Evaluation of pulp wood quality of selected tropical pines raised in the high ranges of Idukki District, Kerala

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Abstract

The present investigation was carried out to evaluate the pulp wood quality of selected tropical pines *viz*, *Pinus caribaea* Morelet, *P. patula* Schldl. et Cham. and *P. oocarpa* Schiede, grown in research trials of the Kerala Forest Department. The research plots were located in the humid tropical high ranges of Idukki district of Kerala The objective was to evaluate their wood quality as well as their potential for pulp and paper manufacture based on the wood physical, chemical and anatomical properties including fibre properties and derived fibre ratios. Increment core samples were collected at breast height from trees selected at random from plots of each species belonging to different age classes. These samples were subjected to intensive wood property analysis to find out radial variation (pith, middle, and periphery), species variation and influence of age on different wood properties. The study revealed that *Pinus caribaea* performed better within the accepted range suitable for pulp and paper making properties for specific gravity, tracheid morphology and fibre ratios. *P. patula* and *P. oocarpa* also were also found to be promising species for pulp and paper with better derived fibre ratios. However, in terms of chemical composition, *P. oocarpa* had an edge over other species with higher cellulose and lower lignin contents.

Keywords: *Pinus caribaea, Pinus patula* and *Pinus oocarpa,* Pulp wood properties, Lignin and cellulose content.

Introduction

Pines have been widely cultivated in many parts of the world as a source of timber, fuel wood, pulp wood and resins. Research wing of the Kerala Forest Department has initiated several pine species (*Pinus caribaea, P. greggii, P. kesiya, P. patula. P. oocarpa, P. taeda* L., *P. elliottii, P. patula, P. pseudostrobus, P.merkusii, P. cubensis* Grisebach and *P. radiata)* introduction trials at different locations (Peerumedu research range, Idukki, Mananthavady research range, Wayanad and Kulathupuzha research range, Kollam) of Kerala state. The plots were established from 1975 to 1986 with the chief objective of evaluating their growth performance under the prevailing eco-climatic conditions of these sites. Wood traits are highly variable and affects the quality of products. Information on wood property variation is currently lacking in species such as *Pinus caribaea, P. patula* and *P. oocarpa*. These species have been found to perform reasonably well in terms of growth under the prevailing conditions in the trials undertaken and need to be tested for their wood properties. The present study was taken up with this objective.

The study investigated wood properties like specific gravity, tracheid morphology, derived ratios, and chemical properties in three pine species viz. *Pinus caribaea, P. patula* and *P. oocarpa* grown in research trials of the Kerala Forest Department in the high ranges of Idukki District of Kerala, India. The information gathered in this investigation will be useful for introduction and popularization of the species in suitable areas of the state by the forest department. The paper industries intending to

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undertake large scale pulp plantation programmes can also benefit from the trial. The information could be further used in tree improvement programmes of these species for wood quality.

Materials and Methods

The study material was collected from Peerumedu research range of Idukki District, Kerala which is a hill station located at an altitude of 914 m above sea level. The climate is equitable, ranging from 32°C in March to 16°C in December with an average annual rainfall of about 3760 mm. The study areas selected in the Peerumedu research range were located at Kolahalamedu, Thottapara, Vilanjikkanam and Thattathikkanam. Three trees from each plot of each species were selected at random for collecting wood samples for further detailed investigation (Table 1).

Wood samples were collected from the selected trees at breast height using an increment borer (Haglof increment borer; CO1512). From each tree, one core sample, 12 mm thick, was taken. Variations in wood properties were studied in the pine species belonging to four ages *viz.* 28, 31, 32 and 35 years.

Estimation of wood properties

Specific gravity of the wood samples was determined using a Specific Gravity Module (Schimadzu AUY 220) attached to a precision electronic balance. The converted core samples from each tree, representing pith, middle and periphery, were used. Wood specimens of size 1.0 cm^3, representing three radial positions viz., middle, pith and periphery were then softened by keeping in water bath at 80°C for 10-15 minutes. Cross and tangential sections of 10- 15 μm thickness were prepared using a Leica sliding microtome (Leica SM 2000 R). Permanent slides of tangential, transverse and radial sections were prepared using the procedure outlined by Johansen (1940).

