LES/WOOD Vol. 73, No. 1, 55-68
DOI: https://doi.org/10.26614/les-wood.2024.v73n01a05

PHYSICAL AND MECHANICAL PROPERTIES OF WOOD OF PLANTATION GROWN *Albizia lebbeck* IN THE SAVANNAH ECOLOGICAL ZONE, GHANA

FIZIKALNE IN MEHANSKE LASTNOSTI LESA VRSTE *Albizia lebbeck* S PLANTAŽ V GANI

Enoch Gbapenuo Tampori[1*], Francis Kofi Bih[2], Kwaku Antwi[2], Issah Chakurah[2]

UDK članka: UDK 630*812:630*176.1 *Albizia lebbeck*
Original scientific article / Izvirni znanstveni članek
Received / Prispelo: 18.1.2024
Accepted / Sprejeto: 14.5.2024

Abstract / Izvleček

Abstract: The increasing scarcity of major commercial tropical hardwood species has necessitated the utilization of plantation grown exotic timber species as a potential means of maintaining Ghana's foundation of timber resources. To better consider *Albizia lebbeck* as a substitute for wood species which are being seriously over-exploited to the point of commercial extinction, its wood properties were characterized to expatiate its utilization potentials. Three mature plantation grown *Albizia lebbeck* trees with diameters 45-50 cm at breast height were purposively selected and sampled at four stem height levels of tree height. The samples were sawn into the required sizes in accordance with the British standard, BS 373 (1957) for testing. The heartwood and sapwood proportions were evaluated and the samples were examined for hardness, bending strength (MOE and MOR), compression strength parallel to grain, shear strength parallel to grain, and air-dry density. All trees had a significantly higher heartwood than sapwood percentage. The air-dry density values at 12% MC were 868 kg/m³, 806 kg/m³, 695 kg/m³ and 564 kg/m³ for four sections of the stem (heights 0-25%, 26-50%, 51-75% and 76-100%). In general, the plantation grown *Albizia lebbeck* exhibited favourable strength values, suggesting that it is endowed with adequate properties for being an alternative species to supply the wood industry.

Keywords: *Albizia lebbeck*, lesser-known timber species, plantation, heartwood, sapwood, wood density, modulus of rupture, modulus of elasticity

Izvleček: Zaradi naraščajočega pomanjkanja lesa tradicionalnih tropskih listavcev morajo v Gani vse bolj uporabljati les eksotičnih lesnih vrst. Ta prihaja s plantaž, kar pripomore tudi k ohranjanju tradicionalnih gozdnih virov. Cilj prispevka je raziskati lastnosti lesa vrste *Albizia lebbeck* in odgovoriti, ali bi les lahko uporabili kot nadomestek za nekatere tradicionalne lesne vrste. V ta namen so bila izbrana tri odrasla drevesa *Albizia lebbeck* s premerom 45–50 cm v prsni višini, vzorce lesa pa so odvzeli na štirih nivojih debla. Vzorci so bili razžagani na zahtevane dimenzije v skladu z britanskim standardom BS 373 (1957). Ocenjen je bil delež jedrovine in beljave, nato pa je bila raziskana trdota, upogibna, tlačna in strižna trdnost ter gostota zračno suhega lesa. Pri vseh drevesih je bil delež jedrovine znatno višji od deleža beljave. Vrednosti gostote na štirih nivojih po višini debla (0–25 %, 26–50 %, 51–75 % in 76–100 % višine) pa so bile 868 kg/m³, 806 kg/m³, 695 kg/m³ in 564 kg/m³. Na splošno so bile trdnostne lastnosti lesa vrste *Albizia lebbeck* s plantaže ugodne, kar nakazuje, da ima les primerne lastnosti, da bi ga lahko uporabili za potrebe lesne industrije in za širšo uporabo.

Ključne besede: *Albizia lebbeck*, manj znane lesne vrste, plantaže, jedrovina, beljava, gostota lesa, upogibna trdnost, modul elastičnosti

1 INTRODUCTION
1 UVOD

Due to unsustainable forest extraction, high-value hardwoods continue to become scarcer worldwide. The high level of global deforestation has several complicated and insufficiently un-

[1] Tamale Technical University, Department of Wood Technology, Tamale, Ghana
[2] Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Department of Wood Science and Technology Education, Kumasi, Ghana
* e-mail: enochgbapenuo@tatu.edu.gh

derstood immediate consequences (Anon, 2012; Opuni-Frimpong et al., 2017; Owoyemi et al., 2017). It is known that the indiscriminate exploitation of forests, large-scale destruction of tree habitats, and adverse effects on populations are among the factors which have caused a number of timber species to disappear from forests (Amoah et al., 2015). Over reliance on the traditional timber species in Ghana has also led to their extinction in forests (Amoah et al., 2012). This has therefore put pressure on Ghana's forests, which are limited in extent with a total land area of about 239,000 km² and a general deforestation rate pegged at 65,000 hectares per annum (Husseini et al., 2020). The forest cover of Ghana is about 0.96 million hectares (42%) of the land area, out of which open forests cover about 0.8 million hectares, while closed forests cover 0.16 million hectares (Ghana Statistical Service, 2021). As such, the timber species such as Khaya spp. (mahogany), *Milicia excelsa* (iroko, odum), *Entandrophragma cylindricum* (sapelli, sapale), *Nesogordonia papaverifera* (kotibe, danta), *Terminalia superba* (limba, afram), and *Turreathus africanus* (avodire) for which Ghana is known in the international markets are becoming very scarce (Ntiamoa-Baidu et al., 2001).

