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Wood Properties and Selection for Rotation Length in Caribbean Pine (*Pinus caribaea* Morelet) Grown in Afaka, Nigeria

Oluwadare A. Oluwafemi

Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria

Abstract: Plantations of Caribbean pine in Nigeria were established to provide the much needed local supply of long fibre pulp for the paper mills. Information on the biological characteristics of the wood is needed towards fibre utilization and selection of rotation length. The materials investigated in this study were woods from five age series –5, 7, 15, 20 and 25 years. These materials were characterized in terms of basic density, tracheid dimensions, kraft pulp and two growth parameters. Basic density increased with age as well as tracheid length and cell wall thickness. Ages 5 and 7 showed greater variability in these properties. Screened pulp yields increased with age with age 15 having the lowest screened yield permanganate ratio. Mean annual increment for tree height and diameter was highest at age 15. Findings showed that all the materials are suitable for papermaking with age 15 as the estimated rotation length for Caribbean pine, grown in Afaka, Nigeria.

Key words: Wood quality · tracheid dimensions · growth indices · *Pinus caribaea (*Morelet)

INTRODUCTION

The demand for wood and wood products is tremendously increasing worldwide. In Nigeria, the consumption of paper and paper products is daily increasing due to increasing awareness of computer technology and advancement in education. Many plantations of both exotic and indigenous species have been established to meet the quest for the required pulp need. Both short and long fibres are required to furnish good grade paper. The quality of paper to a certain extent depends on the quality of its fibres. In Nigeria, meeting the required tonnage of long fibre requirement is a problem moreover, that no single hardwood species have been found suitable to provide the much needed long fibre pulp. Plantation establishment of exotic pine species began as far back as 1960's. Among them, Caribbean pine proved most promising [1, 2]. The rotation length of many pines may be as long as 40 years. Due to competitive demand to which land is put to a shorter year may be preferred. For instance King [3] stated that pine pulpwood rotation length in the temperate region may be between 30-40 years and could be less in the tropics.

Rotation length is an important tool for controlling tree size [4] however; rotation length also markedly influences yield, product quality, profitability and regeneration methods. Rotation lengths are generally determined based on management objectives along with biological characteristics of the commercial trees [5]. Many properties of wood depend on the age of the tree [6], when the wood was formed and the environment of the tree. These combined together with the genetic make up of the tree to produce the best wood for specific end-use. Since different paper and paper board products require different raw material characteristics [7], one cannot say that any one kind of raw fibre is desirable or undesirable without specifying the product. It is pertinent to specify the end-use product for which a tree crop is grown for before the selection of the final rotation length. All pine species grown in Nigeria are to provide long fibre pulp. It is therefore necessary to investigate the wood properties and the age at which these properties showed acceptable range value in meeting the objective of establishment.

This study investigates selected wood properties of Caribbean pine in combination with extrinsic growth parameters to determine appropriate rotation length.

MATERIALS AND METHODS

Samples of wood used in this study were obtained from five age series of *P. caribaea* grown in guinea savanna at Afaka, Kaduna Nigeria. The Afaka Forest Reserve is situated west of Kaduna on latitude 10°7´N and

Corresponding Author: Dr. Oluwadare, A. Oluwafemi, Department of Forestry, Faculty of Agriculture, Nasarawa State University, Shabu-Lafia, Wildlife and Fisheries, P.M.B. 135, Lafia, Nasarawa State

longitude 7° 17′E on 600 m above sea level. Mean annual rainfall is about 1300 mm with daily minimum and maximum temperatures of 18°C and 24°C respectively. The trees selected were 5, 7, 15, 20 and 25 years old respectively. In each age group three trees were harvested with their total tree height and diameter at breast height measured. Discs of 5 cm in the thickness were obtained at breast height. Additional bolts of 20 cm for pulping materials were obtained at base, middle and top of trees sampled in 15, 20 and 25 age series while the entire logs from 5 and 7 age series was used. Based on the experimental design used, each age group was considered a treatment and each tree a replicate meaning five treatments with three replicate with a total sample of 15 trees.

