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Original Article

Preliminary investigation on the utilisation of Douglas Fir (*Pseudotsuga menziesii* Mirb. Franco)

OPEN ACCESS

Faith Ayodeji AJIDELE[1], Josiah Thomas B. RIKI[2] & Abiodun Oluwafemi OLUWADARE[1]

[1]*Department of Forest Production and Products, Faculty of Renewable Natural Resources, University of Ibadan, Ibadan, Nigeria*
[2] *Department of Forestry and Wildlife Management, Faculty of Agriculture and Life Sciences, Federal University Wukari, Wukari, Nigeria*

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ABSTRACT

One of the most abundant and versatile natural resources is wood. Due to its numerous uses, the demand for wood is growing faster than the supply in many developing countries. Selected wood physical and mechanical properties of Douglas Fir wood was evaluated in this study to meet the need of wood for various applications. Wood samples from Ido Local government of Oyo State were obtained from (base, middle, top) and (compression and normal wood side) of a 9-years old main stem for moisture content, wood density and mechanical properties. Data obtained were statistically analyzed and result revealed that moisture contents at the level of stem (base 64.01%, middle 70.02% and top 70.02%) increased from base to top, inversely in Density decreased from base 442.60kg/m^3, middle 404.04kg/m^3 to top 388.20kg/m^3. At type of wood (Normal and compression wood), moisture contents are 66.35% and 69.82% and Densities are 421.01kg/m^3 and 402.22kg/m^3 respectively. Modulus of Elasticity with mean value of 10850 N/mm^2, showed decreased from base 11078.26mm^2 to top 10719.91N/mm^2. Modulus of Rupture decreased from base 92.62N/mm^2, to top 88.82N/mm^2, average value of 90.09N/mm^2. With the average value 55.07 N/mm^2, Compressive strength parallel to the grain also decreased from base 55.07N/mm^2 to top 51.24N/mm^2. All wood properties studied showed that Douglas fir wood can be classified as a medium density wood, suitable for medium construction such as cabinet work, veneer etc and therefore substitute the most used species and reduce overexploitation of wood.

KEYWORDS: *Axial direction, Douglas fir, Mechanical properties, Physical properties, Wood type*

INTRODUCTION

Wood is among the most abundant and versatile natural materials, utilized for various uses such as making furniture, carving, pulp and paper, tools, weaponry, plywood, particleboard, fibreboard, and other industrial raw materials. It is also considered to be the primary strengthening and nutrient conduction tissue of trees and other plants (George, 2019). A diverse range of users are drawn to this complex material because of its adaptability (Riki *et al.*, 2019).

The rising need for wood, driven by its wide-ranging applications such as paper production, construction, furniture, and fuel, has outpaced its supply in many developing nations. Particularly in Nigeria, the demand for wood and its products has outpaced supply, creating

*Corresponding Author: email- rikijosiah@gmail.com; Phone-+2348035592140

concerns regarding a sustainable supply in the future (Nam *et al.*, 2024). According to Falemara (2012), the increase in need for wood would result in over-exploitation of both natural and plantation forest with negative environmental effects. Therefore, to meet this high demand of wood species for various wood purposes, there is a need to research on not only indigenous species but also bringing in exotic wood species to meet local needs and exploration of lesser-known species.

Wood's mechanical properties include its resistance to external forces and its fitness. Any external force that tends to deform a specific piece of material in any way is referred to as an external force. These qualities primarily dictate how wood is used for construction and structural purposes, as well as for countless other applications furniture, automobiles, tools, and tool handles are just a few typical examples. Mechanical characteristics can influence the quality of wood, define whether it is suitable for structural applications, and serve as a gauge for sawn lumber quality (Riki *et al.*, 2021). The quantitative features of wood and how it responds to outside factors other than applied forces are referred to as physical properties. Knowing the physical characteristics such as moisture content, density etc. of wood is important because they have a strong impact on how strong wood is and how the wood performs when used for structural purposes (Jamala *et al.*, 2013).

