-3}(Carsan et al., 2012). In Neotropical systems, Curupay is characterized by very high wood density, typically around 0.86 g cm^{-3} (Reyes, 1992), which corresponds to very high surface hardness and pronounced resistance to indentation and wear, consistent with its use in heavy structural contexts. Within African timber groups, species marketed as Ebiara generally exhibit medium wood density values of approximately 0.60 g cm^{-3} (Reyes, 1992), corresponding to intermediate hardness and good structural stability under mechanical stress. Similarly, Zwarte kabbes presents moderately high density values between 0.63 and 0.74 g cm^{-3} (Reyes, 1992), consistent with elevated hardness and high resistance to surface deformation in hardwood applications. Nectandra species (Canelo) generally exhibit lower density and correspondingly lower surface hardness relative to the other taxa discussed. Nevertheless, there are very different densities between species. For example, density is about 0.42 g cm^{-3} in *Nectandra antillana*, approximately 0.55 g cm^{-3} in *Nectandra rubra*, and 0.91 g cm^{-3} in *Nectandra rodioei,* reflecting greater variability in material performance across species (Reyes, 1992).

Surface hardness of wood is a critical property in furniture and flooring applications, as it directly impacts durability and wear resistance. Harder woods are better able to withstand dents, scratches, and everyday wear, making them ideal for high-traffic areas and surfaces subject to frequent use. In furniture, high surface hardness ensures longer-lasting aesthetics and structural integrity, while in flooring, it helps maintain a smooth, unmarred surface over time. Choosing wood with appropriate hardness contributes not only to the longevity of the product but also to lower maintenance costs and improved user satisfaction. Shore-D hardness is a widely used method for assessing a material's resistance to indentation, distinguished from other hardness tests by its ability to be applied directly on-site. It has been used not only in standard material testing but also in real-time monitoring of material properties, such as during the processing of silicone rubbers (Zhao et al., 2015). Shore-D hardness incorporates 12 distinct scales tailored to various materials, including elastomers, plastics, gels, and cellular materials. Among these, Shore-A is typically used for softer substances, while Shore-D is suited for harder materials. For wood and wood-based composites, Shore-D is the most appropriate and frequently utilized scale (Karamanoglu & Akyildiz, 2013; Mattos et al., 2015). Although less common, Shore-D hardness testing has also been applied to solid woods. Some examples include studies on alternative fruit tree species for playground use (Sahin & Onay, 2020) and investigations into the durability of various woods for landscaping purposes (Şahin et al., 2020). Additionally, heat-treated woods have been examined for their hardness properties, such as Anatolian black pine, Calabrian pine, sessile oak, and chestnut (Karamanoglu & Akyildiz, 2013), as well as poplar subjected to high-temperature treatment to assess surface performance (Chu et al., 2016).

Surface roughness plays a critical role in both gluing and finishing processes, as it directly affects the surface quality of wood products and the performance of adhesives and coatings. Higher surface roughness typically leads to increased glue consumption, as more adhesive is required to fill surface irregularities and ensure a uniform, continuous bonding layer (Bekhta et al., 2022; Darmawan et al., 2020). Additionally, increased roughness enhances the mechanical interlocking between the coating and the wood substrate, generally improving adhesion strength. This effect was reported for ash wood, while in birch, the correlation between roughness and adhesion was less pronounced (Vitosytė et al., 2012). Furthermore, surface roughness is not only a function of sanding or machining but also of wood anatomy. Roughness tends to be higher perpendicular to the grain, a trend associated with larger pore sizes and lower density in the wood structure (Kang et al., 2023).