Wood characterization: Basic density of the wood was based on the oven-dry weight and green volume of samples obtained from the disc.

Tracheids dimensions were measured based on inter-ring wood samples. The Splints obtained from each ring were macerated in equal volume (1:1) of 10% acetic acid and 30% hydrogen peroxide after the method of Franklin [8]. The bleached and soft splints were washed thoroughly in water and shaken in aqueous ethanol solution to free the tracheids. Two slides were prepared for each ring sample and 20 tracheids measured in swollen condition using Rheichart microscope for length (mm) L, diameter (µm) D, lumen width (µm) d and cell wall thickness (µm) w. From these, the derived morphological characteristics viz: felting power (FP), coefficient of flexibility (f) and wall fraction (WF) were determined. The obtained averages for each sample were used for statistical analysis.

Kraft pulping: A 25 litre rotatry laboratory digester was used for kraft pulping. The sampled materials were manually chipped and the following cooking parameters used for all samples:

- oven-dry weight of chips = 2.0kg
- active alkali (% as Na_2O) = 20
- sulphidity (%) = 25
- maximum temperature (°C) (minutes) = 170±2
- Time to maximum temperature = 60 minutes
- Holding temperature (°C) = 130
- Holding time (minutes) = 30
- Time at maximum temperature (minutes)= 180
- Liquor ratio = 6:1

After cooking, pulps were washed on a stainless steel sieve with a mesh size 120 µ and later screened on 1-mm steel sieve. The clean pulp obtained was left in cold water with few drops of formalin before further analysis. The following parameters were determined:

- total yield – ratio of oven-dry weight of pulp + rejects and oven dry weight of chips charged
- screened yield – ratio between oven dry weight of screened pulp and oven dry weight of chips charged.
- rejects – ratio between oven dry weight of total yield – oven dried weight of screened yield and oven dry weight of screened yield and oven dry weight of chips charged.
- Permanganate number: This shows the degree of delignification of pulp or the amount of residual lignin in the pulp. This was carried out using TAPPI T-236 cm 85 as modified in the laboratory manual of Iwopin pulp and paper company test manual. Permanganate number is the volume (ml) of $0.1NKMn0_4$ consumed by 2.0 gramme of oven-dry weight of pulp.

Estimation of rotation length: Rrotation length was first of all determined by identifying the end-use requirement of the pine plantations. The value of this objective was then calculated at each year of the stand's life (in this study-5-age series) using the extrinsic growth parameters (total height and DBH).

Mean annual increment (MAI) was used to estimate the rotation length [9] and vis-à-vis the various biological properties measured [10].

For total height, MAI = TH/age of stand (m/year) and Diameter, MAI = ^{DBH}/age of stand (cm/year)

MAI was calculated for all stand ages and the age where it is greatest is chosen as the rotation age [11].

RESULTS

Basic wood density and Tracheid morphology: The mean wood basic density (WBD) and tracheid dimensions are shown in Tables 1 and 2. In Table 1, the least value of 407 kg/m^3 was obtained for tree age 5 while the highest value of 497 kg/m^3 was obtained for tree age 20. It is interesting to note that within-age class variation decreases with age as depicted by their coefficient of variation. It was highest in age class 5 and lowest in age class 25. These values are consistent with findings of

Table 1: Basic density of the wood

Material	Range	Basic wood density kg/m^3 Average	CV
5-year-old	336-449	407a	15.1
7-year-old	369-451	408a	10.1
15-year-old	425-484	459b	6.6
20-year-old	465-529	497d	6.4
25-year-old	464-519	488c	5.8[a]

values with the same letter are statistically different (DMRT at 0.05 significance level

