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RESEARCH ARTICLE

Sandalwood based agroforestry systems in Bundelkhand region of central India

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Abstract

Sandalwood is one of the world's high-value tree crops and is native to the southern India. It is fast diminishing in its native forest ranges. However, greater and growing demand for its scented wood oil and wood products are encouraging its cultivation on agricultural land parcels under agroforestry systems. Although the existence of sandalwood in Central India has been reported, particularly in parched Bundelkhand region, its cultivation on agricultural lands is rarely reported. Therefore, a study was conducted to describe the prospects of sandalwood cultivation in the semi-arid Bundelkhand region of Central India. A survey was conducted to identify existing plantations in the region. During the survey, a well-established 15-year-old private plantation comprising trees of different age classes was identified at Deligaon, Jhansi, India. To determine the heartwood formation and wood oil content, twenty matured trees were harvested. The heartwood yield ranged from 5 kg-30 kg per tree, while the oil content varied between 1.7 % to 4.0 %. These results indicated that sandalwood, historically revered as the 'royal tree', holds potential to be promoted as a viable household tree in the semi-arid Bundelkhand region. Promotion of sandalwood agroforestry practices in India has multifaceted benefits, as smallholder may get higher farm revenue with low investment and maintenance, enhanced land value, improved ecosystem services (birds, butterflies, bees etc.) besides sequestering considerable amount of atmospheric carbon dioxide and releasing oxygen.

Keywords: agroforestry; Bundelkhand; heartwood formation; *Santalum album*; semi-arid region; wood-oil content

Introduction

The green gold, Indian sandalwood belongs to the family Santalaceae and botanically it is known as *Santalum album* L. The tree is known for its hardiness and its ability to grow in a wide variety of soils and even on degraded lands in dry regions (1). Therefore, it is a suitable candidate for integration into agroforestry systems in different parts of India and other parts of the world. The sandalwood tree naturally occurs over an area of about 9000 km^2 in the dry deciduous forests of the Deccan Plateau. The two Indian states, Karnataka and Tamil Nadu, together account for about 8200 km^2 of natural sandalwood forests (2). It is also known to occur in other states such as Kerala, Maharashtra, Madhya Pradesh, Odisha, Uttar Pradesh, Bihar and Manipur (3).

Due to the continued demand for its expensive wood and oil, destructive activities have affected natural stands, both legally and illegally (4). The Government of Karnataka-owned premium sandalwood industry, Karnataka Soaps and Detergents Limited, imports 90 % of its annual sandalwood oil requirement (~7000 kg) from Australia for making branded soaps and detergent products. Thus, this clearly indicates a drastic decline in sandalwood production in the country. In recent years, production of sandalwood has dwindled while the demand has been increasing (1). Production has dropped from 4000 tonnes in the 1950s to only 500 tonnes a year, mainly due to indiscriminate felling of trees (5). For cultivation of the tree on private lands, there were legal hurdles since 1792, when Tipu Sultan, the then ruler of the Mysore state, declared it a royal tree that would remain government property wherever it grew in the state. However, such regulations have been relaxed and now farmers can grow the trees on private lands in the state (6). No such policy restriction has been reported for the cultivation of sandalwood in the Bundelkhand region.

After 2001, farmers and corporates entities started cultivating the tree (6). According to the Government of India, the ownership now lies completely with the landowner but harvesting and sale remain under the purview of the Forest Department (7).

Further, the Union and State governments have taken initiatives to promote sandalwood cultivation in the country (1). The value of a sandalwood tree is largely determined by the weight of its heartwood and the concentration and composition of the wood oil (8). Therefore, a long maturation period (15-20 years) is required for harvesting sandalwood tree for its commercial utilization (9). Thus, it provides multiple opportunities for cultivating inter-crops in the agricultural fields (10). The size of the tree usually determines the volume of heartwood. Nonetheless, the rate of heartwood formation and its volume in the sandalwood tree are important, as they decide the value of the tree and length of rotation period. However, available information in the literature regarding the heartwood growth rate in farm-grown sandalwood trees is scarce (11).