Sanding grit size is a critical operational variable in wood processing that directly dictates subsequent coating adhesion, wetting behavior, and overall product durability by altering the material's specific anatomical features. Results presented before showed that wood sanded with P60 grit sandpaper exhibited roughness comparable to sawed wood, and finer-grit sandpaper is needed to decrease roughness(Kilic et al., 2006). Because wood is an anisotropic, heterogeneous material, distinct structures react differently to abrasive forces. In ring-porous hardwoods (e.g., Oak, Ash, Chestnut), coarse grits (P80–P120) aggressively tear into large springwood vessel walls to create microscopic frays that increase mechanical interlocking, whereas fine grits (P180–P240) shear edges cleanly but generate cellular debris that packs open pores, acting as a barrier to liquid penetration (Laskowska et al., 2025). According to wood texture and grain characteristics, the sanding process is strongly influenced. Coarse-grained species, such as oak (Quercus sp.) and ash (Fraxinus sp.), possess larger cells and open pores that can mask sanding scratches, whereas fine-grained species with less visible porosity, including maple (Acer sp.) and ebony (Diospyros sp.), tend to reveal scratches more readily. Conifers and softwoods (e.g., Maritime Pine, Scots Pine) present a different challenge due to the abrupt density differential between earlywood and latewood within the same growth ring as seen in *Betula schmidtii* (Kang et al., 2023) Surface roughness is additionally influenced by the sawing orientation, whether radial or tangential, with studies indicating that radially sawn wood generally exhibits slightly smoother surfaces compared to tangentially sawn wood (Aslan et al., 2008; Vitosytė et al., 2012). In this study, surface roughness and Shore-D hardness values were studied for six commonly used species in Turkey to evaluate their suitability for high-performance applications by assessing how wood species and sanding process influence mechanical properties and surface quality. The comparison between wood species is important because Shore-D hardness and surface roughness are governed by intrinsic wood characteristics, including density, porosity, and anatomical structure. These factors influence both the resistance to indentation and the interaction between the material and abrasive processes. As a result, interspecific comparison provides insight into how different woods respond to machining and finishing, enabling a more informed selection of species for industrial applications.

1. METHODS

1.1 Sample

Canelo (*Nectandra* spp.), Limbali (*Gibertiodendron dewevrei*), Difou (*Morus mesozygia*), Curupay (*Anadenanthera macrocarpa*), Ebiara *(Berlinia bracteosa*), and Zwarte kabbes (*Diplotropis martiusii*) samples were obtained from the Duzce industrial zone, Duzce, Turkey. Species identification was based on supplier information and macroscopic wood characteristics; however, the exact geographical origin of the samples could not be confirmed.

The sample dimensions were 100 mm by 100 mm by 10 mm (longitudinal × tangential × radial) and were conditioned according to ISO 554 (1976) prior to testing. After the conditioning, the wood specimens were sanded with 80, 100, 120, 150, and 180 grinding. Afterwards, samples were cut into 100 mm x 100 mm x 20 mm. Specimens were kept in a conditioned room with 65±3% relative humidity and 20±2°C temperature until constant weight was achieved (ISO 554, 1976).

1.2 Determination of Surface Roughness

Surface roughness measurements were made using in a surface roughness tester JTKY JD520 model (Beijing Jitai Tech Detection Device Co., Ltd., Tongxia Gongyuan, Huilongguan, Beijing, China) (Figure 1C), using an average of 10 measurements taken according to (ISO 16610-21, 2025) standard. The surface roughness measurements were made perpendicular to the fibers, with a sample length of 2.5 mm and a sample length of 5 mm (cut-off).

1.3 Determination of Shore-D Hardness

Shore-D hardness measurements on all wood samples were done according to the (ASDTM D2240 − 15, 2017) standard. An average of 20 measurements was made for each sample. Figure 1 shows the Shore-D hardness device (Shenzhen Omena Technology Co., Ltd., Guangdong, China). A 5 kg load was used as the weight to determine hardness.

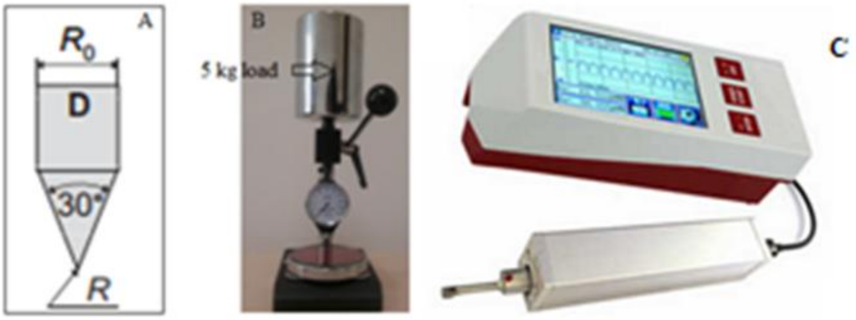

Figure 1 - (A), Shore-D scale Shore-D hardness device (B) and surface roughness (C)

Shore-D hardness ranges from 0 to 100, where 100 corresponds to a spring force of 44.45 N with an indentation depth of up to 2.5 mm (Arndt & Lechner, 2014).

