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Variations in Wood Density of *Ricinodendron heudelotii* and Implications for Pulp and Paper Production

[1]OGUNLEYE B. M., [2]FUWAPE J. A. and [2]FABIYI J. S.
Forestry Research Institute of Nigeria, Ibadan, Oyo State, Nigeria
Forestry and Wood Technology Department, Federal University of Technology, PMB 704, Akure, Ondo State, Nigeria

Abstract

Variations in the wood density of *Ricinodedron heudelotii* were investigated. The wood samples were collected from innerwood, middlewood and outerwood at 10, 50 and 90% of the merchantable tree height. Wood density was determined on oven-dry basis. The data obtained were subjected to a analysis to determine the level of variability in the vertical and radial position. Density of *R. heudelotii* ranged from 0.23 g/cm^3 at 50% to 0.30 g/cm^3 at 90% merchantable height, with mean density of 0.26 g/cm^3. Along the sampling heights, density increased from base to top and decreased from the outer wood to core wood radially. However, the results of the analysis of variance (from split-split plot design) showed that there were significant differences among the three selected trees ($p<0.05$).The interaction among the selected trees and the radial position, longitudinal and radial position as well as interaction among trees, longitudinal and radial positions were also significantly different.

Keywords: wood density, variation, pulping properties, *Ricinodedron heudelotii*

Introduction

Wood possesses unique structural and chemical characteristics that render it desirable for a broad variety of end-uses (Raimo, 2000). Wood density has been confirmed as a complex physical property related to both the anatomical structure and the chemical composition of wood (Zobel and Buijtenen 1989; Silva *et al* 2009). It has been established that density is related to most of the porosity and strength properties of timber as well as many aspects of wood processing (chipping, transport, pulping) and pulp product quality (Santos *et al*., 2012). The wood density of a stem was described as a gross measurement of its internal anatomy; it is not a single wood property but represents a combination of characteristics and hence is often referred to as the “bulk” property of wood (measured as size, mass or volume) (du Plessis, 2012). Wood density has been used for many years as an important parameter of wood quality. It is a property that is relatively easy to measure, and it has been shown to be very significant to the lumber industry and other consumers of wood in terms of its effect on wood behaviour. Wood density provides an excellent means of predicting end-use characteristics of wood such as strength, stiffness, hardness, heating value, machinability, pulp yield and paper making quality . Density variation was rated to be as important as a measure of a wood’s suitability for some end uses. Depending on species and the cambial age of wood, within-ring minimum density values range from 0.25 to 0.40, while maximums are in the 0.6 to 0.9 range (Jozsa and Middleton, 1994). The preferred range for wood density in pulp and paper industry is between 400-600 kg/m^3 (Downes *et al*. 2009).

There is relationship between wood density the pulp and paper manufacturing process and the quality of the final products (Pulkki 1991) along with other wood characteristics such as chemical composition of the wood (cellulose, hemicelluloses, lignin, extractives, ash), and fibre morphology (fibre length, fibre diameter, cell wall thickness, lumen diameter). The outlined characteristics are inter-related; density is a good indicator for both chemical composition (especially the extractive content) and fibre morphology (e.g. cell wall thickness). High extractive content would result in high density and high cell wall thickness would cause high density. In fact, wood density and pulp yield have been considered as key parameters in tree-selection programs for pulping, in addition to tree growth (Silva *et al* 2009, Borralho *et al* 1993). However, high density wood is normally preferred to low density wood. This concept holds true in the paper industry also; one example is that since a digester has a limited volume, filling a digester with high density chips means that more dry weight of wood can be charged per batch than if filled with low density wood chips. This means more pulp production per batch if high density wood is used. Montree (1979) reported the density of Douglas-fir wood had great influence on the Kraft pulping properties and pulp strength properties . Hand sheets Paper made from low density wood pulp had higher tensile strength, bursting strength and folding endurance but the paper from high density wood pulp showed higher tearing resistance (Montree, 1979). The aim of this study is to determine the variation in the density of *Ricinodendron heudelotii wood.*

Materials and Method

Wood samples of *Ricinodedron heudelotii* were obtained from a free forest at Ilaramokin, Ondo State. The forest is located between 7.321°N 5.145°E and 7.389°N 5.097°E of Ondo state, Nigeria. The samples were obtained from three trees. Billets that were 750 mm long were cut from felled sampled trees at 10, 50 and 90% of the merchantable length of each bole. The billets were then sawn through the pith into four quadrants. A board of 20 mm in thickness was sawn from each of the four quadrants toward the pith to bark using circular bench saw. Wood samples for the tests were systematically collected from pith to bark, measuring 20 mm in width and 20 mm in thickness and labeled to identify their origin. The wood samples were collected from corewood , middlewood and outerwood.

