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AXIAL VARIATION IN THE CHEMICAL COMPOSITION OF *Nauclea diderrichii* FROM SOUTHERN NIGERIA

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Abstract:
Nauclea diderrichii (ND), mainly sourced for structural purposes, exhibits within-tree chemical variations that could influence its properties, utilization, and durability in service. Information on the chemical composition of Nauclea diderrichii wood along the bole is sparse. This study aimed to assess the axial variation in the chemical properties of ND wood from the Agoi-Ekpo Forest Reserve, Cross River State, Nigeria, with a view to assessing how these variations influence its utilization potential. Five mature trees were harvested from Agoi-Ekpo Forest Reserve, and bolts (60 cm long) were obtained from various points along Merchantable Height (MH-10%, MH-30%, MH-50%, MH-70%, and MH-90%) of each tree. The bolts were processed into specimens to evaluate ash contents, cellulose, hemicellulose, and lignin contents. Fourier Transform Infra-Red (FTIR) was employed to evaluate variations between the functional groups present in the five trees, axially. The data were analyzed using descriptive statistics and Analysis of Variance (ANOVA) at α = 0.05. Ash content, cellulose, and lignin significantly varied from MH-90% (35.1±1.4 and 18.2±1.3) to MH-10% (46.2±0.7 and 25.2±0.9), indicating a higher proportion of dense latewood cells at the tree base than the top. All spectra exhibited strong O–H stretching bands (3392–3427 cm $^{-1}$), weak C=O stretching (1731–1739 cm $^{-1}$), and consistent aromatic C=C skeletal vibrations (~1633 cm $^{-1}$). Minor peak shifts and intensity variations were observed among samples, indicating intra-species chemical variability likely influenced by environmental conditions and physiological factors. The results confirm the characteristic lignocellulosic structure of the species and a high within-tree variation in the chemical composition of ND.

Key words: *Anisotropy; Chemical Composition; Merchantable Height; Nauclea diderrichii; Opepe Wood.*

INTRODUCTION

Nauclea diderrichii (De Wild.) Merr., commonly known as *opepe* in Nigeria, is a tropical hardwood species belonging to the *Rubiaceae* family (Oyediran *et al*. 2021). Opepe is widely distributed in West and Central Africa and occurs naturally from Ghana, Nigeria, and Cameroon to the Republic of Congo, Gabon, and the Democratic Republic of Congo, signifying its high economic importance (Blanc-Jolivet *et al*. 2020). *Nauclea diderrichii* trees are large and can reach up to 35-48m in height with straight, cylindrical boles up to 2m in diameter with impressive mechanical properties, making them highly suitable for heavy structural applications (Keay 1989; Lemmens 2008). The morphological characteristics of the *opepe* tree and the aesthetic appeal of its wood may have further boosted its use in a wide array of applications. The heartwood is yellow to red-brown, with orange-red streaks, darkening upon exposure, and is clearly distinct from the sapwood; the grains are usually interlocked to wavy (ITTO 2024).

In addition to its excellent strength, *opepe* wood is valued for its natural durability, and resistance to fungi, termites, and marine borers, which enhance its suitability for railway sleepers, hydraulic works, flooring, joinery, and shipbuilding (Keay 1989; Lemmens 2008; U.S. Forest Service 1987). The high density, dimensional stability, and reported natural durability of *Nauclea diderrichii* (Ajayi 2007; Bashir *et al*. 2023), together with its frequent mention in the literature, suggest that it may be regarded as one of the more durable tropical hardwoods used in construction and export trade.

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Wood properties can vary significantly within and between trees of the same species, with factors such as soil, climate, and site conditions contributing to this variability (Zobel and Van Buijtenen 2012; Hernández *et al*. 2025). The chemical composition of wood influences its quality. Cellulose and hemicelluloses enhance tensile strength, stiffness, and pulp yield, whereas lignin acts as a binder, providing rigidity and resistance to biological degradation (Mili *et al*. 2022; Du *et al*. 2025). Extractives, although present in relatively small quantities, may enhance durability by limiting fungal, insect, and weathering damage (Hernández *et al*. 2025). Ash, which is composed of inorganic elements, tends to affect thermal stability and processing but contributes little to mechanical performance (Kollmann and Côté 1968; Rowell 2005).

Studies on intra-tree variation in tropical hardwoods have indicated that chemical constituents often differ with tree height and radial position (Wiemann and Williamson 1988; Woodcock and Shier 2002). Such variations may significantly influence certain physical and mechanical properties of wood and, consequently, its utilization. Axial variation in the chemical composition of wood, characterized by changes in the relative proportions of cellulose, hemicellulose, lignin, and extractives along the stem height has been widely reported in hardwood species (Pereira *et al*. 2003; Shen *et al*. 2024). These variations indicate differences in cambial activity, cell wall development, and the transition from mature to juvenile wood, which influence the biosynthesis and deposition of lignocellulosic constituents (Funda *et al*. 2020; Shen *et al*. 2024). Fourier Transform Infrared (FTIR) spectroscopy has proven effective for assessing such chemical heterogeneity through characteristic absorption bands corresponding to functional groups in cellulose, hemicellulose, and lignin (Schwanninger *et al*. 2004). Although *Nauclea diderrichii* wood, an important tropical timber species, has been studied for growth performance, durability, and general chemical composition (Lemmens 2008; U.S. Forest Service 1987), systematic investigations of its axial variation in chemical and wet-chemical properties appear to be lacking in the literature. Previous studies have reported average values of cellulose (38-43%), lignin (32-35%), pentosans (12-16%), and ash (0.1-0.6%) in *Opepe* wood (PROTA 2008), but there is a dearth of information on how these constituents vary along the trunk.