Maceration of wood samples was done using Jeffrey's method (Sass, 1971). The macerated samples were stained using saffranin and mounted on temporary slides using glycerine as the mountant. From the macerated fibres, observations like tracheid length, tracheid diameter, tracheid wall thickness and trachied lumen diameter for each of the species were measured using the Image Analyzer

Table 1. Details of sampling locations at Peerumade, Idukki District, Kerala

Sl.. No	Name of Plantation (Plot)	Year of planting	Age (Years)	Area (ha)	Species
1	Pinus Research Garden, Thottapara	1975	35	0.65	*Pinus caribaea, P. patula* and *P. oocarpa*
2	1977-78 Research Garden, Vilanjakanam	1978	32	2.63	*Pinus caribaea, P. patula* and *P. oocarpa*
3	Pinatum, Thottapara	1979	31	2.50	*Pinus caribaea, P. patula* and *P. oocarpa*
4	Pinus Research Garden, Vilanjakanam	1982	28	0.70	*Pinus caribaea, P. patula* and *P. oocarpa*
5	Pinus Research Garden, Vilanjakanam	1983	27	2.70	*Pinus patula* and *P. oocarpa*
6	Pinus Research Garden, Vilanjakanam	1984	26	0.90	*Pinus caribaea* and *P. oocarpa*
7	Tropical pine plantation, Thattathikanam	1985	25	7.60	*Pinus oocarpa*
8	1986 pine plantation, Kolahalamedu	1986	24	50.80	*Pinus caribaea*

(Labomed-Digi 2). These observations were taken from pith, middle, periphery of each sample. Different criteria such as the Runkel ratio, slenderness ratio, rigidity coefficient, flexibility coefficient and the shape factor which are important in pulp and paper manufacturing were derived from the data obtained. (Uju and Uewoxe, 1997; Yanez-Espinosa et al., 2004). Cellulose content of the wood was estimated as suggested by Sadasivam and Manikam (1992) and the estimation of insoluble lignin (Klason lignin) was undertaken using Micro-Klason technique (Whiting et al., 1981).

Statistical analysis

At each locality, there were different age groups of species and observations were made at three levels *viz.*, pith, middle and periphery portion of wood at breast height level to find out the radial variation in wood properties. Thus each sample (species) is composed of sub samples (age and position). The sampling and sub sampling gives rise to nested or hierarchical classification (Sokal and Rohlf, 2000). Therefore, nested ANOVA was carried out to find variation between species, age group and positions using the statistical package SAS (Statistical Analysis System ver. 10). Analysis of variance was carried out using univariate mixed model with two levels of errors to explain variation in different parameters studied.

Results and Discussion

Specific gravity

The variation in specific gravity (oven dry) due to age and species is given in the Table 2. Analysis of variance did not reveal any significant variation in specific gravity due to age but species wise variation was significant with *Pinus oocarpa* recording the highest average. Highly significant variation in specific gravity was recorded with respect to radial positions within each species (1% level). Specific gravity was found to increase from pith to periphery in all the three species studied. Variation along radial direction is the best known and most studied within tree variability in wood, which is generally reflected as radial pattern of change in wood properties of juvenile and mature wood. The radial change in wood properties varies in magnitude and type in different species (Uetimane and Ali 2011, Ishiguru et al., 2009 and 2011). Among the physical properties, specific gravity is a key wood property as it has a major effect on the yield and quality of both fibrous and solid wood products (Haslett and Young, 1990). Specific gravity differs between species, sites, trees and within the tree. Generally, it tends to increase from the centre of the tree to the bark. Specific gravity appears to influence machinability, conversion, strength, paper yield and many other properties (Wimmer et al., 2002). Specific gravity of *Pinus caribaea* and *P. patula* is found to fall within the range of d” 0.60 (Chittenden

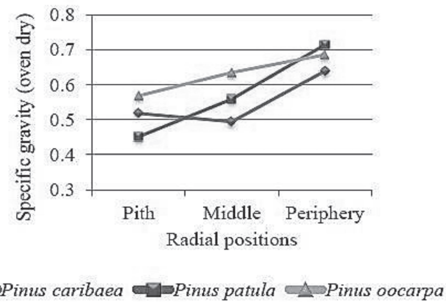

Figure 1. Radial variation in specific gravity (oven dry) of pine species averaged over all ages

