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Physical and Anatomical - wood properties variation among the provenances of Red Sanders (*Pterocarpus santalinus*)

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ABSTRACT

Pterocarpus santalinus is critically endangered as well as an endemic tree which is illegally traded for various reasons, across the globe. There are assumptions that red sanders wood from a particular region of its natural distribution has better quality. Based on this hypothesis, we attempted to investigate the wood – anatomical and physical properties variation in its two predominately growing regions *i.e.* Thiruvallur district in Tamil Nadu and Cuddapah district in Andhra Pradesh. Wood samples were collected from the logs and tress in the study region was used for assessing the physical properties based on Indian Standards. However, IAWA protocol was adopted for anatomical studies for better validation and comparison. Independent t-test was deployed at 95% confidence interval. Finally, we could conclude that there is a wide array of possibility for the edapho-climatic factors to influence the wood properties.

1. Introduction

Pterocarpus santalinus (Leguminosae) is an endemic tree, of height < 10m (Raju and Nagaraju 1999). It has a restricted distribution on the dry hill slopes of the Eastern Ghats and mostly confined to Cuddapah and Chittoor districts of Andhra Pradesh. But it also extends northwards till Kurnool and southwards to Thriuvanamalai and Vellore districts in Tamil Nadu (Rao and Purkayastha, 1972). *P. santalinus* is classified as 'endangered' by the 1997 International Union for the Conservation of Nature Red List of Threatened Species (Walter and Gillet, 1998). It was first listed in the Convention on International Trade in Endangered Species (CITES) in 1995 under Appendix II to regulate trade thereby avoiding the extinction possibility (Ian, *et al.,* 2010). The heartwood is decay and insect resistant. Historically, *P. santalinus* is used as dyes, owing to the presence of red 'santalin' pigments (Mulliken and Crofton, 2008). Extract preparations from heartwood have widely documented in traditional Indian ayurvedic medicine (Gupta and Uniyal 2003).

The wavy grain timber does have traditionally demanded carvings, making musical instruments and luxury furniture. Although the red sanders usage is quite less in India, China and Japan extensively used it. This increased demand for the wood in the global market has led to its large scale smuggling Gasson *et al.* (2011) provide an extremely detailed description of *P. santalinus* wood anatomy including large numbers of measured characters. By comparison, Suresh *et al.* (2017) provide descriptive wood properties of *P. santalinus.* Chauhan and Vijendra Rao (2003) include measurements of specific gravity, vessel diameter, vessel length, number of crystal locules per chain, fibre length, fibre diameter, ray width and height. Recent interest in this endangered species has raised several research questions regarding wood quality from certain provenance. Therefore the objectives of this study to determine the variation in wood physical and anatomical properties of this species belonging to the Thiruvallur, Tamil Nadu and Cuddapah, Andhra Pradesh provenance. The investigation was aimed at analyzing the physical and anatomical differences between two provenances of *P. santalinus*.

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2. Materials and Method

The samples were collected between 2015 - 2016 from logs seized by the Forest Department from Cuddapah forest division of Andhra Pradesh (14°28'2.4594" N and 78°49'26.8674"E) and logs of a tree felled at Gummidipoondi (Thiruvallur forest division) of Tamil Nadu (13°25'42.528"N and 80°0'1.692"E). The plantation of the Gummidipoondi (Nemalur Range, Thiruvallur Division) was established in 1970. The samples in the form of discs were converted into blocks. For this, discs were taken and cut tangentially along lines leaving 2cm on either side of the central axis. The blocks were again divided into 5 equal samples. The samples thus obtained of dimension 4 x 4 x 4 cm were further sub divided into five sub samples each maceration, microtomy and physical properties estimation. The sample collection process was a herculean task.