Objective

This study investigated the axial variation in the chemical and wet chemical properties of *Nauclea diderrichii* wood grown in Nigeria. Specifically, this study evaluated the chemical properties at different axial levels (from base to top). The results of this study are expected to provide valuable information for improved utilization and sustainable management of *Nauclea diderrichii*.

MATERIALS AND METHODS

Materials

Nauclea diderrichii tree samples for this study were harvested from a forest reserve within the Agoi-Ekpo community, under the supervision of the Cross-River State Forest Commission (Fig. 2). The Agoi-Ekpo Forest Reserve is located in Yakurr, in the Southern part of Ugep Local Government Area of the Cross River State, Nigeria. The elevation of the area is 107 m above sea level (ASL). The area is located between latitude 5° 38’ 58’’ North and longitude 8° 11’ 58’’ E with a relief of 300m and a temperature of 30°C as the highest and 21°C as the lowest with rainfall throughout the year. (Simon, 2010). A Map of the Reserve and study areas is shown in Fig. 1.

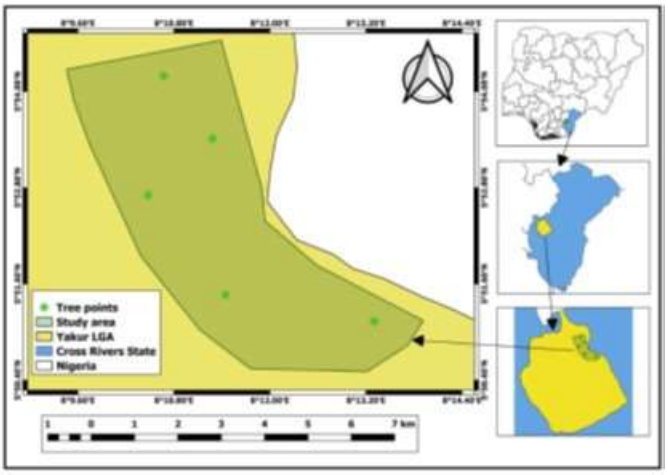

Fig. 1.
Map showing the study areas where samples were collected.

The selection of the tree samples was purposive and based on phenotypic traits, such as straight trunk, absence of defects and reaction tendencies in the selected trees. Information on the total height, merchantable height and diameter at breast height of the trees was collected and documented. The selected trees were harvested and 60cm long bolts were extracted from the butt upwards (10%, 30%, 50%, 70% and 90%) of the merchantable heights (MH) of the trees, as employed by Ogunsanwo and Onilude (2001). Five replicates of wood samples were collected from each tree. Table 1 shows the characteristics and sampling positions of each tree.

a. ***b.***

Fig. 2.
Tree Harvesting and Conversion
a – Harvesting of Nauclea diderrichii; b – Billets Converted from Different Axial Positions of The Five Trees

Table 1

Characteristics and Sampling Positions of each Tree

Tree No.	***DBH (cm)***	***Merchantable Height (m)***	***Total Height (m)***	***Sampling Positions of bolts (m) from the butt***				
				10% (m)	***30% (m)***	***50% (m)***	***70% (m)***	***90% (m)***
1	*45*	*10.86*	*17.06*	*1.09*	*3.26*	*5.43*	*7.60*	*9.77*
2	*36*	*15.44*	*22.86*	*1.54*	*4.63*	*7.72*	*10.81*	*13.90*
3	*44*	*20.53*	*27.46*	*2.05*	*6.16*	*10.27*	*14.37*	*18.48*
4	*38*	*14.10*	*23.56*	*1.41*	*4.23*	*7.05*	*9.87*	*12.69*
5	*52*	*18.67*	*27.52*	*1.87*	*5.60*	*9.34*	*13.07*	*16.80*

Field work, 2025

Determination of Ash Contents

The ash content was determined according to Herrera *et al*. (2016). An empty crucible was ignited in a muffle furnace at 600°C and cooled in a desiccator. The weights of the crucible and the specimen were determined. The crucible and its contents were then placed in a muffle furnace and ignited until the carbon was eliminated. The content was heated slowly at the start to avoid loss of the mechanical strength of the test specimen. The final ignition of temperature was 580-600°C. The crucible was removed from the furnace and placed in a desiccator for cooling and accurate weighing. Ash content was calculated using Equation 1.

$$Ash\ content = \frac{w_2}{w_1} \times 100 \quad (1)$$

where: w_1 = weight of crucible and ash; w_2 = weight of crucible and oven-dried sample of ash.

Sawdust was collected from each of the axial zones of the tree height, and the ash, cellulose, hemicellulose, and lignin contents were determined using wet chemistry analysis. Fourier Transform Infra-Red (FTIR) was also conducted on the sawdust collected from the axial zone through a chemical assessment.

Fig. 3.
Samples from Ash content Determination.

