Chapter 20
Tree Improvement of Sandalwood in India with Special Emphasis on Heartwood and Oil—An Analysis

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1 Introduction

Santalum album L., or Indian sandalwood (Family Santalaceae), is the lone representative of the genus *Santalum* in India [42]. A partial root parasite tree, it is valued for the scented heartwood and the aromatic essential oil in its heartwood. Having earned several epithets such as green gold, dollar earning parasite, queen of essential oil, vegetable gold, the etymology of the generic name *Santalum* is believed to come from '*Chandal'*—a Persian word derived from the Sanskrit *Chandana* meaning fragrant. *Chandal* was later adopted as *Shandal* by the Arabs and subsequently named *Santalon* by the Greeks. The specific epithet *album* means 'white' in Latin which refers to the sapwood colour [45]. Sandalwood and India have a very significant religious and cultural binding, as is evident from its extensive use both during auspicious and inauspicious occasions. Therefore, sandalwood has been given a divine status. The Nobel Laureate Rabindranath Tagore describes what a sandalwood tree is —'*The sandalwood tree as if to prove, how sweet to conquer hate, love, perfumes the axe that lays it low*'.

Tree improvement for any tree species is a continuous programme which enables researchers to identify and develop genotypes with superior traits of commercial importance. To achieve this, various steps and processes are involved running into many years depending on the objectives and the species targeted [50, 51]. An important aspect to be remembered in this entire programme is maintaining a high level of genetic diversity in the base population so that future selection processes continue and the chances of inbreeding are reduced [10]. All these factors should also support the fundamental aspect of forest and ecosystem sustainability. The programme should

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ultimately result in a proper convergence of species improvement and domestication processes so that the targeted species is not only conserved in its natural habitat but also utilized sustainably outside its habitat.

As the first step of tree improvement, an extensive countrywide survey on Indian sandalwood was conducted during 1977–78 by a team of researchers from the erstwhile Sandal Research Centre, Bangalore (presently merged with the Institute of Wood Science and Technology, Bengaluru). Most of the states in India were covered, and around 125 locations comprising nearly 5000 trees were documented. During the survey, commercial traits and health status were given priority. The health status was assessed as the presence/absence of spike disease and heartwood borer infestation. Apart from these, natural regeneration status was also documented. From each population stand density, leaf shape, size and colour, fruit, seed shape and size, flower shape and size, sapwood width, heartwood colour and oil content were recorded. Details of tree characters are provided in Table 1.

Of the 118 locations surveyed (Table 2), 78% were from Karnataka (40 locations) and Tamil Nadu (52 locations). Only 22% of these population were dense, while 42% had medium density (Fig. 1). This indicates that population density was not high even in the states proclaimed to be sandalwood-rich.

The percentage of trees having heartwood ranged from 0 to 100%. It was also observed that in ~50% of the locations heartwood was found in more than 70% of trees. Between Karnataka and Tamil Nadu, trees from nine locations from Tamil Nadu and one from Karnataka did not have heartwood. Among the nine locations in Tamil Nadu, trees without heartwood were found in 3, 4 and 2 populations having dense, medium and sparse populations.

The average percentage of trees with heartwood was 73.08, 72.73 and 64.56%, for the dense, medium and sparse populations, respectively. It is interesting to note that the minimum percentage of trees having heartwood for the dense, medium and sparse population was 28, 17 and 4% (Table 3). There were certain locations in dense (3), medium (4) and sparse (4) populations having trees without heartwood and 46% of the locations had trees with >80% heartwood content (Fig. 2).

From the survey data, it can be deduced that sandalwood is distributed in 9044 km^2 in different parts of India. The different states and the areas accordingly are estimated as follows—Karnataka (5245 km^2); Tamil Nadu (3040 km^2); Andhra Pradesh (175 km^2); Kerala (63 km^2); Madhya Pradesh (33 km^2); Orissa (25 km^2); Maharashtra (08 km^2); Uttar Pradesh (01 km^2); Uttar Pradesh (01 km^2); Rajasthan (8962 ha); Himachal Pradesh (30–35 ha) [49]. Considering pockets of population in different states such as Bihar, Gujarat, West Bengal, Tripura, Manipur, Pondicherry, Goa and Andaman and Nicobar Islands, it is estimated to be in a cumulative area of 5 km^2 and including the private lands across the country accounts for 500 km^2. The survey also provided evidence that sandalwood can be distributed from sea level to 1800 m above sea level. The predominant soil types in which the sandalwood population occurred varied from red loamy to red laterite sometimes extending up to black soil.

