Variability for Heartwood Content in Three Commercially Important Tree Species of Peninsular India—*Hardwickia binata, Pterocarpus santalinus* and *Santalum album*

A.N. Arun Kumar, Geeta Joshi and S. Manikandan

Abstract In most of the tree improvement programs of highly valued wood tree species, generally, height and diameter are the two important factors considered while selecting superior genotypes. However, it is now being realized and accepted that it is essential to include various wood traits while selecting superior genotypes for breeding strategies. We are of the opinion that it is necessary to also include the heartwood content as another important trait because of its commercial value. As a prelude to consider heartwood content as one of the selection traits for tree improvement programs, it becomes imperative to document the variation in this trait in a given population. Information about heartwood formation, progression, and genetics is being studied globally, and preliminary indications are that it is genetically controlled, but the role of environmental factors is also equally important. In this paper, heartwood content variation in known aged plantation and its relationship with tree girth in three important indigenous highly valued tree species—*Hardwickia binata* (Anjan), *Pterocarpus santalinus* (Red Sanders) and *Santalum album* (Indian Sandalwood)—is discussed. Significant variation was observed in young-aged plantations in all the three species.

Keywords Heartwood · Variation · *Hardwickia binata* · *Pterocarpus santalinus* · *Santalum album*

A.N. Arun Kumar (✉) · G. Joshi
Tree Improvement and Genetics Division,
Institute of Wood Science and Technology, Bengaluru, India
e-mail: anarunkumar@gmail.com; arun@icfre.org

S. Manikandan
Karnataka Forest Department, Bengaluru, India

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Introduction

Documenting variability is an important aspect before initiating any strategies in tree improvement work. As a first step, growth traits such as tree diameter, height, and clear bole height are considered. These are supported with some morphological traits such as leaf, fruit, and seed. Generally, the most common practice while selecting superior genotypes was restricting to these morphological traits. However, it is now being realized to essentially incorporate wood traits during selection process. Specific gravity has been considered as an important wood-quality trait that is considered to be heritable and having impact both on wood and on pulp quality. However, in some of those tree species having commercial value for timber applications, the heartwood component of the tree can influence its utilization as it forms an important characteristic of internal stem structure (Knapic and Pereira 2005). Therefore, it becomes necessary to document the variation in heartwood content. However, an important rider while considering heartwood as a trait for selection process is the tree age as heartwood can be significantly affected by the age.

The International Association of Wood Anatomists (IAWA) has defined heartwood as “the inner layers of the wood, which, in the growing tree, have ceased to contain living cells and in which the reserve materials (e.g., starch) have been removed or converted into heartwood substance” (IAWA 1964). In essence, heartwood is the dead part of the tree and is located in the older part of the stem, as an inner core that approximately follows the stem profile. It is physiologically inactive, without water-conducting properties, and contains a large amount of resinous and phenolic extractives with biotic resistance.

The living part of the tree is known as sapwood and is defined by IAWA (1964) as “the portion of the wood that in the living tree contains living cells and reserve materials.” Sapwood has high moisture content, containing reserve material such as starch, and plays an important role in the transpiration stream of the tree (Taylor et al. 2002). It primarily conducts water from the roots to the crown (Gartner 1995), and there is a strong correlation between amount of foliage and sapwood in a tree (Berthier et al. 2001; Dean and Long 1986; Whitehead et al. 1984). The heartwood and the sapwood are distinctly different based on features such as color, natural durability, and suitability for chemical treatment (Panshin and de Zeeuw 1980; Haygreen and Bowyer 1989).

Relatively, most of the work on heartwood and its variation has been extensively carried out in temperate species and conifers. However, some of the tropical species that have been studied are Acacias and Eucalypts, primarily for paper pulp where heartwood is considered to be a deterrent factor due to color and extractive contents in the heartwood. In the case of tree species, even though the presence of heartwood has high technological relevance, the physiological aspects of it are still not clearly understood.

The present study aims at documenting heartwood variation within a known aged population in the case of three important tropical species—*H. binata*, *P. santalinus* and *S. album*, which are popular tree species in India.