Pseudotsuga menziesii is a member of the pine family, Pinaceae (Farjon, 2021). It is commonly referred to as the Christmas tree, identifiable by its tall stature, often reaching heights exceeding 300 feet, and its distinctively conical crown. Its wood possesses unique anatomical and chemical characteristics, making it a subject of considerable scientific inquiry and exploration for various uses. Beyond its conventional application in pulp and paper manufacturing, research by Warlo *et al.*, (2023) Patel *et al.* (2022), has shed light on its potential for engineered wood products, construction materials, and bioenergy generation.

MATERIALS AND METHODS

Wood samples of Douglas fir were collected from a 9-years old mother tree from Awotan area of Ido Local government, Oyo state (latitude 7.4431°N and longitude 3.8619°E). From the main stem, samples were taken from base, middle and top for moisture content, wood density, and mechanical properties (Modulus of Elasticity, Modulus of Rupture and Compression parallel to grain) as well as from the normal wood side and compression wood side.

Determination of Physical Properties

20mmx20mmx60mm samples in 10 replicates were obtained from the base, middle and top and cut from the normal wood side and the compression wood side, making a total of 60 samples. They were labeled for easy identification. Samples were immersed in distilled water until they got sunk, withdrawn and mopped to remove excess water. The initial weight was taken and dried in the oven until a constant weight is gotten in relation to fibre component using ASTM 1348-94 designation (ASTM, 2008).

The percentage maximum moisture content was calculated as

$$MC = \frac{W_0 - W_1}{W_1} * 100 \qquad (1)$$

Where;

W_0= green weight (g), W_1= oven dry weight (g),

The wood density for the samples was obtained using

$$P = \frac{M}{V} \qquad (2)$$

Where;

p = density (kg/m^3), M = mass (kg), V = volume (m^3)

Determination of Mechanical properties

The Mechanical properties tests were carried out in accordance with British Standard Institution Method BSI 373. The test was carried out using a Universal Testing Machine at the department of Agricultural Engineering, Faculty of Technology, University of Ibadan. Samples were taken axially (base, middle and top) and for wood type (normal and compression wood), each were replicated 5 times.

Modulus of Elasticity (MOE)

This was carried out using test samples size of 20mm x 20mm x 300mm according to BS 373.

$$MOE = \frac{PL^3}{4BDT^3} \qquad (3)$$

Where, MOE = Modulus of Elasticity (N/mm^2), P = Load in newton, L = Length of elastic strain (mm), D = Deflection/ deformation of strain, B = Breadth of sample (mm), T = Thickness of sample (mm)

Modulus of Rupture (MOR)

$$MOR = \frac{3PL}{2bd^2} \qquad (4)$$

Where, MOR = Modulus of Rupture (N/mm^2), P = Load needed for failure, L = Span of the material between support (length);

b = Width of the material, d = Thickness of the material

Maximum Compressive strength parallel to Grain (MCS)

The test samples size used was 20mm x 20mm x 60mm according to BS 373.

$$MCS = \frac{L}{A} \quad (5)$$

Where, MCS = maximum compression strength (kg/cm^2), L = Maximum load (kg), A = Cross sectional area (cm^2)

Statistical Analysis

The data analysis was carried out using 2 x 3 factorial experiment in completely randomized design. Data were subjected into analysis of variance; Follow-up test was carried out using the least significance difference (LSD) at 5% level of probability.

RESULTS AND DISCUSSIONS

Physical Properties

Moisture Content

The mean moisture content of Douglas fir recorded in this study increased from base to top from 64.01% to 70.22%, total mean of 68.08% as presented in Table 1 is slightly higher compared to the moisture content values of Douglas fir obtained by Gotz (2005), ranging from 25.3% to 62.9% and this may be due to environmental factors. The increase in moisture content from base to top shown in Table 1 may be due to the tree physiology as different tree species and individual trees within a species have varying rates of water uptake and transpiration also the environmental condition can influence the moisture content within a tree. It was observed that the tree was a reaction which is as a result of the response of the tree to environmental condition like wind, slope etc., and this may have implication on the wood quality for timber production. Moisture content value obtained at the compression wood side increased from the base to middle and then decreased at the top. While at the normal wood type, moisture content increased axially. Mean value obtained at the compression wood side 69.82±7.92% is higher than 66.35±6.95% obtained at the normal wood side. This arises from the physiological differences caused by the tree's reaction to mechanical stress. The analysis of variance at 5% probability level shown in Table 2 shows that there is a significant difference in moisture content axially. Follow up test in Table 3 revealed that the moisture content at the base is lower while middle and top is closer to each other. The same pattern of variation observed in this study is similar to that of some wood species in sudano-sahelian environment of Borno State (Sotannde and Riki, 2019).