1.4 Sanding Procedure

The surface preparation of the wood samples was carried out through a controlled sanding process using abrasive sandpapers with different grit sizes. Five sandpaper grits were considered: 80, 100, 120, 150, and 180, representing a progression from coarse to fine abrasion. Sanding was performed sequentially, with each grit applied to a new set of samples to evaluate its individual effect on surface roughness. The process was conducted under consistent conditions to ensure comparability, maintaining uniform pressure and sanding time for all specimens. The sanding direction was kept parallel to the wood grain to minimize variability associated with fiber orientation. After sanding, all samples were cleaned to remove dust and loose particles prior to roughness measurements. This approach allowed the assessment of the influence of sandpaper grit size on the surface quality of the different wood species.

1.5 Statistical analysis

SPSS 17 (Sun Microsystems, Inc., Santa Clara, CA, USA) program was used for statistical analysis. Minimum, maximum, standard deviations, homogeneity groups, variation coefficients, and averages of the Shore-D hardness test and surface roughness results were determined. ANOVA and Duncan tests were performed.

2. RESULTS AND DISCUSSION

A two-way ANOVA was done to study the influence of wood species and sand grit on several roughness parameters (Table 1). Overall results revealed that wood species, sandpaper number, and their interaction significantly affected the surface roughness parameters (Ra, Rq, and Rz) at the 95% confidence level ($p < 0.05$). Among the factors, sandpaper number exhibited the greatest influence according to F-values. In the case of Ra (arithmetic average roughness), wood species, sandpaper number, and their interaction all had significant effects. However, the sandpaper number had by far the largest influence, as evidenced by the highest F-value (3326.457), suggesting that the surface texture is primarily determined by the grit size of the sandpaper used. The interaction between wood species and sandpaper was also significant, though much less influential compared to the main effects. This means that the same sandpaper grit does not produce identical roughness on all wood species. Optimal sanding conditions depend on the wood species. For Rq (root mean square roughness), the results followed a similar pattern. All effects were highly significant, with sandpaper number again playing the most dominant role (F = 2297.145). Although wood species and the interaction between factors also contributed to variation in Rq, their effects were smaller in magnitude. Regarding Rz (average maximum height of the profile), the sandpaper number remained the most significant factor, followed by wood species. The interaction effect, while statistically significant, had a relatively smaller impact. This pattern reinforces the conclusion that surface roughness is mostly governed by the abrasive properties of the sandpaper rather than the wood species itself.

In summary, the analysis reveals that sandpaper number is the most influential factor on surface roughness parameters, while wood species plays a secondary role. The significant interaction effects indicate that the influence of sanding varies depending on the wood species, highlighting the importance of tailoring sanding processes to specific materials for optimal surface quality.

Table 1 - Two-way ANOVA results for effects of wood species, sandpaper number, and their interaction on the surface roughness parameters (Ra, Rq, and Rz)

Test	Source	Sum of Squares	DF	Mean Square	F	Sig.
R_a	Wood species (A)	60.927	5	12.185	179.228	0.000*
	Sandpaper number (B)	904.648	4	226.162	3326.457	0.000*
	İnteraction (AB)	23.882	20	1.194	17.564	0.000*
	Error	18.357	270	0.068		
	Total	8777.557	300			
R_q	Wood species (A)	90.495	5	18.099	113.717	0.000*
	Sandpaper number (B)	1462.436	4	365.609	2297.145	0.000*
	İnteraction (AB)	52.477	20	2.624	16.486	0.000*
	Error	42.973	270	0.159		
	Total	15582.097	300			
R_z	Wood species (A)	4485.298	5	897.060	149.688	0.000*
	Sandpaper number (B)	31226.732	4	7806.683	1302.664	0.000*
	İnteraction (AB)	1843.343	20	92.167	15.379	0.000*
	Error	1618.073	270	5.993		
	Total	456084.485	300			