Establishing plantations has been implemented to lessen the over exploitation of commercial timber species and help to restore degraded areas in Ghana (Agyeman et al., 2010). Both afforestation and plantation programmes utilizing plantation wood species have attracted a lot of attention, with the aim of balancing the current tropical timber markets and reducing the excessive utilization of the forests, (Bosu et al., 2006). The creation of plantation forests by planting exotic timber species would have numerous advantages, such as substituting natural forests for timber supply, restoring landscapes that have been damaged by deforestation, and offering ecological benefits, like sequestering carbon dioxide to lessen global warming (Onilude et al., 2020). As a result, it is acknowledged that forest plantations are important for their conservation value, for restoring areas that have been damaged, and for easing the burden of extraction on currently existing forests. As a result of all this, plantation forests are now widely regarded as a component of the conservation triangle, which also includes high-yielding plantations, regulated wild forests, and ecological reserves. In tropical Africa, exotic timber species which are not native in Ghana are mostly cultivated as part of agroforestry initiatives aimed at minimizing soil erosion, managing runoff to prevent desertification, and restoring severely damaged areas (Ogunwusi, 2002). Additionally, they aid in the manufacture of sawn timber, firewood, and, occasionally, pulp and paper (Hooper et al., 2005).

Since lumber is one of Ghana's most easily accessible resources, forest plantations have been of interest since the 1920s (Foli et al., 2009; Odoom, 2002). At the time, planting mostly native species in the high forest zone (HFZ) was the typical practice. The few exotic species that were grown in the HFZ were primarily brought in for mining purposes, as well as to provide fuelwood for boilers used to generate electricity and near densely populated areas (Nichols et al., 2006). Starting from 1951, a lot of exotic species were planted in the Savannah Zone (SZ) and Dry Semi-Deciduous Forest Zone (DFSZ) in order to offer fuelwood, poles, and lumber alternatives (Amoah et al., 2012; FAO, 2002). Consequently, plantations of hardwoods in the SZ's northern region are projected to span 2.553 hectares and are mainly used for the generation of fuelwood and the preservation of the environment (Odoom, 2002). The nation's natural forest is one of its many abundant resources (Opuni-Frimpong et al., 2004; Nichols et al., 2006), and it provided the nation's distinct climate and environmental conditions up until their recent overexploitation.

The increasing market demand for tropical hardwoods both locally and internationally is overwhelming. As such, the amount of wood that may be supplied for the lumber industry without endangering the forests exceeds the maximum capacity of Ghanaian sawmills (Appiah, 2003; Hooper et al., 2005). It is therefore imperative that the planting and use of plantation grown exotic timber species should be adopted on a large scale, if it is intended to replenish the depleting forest resources and as well as reduce the urgent demands on the remaining known species in the forest. As such, the current thinking is that industry players in the wood sector must consider the commercial value of the lesser used exotic species to minimize the high dependence on the commercial timber species. This is possible by obtaining the full utilization of the lesser-known timber species to substitute for the limited known tropical hardwoods that remain in the forest, and which are gradually becoming extinct.

The main motives for encouraging forest plantations in the nation are to lessen the strain on the natural forests while adding to their conservation, as well as making sure the nation can satisfy the demand for forest products from its expanding population (Oteng-Amoako, 2006). As such, Ghana's forest plantation initiatives have long been biased toward the establishment of exotic monoculture plantations (Opuni-Frimpong et al., 2008). Indeed, some two decades ago Odoom (2002) asserted that the majority of plantations now in existence in tropical nations, including Ghana, were dominated by exotic species plantations. The inclination towards foreign timber species may stem mostly from their rapid growth and relative lack of pests and diseases, as well as better fire resistance, than the numerous native species (Bobby et al., 2012). Furthermore, a greater variety of options are provided by foreign species because their silviculture is typically better understood than that of native species. Exotic timber species are thus the preferred planting stock, owing to their rapid growth and immediate economic return (Berger, 2006). It has therefore been proposed that the harvesting of abundant but lesser-known/used plantation grown exotic timber species needs to be gradually encouraged and increased in the country. Accordingly, plantation grown exotic species represent over 45% of the existing plantations in Ghana (Nanaag, 2012). Moreover, there are over 500 lesser-known species of timber size in the forests of Ghana which have never been used commercially (Oteng-Amoako, 2006). However, since the properties of plantation timbers are different from those of naturally grown ones, there is a need to investigate their properties and variability (Gorišek et al., 2018), as the present lack of reliable information makes predictions about their structural application hazardous and liable to gross errors. To address this gap in knowledge, the aim of this study is to assess selected physical and mechanical properties of a plantation grown *Albizia lebbeck* (L.) Benth, from the Savannah ecological zone from the Tamale fuel wood plantation reserve which lies between latitudes 9° 16 and 9° 34 north and longitudes 0° 36 and 0° 57 west in Ghana.

Albizia lebbeck, belongs to the family Fabaceae. It is a fast growing medium-sized, multipurpose deciduous tree species with a spreading umbrella-shaped crown of thin foliage and finely fissured, greyish-brown bark. On good sites, it can attain an average maximum height of about 18 to 30 m, and 50 to 80 cm diameter at breast height. The tree grows best on moist, and well-drained soils (Tiwari et al., 2020). The fragrant, cream-colored flowers develop on lateral stalks in rounded clusters about 5 to 7.5 cm across the many threadlike, spreading, whitish-to-yellow stamens tipped with light green, borne at the ends of lateral stalks 4 to 10 cm long. The fruits, flattened pods 10 to 20 cm long and 2.5 to 3.8 cm broad, are produced in large numbers and each contains several seeds. Immature pods are green, turning straw-colored on maturity, usually 6 to 8 months after flowering. Seeds are small, oblong, approximately 9 by 7 mm long and broad, compressed, and light brown in color. The leaves, seeds, bark and roots are all used for traditional medicine (Balkrishna et al., 2022). It was introduced as an ornamental and plantation tree throughout the tropics and northern subtropics (Inside Wood, 2024).