Physical Properties

Moisture content (MC), specific gravity, radial and tangential shrinkage estimation was done as per IS 1708 (part 4): 1986 (ISI, 1986). Specific gravity measurement was estimated on fresh, air dry and oven dry weight basis. Radial and tangential shrinkage at air dry (12% MC) and oven dry conditions (102±1^{0}C) were calculated using the following formula

a) RS or TS from green to air –dry condition (%) =L_g-L_a x100/L_g.
b) RS or TS from the air –dry to oven –dry condition (%) =L_a-L_o x100/L_o.
c) RS or TS from green to oven dry condition (%) =L_g-L_o x 100/L_o.

where,
L_g= length of specimens along radial or tangential plane at green condition (mm)
L_a=length of specimen along radial or tangential plane at air-dry condition (mm)
L_o=length of the specimen along radial or tangential plane at oven –dry condition (mm)

Heartwood colour

Heartwood colour determination of the samples was conducted using munsell system. From the air dried (12% MC) 5 cm thick cross sectional disc, a radial strip of 3 cm width was cut from inner to outer heartwood in both radii excluding the pith. The two cut samples were grounded in a mechanical grinder. The powder was passed through No.40 (420µm) sieve and retained in No.60 (250µm) sieve separately. The colour was determined within a day to avoid colour changes caused by oxidation.

Anatomical Properties

A total of fifteen blocks 2 x 2 x 2 cm were used for the entire anatomical studies.

Microtomy

Small blocks (1 x 1 x 1 cm) representing the pith, middle and periphery portions were used for anatomical studies. Sectioning was carried using the sliding microtome (Leica SM 2000R) after softening the samples by heating in water bath at 100^{0}C for an hour. Cross and tangential sections of 10-15µm thickness were prepared. After sectioning and staining, the samples were mounted and analysed using an Image Analyser (Labomed-Digi 2). Various parameters of vessels and rays including their length, diameter and number per unit area were noted and measurements were repeated ten times from each sample (µm). Ray frequency was measured by counting the number of rays from a selected area in the section and was expressed in number per millimetres (mm).

Maceration

Jeffrey's method was used for wood maceration. Separated fibres were stained using saffranin and mounted on temporary slides using glycerine as the mountant. From the slides prepared, parameters such as fibre diameter, fibre wall thickness and fibre lumen diameter were measured using Labomed-Digi 2. The following ratios were computed.

$$\text{Runkel Ratio} = \frac{2 \times \text{Fibre Wall Thickness (FWT)}}{\text{Fibre Lumen Diameter (FLD)}}$$

$$\text{Slenderness ratio} = \frac{2 \times \text{Fibre Length (FL)}}{\text{Fibre Diameter (FD)}}$$

$$\text{Rigidity Coefficient} = \frac{2 \times \text{Fibre Wall Thickness (FWT)}}{\text{Fibre Diameter (FD)}}$$

$$\text{Flexibility coefficient} = \frac{\text{Fibre Lumen Diameter (FLD)}}{\text{Fibre Diameter (FD)}}$$

$$\text{Shape Factor} = \frac{D^2 - L^2}{D^2 + L^2}$$

where D- Fibre Width, L-Lumen Width

3. Results and Discussion

Physical Properties

There was no significant variation observed in moisture content at the green condition and air condition with regard to provenances ($p<0.05$). Thiruvallur provenance had highest moisture content (wet) of 33.23%. On contrary, Cuddapah provenance had a higher moisture content in the dry condition (12.76%). This trend also reflected in the specific gravity too. There was a significant variation ($p<0.05$) in the specific gravity between the provenances in all the three conditions (green, air dry and oven dry). The values of specific gravity at oven dry condition of Thiruvallur (0.96) and Cuddapah (1.14).

Table 1. Physical properties of Red Sanders from two provenances

Physical Properties	Thiruvallur Provenance	Cuddapah Provenance
Specific gravity		
Air dry	1.09	1.23
Wet	1.24	1.25
Oven dry	0.96	1.14
Radial Shrinkage (%)		
Air dry	22.85	24.80
Wet	23.01	24.86
Oven dry	22.05	24.03
Tangential Shrinkage (%)		
Air dry	16.46	19.10
Wet	16.78	19.09
Oven dry	16.24	18.21
Moisture content (%)		
Wet basis	33.23	16.12
Dry basis	10.56	12.76

Radial shrinkage (green to air dry) was significant between the provenances ($p<0.05$). Thiruvallur showed a higher radial shrinkage value (green to air dry) compared to Cuddapah. Similarly, the radial shrinkage (air dry to oven dry) showed a significant difference between Thiruvallur (0.24%) and Cuddapah (0.28%) ($p<0.01$). Independent t-test carried out revealed that there exists no significant difference between tangential shrinkage of green to air dry condition and air dry to oven dry condition. However, the tangential shrinkage (green to oven dry) was significant ($p<0.01$). The coefficient of anisotropy (ratio of tangential to radial shrinkage) values *viz* air dry to oven dry, green to air dry and green to oven dry was observed to be non-significant ($p<0.05$).