Hardwickia binata (Family: Fabaceae) commonly known as Anjan is a moderate- to large-sized deciduous, gregarious tree and is native to tropical Southeast Asia. The tree attains height up to 36 m and girth of 4 m having a clean cylindrical bole of 12–15 m. *H. binata* is monotypic tree genera (Garad et al., 2015), widely distributed in the dry deciduous forests of Peninsular India and North India, excluding Northeast India (Irwin and Narasimhan 2011). *H. binata* is a typical species of dry and hot climate characterized by long period of drought, scanty to moderate rainfall, and intense heat during the summer season. Within its natural range, the minimum and maximum temperature may vary from 10 to 47 °C and the rainfall may vary from 250 to 1500 mm (Anon 1983). The wood is extremely hard and heavy, fairly durable and moderately strong, and highly resistant to decay and classified as class I timber. The heartwood is dark reddish brown streaked with purple and is clearly differentiated from sapwood which is pale white in color. It is one of the timbers accepted by Indian Railways for sleepers even without treatment. The wood has high calorific value (4900 k cal/kg) and is used for charcoal making. The leaves are classed as good fodder, and the tree is popular now in agroforestry.

Pterocarpus santalinus (Family: Fabaceae) is a deciduous tree commercially known as Red Sanders. As an endemic tree of India, its natural distribution being restricted to tropical dry deciduous forests of Andhra Pradesh being localized and predominantly confined to Cuddapah landscape (Raju et al. 1999). In its natural habitat, the tree girth varies from 90 to 160 cm and height reaching up to 15 m with dense round crown. Red Sanders grows in harsh conditions as is evident by the minimum and maximum temperature varying from 11 to 46 °C and the rainfall being as low as 100–1000 mm. The heartwood color is red to almost purplish black and the wood is strong, hard, and heavy with dried wood-specific gravity ranging from 0.80 to 1.20. Wenbin and Xiufang (2013) reported that in China Red Sanders wood is valued as gold and costs around US$ 150,000/m^3.

Santalum album (Family: Santalaceae) is an evergreen tree commercially known as Indian Sandalwood is known world over for its highly valued heartwood from which fragrant essential oil is distilled. The oil has earned a sobriquet as "queen of essential oil." Sandalwood is naturally distributed from 30°N to 40°S, from Indonesia in the east to Juan Fernandez Islands (Chile) in the west and from Hawaiian Archipelago in the north to New Zealand in the south (Srinivasan et al. 1992). Natural population of sandalwood in India had been predominantly found in southern part of Karnataka and northern part of Tamil Nadu. It has also been found in the states of Kerala and Andhra Pradesh. Isolated populations have been reported in various states such as Bihar, Gujarat, Haryana, Maharashtra, Madhya Pradesh, Orissa, Punjab, Rajasthan, Uttar Pradesh, West Bengal, Himachal Pradesh and Assam which might have been introduced.

Materials and Methods

To document the heartwood variation in *H. binata, P. santalinus* and *S. album*, plantations were selected preferably of 20 years so as to capture the maximum variation. In the case of *H. binata*, a 20-year-old plantation established by Karnataka Forest Department in Madapaura, Bagalkote Range, Bagalkote Division was selected. For *P. santalinus* also a 20-year-old plantation established by Karnataka Forest Department in Jharakbande A Block, Research Range Office, Bengaluru, was considered. In the case of *S. album,* a 20-year-old germplasm bank of sandalwood established by the Institute of Wood Science and Technology at Gottipura Research Station, Hoskote, ~30 kms from Bengaluru, was selected.

Sample plots were randomly laid out in *H. binata* and *P. santalinus* plantation, and all the trees within the sample plot were considered for recording the field data as well as collection of core samples. The number of sample plots varied depending on the plantation area and tree availability; however, care was taken such that observation was recorded from a minimum of 100 trees. In the case of *S. album*, three ramets from each accession were selected, and from 37 accessions, a total 111 ramets were considered for the study. During the collection of core samples in *H. binata,* it was found that in trees of girth size <40 cm, heartwood formation had not been initiated. Therefore, for the present study, trees greater than 40 cm were generally considered for collecting the core samples.

Tree girth was measured at breast height using a measuring tape and expressed in centimeter. To estimate the bark, sapwood, and heartwood thickness, core samples were drawn using increment borer (Haglof). Two core samples from each tree were drawn at breast height at right angles to each other in order to obtain correct length of heartwood, sapwood, and bark thickness. By converting the tree girth into radius using the formula $2\pi r$ (where $\pi = 3.1415$ and r = radial length), the measurement of heartwood radius was calculated. Similarly, bark and sapwood thickness was also calculated.