Table 2. Wood specific gravity (oven dry) of pine species at different ages

Species	Specific gravity (oven dry)				
	Age in years				Mean
	28	31	32	35	
Pinus caribaea	0.51^{a} (0.13)	0.55^{a}(0.11)	0.64 ^{a}(0.12)	0.50^{a} (0.124)	0.55^{B} (0.13)
Pinus patula	0.57^{a} (0.16)	0.57^{a} (0.14)	0.61^{a} (0.20)	0.56^{a} (0.19)	0.58^{AB} (0.17)
Pinus oocarpa	0.61^{a} (0.09)	0.63^{a} (0.09)	0.62^{a} (0.11)	0.67^{a} (0.06)	0.63^{A} (0.09)

and Palmer, 1990) suggested for pulping and paper making (Fig.1), whereas *P.oocarpa* is having a value above the desired range. Higher specific gravity observed towards periphery suggests minimal usage of the high density outer wood portion.

Tracheid morphology

Tracheid morphological parameters such as diameter and lumen diameter significantly varied between species, whereas tracheid length and fibre wall thickness did not vary with respect to species. Tracheid length showed significant difference between radial positions in each species. Among the three pine species, *Pinus caribaea* had the highest tracheid length (4076.48 µm) followed by *Pinus oocarpa* and *Pinus patula* (Table 3). Tracheid diameter was found to have significant difference between species and between radial positions within the species (Fig. 2). *Pinus caribaea* had highest value (53.49 µm) for tracheid diameter followed by *Pinus oocarpa* and *Pinus patula*.

Significant difference in tracheid wall thickness was found between radial positions within species (Fig. 3). Among the three pine species, *Pinus oocarpa* had the highest (5.50 µm) tracheid wall thickness followed by *P. caribaea* and *P. patula* (Table 3). The variation in tracheid lumen diameter was found to be significant between species. *P. caribaea* had highest (43.23 µm) lumen diameter followed by *P. oocarpa* and *P. patula* (Table 3). Cell size and relating dimensions of tracheids have a major influence on the quality of paper and pulp products as well as solid wood products (Clark, 1962). In conformity with the results obtained in the present study, Wright and Sluis-Cremer (1992) reported slight variation between *P. caribaea* and *P. oocarpa* for tracheid characters *viz.*, tracheid diameter, lumen width, and wall thickness. Morphological variations from pith to bark are, quite often, more pronounced than vertically for many species (Evans et al., 1997; Koubaa et al., 1998; Raymond et al., 1998). Tracheid length, diameter, lumen diameter and wall thickness were found to influence bulk, burst, tear, fold and tensile strength of the paper as reported by Horn (1974). Papers made from tracheids of thick cell walls have lower bursting and tensile strength, whereas lower cell

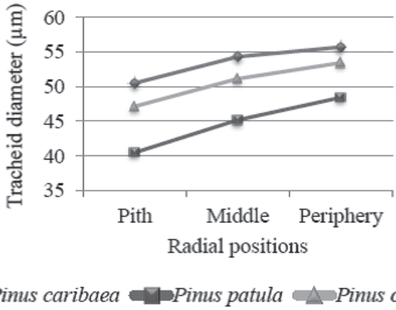

Figure 2. Radial variation in tracheid diameter of pine species averaged over all ages

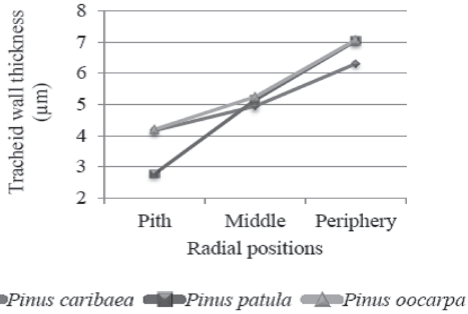

Figure 3. Radial variation in tracheid wall thickness of pine species averaged over all ages

Table 3. Species variation in tracheid dimensions averaged over all ages

Species	Tracheid dimensions (µm)			
	Length	Diameter	Wall thickness	Lumen diameter
Pinus caribaea	4076.48^{a} (931.15)	53.49^{a} (7.14)	5.13^{a} (1.73)	43.23^{a} (7.36)
Pinus patula	3855.49^{a} (1034.72)	48.52^{b} (4.43)	4.98^{a} (2.66)	34.73^{b} (6.05)
Pinus oocarpa	4003.63^{a} (771.63)	49.53^{b} (6.10)	5.50^{a} (2.03)	39.55^{ab} (7.91)