Determination of Lignin Content

The lignin content was determined according to the TAPPI standard T 211 om-02 (2002). Two grams (2g) of oven-dried extractive-free sawdust was digested. 15cm^3 of 72% cold sulphuric acid was added slowly while stirring and mixing in a water bath at room temperature for 2 hrs. Thereafter, 475 cm^3 distilled water was added. The content was allowed to boil for approximately 4 hours with a constant volume by the addition of hot distilled water. The insoluble lignin formed was allowed to settle overnight, filtered and washed with hot distilled water until it became neutral to the litmus paper (Fig. 4). The sample were then oven-dried at 85°C until a constant weight was obtained. The percentage of insoluble lignin was calculated using Equation 2.

$$\%\, lignin \;=\; ADL \qquad (2)$$

where: ADL is Acid Detergent Lignin

a.

b.

Fig. 4.
Determination of Lignin Content
a – Sample preparation for Lignin Content Determination; b – Extracted Lignin.

Determination of Holocellulose Content

Cellulose and hemicellulose make up the holocellulose. According to Fengel and Wegener (2011). cellulose and lignin have a closely connected composition; the more lignin there is in wood, the less cellulose therein. The Holocellulose content was determined using the technique described by Wise *et al*. (1946) (Fig. 5). Distilled water was used to moisten two grams (2g) of extractive-free sawdust with an 18% moisture contents. After five minutes of chlorine treatment, the material was extracted using 50ml of 95% ethanol and heated ethanol-monoethanolamine solution (Fig. 6). After thorough washing with distilled water at the end of each extraction, the residue was extracted once more until it turned white. The washing exercise was repeated until the residue was neutral to the litmus. The obtained residue was then oven dried 85C° to a constant weight. The percentage of holocellulose based on the moisture-free and extractive-free milled samples was calculated using the Equation:

$$Cellulose\ (\%) \;=\; ADF \,-\, ADL \qquad (3)$$

$$Hemicellulose\ (\%) \;= NDF - ADF \qquad (4)$$

where: ADL is Acid Detergent Lignin; ADF is Acid Detergent Fiber, and NDF is Neutral Detergent Fiber.

a. *b.*

Fig. 5.
Determination of Holocellulose Content
a – Extraction of Cellulose at The Heating Motel; b – Hemicellulose After Oven Drying.

Fig. 6.
Cross Section of Chemicals Used in The Laboratory.

Fourier Transform Infrared Spectroscopy (FTIR) in Wood Fibre

Fourier Transform Infrared Spectroscopy (FTIR) was conducted according to ASTM E1252 to characterize *Nauclea diderrichii* wood at different axial levels of the stem (base, middle, and top). Samples were obtained as sawdust during conversion, sieved to 0.2mm, and analyzed both untreated and after chemical treatment with ethanol, nitric acid, acrylic acid, and potassium permanganate. Each fiber sample was oven- or air-dried before analysis and introduced into the cell of a Perkin Elmer FTIR spectrometer covering the range 4000-400cm^{-1}. The spectra obtained from different axial tree positions were compared to assess treatment-induced alterations and inherent compositional differences along the stem.

RESULTS AND DISCUSSION

Ash Content of *Nauclea diderrichii*

The axial variation in the ash content of *Nauclea diderrichii* wood is presented in Table 2. T10%-T90% represent positions corresponding to 10%-90% of the merchantable height, measured from the base to the top of the trunk, respectively. As shown, the ash content decreased from the base to the top. The base of the tree at position ten (T10%) had the highest ash content (0.74 ± 0.039), while the top of tree at position ninety (T90%) had the lowest (0.29 ± 0.015). For the samples obtained from the middle position (T50%), the ash content value was 0.52 ± 0.035. As observed, there is a significant effect of tree position on the ash content of *Nauclea diderrichii* at p = 0.05 (Table 1). The ash content values obtained at 30% and 50% of the stem height were not significantly different, while the values obtained at the 70% and 90% of the stem were also not significantly different. Based on this, the middle can be categorized as 30% and 50% of stem height, while the top as 70 and 90% of stem height, respectively, because these points are not statistically different.

Analysis of variance (Table 3) revealed that tree position significantly influences ash content (p = 0.05), with a decreasing trend from the base to the top. This indicates positional differences in the nutrient distribution and growth conditions. This may influence utilization, where low ash levels are preferred for cleaner combustion.

Table 2

Axial Variation of Ash Contents in Nauclea diderrichii Wood

Tree Position	N	Mean ± SE
T10%	5	0.75 ± 0.039[a]
T30%	5	0.52 ± 0.035[b]
T50%	5	0.49 ± 0.039[b]
T70%	5	0.37 ± 0.024[c]
T90%	5	0.29 ± 0.015[c]
otal	25	0.48 ± 0.030

Table legend: SE = Standard Error. Means with the same superscript are not statistically different at p = 0.05 level.

Table 3

ANOVA showing variation in Ash Contents of Nauclea diderrichii wood

Effects	Degree of Freedom	Ash-SS	Ash-MS	F-cal.	p-value
Intercept	1	592.4356	592.4356	1182.978	0.000000
Tree*Position	4	57.8984	14.4746	28.903	0.000000
Error	20	10.0160	0.5008		
Total	24	67.9144			

Holocellulose Composition of *Nauclea diderrichii* Wood

Table 3 below shows that the chemical properties of *N. diderrichii* wood vary significantly with the tree height. The cellulose content obtained from the tree at the base (46.23±0.70) was found to be the highest and significantly different from the values obtained from the midpoint of the stem, i.e. 50% of the merchantable height (T50%, 41.03±0.89) to the top (T90%, 35.13±1.43). The cellulose content had minimum and maximum values of 44.12% and 48.21% respectively.