The coefficient of anisotropy (green to air dry) of Thiruvallur sample was 1.2 and that of Cuddapah was 1.25. At air dry to oven dry condition, the value of the coefficient of anisotropy for Thiruvallur was 0.82 and for Cuddapah 0.86. While considering green to oven dry condition the value was 1.03 for both samples.

Anatomical Properties

The entire results and discussion section are focused only on the heartwood anatomical properties. Even though, the sapwood anatomical properties are also listed for future works.

Vessel morphology

The vessel diameter was non-significant between the provenances. Higher vessel diameter was 434.78µm by Thiruvallur and it was 158.75µm for Cuddapah. Vessel area was significant between the two provenances. Rationally, a greater value of vessel area was observed in Thiruvallur (31354.31μm^2) than that of Cuddapah (19915.48μm^2). The results for vessel frequency revealed that there was no significant difference between the two samples. Overall, vessel frequency value ranged from 1 to 3 vessels per mm^2. Vessel vulnerability value claims no significant variation with regard to the two sample locations.

Fibre morphology

Fibre morphological parameters are listed in table 2. Fibre length and fibre lumen width showed no significant variation with respect to the provenance ($p< 0.05$). The variation was significant for fibre wall thickness, fibre width at 5 % level. While comparing the values of fibre length, Thiruvallur had a value of 1048.97 µm and Cuddapah had a value of 840.50 µm. Fibre width observed to be 25.56 µm for Thiruvallur and 23.93µm from Cuddapah. The fibre wall thickness is higher for Thiruvallur (7.93µm). Fibre lumen width value showed a considerable difference as Thiruvallur has 11.05µm than that of Cuddapah (8.34µm). The variation in fibre ratio values such as Runkel ratio, Slenderness ratio, Flexibility co-efficient, Shape factor was all significant at 5% and Rigidity co-efficient at 1%. Comparing the Runkel ratios, Cuddapah (1.70) was observed to have a higher value than Thiruvallur (1.47). The slenderness ratio of Thiruvallur is 82.79 and Cuddapah are 70.86. Thiruvallur (86.04) showed a higher value of flexibility coefficient than Cuddapah (72.93). Cuddapah showed higher rigidity coefficient (62.23) and shape factor (0.76) than Thiruvallur provenance.

Ray morphology

The ray morphology parameters such as ray height, ray width, ray frequency showed a significant variation. Ray height was highly significant at 1% whereas ray width, ray frequency was significant at 5 %. Ray height value of Thiruvallur is found to be 187.32µm and that of Cuddapah is 189.5µm. Ray width value was higher in Thiruvallur (22.85µm) than Cuddapah (19.5µm). An average of 35 rays per mm² was observed in Thiruvallur and for Cuddapah, it was 32 rays per mm².

Table 2. Anatomical properties of Red Sanders from two provenances

Anatomical properties	Thiruvallur Provenance	Cuddapah Provenance
Fibre length (µm)	1048.97	840.50
Fibre width (µm)	25.56	23.93
Fibre wall thickness (µm)	7.93	7.30
Fibre lumen width (µm)	11.05	8.34
Runkel ratio	1.47	1.70
Slenderness ratio	82.79	70.86
Flexibility co-efficient	86.04	72.93
Rigidity co-efficient	61.42	62.23
Shape factor	0.68	0.76
Vessel diameter (µm)		
Heartwood	434.78	158.75
Sapwood	186.29	113.12
Vessel area (μm^2)		
Heartwood	31.354.31	19915.48
Sapwood	32.672.50	18514.54
Vessel frequency		
Heartwood	2.49	2.40
Sapwood	2.27	3.18
Ray width (µm)		
Heartwood	22.85	19.50
Sapwood	19.68	18.50
Ray height (µm)		
Heartwood	187.32	189.50
Sapwood	210.75	170.50
Ray Frequency		
Heartwood	34.50	32.30
Sapwood	36.73	30.35

Cudappah provenance had lesser ray frequency which contributed to higher specific gravity. However, the difference in density did not seem to be consistently related to the proportion of vessels.