Table 1 Details about tree characters along with different criteria used during the first sandalwood survey carried out in India in case of sandalwood trees [49]

Sl No	Tree Characters	Criteria for different characters
1	Density	Dense— > 200 trees/ha Medium—between 50 to 200 trees/ha Sparse— < 50 trees/ha
2	Leaf	Shape—ovate, elliptic, linear, lanceolate, big, small and normal Normal—standard leaf size—length 6.00 to 8.00 cm Small— < L/B: 6.00 to 8.00/2.00 to 3.00 cm Big— > L/B: 6.00 to 8.00/2.00 to 3.00 cm Leaf colour—green, yellow-green, light green, copper green and dark green
3	Flower	Shape—companulate, cylindrical and obconical Medium—normal flower L/B: 5.00/3.00 cm Small— < L/B: 5.00/3.00 cm Big— > L/B: 5.00/3.00 cm
4	Fruit	Globose, fusiform, with elongated base Medium—medium normal fruit L/B: 1.00/0.80 cm Small— < L/B: 1.00/0.80 cm Large— > L/B: 1.00/0.80 cm
5	Seed	Round, oval Medium—seed diameter 6.00 to 7.00 mm Small—seed diameter < 6.00 to 7.00 mm Large—seed diameter > 6.00 to 7.00 mm
6	Sapwood width	Very narrow (below 1.00 cm) Narrow (between 1.10 and 2.00 cm) Broad (between 2.10 and 4.00 cm) Very broad (above 4.10 cm) All sap
7	Heartwood colour	Yellow, yellow–brown, light brown, brown, dark brown, pink
8	Oil content	Very rich—6.10 to 7.00% Rich—4.50 to 6.00% Moderately rich—2.00 to 4.40% Poor—below 2.00%

2 Variability for Morphometric Traits

Variation has been documented for flower, leaf, seed, bark, heartwood and oil. An attempt was also made by Srimathi et al. [43] to identify distinct phenotypes available in the natural populations. Based on their survey, three distinct phenotypes were identified, namely Thindlu, Chickballapur and Robust types.

Thindlu phenotype: This phenotype was first recorded in Thindlu Reserve, located in Hoskote Range, Bangalore Forest Division. A similar phenotype was also observed in Kolar (Vakkaleri Reserve) and Hassan Division (Ammanakatte Forest) in Karnataka and in Valliyur Reserve Forest of Kalakkad Wild Life Division in Tamil Nadu. A typical slow growing, 4 to 8 cm diameter (8 cm diameter tree having 25

Table 2 Sandalwood population density across different states estimated during the survey [49]

Sl. No	Name of the state	Number of locations	Density status
1	Tamil Nadu	50	Dense (10), Medium (25), Sparse (15)
2	Karnataka	42	Dense (11); Medium (14); Sparse (17)
3	Kerala	6	Dense (1), Medium (1), Sparse (4)
4	Andhra Pradesh	5	Dense (1), Medium (4)
5	Maharashtra	4	Dense (1), Medium (1) Sparse (2)
6	Rajasthan	3	Sparse (3)
7	Madhya Pradesh	3	Dense (1), Sparse (2)
8	Orissa	3	Dense (2), Sparse (1)
9	Uttar Pradesh	1	Sparse
10	Punjab	1	Sparse

Dense— >200 trees/ha; Medium—Between 50 to 200 trees/ha; Sparse— <50 trees/ha

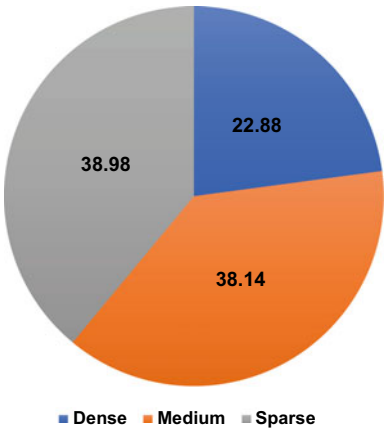

Fig. 1 Pie chart showing the dense, medium and sparse populations of Sandalwood as reported in the first all India sandalwood survey carried out during 1977–78 [49]

Table 3 Basic statistics for the percentage of trees having heartwood in the dense, medium and sparse populations

Population	n	Population with 100% heartwood	Mean	SD	CV(%)	Minimum	Maximum
Dense	27	5	73.08	22.35	30.57	28	100
Medium	45	10	72.73	22.70	31.21	17	100
Sparse	46	8	64.56	27.25	42.21	4	100

to 30 annual rings) trees with dark brown heartwood and narrow sapwood of 2 to 10 mm thickness.