For hemicellulose, the highest content was found at the top with a mean value of 17.79±1.30 while 11.88±0.89 obtained at the base position (T10%). Along the tree height, the hemicellulose values increased from the base position (T10%-90%) to the top. At the base, the hemicellulose content was found to be lowest with a mean value 11.88±0.89 having minimum and maximum values of 10.23% and 15.32% respectively. At the top (T90%), average content of hemicellulose (17.79±1.30) is not statistically different from values obtained at 50% of the stem height (T50%, 15.71±1.17) and 70% of the stem height (T70%, 16.51±0.82).

Along the stem height of the tree, lignin content decreased. The highest content of lignin was obtained at the base (T10%, 25.19±0.87), which was not significantly different from the values obtained at 30% (23.03±0.36) of the stem height as shown in Table 4 and Fig. 2.

From Table 5. showing the analysis of variance (ANOVA) of chemical properties of *N. diderrichii* along the stem height, tree position had significant effect on the chemical constituents of the tree species at $p<0.05$.

As shown in Fig. 2, the cellulose and lignin content decreased along the stem height while the hemicellulose content increases with stem height.

Table 4

Chemical Properties of Nauclea diderrichii Along the Stem Height

Sampling Height		Cellulose (%)	Hemicellulose (%)	Lignin (%)
T10%	Min	44.12	10.23	22.35
	Max	48.21	15.32	27.22
	Mean±SE	46.23±0.70a	11.88±0.89a	25.19±0.87a
T30%	Min	42.33	11.56	22.12
	Max	46.04	17.32	23.83
	Mean±SE	43.64±0.67a,b	14.06±0.94a,b	23.03±0.36a,b
T50%	Min	29.12	13.24	19.41
	Max	43.73	20.11	24.71
	Mean±SE	41.03±0.89b,c	15.71±1.17b,c	21.56±0.92b

T70%	Min	35.34	14.84	15.49
	Max	42.32	19.14	23.32
	Mean±SE	38.15±1.51c	16.51±0.82b,c	20.26±1.36b,c
T90%	Min	30.22	13.12	14.38
	Max	38.63	21.09	22.702
	Mean±SE	35.13±1.43c, d	17.79±1.30c	18.21±1.34b, c

Legend: Values indicate mean ± SE. Means with different letter are significantly different at α = 0.05

Table 5

Analysis of Variance (ANOVA) of Chemical Properties of N. diderrichii Axially.

	Source of Variation	Df	SS	MS	F	P
Cellulose	Intercept	1	41690.29	41690.29	6867.79	0.000
	Tree Position	4	383.85	95.96	15.81	0.000
	Error	20	121.41	6.07		
	Total	24	505.26			
Hemicellulose	Intercept	1	5771.44	5771.44	1043.73	0.000
	Tree Position	4	105.22	26.31	4.76	0.007
	Error	20	110.59	5.53		
	Total	24	215.81			
Lignin	Intercept	1	11718.06	11718.06	2161.24	0.000
	Tree Position	4	141.04	35.26	6.50	0.002
	Error	20	108.44	5.42		
	Total	24	249.48			

(*) = Significantly different at the 0.05 level of probability

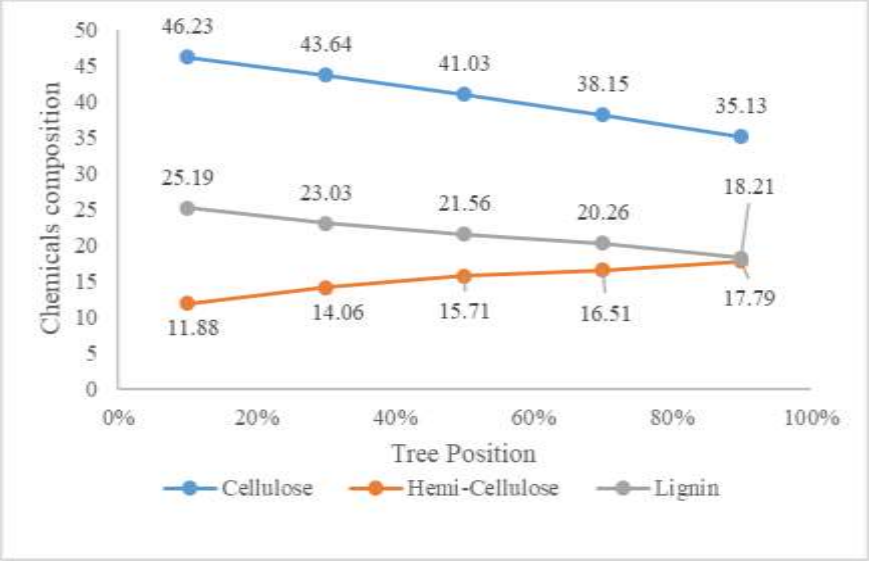

Fig. 7.
Axial variation of N. diderrichii chemical composition wood.