*: Significant

The two factors do not act independently, and their combined influence must be considered to fully understand the results. Ignoring the interaction could lead to misleading conclusions has mentioned before (Esteves et al., 2022). Therefore, following the significant interaction observed in the two-way ANOVA, separate one-way ANOVA analyses were conducted for each wood species to evaluate the effect of sandpaper number on the surface roughness parameters (Table 2). The results demonstrated that sandpaper number significantly affected Ra, Rq, and Rz values for all investigated wood species ($p < 0.001$). Extremely high F-values were obtained across all roughness parameters, indicating that sanding grit had a strong influence on surface quality regardless of wood species. For example, in Canelo, the F-values reached 814.210, 430.324, and 190.390 for Ra, Rq, and Rz, respectively, while Zwarte kabbes exhibited particularly high sensitivity in Ra with an F-value of 930.369. Similarly, Ebiara showed very strong grit-dependent variations, especially for Rz (F = 478.590). These one-way ANOVA results provide additional information beyond the two-way ANOVA by clarifying how sandpaper number individually influences each wood species. While the two-way ANOVA established the presence of a significant interaction between wood type and sandpaper number, the species-specific analyses reveal the magnitude of this effect within each wood separately, demonstrating that the response to sanding conditions differs among species in terms of sensitivity and roughness variation.

For Shore-D hardness, only the effect of wood species was examined (Table 2). The results show a highly significant impact of wood species on hardness values (F = 84.642, p < 0.001). This is consistent with the understanding that Shore-D hardness is an intrinsic property of the material and is not affected by surface treatment like sanding.

Table 2 - One-way ANOVA results for the effects of sandpaper number on the surface roughness and wood species on Shore-D hardness

Wood Species	Test	Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	*: Significant
Canelo (*Nectandra spp.*)	R_a	Sandpaper number	200.288	4	50.072	814.210	0.000**
		Error	2.767	45	0.061		
		Total	1795.138	50			
		Corrected total	203.055	49			
	R_q	Sandpaper number	353.854	4	88.464	430.324	0.000*
		Error	9.251	45	0.206		
		Total	3208.430	50			
		Corrected total	363.105	49			
	R_z	Sandpaper number	9497.627	4	2374.407	190.390	0.000*
		Error	561.208	45	12.471		
		Total	100161.422	50			
		Corrected total	10058.835	49			
Limbali (*Gibertiodendron dewevrei*)	R_a	Sandpaper number	195.130	4	48.782	644.139	0.000*
		Error	3.408	45	0.076		
		Total	1423.435	50			
		Corrected total	198.538	49			
	R_q	Sandpaper number	343.912	4	85.978	566.003	0.000*
		Error	6.836	45	0.152		
		Total	2588.352	50			
		Corrected total	350.748	49			
	R_z	Sandpaper number	7790.113	4	1947.528	322.000	0.000*
		Error	272.170	45	6.048		
		Total	76837.973	50			
		Corrected total	8062.283	49			
Difou (*Morus mesozygia*)	R_a	Sandpaper number	164.335	4	41.084	308.721	0.000*
		Error	5.988	45	0.133		
		Total	1741.103	50			
		Corrected total	170.324	49			
	R_q	Sandpaper number	258.072	4	64.518	182.707	0.000*
		Error	15.891	45	0.353		
		Total	2936.113	50			
		Corrected total	273.963	49			
	R_z	Sandpaper number	4275.273	4	1068.818	194.239	0.000*
		Error	247.616	45	5.503		
		Total	79309.588	50			
		Corrected total	4522.890	49			
Curupay (*Anadenanthera macrocarpa*)	R_a	Sandpaper number	168.187	4	42.047	544.317	0.000*
		Error	3.476	45	0.077		
		Total	1551.374	50			
		Corrected total	171.663	49			
	R_q	Sandpaper number	238.969	4	59.742	594.444	0.000*
		Error	4.523	45	0.101		
		Total	2743.628	50			
		Corrected total	243.492	49			
	R_z	Sandpaper number	5014.447	4	1253.612	231.564	0.000*
		Error	243.616	45	5.414		
		Total	83236.596	50			
		Corrected total	5258.062	49			
Ebiara (*Berlinia bracteosa*)	R_a	Sandpaper number	113.539	4	28.385	767.427	0.000*
		Error	1.664	45	0.037		
		Total	1135.594	50			
		Corrected total	115.203	49			
	R_q	Sandpaper number	204.353	4	51.088	889.503	0.000*
		Error	2.585	45	0.057		
		Total	1984.197	50			
		Corrected total	206.937	49			
	R_z	Sandpaper number	4303.274	4	1075.818	478.590	0.000*
		Error	101.155	45	2.248		
		Total	49065.111	50			
		Corrected total	4404.429	49			