Table 2: Tracheid dimension and derived values

Material	L	D	d	w	Fp	Su (%)	WF (%)
5-year-old	2.34	59.64	47.62	6.01	39	79	20
7-year-old	2.44	54.22	40.78	6.62	45	76	24
15-year-old	2.64	59.14	46.50	6.47	44	78	22
20-year-old	3.23	58.32	42.68	7.82	56	73	27
25-year-old	4.23	62.08	43.07	9.50	68	69	31

L= tracheid length; D = diameter; d = lumen width; w = cell wall thickness; Fp = felting power (L/D); Su = suppleness/flexibility (d/D) x 100; WF= wall fraction (^{2w}/D) x 100

[12-15] on the same species from Jamaica, Fiji Island, Cuba and on maritime pine from France.

In Table 2, tracheid length increased with increasing age from 2.34 mm in age class 5 to 4.23 mm in age class 25. Variability in this trait was highest in age class 7 (10.7%) and least in age class 25 (4.0%). With exception of cell wall thickness, other tracheid parameters intersparsely increased with age. Age class 15 seems a transition age between the juvenile phase and mature phase. It is only in this trait that within-class variation generally decrease with age from (0.8% in age class 5 to 1.4% in age class 25. Reports here is similar to [15, 16] on southern pines and 8-year-old trees from Brazil.

Pulp yield of kraft pulp: The performance of fibrous raw materials during pulping process is an indication of its quality for papermaking. Yields of pulps varied between age classes. The juvenile age classes (age class 5 and 7) had the highest total pulp yield of 55.1 and 52.2%, respectively. Similarly, the amount of rejects was more (8.3 and 6.1%). Age class 15 had the least screened yield of 45.5% and highest permanganate number (8.7%) but lowest screen yield permanganate number ratio of 5.2. The oldest age class (25 years) had the highest screened yield of 49.4%.

Table 3: Total yield, screened yield, rejects and permanganate number

Material	Total yield	Rejects	Screened yield	Permanganate number	Screened yield: permanganate number
5-year-old	55.10	8.26	46.62	8.5	5.5
7-year-old	52.18	6.09	46.09	7.6	6.1
15-year-old	47.58	2.04	45.54	8.7	5.2
20-year-old	49.26	1.99	47.27	5.7	8.3
25-year-old	50.42	1.06	49.36	8.5	5.8

Table 4: Mean tree height, diameter at breast height and their annual increment

Material	Tree height (m)	Diameter at breast height (cm)	MAI TH (m/year)	MAI DBH (cm/year)
5-year-old	4.4	2.4	0.88	0.49
7-year-old	5.7	3.3	0.81	0.47
15-year-old	17.7	26.1	1.18	1.74
20-year-old	22.0	26.5	1.10	1.33
25-year-old	22.0	26.1	0.88	1.04

Selection for rotation length: Table 4 shows the two growth parameters used (TH and DBH) with their derived MAI. The TH increased through the age classes however; circumferential increase in diameter was marginal from age 15 to 25. MAI for TH and DBH was highest at age 15 (1.18 m/yr and 1.74 cm/yr.) and thereafter decreased to 0.88 m/year and 1.04 cm/year at age 25. The need for short rotation length for pulpwood species has been emphasised [5, 14]. From Tables 1-4, the rotation length may be fixed at age class 15. At this age mean density, tracheid length, wall thickness suppleness and wall fraction were 459 kg/m^3, 2.64 mm 6.47 µm, 78% and 22% respectively. These with the biological productivity of the trees (1.18 m/yr and 1.74 cm/yr combined with the management objective made age class 15 the suitable rotation length for *Pinus caribaea* at Afaka.