Chickballapur phenotype: The uniqueness of this tree type is that the leaves are small which resembles a spiked tree; however, the leaf colour is bluish-green. Unlike

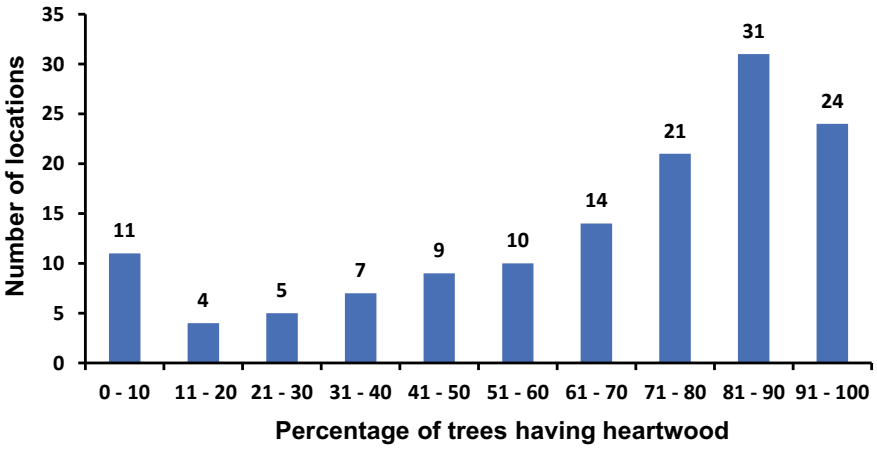

Fig. 2 Number of locations having trees with varied heartwood content percentage in the first all India survey [49]

Thindlu biotype, the sapwood is thicker. These trees were observed in the Shimoga and Kolar Divisions of Karnataka.

Robust phenotype: As the name suggests, it is fast-growing, with a straight and cylindrical bole and a typical rust-brown coloured smooth bark. The crown is compact with lush green coloured leaves and the sapwood is thick. It was predominantly observed in Srinivaspura Forests of the Kolar Division of Karnataka.

Flowering: Flowering starts as early as between two and four years [1, 23, 44], and during flowering, all stages from buds to fruits are seen. Considerable variation has been observed in the flowering pattern of sandalwood, and three distinct patterns have been identified–those that flower once a year, twice a year and throughout the year. Considering the data from the all India Sandalwood Survey, 48.30% of the population flowered twice a year while only 4% of the population flowered exclusively once a year. It was reported that sandalwood trees flowering once in a year produces flower during September–December, while it is once in March–May and the other in September–December in those tree flowering twice a year. Accordingly, 60% of the trees flower twice a year, 36% flowers once a year and only 4% of trees produce flowers throughout the year [1].

Bark: Preliminary assessment of the bark indicated that the colour varies from reddish-brown or dark brown. The brown bark which was also indicated as rust brown is associated with fast growth [21]. However, distinct morphological appearance considering bark as a trait has not been categorized yet.

Leaves: *S.album* has considerable variation, especially for leaf traits. Initially, some of the variations depicted were probably due to the spike disease which at various stages of infection can result in different leaf sizes [5]. An extensive study on biometric analysis of leaf shape and size. Data were arrived at after collecting leaf samples from 14 different locations situated in Karnataka, Tamil Nadu, Andhra

Fig. 3 Variation in leaf shape and size in sandalwood

Pradesh and Kerala. They designated four leaf types, ovate, lanceolate, elliptic, linear and big and small leaf type. A standard leaf varies from 4 to 9 cm in length and 1.8 to 3.7 cm in breadth. Leaves having lesser/higher length and breadth than the standard leaf was considered as small/big leaf, and these leaves were either ovate or elliptic. Based on length: breadth ratio, the leaf shape of spike and healthy leaves were differentiated. However, the authors cautioned before using these differences. The average leaf length: leaf breadth ratio for various leaf types were as follows–ovate (2.30); elliptic (1.71); lanceolate (2.55); linear (5.15); small (1.93) and big (2.12) [21]. Variation in leaf shape and size is shown in Fig. 3.