Table 1: Mean of Moisture Content and Density of 9-years old Douglas Fir Wood

Physical Properties	Level	Base	Middle	Top	Pooled
MC (%)	CW	63.83±3.88	74.04±7.43	71.59±8.32	69.82±7.92
	NW	64.18±6.32	66.00±6.08	68.86±8.16	66.35±6.95
	Pooled	64.01±5.09	70.02±7.78	70.22±8.14	
Density (kg/m^{-3})	CW	451.14±17.13	393.01±47.87	379.59 45.91	402.22±45.57
	NW	434.06±22.45	415.04±45.28	396.81±47.64	421.01±44.26
	Pooled	442.60±21.32	404.04±46.73	388.20±46.39	

Notes: *Values in Table are Mean± Standard deviation of 10 replicates, MC= Moisture content, NW= Normal wood, CW= Compression wood

Wood Density

Wood density decreased from the base to the top of the sample, with an average value of 411.33 kg/m³ presented in Table 1. The mean result obtained at the compression wood of the species 402.22±45.57 kg/m^3 is lower than 421.01±44.26 kg/m^3 obtained at the normal wood side. This follows the normal pattern which is due to differences in cellular composition, composition of lignin content, mechanical stress responses, and growth patterns associated with each wood type. The analysis of variance at 5% probability level presented in Table 2 revealed that there is significance difference in the axial direction as density at the base is higher to middle and top which are closer to each other.

The density of 411.33 kg/m³ recorded from this study is lower than the average density of 426.0 kg/m³ found in a study by Hatton and Cook (1992), which investigated Kraft pulps from second-growth Douglas-fir and the relationships between wood, fiber, pulp, and handsheet properties, lower than 524 kg/m^3 obtained for *Acacia melanoxylon* by Antonio *et al.* (2012). A similar trend in wood density variation across axial and radial positions was also reported by Riki *et al.* (2019), for Caribbean pine (*Pinus caribaea* Morelet). Additionally, Sotannde and Oluwadare (2010), and Riki *et al.* (2019), found similar patterns in wood species such as *Tectona grandis* and *Azadirachta indica*. The differences observed in this study could be attributed to factors such as tree age (specifically the age of the cambium layer), as well as environmental, genetic, and silvicultural influences on different trees (Evans, 1991).

Table 2: Anova Results of Variation in Physical Properties of 9-years old Douglas fir Wood

Physical properties	Sources of variation	Df	F-cal.	Sig.
Moisture content (%)	Wood Type	1	3.84	0.06ns
	Sampling height	2	5.29	0.01*
	Wood type* Sampling height	2	1.91	0.16ns
	Error	54		
	Total	59		
Density (kg/m^3)	Wood type	1	1.41	0.24ns
	Sampling height	2	5.70	0.01*
	Wood type*sampling height	2	1.56	0.23ns
	Error	54		
	Total	59		

Notes: *=Significant ($P<0.05$), ns= not significant ($p>0.05$), Df = Degree of freedom

Table 3: Fisher's LSD Follow-up Test for Physical Properties of 9-years old Douglas fir Wood

Variable	Position along the Stem	
Moisture content (%)	Top	70.22^a
	Middle	70.02^a
	Base	64.01^b
Density (Kg/m^3)	Top	388.20^a
	Middle	404.04^a
	Base	442.60^b

Notes: *Values with the different alphabet are significantly different at ($P<0.05$), N=20

Mechanical Properties

Modulus of Elasticity (MOE)