DISCUSSION

Basic density and Tracheid dimensions: The importance of basic density as a sole trait that is often measured in wood cannot be over-emphasised. It is a trait that gives indication of relative value of other wood properties such as strength properties, calorific value and pulp properties [14, 15, 17, 18]. Though basic density increased with age especially between the transition period of 15 years to mature period at 20 years due to increasing age as more mature wood is formed. However the higher rate of variability observed in the lower age series may be due to

juvenile nature of the wood. Generally, it is believed that juvenile wood varied considerably in their wood properties [6]. Whereas, mature wood is more stable hence lower variability, compare to samples from Tanzania, Cuba, Jamaica, Fiji Island, Brazil [12, 13, 15, 19] the differences observed may be due to the number of trees sampled and locations. Nevertheless, wood that is high in density in excess of 600 kg/m^3 and above may not be suitable for papermaking [20]. Therefore the observed values are still within acceptable range for wood meant for pulp production.

It has been documented that tracheid properties of wood are of great importance in pulp and papermaking. The general increase in tracheid length as the tree matures with age is due to the aging of the cambium. The benefit of this is that better paper with higher paper strength will be produced provided there is no concomitant increase in other cell parameters especially cell wall thickness. Also the variation observed may be due to differences between juvenile wood (ages 5 and 7) and the mature wood (age 25) [15]. Variation in cell diameter and lumen width were not consistent, this may be due to the nature of individual tracheid that were selected for measurement. However, cell wall thickness increased with age with greater stability in the oldest trees (Table 1). This may not be unconnected with individual tracheid that constitutes the entire components of the cell wall substance.

The increase in derivatives of cell dimensions as observed for felting power is as a result of increasing cell length. This value however is lower than the values obtained by [11, 15, 21]. The disparity may be attributable to the longer cell length obtained in their studies compared to the shorter length in the present study. Nevertheless, suppleness and wall fraction were both similar to the values obtained by these authors. It is expected that the older trees may be difficult to refine compare to younger trees; however, in terms of strength the older trees will produce paper with greater strength properties especially in tear [6].

Pulp yield: From Table 3, screened yield of pulp was highest in the oldest tree. The increasing cell wall thickness may be responsible for this trend. This is further exemplified by higher wall fraction culminating in higher basic density. Also, the rejects in the older trees were generally low compared with younger trees with higher amount of rejects, low density and wall fraction which is typical characteristics of juvenile wood [15]. From this study, tracheid dimensions seem to have greater influence on pulp yield and thus, it is expected that the final influence on paper properties will be advantageous. On the whole, the range of 45.5-49.4% for screen yields is still within acceptable range for most softwood tropical pine pulp yield [15, 21-23].

Selection of rotation length: There is a rapid and steady increase in demand for pulp products and an increasing shortage of wood supplies. Hence, short-rotation intensive culture plantations are being recommended [14]. In Tables 1-4, it may be suggested that age 15 be the most appropriate time to crop the trees for paper production. At this age, density was moderate while tracheid dimensions and it derivatives such as felting power, suppleness and wall fraction are still within acceptable standard for pines utilized for papermaking [15]. From age 15 upward, felting power and wall fraction increased while suppleness that determines to a greater extent inter-fibre bonding power was decreasing. Though, pulp yield was lowest, the value of ratio of screened yield to permanganate number showed that the yield is still within acceptable standard desirable for papermaking.

The extrinsic growth parameters (TH and DBH) evidently show that beyond age 15, the trees are growing at diminishing rate. This means that it may be economically unreasonable to keep the trees in the site bearing in mind the objective of establishment, the biological characteristics of the wood and production capacity of the forest sites [5]. To a fair approximation based on these findings, it is suggested that Caribbean pines grown in Afaka, a savanna zone in Nigeria should be cropped for pulp and paper production as the tree reaches age 15.

CONCLUSIONS

The five age series used in this study may be classified as juvenile wood-ages 5 and 7, transition wood-age 15 and mature wood-ages 20 and 25. Based on this classification ages 5 and 7 showed juvenile wood characteristics of low density, higher variability in wood properties, shorter cell length and thinner wall thickness with greater flexibility. In the other hand, mature wood was more stable in their properties with higher pulp yield, longer cell length but with thicker cell wall.

More importantly, the rotation length of Caribbean pine in the Afaka savanna zone should be 15 years. This is still subject to further studies as shorter length will be more preferable.

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