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 SAMPLE PREPARATION
2.1 PRIPRAVA VZORCEV

Three (3) mature plantation grown *Albizia lebbeck* trees were purposively sampled from the Savannah ecological zone from the Tamale plantation reserve in Ghana. The age of the plantation *Albizia lebbeck* trees was about 45 years. Trees with similar diameters (45-50 cm) at breast height (1.3 m from the ground level) were felled and the merchantable length of the clear bole of each tree was measured and divided into four parts of the same size (0-25%, 26-50%, 51-75% and 76-100%). A stem sectional disc approximately 7.5 cm in thickness was cut at each end of the divided sections for the determination of the heartwood and sapwood proportions, and air-dry density at 12% moisture content.

An experimental study in the laboratory was employed to test the material properties. The wood specimens were prepared at the Tamale Technical University Wood Technology Workshop and every

Figure 1. *Albizia lebbeck* trees used for the study from Savannah ecological zone of Ghana.
Slika 1. Drevesa vrste *Albizia lebbeck*, uporabljena za študijo, z ekološkega območja Savannah v Gani.

test was conducted at the Council for Scientific and Industrial Research's (CSIR) of the Forestry Research Institute of Ghana (FORIG) at the Timber Mechanics and Engineering Laboratory. The specimens have been produced following British Standard BS 373, which specifies the use of an Instron machine to test small clear specimens of timber for mechanical properties (MOE, MOR, compression parallel to grain, shear parallel to grain, and hardness) and density at 12% MC. To ensure that the heartwood and sapwood portions of each billet were extracted, great care was taken in marking and sawing (Figure 1). The sawn planks were carefully chosen from visually verified defect-free areas to prepare the specimens. Following sawing, each wood sample was further ripped into the appropriate sizes for testing, and the boards underwent additional planning.

2.2 HEARTWOOD AND SAPWOOD PROPORTIONS
2.2 RAZMERJE JEDROVINE IN BELJAVE

To determine the heartwood and sapwood proportions, lines were drawn on the surface across the disc (South, South-East, East, North-East, North, North-West, West and South-West) as a reference point for the measurements to follow. A pencil dot was then marked directly on the line of each heartwood and sapwood borderline as shown in Figure 2. With the aid of a microscope, the borderline was determined on the basis of the natural color difference between the heartwood and sapwood. Each disc's diameters (heartwood and sapwood) were carefully identified and linear measurements were taken to the nearest ± 0.001 mm using a digital caliper, steel ruler and a tape measure in order to determine the heartwood and sapwood proportions as follows:

$$Total\ Disc\ Surface\ Area = \pi R^2 \quad (1)$$

Where

$$\pi = 3.142$$

$$R = \frac{R1 + R2 + R3 + R4 + R5 + R6 + R7 + R8}{8} \quad (2)$$

$$Heartwood\ Surface\ Area = \pi r^2$$

Where

$$r = \frac{r1+r2+r3+r4+r5+r6+r7+r8}{8} \quad (3)$$

$$Therefore;\ Sapwood\ Area = \pi\left(R^2 - r^2\right)$$

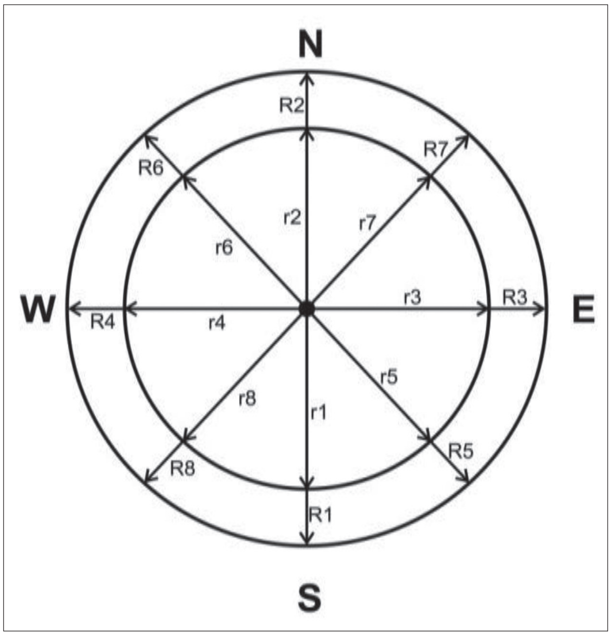

Figure 2. Lines drawn across disc surface for the measurement of the heartwood and sapwood portions.

Slika 2. Črte, narisane na prečno površino diska za merjenje deležev jedrovine in beljave.

2.3 PHYSICAL PROPERTIES OF *Albizia lebbeck* WOOD

2.3 FIZIKALNE LASTNOSTI LESA VRSTE *Albizia lebbeck*

2.3.1 Moisture Content (MC)

2.3.1 Vlažnost lesa (MC)

The green specimens that were obtained from all merchantable parts of the stems (0-25%, 26-50%, 51-75%, and 76-100%) were sawn into blocks 20 mm × 20 mm × 20 mm to determine the moisture content (MC) using the oven-dry method. The test specimens were instantly weighed using an electronic balance once they were prepared. After being oven-dried at 103 ± 2 °C, the specimens were cooled in desiccators and weighed again using an electronic scale. Until the weight remained constant, the process was repeated. The proportion of the wood's oven-dry weight was used for determining the moisture content (Panshin & de Zeeuw, 1980). To determine the moisture content, the original weights (W_1) and the oven-dry weight (W_2) were used to calculate the MC:

$$MC\% = \frac{W_1 - W_2}{W_2} x100 \quad (4)$$

Where MC = moisture content, W_1 = initial weight of sample (g), W_2 = oven-dry weight of samples (g).

2.3.2 Wood Density

2.3.2 Gostota lesa

The air-dry density for each sample (20 mm × 20 mm × 20 mm) was determined for parallel stem sections. The wood samples were air-dried in order to reach an appreciable percentage of moisture content before they were oven-dried at 103 ± 2 °C with intermittent weighing until a constant oven-dry mass (W_0) was obtained. After that, the specimens were conditioned for 120 days at 20 °C and 65% relative humidity to achieve a moisture content of roughly 12%. The specimens' masses and dimensions at 12% MC were utilized to determine the air-dry density:

$$\rho = \frac{m}{V} \quad (5)$$

Where ρ = air-dry density (kg/m³), m = air-dry mass (kg), V = volume of wood sample at 12% MC (m³).