3 Tree Improvement Trials and Their Status

Extensive research on sandalwood tree improvement was carried out from 1978 to 1985–which can be considered as the 'golden period' of sandalwood research in India. Various trials such as seed stands/seed production areas, clonal banks, biotype germplasm banks, provenance trials, clonal/seedling seed orchards, progeny trials were established in different parts of sandalwood growing areas during this period which have been summarized along with its present status (Table 4).

It is evident from Table 4 that most of the trials established did not provide conclusive results and most of the trials ceased to exist. Clonal germplasm bank established at Gottipura, Hoskote, (Karnataka) was assessed for its seed, germination, heartwood and oil traits. The details are provided elsewhere in this book. Seeds from

Table 4 Various tree improvement field trials of sandalwood established during 1980–1984

Activity	Location	Year	Area (ha.)	Present status
Seed Stands	Marayoor (Kerala)	1980	3.00	Seed collection is regularly carried out
	Chitteris (Tamil Nadu)	1980	5.00	No information
Provenance trials	Nallal at Hoskote (Karnataka)	1981	3.14	No information regarding any data that has been collected and the trial does not exist
	Kuderu at Anantapur (Andhra Pradesh)	1982	0.24	Preliminary observations on growth were recorded for three years and the trial does not exist
Clonal germplasm banks	Gottipura at Hoskote (Karnataka)	1980–82	1.00	This germplasm bank was assessed for variability in seed, heartwood and oil content. However, the number of accessions in the germplasm bank has reduced from 60 to 35 accessions including a reduction in the number of ramets per clone
	Karvatnagar at Chittoor (Andhra Pradesh)	1983	0.10	Information regarding any data being collected is not there. The trial does not exist
	Kurumbapatty at Salem (Tamil Nadu)	1983	0.50	Germplasm bank exists
Biotype germplasm bank	Gottipura at Hoskote (Karnataka)	1982	0.75	No data were collected from this germplasm bank and the trial does not exist
Clonal seed orchards	Nallal at Hoskote (Karnataka)	1982	1.35	Assessed for seed variability. The trial does not exist
	Akkarampalli at Tirupati (Andhra Pradesh)	1983	1.00	The trial does not exist
	Jarakabande at Bangalore (Karnataka)	1984	1.50	The trial does not exist
Half sib progeny trials	Nallal at Hoskote (Karnataka)	1980 1981 1983	0.20 0.65 1.20	The trial does not exist

the clonal seed orchard established at Nallal, Hoskote (Karnataka), were collected until 2002, and the seedlings obtained were also distributed. The clonal germplasm bank and seed orchard served as a source material for establishing seedling seed orchard and clonal seed orchard during the World Bank Project. The provenance trial established at Kuderu consisted of seeds collected from 10 different provenances, and a preliminary assessment was carried out by the end of three years. The results revealed that there was no significant difference between the provenances for survival percentage and height growth [23].

Srimathi and Kulkarni [42] carried out a progeny trial of selected trees to assess variation in seedlings. From 16 sources mostly from southern and central India, seeds were collected from 60 individual trees and seedlings were raised. As depicted in Fig. 3, the average maximum and minimum germination percentage of seed sources varied from 33.20 (Madras) to 84.09% (Jamnamarthur). The authors also reported segregation, variegation, albinism and pleiocotyly in seedlings. Twin and triplet seedlings were recorded, and twin seedlings were found in 50 per cent of the seeds (0.6 to 4.6 per tree). Twin seedlings were also reported by [6, 16]. Variability was evaluated among the clones in the clonal seed orchard for two consecutive years for seed morphometric and germination traits. A significant variation was observed among the clones for the seed and germination traits [2].

Status of various tree improvement activities and trials established from 1995 onwards by Institute of Wood Science and Technology

During 1994 to 2001, sandalwood research again gained impetus in one of the research components 'Research on Sandal' by the World Bank Aided Forestry Research Education and Extension Project (FREEP).