Wood Species	Test	Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	*: Significant
Zwarte kabbes (*Diplotropis martiusii*)	R_a	Sandpaper number	87.052	4	21.763	930.369	0.000*
		Error	1.053	45	0.023		
		Total	1130.915	50			
		Corrected total	88.104	49			
	R_q	Sandpaper number	115.752	4	28.938	334.892	0.000*
		Error	3.888	45	0.086		
		Total	2121.377	50			
		Corrected total	119.640	49			
	R_z	Sandpaper number	2189.342	4	547.336	128.076	0.000*
		Error	192.308	45	4.274		
		Total	67473.795	50			
		Corrected total	2381.650	49			
Shore-D		Wood species	1798.267	5	359.653	84.642	0.000*
		Error	484.400	114	4.249		
		Total	584696.000	120			

Table 3 presents the Shore-D hardness values for the six-wood species studied, with measurements taken from 20 samples of each species. The results show that Curupay exhibited the highest mean Shore-D hardness at 74.65, followed by Zwarte kabbes at 72.70 and Canelo at 71.65. Difou and Limbali showed intermediate values of 69.35 and 66.40, respectively, while Ebiara demonstrated the lowest hardness among the group, with a mean value of 63.25. Overall, the hardness results broadly align with the expected positive relationship between wood density and surface hardness, but with some notable deviations that are important to interpret. The strongest consistency appears in Curupay, which shows the highest mean Shore-D hardness (74.65). This matches well with its characterization as a very high-density hardwood (0.86 g cm^{-3})(Reyes, 1992). High density typically reflects a greater proportion of cell wall material per unit volume, which directly increases resistance to indentation, so this result reinforces the expected density–hardness relationship. Similarly, Zwarte kabbes shows both moderately high density (0.63–0.74 g cm^{-3}) and high hardness (72.70)(Reyes, 1992), again supporting the general trend that denser woods tend to be harder and more resistant to surface deformation. Difou and Limbali fall into the expected intermediate range, with hardness values of 69.35 and 66.40, respectively, consistent with their moderate-to-high density classification and typical canopy hardwood behavior (Carsan et al., 2012; Reyes, 1992). In relation to Canelo (Nectandra spp.), it exhibits a relatively high hardness (71.65), but the strong interspecific variability of density within the genus limits broader conclusions. Finally, Ebiara shows the lowest hardness (63.25), which is somewhat consistent with its medium density (~0.60 g cm^{-3})(Reyes, 1992), but it appears slightly lower than expected relative to Limbali and Difou. This could indicate greater cellular porosity or less stiff fiber architecture, reducing resistance to indentation despite similar mass per unit volume. In summary, the results confirm a general positive density–hardness relationship, especially evident in Curupay and Zwarte kabbes, but also highlight meaningful species-specific deviations that suggest mechanical performance in tropical hardwoods is governed by a combination of density and microstructural/anatomical traits rather than density alone. The coefficients of variation (COV) ranged from 2.05% to 3.60%, indicating consistent and reliable measurements within each wood species. The homogeneity grouping (HG) analysis confirmed significant statistical differences between species, categorizing Curupay alone in group A*, Ebiara in group E**, and the remaining species across intermediate groups. When these findings are compared with the Shore-D hardness values reported in previous studies, it becomes clear that all six wood species in the current study exhibit notably higher hardness compared to many commonly studied species. Earlier research identified Limba wood as the softest among untreated woods with a Shore-D value of 35.3, while Santos wood had the highest value at 77.2 (Esteves et al., 2021). Several other species reported in the literature fall well below the values observed in the present study. For instance, Ayous wood (*Triplochiton scleroxylon*) had a Shore-D hardness of 37.6 (Ayata, 2020), Simul wood (*Salmalia malabarica*) 40.0 (Devi & Maji, 2012), Loblolly pine (*Pinus taeda*) 42.6 (Mattos et al., 2015), 45.6 for Spruce (Perçin et al., 2024), Poplar (*Populus tomentosa*) 46.4 (Yan et al., 2015) , 49.1 for Fir and 49.6 for Scotch pine (Perçin et al., 2024). Even Chestnut (*Castanea sativa*), a relatively harder species, had a reported Shore-D hardness of only 64.1 (Karamanoglu & Akyildiz, 2013), making it comparable only to the softest species in the current study, Ebiara. These comparisons indicate that the woods examined in this study possess excellent resistance to surface indentation, with Curupay approaching the hardness levels of Santos wood. Zwarte kabbes and Canelo also showed high values, suggesting strong performance in terms of durability and surface resilience. The statistical differences reflected in the homogeneity groups further support the distinction between these species in terms of mechanical behavior.