2.4 MECHANICAL PROPERTIES

2.4 MEHANSKE LASTNOSTI

For the mechanical properties testing, the test specimens were prepared to the sizes and orientations required by the British Standard, BS 373. Samples were obtained from the tree sections (for each of the three trees). Having air-dried the specimens to an appreciable amount of moisture content they were conditioned to achieve the 12% moisture content and were stored for testing in a controlled chamber.

2.4.1 Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)
2.4.1 Modul elastičnosti (MOE) in upogibna trdnost (MOR)

The three-point bending (central loading) system on an Instron Universal Testing Machine was utilized to perform the static bending tests (modulus of elasticity and modulus of rupture). The machine applied the loading automatically at a rate of 6.5 mm/min. The machine recorded the applied load and related deflection every 0.1 N intervals. The test piece was loaded at this speed until failure occurred. The maximum load at failure as well as the maximum load at the limit of proportionality was recorded by the computer component of the Instron Universal Testing Machine with reference to the outer points of loading. The duration of the test was 90 ± 30 seconds.

The modulus of elasticity, E, is computed as:

$$E = \frac{P_1 L^1}{4\Delta_1 A^2} \tag{6}$$

Where E = Young's modulus, i.e. modulus of elasticity (N/mm²), P_1 = load applied at the limit of proportionality (N), A = area of cross-section of beam normal to direction of load (mm²), Δ_1 = deflection at mid-length at limit of proportionality (mm), L = distance between supports (mm).

The highest load a wood sample can withstand before breaking is known as the modulus of rupture. A test approach identical to that described for MOE was employed to determine the MOR.

The modulus of rupture R, is calculated as:

$$R = \frac{3PL}{2bd^2} \tag{7}$$

Where R = modulus of rupture (N/mm²), P = maximum load applied at the midpoint of the sample (N), L = distance between supports (mm), b = breadth of test piece (mm), d = depth of the test sample (mm).

2.4.2 Compression Parallel to Grain
2.4.2 Tlačna trdnost vzporedno z vlakni

The parallel to longitudinal grain method (BS 373, 1957) was used to determine the resistance to compression. The sample sizes were divided into 2 cm × 2 cm x 6 cm sections using the 2 cm standard. Every specimen was examined to confirm that the testing apparatus was built of the appropriate materials and that the rectangular test piece was parallel, smooth, and normal to the axis. Throughout the whole test duration, the plates that held the test component were parallel to one another. To ensure that correct findings were produced, several checks were carried out. In compliance with BS 373, a total of 240 samples were tested using the Instron Universal Testing Machine. The duration of the test was 90 ± 30 seconds. This formula is used to calculate the compressive stress at maximum load:

$$C = \frac{P}{A} \tag{8}$$

Where C = compressive stress at maximum load (N/mm²), P = maximum load (N), A = cross sectional area of sample (mm²).

2.4.3 Shear Parallel to Grain
2.4.3 Strig vzporedno z vlakni

BS 373 (1957) was followed in the conducting of the test, with the standard specifying that the sample sizes were 5 cm x 5 cm x 5 cm. Two hundred and forty (240) samples of each billet's sapwood and heartwood were examined using the 100 kN load cell capacity of the Instron Universal Testing Machine. The crosshead moved at a steady pace of 0.635 mm/min as the load was applied. The grain's longitudinal direction and the shearing direction were parallel. The item was subjected to the load until it broke. The Instron Universal Testing Machine automatically documented the load at which failure occurred. The duration of the test was 90 ± 30 seconds. Shear parallel to the grain (V) is computed as follows:

$$S = \frac{P}{A} \tag{9}$$

Where S = shear (N/mm²), P = maximum load (N), A = area in shear (mm²).

2.4.4 Janka Hardness
2.4.4 Trdota po Janki

The BS 373 (1957) was followed while conducting the test. The specimen was chopped tangentially and radially to measure 5 cm x 5 cm x 15 cm for the hardness test. A total of 240 sapwood and heartwood samples were subjected to a hardness test fixture on the Instron Universal Testing Machine. The fixture consists of an 11.3 ± 2.5 mm diameter steel ball at one end of a steel bar. The hemispherical end of the steel bar (steel ball) enters the test piece when a load is applied. The Instron machine automatically records the failure load as the amount of force required to drive the steel ball's hemispherical end into the test piece to a depth of 5.6 mm, i.e. equal to the steel ball's radius. The determined maximum force required to indent the steel ball halfway into the wood was used to determine the Janka hardness. Merely the tangential and radial surfaces were determined. The radial and tangential surfaces that most closely resembled the actual radial and tangential directions of the grain were selected for testing.

2.4.5 Data Analysis
2.4.5 Analiza podatkov

Analysis of Variance (ANOVA) was used to compare the results from the radial portions and to determine whether the differences found between the sapwood and heartwood were significant. The statistical tool used for the analyses was SigmaPlot version 14.0. Descriptive statistics consisting of means with standard deviations were presented for each tree section used for the study.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 HEARTWOOD AND SAPWOOD PROPORTIONS
3.1 DELEŽ JEDROVINE IN BELJAVE

The mean percentages of heartwood and sapwood proportions were 74% (26%), 75% (25%) and 74% (26%) for trees 1, 2 and 3, respectively (Figure 3). The bottom portion of each tree recorded a greater percentage of heartwood and the heartwood portion of the stem decreased from the bottom to the top of the stem whereas the sapwood portion of the stem increased from the bottom to the top, which is consistent with Qadri and Mahmood (2005). Heartwood is more durable than sapwood and less subjected to attack by insects, stain and mould producing fungi (Elzaki et al., 2012). The heartwood is also coloured and therefore considered more decorative than the light coloured sapwood (Hassan et al., 2007; Taylor et al., 2002; Zia-Ul-Haq et al., 2013).