Under this project, an extensive survey of sandalwood population was carried out during 1995–97. The survey was carried out especially in some of those Forest

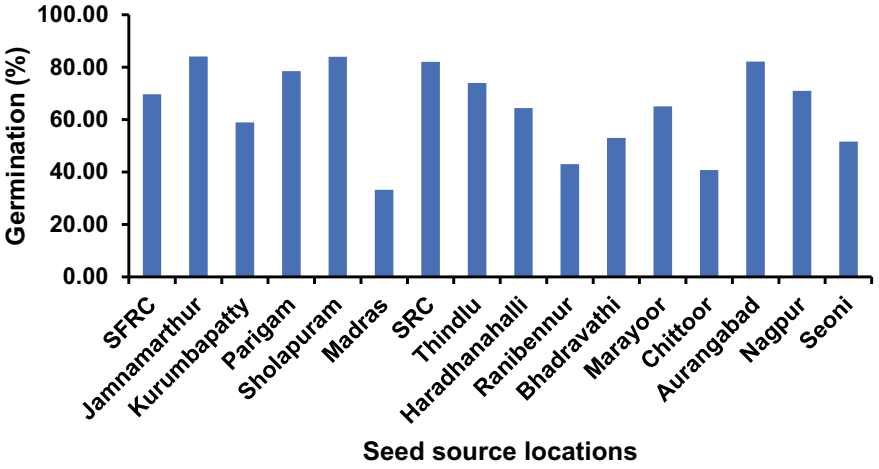

Fig. 4 Variability for germination percentage in seed sources collected from different locations [42]

Divisions known for sandalwood populations. In Karnataka, Forest Divisions of Shimoga and Chickmagalur had dense and Sagar and Mysore had a sparse population. In Tamil Nadu, two Forest Divisions, Harur and Tirupattur, had dense population, and Munnar division in Kerala had a dense population. Paderu Forest Division in Andhra Pradesh had a sparse population, while Rayagada and Seoni Forest Divisions representing Orissa and Madhya Pradesh had medium dense populations. The general observation was that in most of the areas mentioned in the first sandalwood survey the population density had drastically reduced across all the states. The reduction in population was more extensive in Karnataka and Tamil Nadu.

Based on the survey and the population density, nine potential provenances were identified. In Karnataka three potential provenances, namely Bangalore, Thangali (Chickmagalur Forest Division), Mandagadde (Shimoga Forest Division); from Tamil Nadu two potential provenances, namely— Chitteri (Harur Forest Division) and Javadis (Tirupattur Forest Division); one each potential provenance from Kerala—Marayoor (Munnar Forest Division), Orissa—Koraput (Rayagada Forest Division), Madhya Pradesh—Seoni (Seoni Forest Division) and Andhra Pradesh—Horsely Hills. [17, 18]. The first author was a part of the team that carried out this survey. Subsequently, during 2004–2006, the author conducted an extensive survey in most of the sandalwood bearing areas in Karnataka, Tamil Nadu and Kerala. Except for Marayoor in Kerala, which has a considerable population even now, in most areas, the sandalwood population had dwindled and economically viable trees; *i.e.,* trees above 30 cm girth were more or less absent. Interestingly, the first sandalwood survey carried out extensively during 1978–80 remains to be the only comprehensive survey to date in India.

Under this project, provenance trials, seedling seed orchard, clonal seed orchard of sandalwood were also established. The status of those are provided in Table 5.

4 Progress of Research on Heartwood and Oil Variability

Information about variation in heartwood can be traced to Hutchins [14] who mentioned that the scent in the wood varied due to soil conditions and the tree attains maturity by 27 to 30 years. Lushington [25], based on his studies conducted on 12 trees in Srivilliputtur forests and two billets obtained at North Coimbatore suggested that the quality of heartwood and oil is dependent on elevation and exposure and is not based on the soil. Lushington [26] further segregated the trees based on girth and the availability of scented wood (heartwood) from the stem and roots in different coupes at varied elevations such as Mavihalla (1220 m; n = 192), Kotadai (1220 m; n = 150), Talakarai (915 m feet; n = 1445), Karlia (700 m; n = 823) and Kodampalli (700 m feet; n = 128). Scented wood was available in very few trees having a girth less than 30.48 cm. Even though Mavihalla and Kotadai were at the same elevation, the quantity of scentwood obtained was different. Similar variation in outturn was also recorded in Karlia and Kodampalli which were of the same elevation but 20 miles away. He opined that '*there is an immense variation of Sandal even when*

Table 5 Tree improvement trials established by the Institute of Wood Science and Technology, Bengaluru