Table 3 - Shore-D hardness results

Wood Species	N	Mean	*HG*	Std. Deviation	Minimum	Maximum	COV
Canelo (*Nectandra spp.*)	20	71.65	B	2.58	69.00	76.00	3.60
Limbali (*Gibertiodendron dewevrei*)	20	66.40	D	2.21	63.00	69.00	3.33
Difou (*Morus mesozygia*)	20	69.35	C	1.42	67.00	71.00	2.05
Curupay (*Anadenanthera macrocarpa*)	20	74.65	A*	2.06	72.00	77.00	2.76
Ebiara (*Berlinia bracteosa*)	20	63.25	E**	1.89	60.00	66.00	2.99
Zwarte kabbes (*Diplotropis martiusii*)	20	72.70	B	2.03	69.00	75.00	2.79

N: Number of Measurements. HG: Homogeneity Group. COV: Coefficient of Variation.

*: Highest Value. **: Lowest Value.

Table 4 presents the surface roughness values for the six wood species sanded with grit numbers 80, 100, 120, 150, and 180. The roughness parameters measured include Ra, Rq, and Rz, which are critical indicators of surface texture. Ra (arithmetical mean roughness) represents the average deviation of surface peaks and valleys from the mean line, offering a general measure of surface smoothness. Rq (root mean square roughness) is the square root of the average of the squared deviations and is more sensitive to larger deviations than Ra. Rz (maximum height of the roughness profile) measures the average height difference between the five highest peaks and five deepest valleys over the evaluation length, providing a sense of extreme surface variations. All species showed the same general trend: increasing sandpaper grit reduced Ra, Rq, and Rz values, resulting in smoother surfaces. Canelo had the highest initial roughness (Ra = 8.677 µm at grit 80) but decreased markedly to 2.885 µm at grit 180, with similar reductions in Rq and Rz. Limbali also showed great improvement, with Ra decreasing from 7.921 µm to 2.504 µm and relatively low Rz values, indicating a smooth and uniform finish. Difou followed the same pattern, although its final roughness values remained slightly higher than Limbali and Ebiara, suggesting more residual texture. Curupay exhibited a steady reduction in all parameters, demonstrating a good response to progressive sanding. Ebiara produced the smoothest surfaces overall, reaching the lowest final values for both Ra (2.417 µm) and Rz (15.499 µm), highlighting its strong finishing potential. Zwarte kabbes also showed consistent improvement, though its final Rz remained slightly higher than Ebiara, indicating somewhat greater peak-to-valley variation despite good surface uniformity.