3.2 PHYSICAL PROPERTIES (DENSITY) OF *Albizia lebbeck* WOOD
3.2 FIZIKALNE LASTNOSTI LESA (GOSTOTA) VRSTE *Albizia lebbeck*

Air dry density at 12% moisture content (MC) of three plantation grown *Albizia lebbeck* trees, showed the following results at different levels in

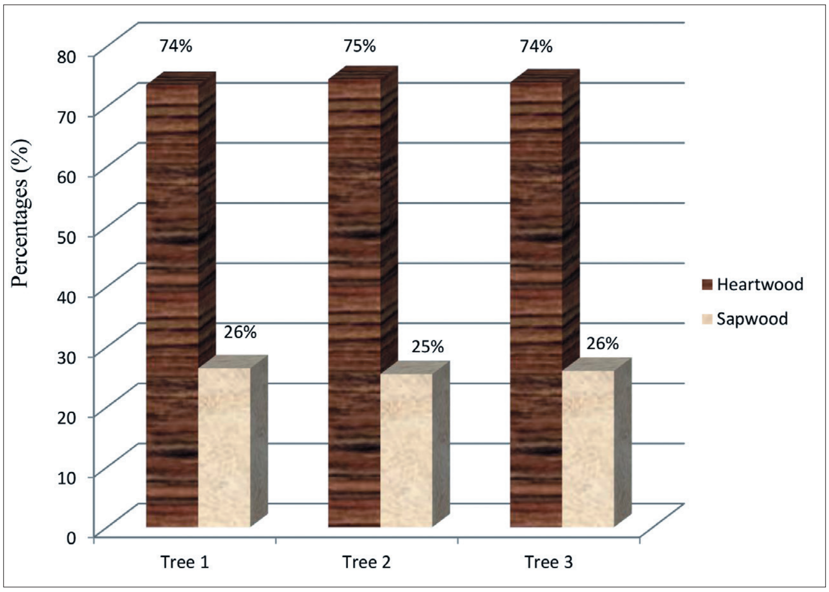

Figure 3. Average percentage (%) of heartwood and sapwood in the test trees.
Slika 3. Povprečni delež (%) jedrovine in beljave v testnih drevesih.

the stems: tree 1 recorded an average density of 842, 790, 659 and 573 kg/m³, tree 2 recorded 871, 788, 699 and 562, while tree 3 recorded an average density of 892, 841, 726 and 561 for sections 0-25%, 26-50%, 51-75% and 76-100% respectively (Table 1).The mean difference between two close sections, for example 26-50% compared with 51-75%, was statistically insignificant. However, the mean difference for sections which are far apart, for example 0-25% and 76-100%, was statistically significant (Table 2 and 3). This trend was also reported by Moya and Ledezma (2003), as supported by the findings of Forest Products Laboratory (2010).

For radial variation, the heartwood displayed higher air-dry density than its corresponding sapwood portion. There was a significant difference in density between the heartwood and sapwood in all the trees studied. According to Onilude et al. (2020), wood generally increases in density during the transformation from sapwood to heartwood. The change in density is ascribed to deposition of extractives such as phenols and quinines, which enhances the durability of wood. Factors that might have had ab influence on the density values include the growth rate, plantation site, climate and geographical location (Sasmal et al., 2013; Wanneng et al., 2014), and as we showed the position in the

Table 1. Axial variation of air-dry density at 12% MC (kg/m³) of plantation grown *Albizia lebbeck.*
Preglednica 1. Aksialna variacija gostote zračno suhega lesa plantažno gojene vrste *Albizia lebbeck*.

Tree Section	Density at 12% MC (kg/m³)		
	Tree 1	Tree 2	Tree 3
0–25%	842.11 (±81.26)	871.41 (±77.66)	892.42 (±100.63)
26–50%	790.02 (±67.36)	788.08 (±64.00)	841.00 (±77.33)
51–75%	659.59 (±69.28)	699.85 (±63.57)	726.34 (±73.71)
76–100%	573.59 (±67.58)	562.40 (±54.64)	561.11 (±51.46)

Average value and standard deviation in parentheses.

Table 2. ANOVA for comparison of density between heartwood and sapwood portions. Number of replicates (N), standard deviation (Std. Dev), standard error of the mean (SEM), degrees of freedom (df), sum of squares (SS), mean square (MS), F-statistic (F), P-value (P).
Preglednica 2. Analiza variance (ANOVA) za primerjavo gostote med jedrovino in beljavo. Legenda: število ponovitev (N), standardni odklon (Std. Dev), standardna napaka povprečja (SEM), stopnje prostosti (df), vsota kvadratov (SS), srednji kvadrat (MS), F-statistika (F), P-vrednost (P).

Descriptive statistics						One Way RM ANOVA					
Tree portion	N	Missing	Mean	Std. Dev	SEM	Source of variance	df	SS	MS	F	P
T1 Heart	10	0	847.53	33.36	10.55	Between Subjects	9	14006.95	1556.33		
T2 Heart	10	0	845.95	31.91	10.09	Between portions	5	1922348.81	384469.76	834.71	<0.001
T3 Heart	10	0	840.21	34.90	11.04	Residual	45	20727.14	460.60		
T1 Sap	10	0	486.74	12.71	4.02	Total	59	1957082.89			
T2 Sap	10	0	482.68	14.07	4.45						
T3 Sap	10	0	490.48	12.29	3.89						

Table 3. Pairwise Multiple Comparison of density between heartwood sapwood. Degrees of freedom (df), t- value (t), P- value (P).

Preglednica 3. Večkratna primerjava parov povprečij gostote med jedrovino in beljavo. Legenda: stopnje prostosti (df), t-vrednost (t), P-vrednost (P).