Activity	Location	Year	Clones/families	Area (ha.)	Present status
Seedling seed orchard	Siddalagandi farm (Bhakrapet Range, Andhra Pradesh)	1998	25	4.0	The trial does not exist
	Kuchuvarapalli VSS (Bhakrapet Range, Andhra Pradesh)	1998	25	1.0	The trial does not exist
Clonal seed orchard	S. V. University, Tirupathi	1998	25	4.0	No data on seed collection
Seedling seed orchard/progeny trial	Gottipura (Hoskote Range), Karnataka	2004	20	1.0	No data have been recorded. A small quantity of seed is being collected
Germplasm bank (Seedling origin)	Gottipura (Hoskote Range), Karnataka	2007	20	1.0	No data have been recorded

grown under similar conditions'. Rao [32] consolidated heartwood yield from the fellings carried out during 1902–1904 at different elevations (~2000 to 3200 feet) on the Salem Javadis. There was considerable variation within and between girth classes for heartwood content in trees with girth above 91 cm girth. Rao also suggested that factors like tree density, associated host species, growing conditions can impact the heartwood formation. Based on small sample of sandalwood collected from Madras ($n = 15$), Singh [38] concluded that trees growing in poor rocky/gravelly soils had higher oil content (3.75 to 5.02%) than trees growing in fertile soils (3.26 to 4.24%) based on a small sample of sandalwood collected from Madras. Singh [39] later conducted a similar study on the roots and stems obtained from 44 trees. The oil percentage from the Madras samples varied from 3 to 6 per cent irrespective of the plant part. However, it was categorically mentioned earlier that locality, elevation or age had relationship with heartwood and the essential oil in it. The author was of the firm opinion that soil is the only factor responsible for high heartwood and oil content in sandalwood. Troup [47] and Fischer [13] opined that there is a need for detailed study in the case of heartwood and oil formation. Sreenivasaya and Rangaswami [40] reported that conditions not favouring profuse vegetative growth would enhance heartwood formation. They also documented variation in heartwood content in trees recorded from different localities (Fig. 5). In the 5th Silviculture Conference, 1941, held at Dehra Dun, three important papers on sandalwood exclusively about heartwood and oil were presented. Mitchell [29] reported that trees with similar girth growing in deciduous forests had higher heartwood content compared to that of trees growing in evergreen forests. Laurie [24] mentioned that there was

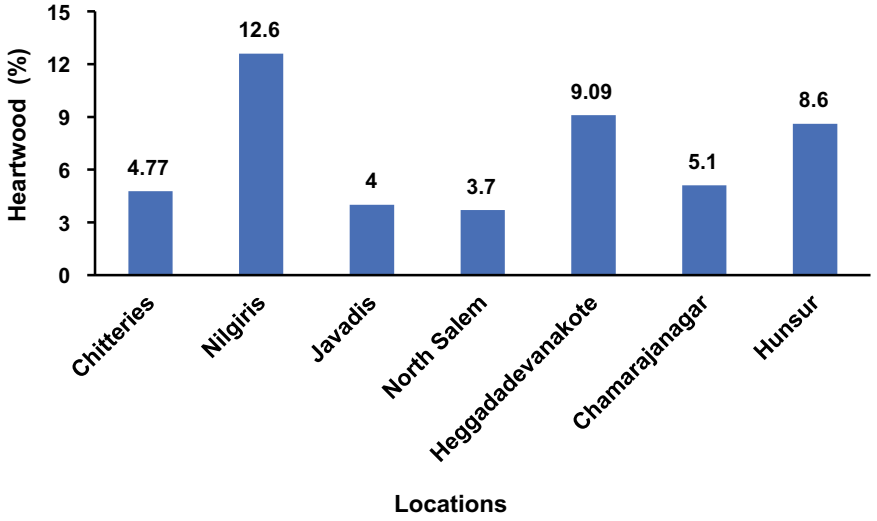

Fig. 5 Heartwood percentage in trees grown in different sandalwood locations [40]

a high degree of variation in heartwood quantity for a given sized tree. Venkata Rao [32] was of the view that heartwood formation occurs when the tree is 15 to 20 years old. All of them urged that scientific evaluation is to be further carried out to understand the heartwood and oil variation. In his article, Rao [31] addresses the issues of forest plant breeding categorically mentioning that heartwood formation in sandalwood trees needs to be critically addressed.