Fourier Transform Infra-Red (FTIR) Results on the Wet Chemistry of Five Stands of *N. diderrichii* Wood

FTIR Spectra revealed the identity of the functional groups present in an organic material (wood). The functional groups of the wood components were identified using FTIR spectroscopy. A high FTIR intensity usually indicates strong bonding, whereas weak absorption indicates weaker bonding of the chemical component. FTIR uses infrared light as an energy source, and the generated spectra use wavenumbers as units that are directly proportional to the energy (a higher wavenumber correspond to a higher energy). A high chemical content was also indicated by the high intensity of these elements. This is possible because certain absorptions of the functional group within the molecule of the material always occur at a particular frequency. FTIR was used to probe the vibrational properties of the functional. Each functional group has a specific absorption frequency. It is a plot of the percent (%) transmittance (T) against the wavenumber (cm^{-1}). As shown in Fig. 3-7, there are two major regions in the FTIR spectra. The fingerprint region (which runs from 400 to 1500cm^{-1}) and the functional group region (which runs from 1500 to approximately 4000m^{-1}) (Berthomieu and Hienerwadel 2009).

Fourier Transform Infra-Red (FTIR) on Tree One

In the FTIR spectra of wood of *N.diderrichii* in tree one (T1) and Fig. 8 below, a strong and broad peak was observed at 3417.03cm^{-1}. This was attributed to the high presence of O-H stretch. The peak 1731.30cm^{-1} is ascribed to the carbonyl (C=O) which is quite weak. This may be a result of the involvement of the carbonyl group in some intermolecular attractive forces. The strong peak at 1632.75cm^{-1} was ascribed to C=C bond. The peaks at 1507.26cm^{-1} can also be attributed to the C-O glycosidic linkage in wood cellulose. In addition, the bands (cm^{-1}) 1464.89, 1425.84, 1377.7, and 1324.67 observed in the fingerprint region of the spectra may be as a result of the bending, stretching vibration and deformation of some functional groups present in cellulose and lignin (Bader *et al*. 2020). The weak band 1161.71cm^{-1} also indicated the presence of C-O-C asymmetric stretching in cellulose and hemicellulose (Traoré 2018).

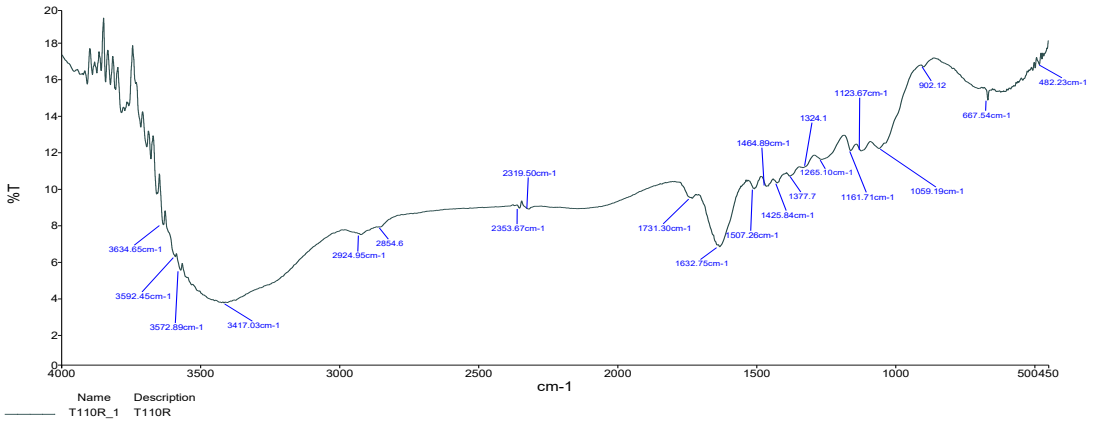

Fig. 8.
FTIR Spectra for tree 1.

Fourier Transform Infra-Red (FTIR) on Tree two (T2)

In the FTIR spectra of wood of *N. diderrichii* labelled tree two (T2) and Fig. 9 below, a strong and broad peak was observed at 3407.96cm^{-1}. This is attributed to O-H stretching with high bonding. The peak 1731.21cm^{-1} is ascribed to the carbonyl (C=O) group which is quite weak. This may be a result of the involvement of the carbonyl group in some intermolecular forces of attraction, which causes low bonding of the fiber while the strong peak at 1633.29cm^{-1} can be ascribed C=C bond. The peaks at 1510.60cm^{-1} can also be attributed to the C-O glycosidic linkage in wood cellulose. In addition, the bands (cm^{-1}) 1465.03, 1424.6, 1374.3, and 1320.8 observed in the fingerprint region of the spectra of *N. diderrichii* tree two (T2) are the result of the bending, stretching vibration and deformation of some functional groups present in cellulose and lignin (Bader *et al*. 2020). The weak band 1160.28cm^{-1} also indicated the presence of C-O-C asymmetric stretching in cellulose and hemicellulose (Traoré 2018).