Comparison	df	t	P	P<0.050
T1 HEARTWOOD vs. T2 SAPWOOD	364.852	38.014	<0.001	Yes
T2 HEARTWOOD vs. T2 SAPWOOD	363.275	37.849	<0.001	Yes
T1 HEARTWOOD vs. T1 SAPWOOD	360.793	37.591	<0.001	Yes
T2 HEARTWOOD vs. T1 SAPWOOD	359.216	37.426	<0.001	Yes
T3 HEARTWOOD vs. T2 SAPWOOD	357.529	37.251	<0.001	Yes
T1 HEARTWOOD vs. T3 SAPWOOD	357.056	37.201	<0.001	Yes
T2 HEARTWOOD vs. T3 SAPWOOD	355.479	37.037	<0.001	Yes
T3 HEARTWOOD vs. T1 SAPWOOD	353.470	36.828	<0.001	Yes
T3 HEARTWOOD vs. T3 SAPWOOD	349.733	36.438	<0.001	Yes
T3 SAPWOOD vs. T2 SAPWOOD	7.796	0.812	0.962	No
T1 HEARTWOOD vs. T3 HEARTWOOD	7.323	0.763	0.949	No
T2 HEARTWOOD vs. T3 HEARTWOOD	5.746	0.599	0.960	No
T1 SAPWOOD vs. T2 SAPWOOD	4.059	0.423	0.965	No
T3 SAPWOOD vs. T1 SAPWOOD	3.737	0.389	0.909	No
T1 HEARTWOOD vs. T2 HEARTWOOD	1.577	0.164	0.870	No

significance level = 0.05

stopnja značilnosti = 0,05

tree, too. These qualities can be compared to those of the most well-known timber species, including *Milicia excelsa* (odom), *Khaya* spp. (mahogany), *Cylicodiscus gabunensis* (denya), *Piptadeniastrum africanum* (dahoma), and *Aningeria* spp. (asanfena) that are in short supply in the timber markets.

3.3 MECHANICAL PROPERTIES
3.3 MEHANSKE LASTNOSTI

The average MOE of the wood of all the trees under study was 14356 N/mm², 14071 N/mm², 13322 N/mm², and 12367 N/mm² for all the tree sections 0-25%, 26-50%, 51-75% and 76-100%, respectively. Also, the MOR of all the trees had an average of 129 N/mm², 115 N/mm², 112 N/mm² and 101 N/mm² for the sections, respectively. Moreover, the average strength in compression parallel to grain of all the trees recorded 59 N/mm², 50 N/mm², 49 N/mm² and 46 N/mm² for the sections. Furthermore, shear parallel to grain for the trees under study recorded an average of 21 N/mm², 20 N/mm², 20 N/mm² and 17 N/mm² for the sections, respectively. Finally, the average hardness property obtained for all the trees recorded 11 kN, 11 kN, 9 kN and 7 kN for sections 0-25%, 26-50%, 51-75% and 76-100%, respectively (Table 4). Axial variation in the parameters strongly suggests that all the mechanical properties of all three trees decreased from the bottom portion of the trees to the top portion.

3.3.1 Modulus of Elasticity
3.3.1 Modul elastičnosti

Axial variation of all the plantation grown *Albizia lebbeck* strongly suggests that the MOE values reduce from the bottom portion of the tree to the top portion, with an average strength of 14356 N/mm², 14071 N/mm², 13322 N/mm², and 12367 N/mm², respectively, as shown in Table 3. However, the difference between the means was insignificant. This result confirms the assertion that the axial variation of some timber species decreases significantly along the bole height from the bottom portion to the top (Chulet et al., 2010). The analysis

Table 4. Means of mechanical properties of plantation grown *Albizia lebbeck.*
Preglednica 4. Mehanske lastnosti lesa vrste *Albizia lebbeck*, gojene v nasadih.

Mechanical Properties		Tree sections			
		0-25%	26-50%	51-75%	76-100%
MOE (N/mm²)	Tree 1	14688 (±1950.12)	14289 (±1885.69)	12212 (±1257.56)	11932 (±1465.17)
	Tree 2	15087 (±1230.09)	14746 (±1321.94)	14667 (±1285.54)	14022 (±1644.44)
	Tree 3	13292 (±2160.50)	13178 (±2529.27)	13087 (±1939.03)	11147 (±4024.22)
MOR (N/mm²)	Tree 1	128.65 (±12.62)	108.90 (±27.23)	108.43 (±16.68)	98.35 (±18.27)
	Tree 2	135.77 (±15.54)	121.06 (±14.38)	118.87 (±14.00)	115.28 (±18.87)
	Tree 3	122.70 (±24.44)	114.41 (±23.71)	108.46 (±21.04)	89.46 (±34.97)
Compression Parallel to grain (N/mm²)	Tree 1	66.63 (±9.66)	49.33 (±4.60)	47.60 (±5.55)	46.09 (±3.95)
	Tree 2	54.70 (±6.43)	52.69 (±5.66)	51.59 (±4.48)	45.94 (±4.65)
	Tree 3	54.23 (±5.43)	49.28 (±3.95)	47.65 (±2.25)	46.92 (±6.53)
Shear parallel to grain (N/mm²)	Tree 1	21.45 (±3.64)	20.02 (±7.24)	18.78 (±5.26)	15.18 (±3.91)
	Tree 2	21.45 (±2.59)	20.52 (±3.98)	20.49 (±2.76)	19.94 (±4.77)
	Tree 3	21.33 (±3.40)	20.80 (±2.42)	19.88 (±2.90)	16.88 (±3.88)
Janka Hardness (kN)	Tree 1	12.53 (±4.00)	12.31 (±8.30)	9.57 (±3.23)	7.07 (±2.01)
	Tree 2	8.70 (±2.15)	8.68 (±4.47)	6.12 (±1.96)	5.08 (±3.05)
	Tree 3	11.15 (±2.40)	10.83 (±2.42)	10.43 (±2.27)	8.18 (±1.00)

Average value and standard deviation in parentheses.
Povprečna vrednost in standardni odklon v oklepajih.

of variance (ANOVA) shows that there is an insignificant difference with regard to the modulus of elasticity between the tree sections within each individual tree of species.