Bhatnagar [6] opined that even though a sandalwood tree reaches physiological maturity, the heartwood may not have been formed and the tree reaches full maturity at the age of 50–80 years. Even in the first and second All India Sandal Seminar held in 1977 and 1981, respectively, information related to heartwood and oil remained unexplored. Kaikini [20] and Shanmuganathan [37] had a similar opinion and stressed that growth rate and yield have to be intensified. An empirical table depicting girth and heartwood yield based on personal observations was published by Venkatesan [48] which mentioned that a tree of 15 cm girth would yield 2.4 kg of heartwood while it would be 127 kg from trees with girth class 75–90 cm. The average yield mentioned included stem and root wood. Another study was carried out in Belgaum, Karnataka, by Rai and Sarma [30] with the trees DBH ranging from 6.8 cm to 23.6 cm. Trees with DBH class of 6.8–9.2 cm yielded 1.814 kg of heartwood while DBH class of 21.2–23.6 yielded 54.431 kg. Considering various factors playing a role in heartwood formation and its variation, a study was carried out by Srimathi and Kulkarni [41] to assess the variation in the 50 trees growing in a similar area (Sandal Research Centre) falling between the girth class of 10.65–11.7 cm (Fig. 6). It was found that in three trees heartwood had not formed. The radial heartwood proportion deduced from the original data indicated that it varied from 0.91 to 86.21%. There was no correlation between girth and radial heartwood proportion ($r = 0.13$).). Considering

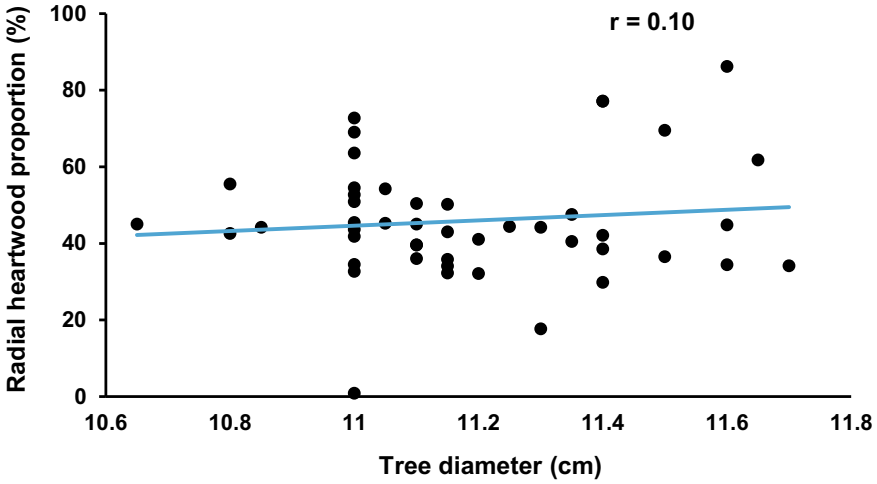

Fig. 6 Relationship between tree diameter (10.65 to 11.7 cm) and radial heartwood proportion in trees grown at Sandal Research Centre (modified from [41])

the heartwood colour, 64% of the trees had brown or yellowish-brown heartwood. The authors concluded that heartwood formation can occur in some trees at an early age of five to six years and can extend as late as 15 years in some others. The study proved that emphasis on the tree age is also important and can play a significant role in heartwood formation.

Various working plans, unpublished information were reviewed to collate information pertaining to variation for heartwood (%) and tree diameter in different locations in 10 trees. One of the criteria used was that the average tree diameter was between 10 to 20 cm. Heartwood had not yet developed in two trees out of ten trees from Kurumbapatti having an average diameter of 20.08 cm, and in all the ten trees from Seoni with an average diameter of 10.17 cm. The heartwood percentage varied from 24.69% (average diameter of 20.08) in Kurumbapatti to 49.94% (average diameter of 11.80 cm) in Kollapur (Table 6).