Determination of wood density was carried out in accordance with the ASTM D143 (2007) at the Forestry Research Institute of Nigeria (FRIN), Jericho, Ibadan. Wood samples from the core-wood, middle-wood and outer-wood regions at different sampling height were prepared into 20 mm × 20 mm × 60 mm. It was determined on oven dry condition at 103±3°C until constant weight was attained. Oven dried weight and dimensions (thickness, width, and length) of wood specimens were taken and used to compute the density as follows:

$$\textbf{Density} = \frac{\textbf{mass (g)}}{\textbf{volume (cm}^3\textbf{)}}$$

The appropriate experimental design for this study was split-split plot. Factor A: Trees (3 sample trees). Factor B: position of wood samples along the longitudinal directions (3 levels: 10, 50 and 90% of the merchantable height). Factor C: position of wood samples across the radial direction (3 levels: corewood, middlewood and outerwood).

Results and Discussion

Wood density of *Ricinodendron heudelotii* ranged from 0.23 g/cm^3 at 50% to 0.30 g/cm^3 at 90% merchantable height, with mean density of 0.26 g/cm^3 (Table 1). The mean density obtained for *R. heudelotii* wood is lower than previously published reports on tropical wood; Erakhrumen (2008) reported wood density of 0.81, 0.85, 0.42, 0.64,0.79, 0.71, 0.73, 0.81, 0.81, 0.83, 0.83, 0.81 g/cm^3 for *Lophira lanceolata, Vitellaria paradoxa, Triplochiton scleroxylon, Daniellia oliveri, Terminalia avicennioides, Annona senegalensis, Detarium microcarpum, Hymenocardia acida, Gardenia ternifolia, Parkia biglobosa, Anogeissus leiocarpus* and *Bridelia ferruginea,* respectively while the densities of *Pinus strobes, P. taeda, P. palustris, P. rigida, P. resionsa and P. echinata* were 0.37, 0.59, 0.64, 0.54, 0.51 and 0.58 g/cm^3, respectively (http://www.csudh.edu/oliver/chemdata/woods.htm).

Density is influenced by various factors including growth rate, proportion of early wood and latewood as well as cellulose content and lignin content (Simpson 1993; Forest Products Laboratory 1999). Along the sampling heights, density increased from base to top and increased from core-wood to outer-wood (Table 1). The low density of *R. heudelotii* (0.26 g/cm^3) might be as a result of the wood structure which is characterised by thick fibre cell walls.

The longitudinal variation of wood density was characterised by a slight increased from base to top. The trend is in agreement with a study carried out by Harvald and Olesen (1987) on the variation of basic density within the juvenile wood of *Sitlca spruce.* It was reported that basic density decreased with increase in height. This is also supported by Hashemi and Kord (2011) who found that wood basic density of *Cupressus sempervirens* decreased from base to top. Koch (1985) explained that wood properties generally depend on factors like climate, provenance, ecological conditions and wood positions in different parts of tree, between and within species. Wood properties such as density and fibre length determine the end-product quality in industrial processes and are both positively correlated with tear strength of paper (Fuglem *et al.* 2003). The decrease in wood density from base to top agrees with the auxin gradient theory (Larson 1973). The theory states that endogenous auxin arising in the apical regions of growing shoots stimulates cambial division and xylem differentiation and formation of juvenile wood. Hence, high production of early wood towards the tree crown results in low density.

The increase in wood density from corewood to outerwood could be explained on the basis of the increase in length of cambial initials with increasing cambial age and crown formation (Jorge *et al.* 2000). Furthermore, the many molecular and physiological changes that normally occur in the vascular cambium during the aging process could be responsible for the increase in the fibre length (Plomion *et al* 2001). The cells produced in the primary xylem divide less frequently, thus allowing more time for the fusiform initials section to elongate longitudinally and transversally (Horacek *et al*., 1999). Radially, wood density increased from corewood to outerwood (as the cambium matures) (du Plessis, 2012). Similar trend was reported by Izekor and Fuwape (2010) on Teak.