The mean Modulus of Elasticity obtained for Douglas fir in this study was 10850 N/mm^2 shown in Table 4. MOE observed at the compression wood side 10842.14±346.69 N/mm2 is lower than that observed at the normal wood side 10859.26±304.34 N/mm^2. this followed the pattern of its density as it is lower as the compression wood side and higher at the normal wood. Normal wood typically exhibits a higher modulus of elasticity due to it straight and parallel fibre alignment and uniform structure, while compression wood has less flexible composition and more irregular orientation. There is a noticeable variation in the modulus of elasticity axially shown in Table 5, base significantly different from the middle and top shown in Table 6. While the wood type normal and compression wood side of the wood are not significantly different. This implies that any part can be used for utilisation purpose. The MOE (10850 N/mm^2) observed is this study is within the range of MOE 5000-11000 N/mm^2 obtained by Bawcombe (2012). Lower than 11000-15000 N/mm^2 observed for older trees in the same study. Lower than 13800 N/mm^2 observed in a study carried out by Christopher *et al.*, (2009) on physical and mechanical properties of young growth Douglas fir and western hemlock from Western Washinton. The higher MOE in these studies may be due to the higher density observed, the age of the trees sampled as well as silvicultural effect and environmental conditions. The pattern of density variation observed in this study decreased from base to top as shown in Table 4 following same trend reported by Christopher *et al.* (2009) for Douglas fir, Ogunsanwo and Akinlade (2011), for *Gmelina arborea* wood. This is because wood density is closely linked to its mechanical properties (Panshin and Dezeeuw, 1980). This aligns with the findings of Kayumba (2015), who noted that wood strength is strongly correlated with wood density. Therefore, it is possible to estimate the strength of wood depending on its wood density, even without having detailed knowledge of the species.

Modulus of Rupture (MOR)

Modulus of Rupture average value obtained was 90.09 N/mm^2 (Table 4) and Analysis of variance presented in Table 5 revealed that there was significant difference along the stem presented in Table 5, in wood type and interaction, MOR was not significantly different. Follow up test presented in Table 6 shows that middle and top are not significantly different from each other, but both are significantly different from the base.

MOR of 90.09 N/mm^2 found in this study is slightly lower than the 94.4 N/mm^2 reported for Douglas fir wood by Christopher *et al.* (2009) and lower than the 97 N/mm^2 obtained by Pollet *et al.* (2017). The variation in Modulus of Rupture values as presented in Table 4 could be attributed to differences in climatic and environmental conditions, the age of the wood, storage conditions, and the processing it has experienced in different regions. When compared to other species, the value obtained for Douglas fir wood is higher than the 89.05 N/mm^2 reported for *Aningera robusta* wood by Olaoye *et al.* (2016). The pattern of variation of MOR in this study decreased from base to top following the trend of wood density. This is likely because the top of the tree contains more juvenile wood, which is less dense. According to Aguda *et al.*

(2020), Modulus of Rupture decreases as the sampling position moves up the tree. MOR at the normal wood side 90.50±2.54 N/mm^2 was higher than the compression wood side 90.09±3.30 N/mm^2 because of the irregularities in the wood structure of compression wood, reducing its resistance to bending and lowering the MOR compared to more uniform structure in normal wood.

Table 4: Mean of Mechanical Properties of 9-years old Douglas fir Wood

Physical Properties	Level	Base	Middle	Top	Pooled
MOE (N/mm^2)	CW	11102.50±254.86	10722.42±378.45	10701.49±291.75	**10842.14±346.69**
	NW	11054.02±342.10	10785.42±302.20	10738.33±209.78	**10859.26±304.34**
	Pooled	**11078.26±285.01**	**10753.92±324.57**	**10719.91±240.35**	
MOR (N/mm^2)	CW	93.10±2.34	89.02±3.36	88.15±1.97	**90.09±3.30**
	NW	92.13±2.85	89.88±2.51	89.48±1.75	**90.50±2.54**
	Pooled	**92.62±2.51**	**89.45±2.86**	**88.82±1.89**	
MCS (N/mm^2)	CW	55.39±4.39	51.32±6.20	50.92±1.44	**52.54±4.63**
	NW	54.75±4.33	52.02±6.63	51.56±1.43	**52.78±4.54**
	Pooled	**55.07±4.12**	**51.67±6.06**	**51.24±1.39**	