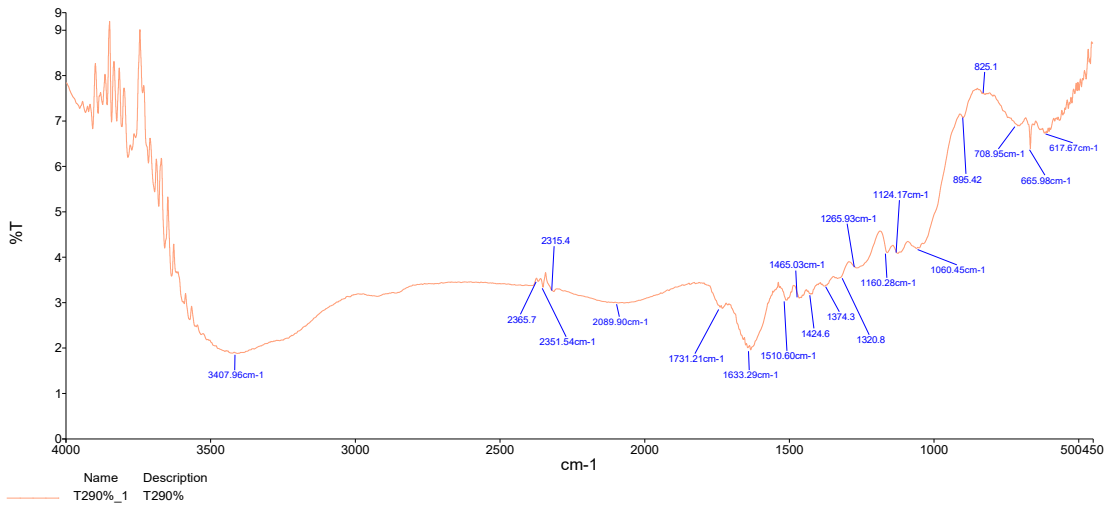

Fig. 9.
FTIR Spectra for Tree 2.

Fourier Transform Infra-Red (FTIR) on Tree three (T3)

In the FTIR spectra of wood of *N. diderrichii* labeled tree three (T3) and Fig. 5. a strong and broad peak was observed at 3411.90cm^{-1}. The O-H stretch is responsible for this. The presence of C-H was attributable to a weak band at 2925.04cm^{-1}. The carbonyl (C=O) group was attributed to the Fourier transform infra-Red (FTIR) on tree three (T3).

In the FTIR spectra of *N. diderrichii* wood labelled tree three (T3) and Fig. 10 below a strong and broad peak was observed at 3411.90cm^{-1}. This is attributed to O-H stretch. A weak band at 2925.04cm^{-1} is attributed to presence of C-H. The peak observed at 1738.88cm^{-1} is assigned to the carbonyl (C=O) group while the strong peak at 1633.77cm^{-1} is ascribed to C=C bond. The peaks at 1509.04cm^{-1} can also be attributed to the C-O glycosidic linkage in the wood cellulose. Besides, the bands (cm^{-1}) 1466.21, 1424.6 and 1374, and 1324.1 observed in the fingerprint region of the spectra is as a result of the bending, stretching vibration and deformation of some functional groups present in cellulose and lignin (Bader *et al.* 2020). The weak band 1161.15cm^{-1} also characterizes the presence of C-O-C asymmetric stretching in cellulose and hemicellulose (Traore 2017).

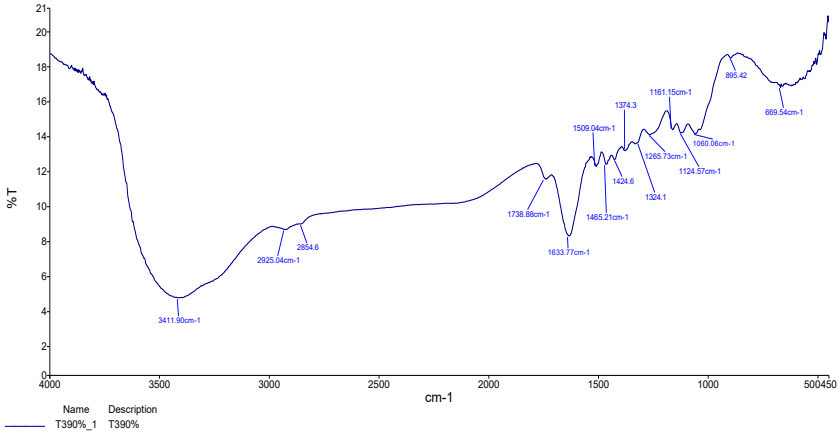

Fig. 10.
FTIR Spectra for Tree three (T3).

Fourier Transform Infra-Red (FTIR) on Tree four (T4)

In the FTIR spectra of wood of *N. diderrichii* labelled tree four (T4) and Fig. 11 below, a strong and broad peak was observed at 3392.66 cm^{-1}. The O-H stretch is responsible for this. According to Salim *et al*. (2021), the existence of C-H stretching vibrations in the aromatic methoxy group, as well as methyl and methylene groups, may be the cause of the weak band at 2917.94 cm-1. The carbonyl (C=O) group is responsible for the weak signal at 1736 cm-1. The involvement of the carbonyl group in certain intermolecular attractive forces could be the cause of this phenomenon. However, the C=C bond was attributed to the prominent peak at 1633.26 cm-1. The C-O glycosidic bond of wood cellulose was also responsible for the peaks at 1508.34 cm-1. Additionally, some functional groups found in cellulose and lignin may bend stretch, vibrate, and deform, resulting in the range bands (cm-1) 1458.48, 1428, 1374.3, and 1327.5 shown in the fingerprint region of the spectra (Bader *et al*., 2020). In addition, the existence of C-O-C asymmetric stretching in cellulose and hemicellulose is characterized by a weak band 1161.80 cm-1 (Traoré 2018).