Values with same superscript within a column are homogenous

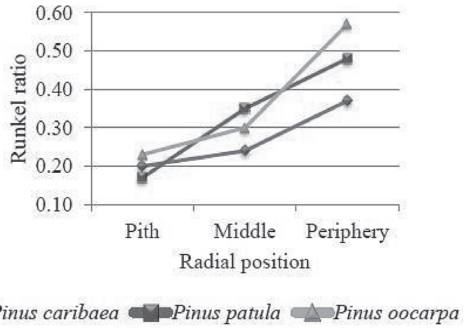

Figure 4. Radial variation in Runkel ratio of pine species averaged over all ages

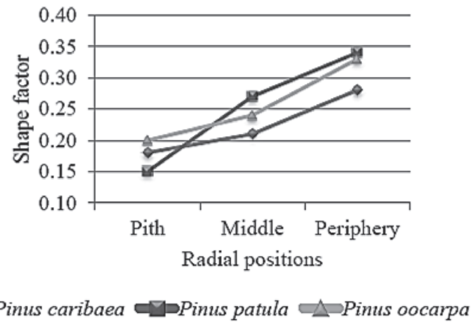

Figure 5. Radial variation in shape factor of pine species averaged over all ages

wall thickness of tracheids results in paper having higher double folding strengths (Tutus et al., 2010).

Considering the importance of pines as raw material for paper and pulp, the different types of ratios like Runkel ratio, slenderness ratio (felting rate or peteri coefficient), coefficients of flexibility and rigidity and shape factor were determined from the basic data on tracheid morphology. All the five attributes showed significant difference among the three radial positions, whereas no significant difference was observed due to age. Radial variation was found to be significant within species with respect to Runkel ratio (Fig. 4). All the three species had Runkel ratio within the acceptable range of d ≤ 1 (Okereke, 1962) for pulping and paper making. Among the three species, *Pinus oocarpa* had highest Runkel ratio (0.37) followed by *P. patula* and *P. caribaea*. In studies utilising *P. radiata* and *P. elliottii* for Kraft pulp production, it was found that the Runkel ratio was the best fibre dimension ratio, and accounted for 80 to 85 per cent (Barefoot et al., 1964; Kibblewhite, 1982) of the variation in the hand sheet tear.

Shape factor was found to have significant radial difference between species (Fig. 5). All the species had lower values of shape factor indicating their suitability for pulping and paper making. Fibers with lower values of shape factor will give better strength to paper and lower tensile stiffness (Page and Seth, 1980). So species with lower shape factor is suitable as a raw material for pulping and paper making.

The findings of our study suggest the suitability of *Pinus caribaea* as a potential one over the other species for pulping, since it has the lowest value for shape factor among the three species studied. Significant difference was observed between species and radial positions within the species also with regard to slenderness ratio (Fig. 6). It is stated that if felting coefficient or slenderness ratio of a fibrous material is lower than 70, it is not valuable for quality pulp and paper production (Young, 1981; Bektas et al., 1999). Average slenderness ratios of the three species suggest their suitability for pulping and paper making. Among them, *Pinus patula* had the highest slenderness value, followed by *P. oocarpa* and *P. caribaea.*

Elasticity coefficient is also referred as Istas coefficient or flexibility coefficient or coefficient of suppleness and it is related with individual elasticity of fibers. According to elasticity rate fibers are grouped into the following four classes (Bektas

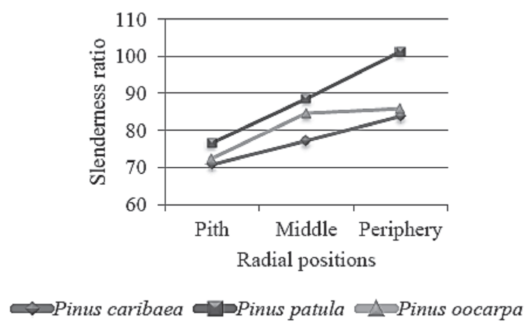

Figure 6. Radial variation in slenderness ratio of pine species averaged over all ages