Results

The average girth of *H. binata* trees ($n = 100$) selected for the study was 58.87 cm and the girth ranged from 43 to 86 cm. It is evident from Table 1 that there is a considerable variability in the case of radial heartwood thickness (CV = 48.68%). The highest heartwood content was 68.09%, and the lowest heartwood content of 6.35% was found in a tree of 52 cm girth. Among the trees from which core samples were collected ($n = 100$), heartwood had not formed in five trees of girth sizes, 43, 48, 49, 53, and 58, respectively. There was a strong positive correlation

Table 1 Summary of statistics on girth, bark, sapwood, and heartwood thickness (%) for *H. binata* trees of 20 years old in Madapura plantation (n = 95[a])

Parameters	Girth (cm)	Bark thickness (%)	Sapwood thickness (%)	Heartwood thickness (%)
Range	43–86	6.18–20.56	21.10–89.76	6.35–68.09
Mean	58.87	10.26	53.70	36.02
Standard deviation	2.68	2.63	16.80	17.54
CV (%)	15.82	25.64	31.29	48.68

[a]Five trees which did not have heartwood have been excluded

Table 2 Correlation between girth and wood traits in 20-year-old trees of *H. binata*

	Girth	Bark thickness	Sapwood thickness	Heartwood thickness
Girth	1			
Bark thickness	−0.63[a]	1		
Sapwood thickness	−0.45[a]	0.39[a]	1	
Heartwood thickness	0.74[a]	−0.57[a]	−0.98[a]	1

[a]Significant at $p < 0.01$

Table 3 Summary of statistics on girth, bark, sapwood, and heartwood thickness (%) for *P. santalinus* trees of 20 years old in Jharakbande plantation (n = 98[a])

Parameters	Girth (cm)	Bark thickness (%)	Sapwood thickness (%)	Heartwood thickness (%)
Range	32–79	11.26–33.79	22.86–78.08	3.36–65.71
Mean	49.84	18.67	45.68	35.66
Standard deviation	9.76	4.06	12.35	12.54
CV (%)	19.58	21.74	27.01	35.16

[a]32 trees which did not have heartwood have been excluded

between girth and heartwood thickness suggesting that higher the tree girth, the more would be the heartwood thickness (Table 2).

In the case of *P. santalinus*, the average girth was 49.84 cm and the heartwood thickness varied from 3.36 to 65.71% with a CV value of 35.16% (Table 3). Out of the 130 trees selected for the study, in 98 trees heartwood had formed. Out of the 32 trees in which heartwood had not formed, 12 trees were within the girth class of 30–40 cm, 17 trees were in 40–50 cm girth class, and three trees in 50–60 cm girth class. There was a strong positive relationship between girth and heartwood thickness (Table 4).

Considerable variation was observed in *S. album* for girth and wood traits. Heartwood thickness had maximum coefficient of variation value (33.63%) and it

Table 4 Correlation between girth and wood traits in 20-year-old trees of *P. santalinus*

	Girth	Bark thickness	Sapwood thickness	Heartwood thickness
Girth	1			
Bark thickness	−0.41[a]	1		
Sapwood thickness	−0.43[a]	−0.12	1	
Heartwood thickness	0.56[a]	−0.21	−0.95[a]	1

[a]Significant at $p < 0.01$

Table 5 Summary of statistics on girth, bark, sapwood, and heartwood thickness (%) for *S. album* trees of 20 years old in Hoskote germplasm bank (n = 96[a])

Parameters	Girth (cm)	Bark thickness (%)	Sapwood thickness (%)	Heartwood thickness (%)
Range	26–56	5.32–13.96	22.44–81.95	12.75–78.93
Mean	36.97	5.41	54.06	40.58
Standard deviation	6.34	1.60	13.14	13.64
CV (%)	17.14	29.57	24.30	33.63

[a]15 trees which did not have heartwood have been excluded

Table 6 Correlation between girth and wood traits in 20-year-old trees of *S. album*

	Girth	Bark thickness	Sapwood thickness	Heartwood thickness
Girth	1			
Bark thickness	−0.08	1		
Sapwood thickness	0.46[a]	−0.19	1	
Heartwood thickness	0.63[a]	−0.06	−0.38[a]	1

[a]Significant at $p < 0.01$

varied from 12.75 to 78.93% (Table 5). Out of 111 trees, heartwood had not formed in 15 trees in sandalwood. There was a strong positive linear relationship between girth and heartwood (r = 0.64) (Table 6).

Discussion

Heartwood is one of the important components in determining wood quality in most of the commercially important tree species. Panshin and Zeeuw (1980) reports that those species that are less efficient in utilizing food products through photosynthesis have the tendency to initiate the early formation of heartwood while it is the other way in the case of species which are efficiently utilizing the photosynthates as food. However, formation of heartwood and sapwood especially in hardwoods varies with species, location, and season, and little is known about the variation in heartwood and the factors associated with it especially in most of the tropical tree species except for teak and eucalypts. Three commercially important tree species of India, *H. binata*, *P. santalinus* and *S. album,* were studied for understanding the variation especially in growth and heartwood. Age plays a significant role in heartwood formation. For better comparison, in the present study, age of the trees were kept constant which was twenty years in all the three species. There was considerable variability in girth among all the three species, and the CV values were >15%.