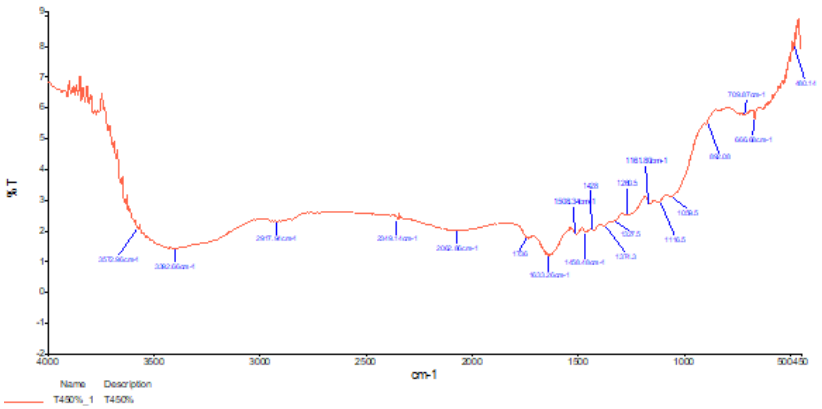

Fig. 11.
FTIR Spectra for Tree 4.

Fourier Transform Infra-Red (FTIR) on Tree five

The FTIR spectra of wood of *N. diderrichii* labeled tree five (T5) and Fig. 12. The strong peak 3426.84 cm^{-1} can be attributed to the presence of O-H stretch of cellulose; the strong, sharp peak at 1632.77 cm^{1}.Generally, irrespective of the location or type of the tree sample, all spectra showed the same frequency vibration at 1633cm-1. This indicate that they all have C-O glycosidic linkages. This is supported by the presence of C-O-O ester linkages in all spectra, except that of T5. Besides, all of them have a strong band at approximately 3400 cm^{-1}, which is attributed to the presence of O-H functional groups (either free, phenolic or O-H of moisture) in the wood sample. This confirmed that all tree samples contained cellulose, hemicellulose, lignin, pectin, and other extractives. However, there was a slight variation in the spectra of the wood samples because of their varied locations, soil types, minerals intake and environments.

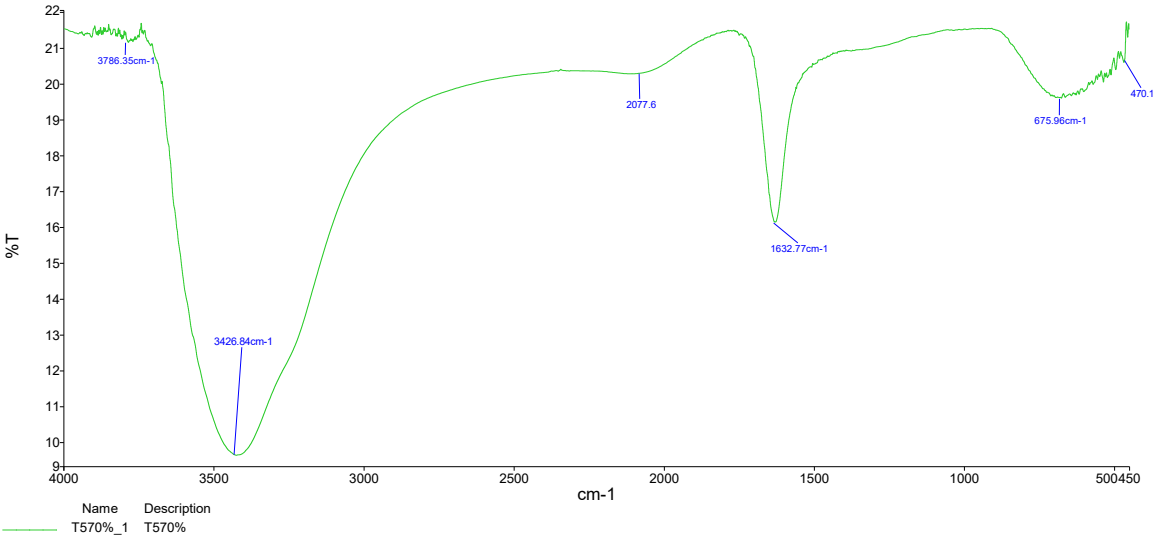

Fig. 12.
FTIR Spectra for Tree 5.

The FTIR spectra of samples T1-T5 revealed characteristic absorption bands typical of lignocellulosic materials. The strong O-H stretching vibrations indicate high hydroxyl content typical of cellulose-rich hardwood species. Variations in peak intensity suggest differences in hydrogen bonding and moisture interaction. The carbonyl region (1731 to 1739cm^{-1}) exhibited weak absorption, suggesting limited free acetyl groups or partial involvement in intermolecular bonding. Slight differences in this region may reflect hemicellulose variation due to growth conditions along the tree height. The uniform presence of aromatic skeletal vibration at 1633cm^{-1} confirms structural consistency in lignin composition across all samples.

Differences observed in the fingerprint region (1500 to 400cm^{-1}) are attributed to subtle changes in cellulose crystallinity and extractives content. The findings demonstrate that while the fundamental chemical structure remains stable, quantitative differences in functional group levels occur within the species.

Comparison of Functional Groups Variations of Between Tree 1-5

A summary of the functional groups of the five trees is presented in Table 5 below. The FTIR spectra of samples T1-T5 (Tree1 to Tree 5) revealed characteristic functional groups typical of lignocellulosic materials. A broad O-H stretching band was observed within 3392.66–3426.84cm^{-1} in all samples, which corresponds to hydroxyl groups in cellulose and hemicellulose as well as absorbed moisture, with slight variations indicating differences in hydrogen bonding and hygroscopicity. The C–H stretching vibration associated with aliphatic chains appeared only in T3 (2925.04cm^{-1}) and T4 (2917.94cm^{-1}), suggesting the presence of extractives and different moisture absorption along the tree height in these samples.