The digester productivity increase with wood density (Santos *et al.* 2012), therefore, the digester productivity will be lower for *R. heudelotii* (0.26 g/cm^3) than most hardwood species (*L. lanceolata, V. paradoxa, T. scleroxylon, D. oliveri, T. avicennioides, A. senegalensis, D. microcarpum, H. acida, G. ternifolia, P. biglobosa, A. leiocarpus* and *B. Ferruginea*) reported by Erakhrumen (2008). Wood density did not significantly affect pulp yield or active alkali consumption (Wimmer *et al.* 2002). The path coefficient between wood density and tear index was negative and weak for the unbeaten, but positive and strong for the beaten pulp.

The relationship between wood density and pulp and paper properties cannot be over-emphasized. The preferred range for wood density in pulp and paper industry is between 0.40-0.60 g/cm^3 (Downes *et al.* 1997). High density woods produced bulkier, more porous sheets with higher bending stiffness, while lower density woods produced smoother, denser sheets with higher tensile strength (Wimmer *et al.* 2002). The wood density effects on hand sheet properties were highly significant, particularly with bulk and air permeance. Significant negative path coefficients were evident for tensile index, burst, tensile energy absorption, and stretch; all other parameters showed positive links. Path coefficients for correlations between wood density and tear index, light scattering coefficient, bending stiffness, roughness and opacity became stronger with beating. Wimmer *et al.* (2002) also reported that the path coefficients for the effects between wood density and tensile index, permeance, tensile energy absorption and stretch were weakened by beating. From the influence of high or low density of wood on the bending stiffness or tensile strength, respectively, *R. heudelotii* would have favor the production of paper with smoother surface, denser sheets and higher tensile strength. However, the acceptable range of density (0.40 - 0.60 g/cm^3) for high quality paper is higher than the obtained density for *R. heudelotii* (0.26 g/cm^3), therefore, the suitability of *R. heudelotii* for pulp and paper industry is not guaranteed on the basis of its density but it could be mixed with other high density wood for pulp and paper production.

Table1. Variation in the density of *Ricinodendron heudelotii* wood

Radial position	Base (10%)	Middle (50%)	Top (90%)	Pooled mean
Outerwood	0.32±0.03	0.30±0.02	0.30±0.02	0.29±0.03
Middlewood	0.28±0.03	0.24±0.02	0.27±0.03	0.26±0.03
Corewood	0.24±0.03	0.23±0.03	0.25±0.02	0.24±0.03
Pooled mean	0.26±0.03	0.26±0.04	0.27±0.03	0.26±0.03

Table 2: Analysis of variance (Split-Split-Plot Design) of wood density (g/cm^3) of *Ricinodendron heudelotii*

Source of Variation	Degree of freedom	Sum of squares	Mean square	Computed F ^{b}	Sig
Main-plot analysis					
Replication	4	0.002	0.001	1.366	0.254^{ns}
Tree(A)	2	0.003	0.001	13.621	0.003
Error(a)	8	0.001	0.000		
Sub-plot analysis					
Longitudinal(B)	2	0.005	0.003	8.232	0.002
AxB	4	0.014	0.003	8.382	0.000
Error(b)	24	0.008	0.000		
Sub-subplot analysis					
Radial(C)	2	0.046	0.023	54.755	0.000
AxC	4	0.007	0.002	4.199	0.004
BxC	4	0.026	0.006	15.551	0.000
AxBxC	8	0.019	0.002	5.730	0.000
Error(C)	72	0.030	0.000		
Total	135	9.526			

^{b**}=significant at 5% level, ^{ns}= not significant.

The results of the analysis of variance (from split-slip plot design) conducted on wood density showed that there were significant differences among the three selected trees (main plot) ($p<0.05$). Under the sub plot analysis, there was significant difference in the wood density from the base to the top. Likewise the interaction between the trees and the longitudinal position was significant ($p<0.05$). Under the sub-subplot analysis, the wood density was significantly different across the radial position ($p<0.05$). The interaction among the selected trees and the radial position, longitudinal and radial position as well as interaction among trees were significantly different.

Separation of means of the wood density was carried out using Duncan multiple range test (DMRT) at 5% probably level. The density of the wood obtained from longitudinal position (base to top) was not significantly different except for the top that was significantly high. For the radial position (core-wood to outer-wood), the density was significantly different with the outer-wood having the highest.

Conclusion

The density of wood samples of *Ricinodedron heudelotii* was determined for possible utilisation as a source of fibrous raw material for pulp and paper production. The average wood density for the *R. heudelotii* was 0.26 g/cm^3. Generally, wood density increased from base to top and increased from corewood to outerwood. The preferred range for wood density in pulp and paper industry is between 0.40-0.60 g/cm^3. Therefore, the suitability of *R. heudelotii* for pulp and paper industry is not guaranteed on the basis of its density.

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