Among the three species, bark thickness was the highest in the case of *P. santalinus* but the CV value was less compared to the other two species. CV values for bark thickness varied between 21.74 and 29.57%. Heartwood thickness was maximum in sandalwood (78.93%) compared to *P. santalinus* (65.71) and *H. binata* (68.09%). Heartwood formation starts much earlier in the case of sandalwood and it is reported to start by the end of seventh or eighth year. However, not much information is available for the other two species. But the CV value was more or less similar in the case of sandalwood (33.63%) and Red Sanders (35.16%). Though sandalwood grows well in adjoining area of Bengaluru, being an endemic species, growth of Red Sanders in Bengaluru seems to be encouraging considering the extent of heartwood formation. However, maximum variability in heartwood thickness was recorded in the case of *H. binata* (CV = 48.68%) which may be attributed to the stress condition in which it was growing as the area is prone to high temperature with scanty rainfall. Heartwood and sapwood formations of living trees, especially in hardwoods, vary with species, site, parts of the tree, and season and water distribution inside the stem. Björklund (1999) while identifying heartwood-rich stands of *Pinus sylvestris* found that heartwood content varied considerably between individual trees and between stands. It was found that the variation between trees within the same diameter at breast height (DBH) class, growing in the same stand, was higher than the variation between stands. Wide range of variability was observed for heartwood content in different half-sib progenies of *Eucalyptus tereticornis* (Kumar and Dhillon 2014). The heartwood content increases with tree age and various authors found evidence that, after a certain initiation age, heartwood is formed at a constant annual ring rate especially in the case of temperate species (Hazenberg and Yang 1991; Wilkes 1991; Sellin 1994; Björklund 1999; Gjerdrum 2003). In the case of tropical tree species *Tectona grandis*, Moya et al. (2014) reported that some of the factors that play an important role in heartwood properties of trees when grown as fast growth plantations are tree age, longitudinal variation, geographic location, environmental conditions and silvicultural activities.

Tree girth and diameter have always been considered as an important trait in plantation management. While selecting genotypes for superior traits it would always be easy if tree girth can be considered as one of the criteria. Therefore, relationship between tree girth and sapwood/heartwood contents if any would facilitate not only in identifying superior genotypes, but also in applying suitable management practices so that tree girth is enhanced. In the present study, there was positive linear relationship between tree girth and heartwood in *H. binata* ($r = 0.74$), *P. santalinus* ($r = 0.56$), and *S. album* ($r = 0.63$). Strong positive genetic and phenotypic correlations of heartwood diameter were found with stem DBH and with heartwood proportion in *Eucalyptus globulus* (Miranda et al. 2009, 2014). Positive variations in tree growth and heartwood dimensions have been reported in *Larix decidua* (Leibundgut 1983), *E. globulus* (Gominho and Pereira 2000), while stem diameter was a good predictor of heartwood diameter in *Pinus pinaster* (Pinto et al. 2004; Knapic and Pereira 2005) and (Climent et al. 2003), suggesting that larger trees have higher heartwood diameter. Nocetti et al. (2010) found significant differences between clones of *Prunus avium* for growth and heartwood traits which indicate that they are moderately genetic controlled. Similarly, moderate to high genetic control has been reported in black walnut (Rink 1987; Woeste 2002). Björklund (1999) was of the opinion that to obtain stems richer in heartwood, genetical breeding plays an important role than through silviculture and site selection. The variation in heartwood and sapwood content is essential in understanding within tree wood trait variability especially for breeding purposes. But, at the same time, the clear correlation between girth and heartwood paves way for early selection of superior genotypes.

Conclusions

The present study clearly demonstrates that considerable variability occurs in heartwood content at the age of 20 years in trees of *H. binata, P. santalinus* and *S. album*. As age plays a significant role in heartwood formation, selection of genotypes based on heartwood at young age would be apt as the variability would be at maximum and option for better selection would be higher. A positive linear relationship between girth and heartwood content was found in all the three species which would also assist in quicker selection process.