Variability for oil content (%) and its constituent α and β Santalol (%) was estimated by Jayappa et al. [19], and root samples had the highest content. They collected root wood samples and two categories of heartwood (*Jaj* and *Milwa*) from various locations of Karnataka and Tamil Nadu. The minimum and maximum oil content for the root samples, *Jaj* and *Milwa,* were from Mysore (6.56%), Satyamangalam (4.22%) and Tarikere (2.42%), respectively. The maximum oil content was from the samples collected from Hassan—8.43% for roots, 5.79 and 3.52% for *Jaj* and *Milwa*, respectively. Interestingly, α and β Santalol (%) was minimum in the root samples from Hassan–88.07; 89.09% from *Jaj* and 88.62% from *Milwa.* Maximum α and β Santalol for root sample was from Dharwad (95.16%), Tarikere for the *Jaj* sample (94.98%), and the *Milwa* samples from Mysore (94.12%). Shankaranarayana and Parthasarathi (1984) reported that oil percentage ranged from 0.7 to 2.5%, while

Table 6 Consolidated information from different sources showing variability in the heartwood at different locations

Location	Average diameter (cm)	Trees without HW	Average HW depth (cm)	HW (%)
Seoni	10.17	0	2.21	44.27
Dindigul	10.77	5	1.48	26.49
Coimbatore	11.33	3	1.85	32.01
Puttur	11.67	2	2	34.7
Kollapur	11.8	2	2.92	49.94
Courtallum	12.59	2	2.24	35.57
Wynad	12.89	4	2.8	36.12
Chamarajnagar	13.21	2	2.58	36.44
Hyderabad	13.87	3	3.26	47.24
Kuchnahalli	14.62	0	2.69	37.43
Guindy Park	14.97	2	3.02	39.92
Janiguda	14.98	0	3.53	47.65
Kurumbapatti	20.08	2	2.55	24.69
Kushalnagar	20.76	0	3.97	42.42

HW: Heartwood

santalol varied from 76 to 80% in 10-year-old trees. In trees aged 20 years and above, the oil value ranged from 2.5 to 6.3 per cent, while the santalol varied from 88 to 92 per cent. Light brown heartwood had 2.5–6.2% oil per cent with 90% santalol. Yellow heartwood had 2.0–3.5% oil and 90% santalol. Dark brown and brown heartwood had 2.5% oil and ~85% santalol [35].

From most of the studies mentioned earlier, it is evident that age was never a common factor. It is difficult to estimate age in sandalwood, and the error involved while estimating the age is very large [11]. A study carried out by Arunkumar [3] assessed 111 trees in a 20-year-old clonal germplasm bank established at Gottipura, Hoskote (Karnataka). In 14% of trees, heartwood had not formed. Heartwood proportion varied from 29.34 to 65.77%. Similarly, oil yield varied from 0.62 to 2.29%. To elucidate the inherent variability in a better way, trees with 11 cm diameter were segregated and variation for heartwood proportion and oil content is depicted in Table 7. The study revealed a significant positive relationship between girth and heartwood proportion. It clearly demonstrated that genetics plays a significant role in heartwood formation and experiments under controlled conditions are needed for a better understanding of the variation for heartwood and oil in sandalwood. Similar observations have also been recorded in Australia by Brand et al. [5], McComb [27] and Brand [9]. Recently, few other studies have reported variability for heartwood and oil content in India [7, 28, 34].

Extensive studies have been carried out on sandalwood in India for more than 150 years. Though predominant work has been on spike disease, sufficient studies

Table 7 Variability for heartwood proportion (%) and oil yield (%) in 20-year-old trees having ~11 cm diameter [3]

Tree diameter (cm)	Heartwood proportion (%)	Oil yield (%)
11.03	42.52	1.81
11.09	42.11	2.29
11.14	65.77	1.19
11.19	59.78	2.04
11.41	41.63	1.85
11.57	36.56	2.09
11.62	29.34	0.62
11.67	43.44	1.86
11.67	46.78	1.16
11.99	30.10	0.88

report that sandalwood has substantial morphological and genetic diversity. Considerable variability has been documented for morphological traits, however, studies on variability for heartwood and oil are still not conclusive. It is essential to understand the role of genetics and the environment on heartwood and oil formation. Now that sandalwood is cultivated in large areas in India, it is hoped that there would be a better understanding of many of the grey areas. Sandalwood has already been categorized as 'Vulnerable' by the International Union for Conservation of Nature [4]. To reinitiate tree improvement studies, another extensive all India Survey of Sandalwood has to be carried out. The status of its presence/absence across the country needs to be updated. Unlike other tree species, further tree improvement studies on sandalwood will not necessarily be initiated from its natural habitats as the population has dwindled. As numerous plantations are being raised in different parts of India, these plantations would be the future base population for developing tree improvement programmes on Indian sandalwood.

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