At the 180-grit sandpaper level, the Ra values varied among the six wood-species tested, reflecting how each responds to fine sanding based on its anatomical and physical characteristics. Difou showed the highest Ra value at 3.194 µm while Canelo and Curupay followed with Ra values of 2.885 µm and 2.812 µm, respectively. On the other end, Ebiara exhibited the lowest Ra value at 2.417 µm, achieving the smoothest surface among the tested species. These results are somewhat lower than the findings reported by Yu et al. (2023), where *Pinus radiata* showed the highest roughness at 180 grit with an Ra value of 4.620 µm, while Camphor had the lowest at 3.330 µm, emphasizing the influence of species-specific factors like density and fiber structure. Bekhta et al. (2022) also reported higher roughness values for Black Alder (6.74 µm) and Birch (5.29 µm) using the same 180-grit sanding. Adamčík et al. (2025) used 100-grit sandpaper to determine the surface roughness of Cedar (8.39 µm), Beech (9.63 µm), Pine (8.32 µm), Chestnut (9.96 µm), and Oak (11.81 µm), all of which exhibited generally higher roughness values compared to those obtained in the present study using similar sandpaper.

Table 4 - Results for surface roughness parameters (Ra, Rz ve Rq) (µm)

Wood Species	**Sandpaper Number**	**N**	**Ra**				**Rq**				**Rz**			
			Mean	**HG**	**SD**	**COV**	**Mean**	**HG**	**SD**	**COV**	**Mean**	**HG**	**SD**	**COV**
Canelo (*Nectandra spp.*)	80	10	8.677	A*	0.35	3.98	11.501	A*	0.43	3.73	62.520	A*	4.10	6.55
	100	10	6.866	B	0.24	3.55	9.226	B	0.40	4.35	51.763	B	3.80	7.34
	120	10	5.442	C	0.26	4.82	7.384	C	0.60	8.10	42.143	C	3.43	8.13
	150	10	4.345	D	0.21	4.86	5.767	D	0.48	8.25	32.243	D	3.48	10.78
	180	10	2.885	E**	0.13	4.34	3.840	E**	0.31	8.19	23.584	E**	2.71	11.47
Limbali (*Gibertiodendron dewevrei*)	80	10	7.921	A*	0.22	2.80	10.687	A*	0.40	3.76	56.175	A*	1.27	2.26
	100	10	6.292	B	0.15	2.39	8.388	B	0.43	5.11	44.674	B	2.69	6.03
	120	10	4.777	C	0.51	10.70	6.429	C	0.53	8.19	36.438	C	3.77	10.36
	150	10	3.255	D	0.20	6.04	4.560	D	0.34	7.40	27.090	D	2.16	7.96
	180	10	2.504	E**	0.08	3.27	3.384	E**	0.15	4.52	21.064	E**	1.57	7.47
Difou (*Morus mesozygia*)	80	10	8.341	A*	0.18	2.15	10.769	A*	0.64	5.91	53.180	A*	3.29	6.18
	100	10	6.818	B	0.64	9.38	8.721	B	0.85	9.78	43.209	B	2.25	5.22
	120	10	5.324	C	0.28	5.25	7.006	C	0.36	5.19	38.585	C	1.70	4.40
	150	10	4.348	D	0.25	5.86	5.712	D	0.27	4.65	32.120	D	1.94	6.03
	180	10	3.194	E**	0.28	8.91	4.276	E**	0.66	15.34	26.281	E**	2.24	8.50
Curupay (*Anadenanthera macrocarpa*)	80	10	7.961	A*	0.36	4.50	10.321	A*	0.28	2.71	53.926	A*	2.73	5.06
	100	10	6.462	B	0.30	4.70	8.466	B	0.49	5.74	46.260	B	2.76	5.98
	120	10	5.216	C	0.13	2.48	6.955	C	0.14	1.99	38.765	C	0.99	2.55
	150	10	3.815	D	0.29	7.73	5.556	D	0.25	4.54	33.561	D	2.19	6.51
	180	10	2.812	E**	0.25	8.87	4.058	E**	0.32	7.97	24.945	E**	2.49	10.00
Ebiara (*Berlinia bracteosa*)	80	10	6.536	A*	0.23	3.49	8.622	A*	0.26	3.02	42.883	A*	1.05	2.45
	100	10	5.658	B	0.19	3.38	7.548	B	0.13	1.68	35.736	B	1.56	4.35
	120	10	4.698	C	0.06	1.24	6.134	C	0.15	2.40	29.921	C	0.71	2.37
	150	10	3.278	D	0.09	2.62	4.481	D	0.26	5.69	25.394	D	1.92	7.57
	180	10	2.417	E**	0.29	12.10	3.026	E**	0.34	11.28	15.499	E**	1.87	12.09
Zwarte kabbes (*Diplotropis martiusii*)	80	10	6.636	A*	0.11	1.63	8.674	A*	0.21	2.38	44.911	A*	2.29	5.10
	100	10	5.231	B	0.13	2.42	6.982	B	0.35	5.08	40.779	B	2.11	5.17
	120	10	4.418	C	0.23	5.10	6.431	C	0.33	5.11	37.205	C	2.53	6.80
	150	10	3.834	D	0.14	3.77	5.412	D	0.34	6.32	31.024	D	2.12	6.82
	180	10	2.716	E**	0.13	4.87	4.138	E**	0.20	4.74	26.487	E**	0.90	3.41