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References

Anonymous (1983) Troup's silviculture of Indian trees, Vol 4. Controller of publications, Delhi

Berthier S, Kokutse AD, Stokes A (2001) Irregular heartwood formation in maritime pine (*Pinus pinaster* Ait.): consequences for biomechanical and hydraulic tree functioning. Ann Bot 87:19–25

Björklund L (1999) Identifying heartwood-rich stands or stems of *Pinus sylvestris* by using inventory data. Silva Fennica 33(2):119–129

Climent J, Chambel MR, Gil L, Pardos JA (2003) Vertical heartwood variation patterns and prediction of heartwood volume in *Pinus canariensis* Sm. For Ecol Manag 174:203–211

Dean TJ, Long JN (1986) Variation in sapwood area-leaf area relations within two stands of lodgepole pine. For Sci 32(3):749–758

Garad KU, Gore RD, Gaikwad SP (2015) A synoptic account of flora of Solapur district, Maharashtra (India). Biodivers Data J 3:e4282. Doi:10.3897/BDJ.3.e4282

Gartner BL (1995) Plant stems: physiology and functional morphology. Academic Press, Inc. San Diego, CA, 440 p

Gominho J, Pereira H (2000) Variability of heartwood content in plantation growth *Eucalyptus globulus* Labill. Wood Fiber Sci 32:189–192

Haygreen J, Bowyer J (1989) Forest products and wood science—an introduction. Iowa State University Press, USA, 516 p

Hazenburg G, Yang KC (1991) The relationship of tree age with sapwood and heartwood width in black spruce, *Picea mariana* (Mill.) B.S.P. Holzforsch 45(5):317–320

International Association of Wood Anatomists (1964) Multilingual glossary of terms used in wood anatomy. Verlagsanstalt Buchdruckerei Konkordia, Winterthur, Switzerland 186 p

Irwin SJ, Narasimhan D (2011) Endemic genera of Angiosperms in India. Rev Rheedea 21(1):87–105

Knapic S, Pereira H (2005) Within-tree variation of heartwood and ring width in maritime pine (*Pinus pinaster* Ait.). For Ecol Manag 210:81–89

Kumar A, Dhillon GPS (2014) Variation in sapwood and heartwood content in half sib progenies of *Eucalyptus tereticornis* Sm. Ind J Nat Prod Res 5:338–344

Gjerdrum P (2003) Heartwood in relation to age and growth rate in *Pinus sylvestris* L. Scand J For Res 76(4):413–424

Leibundgut H (1983) Untersuchungen verschiedener Provenanzen von Larix decidua. Schweizerische Zeitschrift fur Forstwesen 134(1):61–62

Miranda I, Gominha J, Pereira H (2009) Variation of heartwood and sapwood in 18-year-old *Eucalyptus globulus* trees grown with different spacings. Trees 23(2):367–372

Miranda I, Gominha J, Araujo C, Pereira H (2014) Family effects in heartwood content of *Eucalyptus globulus* L. Eur J For Res 133(1):81–87

Moya R, Bond B, Quesada H (2014) A review of heartwood properties of Tectona grandis trees from fast-growth plantations. Wood Sci Technol 48(2):411–433

Nocetti M, Brunetti M, Ducci F, Romagnoli M, Santi F (2010) Variability of wood properties in two wild cherry clonal trials. Wood Sci Technol 44:621–637

Panshin AJ, de Zeeuw C (1980) Textbook of wood technology, vol 1. McGraw-Hill, New York 722 p

Pinto I, Pereira H, Usenius A (2004) Heartwood and sapwood development within Maritime pine (*Pinus pinaster* Ait.) stems. Trees 18(3):284–294

Raju KK, Raju AN, Sudheer AS (1999) Biogeochemistry of red sanders from southeastern part of Andhra Pradesh, south India. Fresenius Environ Bull 8(3–4):204–212

Rink G (1987) Heartwood color and quantity variation in a young black walnut progeny test. Wood Fiber Sci 19(1):93–100

Sellin A (1994) Sapwood—heartwood proportion related to tree diameter, age, and growth rate in *Picea abies*. Can J For Res 24:1022–1028

Srinivasan VV, Sivaramakrishnan VR, Rangaswamy CR, Ananthapadmanabha HS, Shanakaranarayana KH (1992) Sandal. ICFRE, Dehra Dun, 233 p

Taylor AM, Gartner BL, Morrell JJ (2002) Heartwood formation and natural durability—a review. Wood Fiber Sci 34(4):587–611

Wenbin H, Xiufang S (2013) Tropical hardwood flows in China: case studies of rosewood and Okoumé. For Trends Assoc, Washington DC, USA

Whitehead D, Edwards WRN, Jarvis PG (1984) Conducting sapwood area, foliage area and permeability in mature trees of *Picea sitchensis* and *Pinus contorta*. Can J For Res 14:940–947

Wilkes J (1991) Heartwood development and its relationship to growth in *Pinus radiata*. Wood Sci Technol 25:415–423

Woeste KE (2002) Heartwood production in a 35-year-old black walnut progeny test. Can J For Res 32:177–181