3.3.2 Modulus of Rupture
3.3.2 Upogibna trdnost

In terms of axial variation, the species' bending strength, i.e. modulus of rupture, values typically decrease from the base to the apex of the tree. There was a noticeable marginal drop in MOR from the base to the top of the tree. This supports earlier claims (Ayarkwa et al., 2000; Uma et al., 2009) that strength qualities increase with decreasing moisture content. When comparing the heartwood's modulus of rupture sectionally, the mean difference amongst the trees was negligible. Most heavy construction species, including essa (104 MPa) and dahoma (109 MPa), compare favorably to the average mean values of MOR reported for *Albizia lebbeck* (129 N/mm², 115 N/mm², 112 N/

mm² and 101 N/mm²) for all three trees (Ayarkwa et al., 2000). *Albizia lebbeck* belongs to class S3, according to Bolza and Keating's (1972) classification.

3.3.3 Compression Parallel to Grain
3.3.3 Vzdolžna tlačna trdnost

The average compressive strength results obtained for *Albizia lebbeck* were 59 N/mm², 50 N/mm², 49 N/mm² and 46 N/mm² (Table 3, Table 4 and Table 5) for trees 1, 2 and 3, respectively, compares favourably with the values of most timber species used for heavy construction. Some of these include odum (*Milicia exelsa*) with a compressive strength of 52 MPa, ofram (*Terminalia superba*) with 33.80 MPa, iroko (*Chlorophora spp*) with 32.62 MPa, emeri (*Terminalia ivorensis*) with 35.00 MPa and dahoma (*Piptadeniastrum africanum*) with 23.00 MPa (Bosu et al., 2006; Forest Products Laboratory, 2010; Appiah-Kubi et al., 2012). Farmer (1972) classed the compressive strength parallel to the grain as follows: very low, low, medium, high, and very high when the strength values are under 20 MPa, 20–35 MPa, 35–55 MPa, 55–85 MPa, and over 85 MPa, in that order. As a result, the compressive strength of *Albizia lebbeck* is rated as medium in this classification.

3.3.4 Shear Strength Parallel to Grain
3.3.4 Vzdolžna strižna trdnost

The shear strength comparison indicated a significant mean difference between the heartwood and sapwood. This suggests that the radial variation strength of heartwood is greater with regard to resisting failure than that of the sapwood. Though the axial shear strength properties marginally decrease from the bottom portion to the top portion of the tree (21 N/mm², 20 N/mm², 20 N/mm² and 17 N/mm²), as depicted in Table 3, for all the trees. This trend confirms an earlier assertion by Hassan et al. (2007) and Sasmal et al. (2013). The strength values obtained for plantation grown *Albizia lebbeck* trees (19.72 N/mm²) compare favourably to those of most heavy construction species, including denya (*Cyclidiscus gabunensis*) at 11.10 MPa, dahoma (*Piptadeniastrum africanum*) at 9.60 MPa, and asanfena (*Aningeria altissima*) at 9.50 MPa, (Antwi et al., 2014).

3.3.5 Janka Hardness (Radial and Tangential)
3.3.5 Trdota po Janki (radialna in tangencialna)

There was no significant variation among the axial positions along the bole (0-25%, 26-50%, 51-75% and 76-100%) for hardness (Table 3, Table 4 and Table 5) for trees 1, 2 and 3, respectively. Evidently, these results demonstrate the ability of the various parts of all the trees of the plantation grown *Albizia lebbeck* to resist indentation. The resistance of *Albizia lebbeck* to indentation. i.e. Janka hardness, was relatively high (9.22 kN) for all the trees and it can be classified as a class IV hardwood, and thus used for high-class furniture production.

4 CONCLUSIONS
4 SKLEPI

The examination of the plantation grown timber species *Albizia lebbeck*, exotic in Ghana, has provided useful information in terms of the full utilization potential of this species as a good possible substitute for the limited known tropical hardwoods with similar properties, which are now facing extinction. Based on the findings of this study, the following conclusions were made. The heartwood and sapwood proportions (74%, 26%) of the plantation grown *Albizia lebbeck* varied considerably and statistically significantly in all the trees studied. The studied trees with a diameter of 40-50 cm generally had a greater percentage of heartwood than sapwood, suggesting that enough heartwood can be obtained from the stems for furniture and structural utilization. Heartwood is desired for furniture and other engineering purposes in the tropical zones where biodegradation by organisms is common. However, the sapwood of some species of timber could perform equally well when properly treated.

It was also observed that the plantation grown *Albizia lebbeck* species exhibited a mean density of 734 kg/m³ for all the trees under study. This reveals that *Albizia lebbeck* has the potential required by the furniture and construction industries to serve as a substitute for the rarer timber species. The mean density found in the present study is comparable to that reported for other timbers, such as *Celtis mildbraedii*, *Celtis zenkeri, Petersia africana* (essia), and *Nesogordonia papaverifera* (danta), which have densities of 781 kg/m³, 743 kg/m³, 738 kg/m³ and 712 kg/m³, respectively, and which are mostly used in the Ghanaian furniture and construction industries (Ofori et al., 2009).

In terms of the mechanical properties, the mean values for the modulus of elasticity (13528 N/mm²), modulus of rupture (114 N/mm²), maximum compressive strength parallel to grain (51 N/mm²), shear parallel to grain (19 N/mm²), and hardness (9 kN) varied significantly along the sampling height. Generally, all the mean values decreased along the tree height from the bottom to the top portion. The results showed that the MOE and MOR values were high and compared favorably with those of other commercial tree species, which confirmed the suitability of the plantation grown *Albizia lebbeck* species for various furniture and construction work.

Moreover, the compressive strength, resistance to shear and hardness values of *Albizia lebbeck* mean this wood has relatively high resistance to deformation and indentation, and there is always a strong correlation between wood hardness and strength. It can therefore be concluded that the plantation grown *Albizia lebbeck* species could be used for medium to heavy timber structures. The values recorded for the mechanical properties of the wood species have validated its suitability for use in high-quality furniture products and other interior applications.