The FTIR spectra of Trees 1-3 were very similar. However, Trees 4 and 5 samples showed noticeable spectral differences from the rest, despite being of same species. These variations in FTIR spectra are unlikely due to varying environmental conditions, since all trees were obtained from the same site, but may indicate intra-specific variability in wood chemistry, like differences in the relative proportions of cellulose, hemicellulose, lignin, and extractives among individual trees. Similar intra-specific variations in FTIR spectra associated with differences in lignin and extractive contents and juvenile wood have been reported in wood species by Zhou *et al*. (2011) and Funda *et al*. (2020). Conversely, Rana *et al*. (2010) observed relatively consistent FTIR profiles among individuals of the same species. This suggests that the degree of variability

within-species may depend on chemical heterogeneity that are peculiar to the species. However, to a large extent, the major absorption bands were similar between Trees 4 and 5, despite minor chemical variations.

C=O stretching band was observed around 1731–1739cm^{-1} in T2-T4. This may be attributed to hemicellulose acetyl groups, with the slightly higher peak in T3 indicating relatively higher acetylation. Also, the C=C band (~1632-1634cm^{-1}) and aromatic skeletal vibration (~1507-1511cm^{-1}) confirm the presence of lignin, while the C–O–C stretching vibration (~1160-1162cm^{-1}) indicates cellulose and hemicellulose structures. Therefore, the spectra show similar fundamental lignocellulosic functional groups across the samples with only minor variations.

Table 5

Functional Groups of Nauclea diderrichii, From Tree 1 to Tree 5

S/N	*Functional groups*	*T1 (cm^{-1})*	*T2 (cm^{-1})*	*T3 (cm^{-1})*	*T4 (cm^{-1})*	*T5 (cm^{-1})*	*Interpretations*
1	*O–H Stretch*	*3417.03*	*3407.96*	*3411.90*	*3392.66*	*3426.84*	*Cellulose, hemicellulose, moisture*
2	*C–H Stretch*	*-*	*-*	*2925.04*	*2917.94*	*-*	*Aliphatic chains, extractives and different moisture level*
3	*C=O Stretch*	*1731.30*	*1731.21*	*1738.88*	*1736.00*	*Weak/absent*	*Hemicellulose acetyl groups*
4	*C=C Aromatic*	*1632.75*	*1633.29*	*1633.77*	*1633.26*	*1632.77*	*Lignin structure*
5	*Aromatic skeletal*	*1507.26*	*1510.60*	*1509.04*	*1508.34*	*-*	*Lignin confirmation*
6	*C–O–C Stretch*	*1161.71*	*1160.28*	*1161.15*	*1161.80*	*-*	*Cellulose & hemicellulose*

CONCLUSIONS

This study was able to assess the axial variation in the chemical properties of *ND* wood from the Agoi-Ekpo Forest Reserve, Cross River State, Nigeria. The following conclusions and recommendation(s) were drawn from the study:

1. Generally, there was significant axial variation in the chemical composition of *Nauclea diderrichii* wood from the base to the top of the trees. The distribution of major lignocellulosic constituents was not uniform along the stem axis. This was indicative of the general decrease in cellulose, lignin, and ash contents from the base towards the upper portions of the stem, and the increasing trend of hemicellulose with height.
2. Despite minor variations, there was consistent presence of key functional groups such as O–H stretching (cellulose/hemicellulose), C=C aromatic vibrations (lignin), and C–O–C linkages across the five *Nauclea diderrichii* trees, indicating a fundamentally similar lignocellulosic chemical structure.
3. There were subtle variations in extractives, moisture, and hemicellulose acetylation among individual trees, reflecting natural intra-species and sample-level chemical heterogeneity, indicative of the small shifts in peak positions and the intermittent presence or absence of bands such as C–H and C=O stretching among the trees.
4. The lower stem (MH 10-30%) was characterized by relatively higher cellulose and lignin contents, while the upper stem (MH 70-90%) had comparatively higher hemicellulose content. This indicates that stem position influences the distribution of major lignocellulosic constituents within *Nauclea diderrichii*.
5. The relatively higher cellulose and lignin contents observed in the lower portions of the stem (10-30% merchantable height), suggest that wood from these regions may possesses greater higher strength. However, further studies relating these chemical characteristics to mechanical and physical properties are necessary to confirm this suitability.

Revealing how the variations at each growth position influence its utilization potential. Cellulose and ash contents were highest at the base of the tree and decreased toward the top, aligned with patterns reported for other species. This reflects the structural role of cellulose in providing mechanical support to the lower stems. In contrast, hemicellulose increased with height, consistent with its contribution to the cell wall flexibility required in the upper stem regions. Lignin followed a decreasing trend along the stem, indicating reduced rigidity and greater flexibility toward the crown.

These variations highlight important implications for wood utilization: lower-stem wood, with higher cellulose and lignin, is better suited for strength-demanding applications, while upper-stem wood may favour uses where flexibility is desirable. Chemical gradients also reflect the adaptive responses species to mechanical and environmental demands at different heights. The FTIR analysis confirmed similar functional groups across positions, with only minor spectral differences attributable to age, temperature, and sampling position.

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