The larger vessels diameter lowers the specific gravity of *P. dalbergioides* and *S. macrophylla* (Ziemińska *et al*., 2015). Here too in this study, Thiruvallur provenance had larger vessel diameter which also contributed to lower specific gravity. Dry climatic condition indeed favours higher specific gravity. This was reflected in Cuddapah provenance (Fortunel *et al*., 2014). As it is proven fact that climate condition does exert an influence on the wood specific gravity. It also is seen in the study that Cuddapah provenance had a high moisture content.

Density may vary among trees of the same species due to genetics and ecological differences, as well as within a tree, *i.e.* age-related longitudinal and radial variation (Wate *et al*., 1999). Regardless of the environment in which the trees are grown, within each population, some individuals will have relatively high while others have low densities when compared to the average of the stand. This is due to strong genetic control of wood specific gravity among individual trees. The environment exerts strong control over the average wood specific gravity, while genetic control results in the tree to tree differences within the same environment. Madsen *et al*. (1978) had stated that the basic density of wood is negatively correlated with the amount of water accessible to the tree. Moisture content is one of the important factors that is commonly associated specific gravity. For example, the change from the early wood to late wood can be attributed entirely to soil moisture availability. Moisture content at dry conditions was found to be significantly greater for Cuddapah. The higher value of moisture content of Cuddapah can be related to the higher specific gravity.

Dimensional movement in wood is basically manifested by water absorption but is attributable to a number of other factors related to its physical, chemical nature and anatomical structure. Swelling and shrinkage could also be considered as 'intelligent' characteristics of wood because wood can change dimensions by itself in response to the atmosphere (Okuma, 1998). The anisotropicity in shrinkage behaviour of wood is attributed to the microscopic orientation of the various cells, their distribution and alignment as well as the differences at the ultrastructural level. The anisotropy on the transverse face of the wood relates to the difference in the shrinkage ratio in the tangential and radial directions. There are greater numbers of factors contributing to anisotropy in the transverse face in comparison with the longitudinal face. Taguchi *et al*. (2011) studied the effect of rays on the coefficient of anisotropy. Present study observed to have the inverse relation between ray morphological parameters and coefficient of anisotropy.

Heartwood colour

Colour variation of heartwood by determining the components (hue, value, and chroma) did not show any significant variation. The variability in luminescence (*i.e.* darkness or lightness) is considered as the primary cause of heartwood colour variability (Thulasidas *et al*., 2006). Samples obtained from Thiruvallur had pale yellowish sapwood. Both samples had red coloured heartwood which on exposure turns dark brown (Siva, 2007). However, Cuddapah provenance was characterized by peculiar heartwood colour and odour (4YR/4/6). Deposits of resinous, phenolic and other compounds which contribute considerably to the colour of heartwood.

Table 3. Variation in heartwood colour components between Thiruvallur and Cuddapah

Parameters		**Provenance**	**Value**
Heartwood colour	Hue	Thiruvallur	2.5 YR
		Cuddapah	4 YR
	Value	Thiruvallur	2.5
		Cuddapah	4
	Chroma	Thiruvallur	6
		Cuddapah	8

Table 4. Comparison of physical and anatomical properties between Thiruvallur and Cuddapah