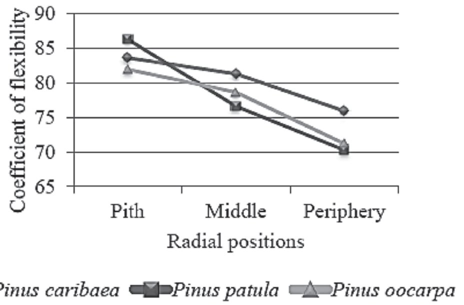

Figure 7. Radial variation in coefficient of flexibility of pine species averaged over all ages

et al., 1999). 1. Highly elastic fibres having elasticity coefficient greater than 75; 2. Elastic fibres having elasticity ratio 50 to 75; 3. Rigidity fibres having elasticity ratio 30 to 50 and 4. Highly rigid fibres having elasticity less than 30. The mean coefficient of flexibility of the three pine species averaged across all ages was found to be within the accepted range of > 70, (Peteri, 1952; Okereke, 1962). Among the three species, *Pinus caribaea* had the highest value followed by *P. patula* and *P. oocarpa*. Coefficient of flexibility had significant radial differences within the species (Fig. 7). Based on this information, it appears that the three pine species in the present study can be included in the highly elastic fibre category. The three radial positions differ significantly from each other and it shows a decreasing pattern from pith to periphery in all the three pine species. This is because of the fact that tracheid diameter increases from pith to periphery, while lumen diameter did not show much difference along the radial positions.

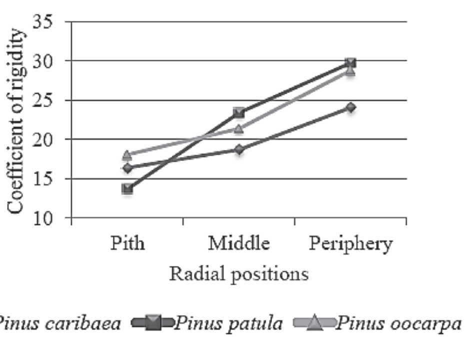

Figure 8. Radial variation in coefficient of rigidity of pine species averaged over all ages

Rigidity coefficient is a measure of physical resistance properties of paper. Higher values for this coefficient affect tensile, tear, burst and double fold resistance of paper negatively (Hus et al., 1975). Radial difference within the species was found to be significant with regard to coefficient of rigidity (Fig. 8). All the three species were found to have lower values for coefficient of rigidity indicating their suitability for pulp and paper making. *Pinus caribaea* had the lowest value (19.72) followed by *P. patula* and *P.oocarpa*. Rigidity coefficient of softwoods were found as 19.97 for *P. sylvestris* (Akkayan, 1983), 20.00 for *P. brutia* (Bektas et al., 1999) and 17.82 for *P. pinaster* (Bektas et al., 1999).

Chemical composition

Cellulose and lignin content were found to differ between species. Cellulose content was found to be highest in *Pinus oocarpa* followed by *P. patula* and *P. caribaea.* These differences in cellulose content among the species might be due to variation in the oven dry specific gravity observed among the species. On the other hand, *P. caribaea* had a higher value for lignin content followed by *P. patula* and *P. oocarpa* (Table 4). For pulping, wood with lower lignin content is preferred as this greatly reduces the cost of chemicals used for its removal. This suggests the superiority of *P. oocarpa* for pulping and paper making.

The findings of the present investigation revealed significant differences between species and within species, between radial positions for specific gravity,

Table 4. Mean cellulose and lignin content of pine species

Species	Cellulose content (%)	Lignin content (%)
Pinus caribaea	33.54^{b} (2.78)	29.54^{a} (1.12)
Pinus patula	40.32^{b} (4.85)	26.20^{b} (1.85)
Pinus oocarpa	47.55^{a} (2.09)	23.80^{b} (1.89)

Means with same letter as superscript are homogenous tracheid morphology, fibre ratios and chemical properties. With regard to suitability for pulp and paper making, *Pinus caribaea* performed better within the accepted range. *P. patula* and *P. oocarpa* were also found to be promising species for pulp and paper with better derived fiber ratios whereas, in terms of chemical composition, *P. oocarpa* performed better with higher cellulose and lower lignin content. Within and between species variation wood properties suggest the possibility of altering these properties either through silvicultural techniques, genetic manipulation or their combination. Further studies are required to determine the relationship, if any, between wood and tracheid properties of these species and the products which can be manufactured from this renewable resource. Results of this study could be used as a base line data for future tree improvement and breeding programme of these tropical pines.

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