Notes: *Values in Table are Mean± Standard deviation of 5 replicates, MOE= Modulus of Elasticity, MOR= Modulus of Rupture, CS= Compressive Strength

Table 5: Anova Results of Variation in Mechanical Properties of 9-years old Douglas fir Wood

	Sources of variation	Df	F-cal.	Sig.
Modulus of Elasticity (N/mm^2)	Wood Type	1	0.02	0.87ns
	Sampling height	2	4.31	0.02*
	Woodtype* Sampling height	2	0.09	0.91ns
	Error	24		
	Total	29		
Modulus of Rupture (N/mm^2)	Wood type	1	0.19	0.66ns
	Sampling height	2	6.51	0.01*
	Wood type*sampling height	2	0.58	0.56ns
	Error	24		
	Total	29		
Compressive strength (N/mm^2)	Wood type	1	0.02	0.88ns
	Sampling height	2	2.11	0.14ns
	Wood type*sampling height	2	0.06	0.93ns
	Error	24		
	Total	29		

*= Significant (P<0.05), ns= not significant (p>0.05), Df = Degree of freedom

Table 6: LSD Fisher's follow up Test for Mechanical Properties of 9-years old Douglas fir Wood

Variable	Position along the Stem	
Modulus of Elasticity	Top	10719.91[a]
	Middle	10753.92[a]
	Base	11078.26[b]
Modulus of Rupture	Top	92.62[a]
	Middle	89.45[a]
	Base	88.82[b]

Notes: *Values with the different alphabet are significantly different at (P<0.05). N=10

Compressive strength parallel to the Grain

The average Compressive strength parallel to the grain (MCS) obtained in this study was 52.66 N/mm^2 and analysis of variance presented in Table 5 shows that in wood type, sampling height and interaction, compressive strength is not significantly different from each other at 0.05 significance level. The MCS (52.66 N/mm^2) recorded from this study is higher than the 49 N/mm^2 observed by Pollet *et al.* (2017) in Western Europe and the 38 N/mm^2 reported by Bawcombe (2012), for the same species. It is also significantly higher than the 13 N/mm^2 found in *Magnifera indica* by Areo *et al.* (2015). The compressive strength value found in this study suggests that Douglas fir wood is capable of withstanding loads during construction, making it suitable for use in various building projects. The pattern of compressive strength variation shows a downward pattern from the base to the top of the tree as shown in Table 4, base of the tree exhibits higher compressive strength because it also has a higher density compared to the top. This conforms with reports by Adejoba and Onilude (2009), on *Ficus mucuso*, Adedipe (2004) on *Gmelina arborea*. In wood type, compression wood is lower 52.54 N/mm^2 to normal wood 52.78 N/mm^2. This is due to the structure of compression wood having an irregular fibre alignment compared to normal wood with parallel and straight fibre arrangement.

CONCLUSION AND RECOMMENDATIONS

The properties evaluated in this study indicate that *Pseudotsuga menziesii* is moderately suitable for structural applications, including construction, furniture, and engineered wood products. It demonstrates notable bending strength and stiffness, making it a good candidate for use in furniture, bridge construction, cabinetry, and similar applications. It also exhibits the ability to withstand load before failure which can be utilized in load-bearing structures such as, joists, walls, foundations etc. The values obtained for the modulus of elasticity, rupture and compressive strength falls within medium construction, this could be due to the age of the tree as it is categorized as a young tree. The study found out that the mechanical properties of the wood were higher at the base of the tree due to the higher density there, compared other parts. This increased density at the base contributes to the stronger mechanical properties observed in that part of the tree. More comprehensive mechanical testing across different grades and ages of the wood should be carried out for in-depth properties of the wood for structural applications. Based on the preliminary investigations carried out, this species can be used for structural applications aside its pulp and paper potentials. Propagation of Douglas fir in Nigeria should be encouraged as well as investigating the influence of factors such as growth conditions and harvesting practices in order to increase it availability.

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Authors' contributions

Author FAA and JTBR managed data collection, interpretation of data, data analysis and writing of the manuscript and AOO managed the development of methodology and reviewed the manuscript.

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