5 SUMMARY
5 POVZETEK

V nasadih na ekološkem območju Savannah v Gani gojijo več eksotičnih lesnih vrst, za katere imamo malo informacij o lastnostih njihovega lesa. Znano je, da je trenutno že veliko dreves na plantažah zrelih za posek, a jih še vedno ne sekajo za komercialne namene. Medtem beležijo v Gani vse večje pomanjkanje lesa glavnih znanih komercialnih tropskih listavcev, zlasti tistih z gostejšim lesom. To spodbuja potrebo po uporabi lesa eksotičnih listavcev s plantaž, kar bi lahko delno zadostilo potrebam države po lesu. Med potencialno zanimivimi drevesnimi vrstami je *Albizia lebbeck*, ki bi lahko nadomestila nekatere bolj znane komercialne lesne vrste. Zato moramo bolje poznati lastnosti lesa te vrste in možnosti njegove uporabe. Namen te študije je bil določiti nekatere fizikalno-mehanske lastnosti lesa vrste *Albizia lebbeck* s plantaže na ekološkem območju Savannah, Tamale, v Gani. Specifični cilji raziskave so bili ovrednotiti deleže jedrovine in beljave in določiti nekatere fizikalne lastnosti (gostoto zračno suhega lesa) ter mehanske lastnosti (vzdolžna tlačna trdnost, vzdolžna strižna trdnost, trdota po Janki, upogibna trdnost in modul elastičnosti) in njihovo variabilnost vzdolž debla.

Izbrana so bila tri zrela drevesa vrste *Albizia lebbeck* s premeri od 45 do 50 cm v prsni višini (1,3 m). Drevesa so bila posekana in izmerjene so bile tehnične dolžine hlodov od baze drevesa do nivoja krošnje. Iz posameznih debel so bili izžagani hlodiči za raziskave na štirih nivojih glede na višino v drevesu (0–25 %, 26–50 %, 51–75 % in 76–100 % višine). Vzorci za določanje fizikalnih in mehanskih lastnosti so bili razžagani na zahtevane velikosti v skladu z britanskim standardom BS 373 (1957) za testiranje majhnih čistih vzorcev lesa. Označevanje in žaganje je bilo opravljeno tako, da so pridobili vzorce beljave in jedrovine iz vsakega segmenta raziskanih dreves. Za pripravo vzorcev so bile izbrane deske brez napak kot so grče, odklon vlaken in poškodbe, ki jih povzročajo biološki škodljivci ter abiotski dejavniki. Po žaganju smo deske še dodatno skobljali in skrbno pregledali z vidika morebitnih napak. Po sušenju do zračne suhosti so bili vzorci lesa izdelani v delavnici za lesno tehnologijo Tehniške univerze Tamale (Tamale Technical University Wood Technology Workshop). Vlažnost lesa pri zračni suhosti in v absolutno suhem stanju ter gostoto lesa smo določili v Laboratoriju za gradbeništvo in les (Construction and Wood Laboratory of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana). Vsi ostali testi so bili opravljeni v Laboratoriju za lesno mehaniko in inženiring Inštituta za gozdarske raziskave Gane (FORIG), Sveta za znanstvene in industrijske raziskave (CSIR) (Timber Mechanics and Engineering Laboratory, of the Forestry Research Institute of Ghana (FORIG) of Council for Scientific and Industrial Research (CSIR)).

Približno 7,5 cm debeli koluti s štirih nivojev v deblu posameznega drevesa so bili uporabljeni za oceno deleža jedrovine in beljave. Izmerjeni so bili premeri kolutov in premeri delov z jedrovino vzdolž več radijev za izračun deležev jedrovine in beljave. Upogibna trdnost (MOR) in modul elastičnosti (MOE), vzdolžna tlačna in strižna trdnost ter trdota

so bili določeni za zračno suh les, pri pribl. 12 % lesni vlažnosti.

Rezultati so pokazali, da ima *Albizia lebbeck* danih premerov višji delež jedrovine (74,04 %) kot beljave (25,96 %). Les je dokaj gost in ima gostoto zračno suhega lesa 869 kg/m³, 806 kg/m³, 695 kg/m³ in 565 kg/m³ na nivojih debla 0–25 %, 26–50 %, 51–75 % oziroma 76–100 % aksialne višine (preglednica 1). Na splošno je *Albizia lebbeck* imela dobre trdnostne lastnosti (Preglednica 4), kar kaže na to, da bi jo lahko uporabili kot alternativno vrsto za oskrbo lesne industrije. Očitno lahko plantaže dreves vrste *Albizia lebbeck* izkoriščamo za pridobivanje kvalitetnih žagarskih sortimentov. Sicer je les jedrovine temno rjav, prepreden s temnimi in belimi odtenki, to daje jedrovini dober videz in dekorativno teksturo, kar je pomembno za rabo v notranjih prostorih in za izdelavo pohištva. Čeprav gostota lesa variira v aksialni smeri dreves, in od spodnjega do zgornjega dela drevesa upada, razlika povprečij gostote med testiranimi četrtinami delov debel ni bila značilna (t-test; p > 0,05). Srednje vrednosti mehanskih lastnosti so bile primerljive z vrednostmi lesnih vrst, kot so denia (*Cyclidiscus gabunensis*), dahoma (*Piptadeniastrum africanum*), asanfena (*Aningeria altissima*) in druge, ki jih uporabljajo v Gani za gradbene namene. Na splošno je bila trdota lesa vrste *Albizia lebbeck* razmeroma visoka, kar nakazuje, da je les uporaben za pohištvo in druge notranje konstrukcije.

ACKNOWLEDGEMENT
ZAHVALA

The authors are grateful to the management and staff, especially Seidu Haruna of the Forestry Research Institute of Ghana – Fumesua, Kumasi for making their furniture test laboratory available for the study.

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