S. No	**Properties**	**Overall mean**	**p value**	**t value**
1	Specific Gravity (Air Dry)	1.13*	0.053	11.95
2	Specific Gravity (Wet)	1.24**	0.003	249.00
3	Specific Gravity (Oven Dry)	1.05*	0.051	12.41
4	Fibre Length (µm)	944.73^{ns}	0.070	9.06
5	Fibre width (µm)	24.74*	0.021	30.54
6	Fibre wall Thickness (µm)	7.61*	0.026	24.55
7	Fibre Lumen Width (µm)	9.69^{ns}	0.088	7.18
8	Runkel Ratio	1.58*	0.046	13.78
9	Slenderness Ratio	76.82*	0.049	12.88
10	Flexibility Co-efficient	79.48*	0.052	12.13
11	Rigidity Co-efficient	61.82**	0.004	152.65
12	Shape Factor	0.72*	0.035	18.00
13	MC at wet weight basis (%)	24.67^{ns}	0.212	2.88
14	MC at dry weight basis (%)	11.66^{ns}	0.060	10.60
15	Ray Height(µm)	188.41**	0.004	172.85
16	Ray Width(µm)	21.18*	0.050	12.62
17	Ray Frequency (No/mm²)	33.40*	0.021	30.36
18	Vessel Area (µm²)	21177.78*	0.038	16.78
19	Vessel Frequency (No/mm²)	1.99^{ns}	0.155	4.03
20	Vessel diameter (µm)	296.76^{ns}	0.277	2.15
21	Vessel vulnerability	0.26^{ns}	0.060	10.51
22	Radial shrinkage (Grn to AD)	0.26*	0.046	13.77
23	Radial shrinkage (AD to OD)	0.53**	0.008	83.48
24	Radial shrinkage (Grn to OD)	0.33*	0.047	13.47
25	Tangential shrinkage (Grn to AD)	0.22*	0.059	10.69
26	Tangential shrinkage (AD to OD)	0.22*	0.059	10.69
27	Tangential shrinkage (Grn to OD)	1.23**	0.013	47.43
28	Coefficient of anisotropy (Grn to AD)	0.84**	0.013	47.37
29	Coefficient of anisotropy (AD to OD)	0.41^{ns}	0.067	9.48
30	Coefficient of anisotropy (Grn to OD)	140.22^{ns}	0.153	4.08

*ns- non significant at 0.05 levels; ** significant at 0.01 levels; * significant at 0.05 levels*

Vessel area was found to have significant variation. Varghese *et al.* (2000) studied the variation in growth and wood traits among 9 populations of teak in peninsular India and indicated that latitudinal effects have little influence on vessel parameters. In the present study, the vessel frequency and vessel diameter values were higher though non-significant. Vessel morphology is substantially influenced by the environment. This view is supported by Tyree *et al.* (1994) who showed that vessel ratio in the tangential and radial directions. Fibre length and fibre lumen width were found to have no significant variation with respect to location. The variation was significant for fibre wall thickness and fibre width. Wood elements and the anatomical ratio of *Dipterocarpus indicus* were studied by Prasad and Al Sagheer (2012). The study revealed significant variations in fibre length, fibre diameter and wall thickness among populations. The variations in their wood traits were attributed to the site factors. The interaction between the genetic makeup of wood traits combined with effects of edaphic, local and regional climatic conditions reflect the amount of variation among populations. Hence this variation between the same species of Thiruvallur and Cuddapah can be attributed to the local edaphic as well as climatic differences.

Comparison of the wood of *P. santalinus* with the other species of the *Pterocarpus* genera was done by Ian, *et al*. (2010). These brief comparisons highlight the primary differences between *P. santalinus* and the other *Pterocarpus* species which showed that *P. santalinus* has thin non-uniform fibre wall thickness in early wood and thick in latewood. *P. santalinus* have uniform cell wall thickness. In our study, Cuddapah and Thiruvallur provenances, *P. santalinus* had uniform cell wall thickness.

Kiaei *et al.* (2014) reported desirable values of Runkel ratio, slenderness ratio, flexibility co-efficient in hardwoods and softwoods. According to him the values of Runkel ratio, slenderness ratio, and flexibility co-efficient are 0.04 - 0.07, 55-70 and 55-75 respectively for hardwoods. Runkel ratio which refers to the ratio between double the wall thickness and lumen diameter is commonly used as an indicator of collapsibility of tracheids. Even though, the main purpose of table 4. is to indicate the t-value, the overall mean value has been listed to give a summation average of the wood properties

On the whole, the present studies clearly show the variation in the wood properties between the red sanders of two provenances. The very important physical property – specific gravity is statistically significant across the two selected provenances.

Red Sanders being an endangered species and highly protected. There were many difficulties in obtaining samples. However, our findings summaries the wood properties of *P. santalinus*. Subsequently, this study can be the base for the future studies to be carried out.

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