N: Number of Measurements. *SD*: Standard Deviation, *HG*: Homogeneity Group.
COV: Coefficient of Variation, *: Highest Value. **: Lowest Value.

Overall, Ra, Rq, and Rz values across all species demonstrated predictable behavior: smoother surfaces were achieved with finer sandpaper. Canelo and Difou tended to have the roughest initial textures, while Ebiara showed the smoothest final finishes. These differences are statistically supported by homogeneity grouping and coefficients of variation, confirming that wood species and sanding level significantly influence surface roughness. Understanding the behavior of these roughness parameters is vital for applications requiring specific tactile or visual surface qualities, such as in furniture making, flooring, or high-end interior wood products.

CONCLUSION

This study demonstrates that both the standing process and wood species significantly influence surface roughness and Shore-D hardness, two critical properties for determining the quality and performance of wood in various applications. The results clearly indicate that sandpaper grit size is the dominant factor affecting surface roughness parameters (Ra, Rq, and Rz), with finer grits consistently producing smoother surfaces across all species. Among the woods studied, Ebiara achieved the lowest roughness values, making it highly suitable for applications requiring fine finishes, such as high-end furniture or interior paneling. Shore-D hardness, on the other hand, was primarily influenced by wood species, with Curupay showing the highest hardness, followed by Zwarte kabbes and Canelo. These species are better suited for use in load-bearing or wear-resistant applications where high mechanical durability is essential. The significant interaction between sandpaper grit and wood species indicates that the effectiveness of surface preparation varies by species, emphasizing the need for material-specific processing techniques. The results generally support a positive relationship between wood density and surface hardness among the studied tropical hardwoods, although species-specific anatomical variability, particularly within Canelo, may influence mechanical performance beyond density alone. Understanding how different tropical wood species respond to sanding and how their inherent hardness compares with previously studied materials provides valuable insights for manufacturers, designers, and material scientists. These findings support the strategic selection of wood species and surface treatments in industries where aesthetics, durability, and tactile qualities are predominant. Overall, the results contribute to more efficient, targeted utilization of tropical woods in both structural and decorative applications.

ACKNOWLEDGEMENTS

This research was funded by National Funds through the FCT - Foundation for Science and Technology, I.P., through CERNAS-IPV Research Centre under the project UIDB/00681/2020. Furthermore, we would like to thank the CERNAS Centre and the Polytechnic Institute of Viseu for their support.

AUTHORS' CONTRIBUTION

Conceptualization, U.A. and B.E.; data curation, U.A. and B.E.; formal analysis, U.A.; funding acquisition, U.A., B.E., I.D., J.F. and L.C-L.; investigation, U.A. and B.E.; methodology, U.A., B.E., I.D., J.F. and L.C-L.; writing – original draft, U.A. and B.E.; writing – review & editing, U.A. and B.E.

CONFLICT OF INTEREST

The authors declare no conflict of interests.

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