Under natural conditions, a sandalwood tree aged 27-30 years would yield 25 kg-30 kg of heartwood. However, under managed plantations, it is reported that the trees yield at least 15 kg of heartwood in 15 years of age due to irrigation, fertilization thinning and pruning (12). There are studies indicating that, the heartwood formation starts at the age of 6-8 years and sizable heartwood is formed by 15 years (10). Since, the prevailing average market price of the wood is around ₹ 6000 kg^{-1}, the marginal profit to the producing farmer is very high (6). Hence, it is a suitable candidate tree for integration into agroforestry systems. Despite favourable regulatory policies allowing cultivation on private lands and its ecological and silvicultural advantages as an agroforestry species, there is a considerable scepticism about the marketing and economic prospects of sandalwood cultivation due to the long maturation period and high investment for tree protection against theft (13).

The essential oil content in the wood varies from 1.0 % to 8.0 %, depending on the age and girth of the tree and is also influenced by climatic, soil and genetic factors (14, 15). The price of oil in the international market is ₹ 150 - ₹ 300 thousand kg^{-1} (11). Heartwood formation has been reported in trees less than 10 years old, having a girth of less than 50 cm and wood containing 0.2 % to 1.0 % of oil in Australia and Indonesia (14). For mature trees 30 to 50 years old and having 100 cm girth, the reported wood oil content ranges from 2.8 % to 6.2 %, whereas in older trees 50-80 years of age, having a girth of more than 125 cm, the wood oil content varies between 4.5 % to 8.0 % (14). Under cultivated conditions in India, the reported tree girth growth rate is relatively higher (5 cm $year^{-1}$) (10). The reported average growth rate in natural forest was one cm $year^{-1}$ (16). It was also recorded that the rate of increase in heartwood formation at higher girth class (> 81 cm) is slow.

Sandalwood trees aged between 8 to 35 years and having girth classes between 30 cm to 80 cm recorded oil contents ranging between 1.0 % to 4.0 %, which increase with age (12). In Maharashtra, Odisha, Punjab and Rajasthan, the reported wood oil concentration was in the range of 1.0 % to 2.3 %, with significant variation in heartwood content (17). Considerable heartwood initiation in the trees of 41 cm-50 cm girth class, more than 50 % heartwood in the 51 cm-60 cm girth class and up to 70 % heartwood in the girth class 71 cm-80 cm (17). The associated oil content of those trees was around 1.5 % to 3.0 % and a maximum oil content of 4 % was observed in the trees of 91 cm-100 cm girth class. Though there were a variation in wood oil content, the reported oil content of trees planted in Punjab was about 3 %, which is comparable to the south Indian average (12). Heartwood formation in the girth class of 41 cm-50 cm, with a corresponding age of 10-12 years, has been reported from different locations such as Diphu in Assam and Bangalore, Shivamogga and Mysore in Karnataka (12). Heartwood formation is not uniform with respect to different host plants and it also depends on the genetic makeup of the tree and girth (1, 11, 17-20). The influence of growing conditions on heartwood formation and wood oil content has been highlighted in the earlier studies (21). Tree growing on rocky and gravelly soil of semiarid regions and in association with xerophytes produce higher proportion of oil-bearing heartwood than the one thriving on fertile soil in high rainfall region (21).

In India, sandalwood production is largely confined to the states of Karnataka and Tamil Nadu, however, the species occurs all over the country with varied growth, heartwood production and oil contents. The forests of Bundelkhand have been described by Champion and Seth under the Northern Dry mixed deciduous forests, having typical semi-arid transitional zones with the occurrence of sandalwood in the Bar hills (22). The occurrence of sandalwood in the forest reserves of the Bundelkhand forest division (Jhansi) was first reported in 1961, with an area of 35 acres under sandalwood (22).

Sandalwood trees adapt well in terms of growth, heartwood and oil content under diverse locality factors. Though there are studies, on the growth of the sandalwood tree in agroforestry systems, conducted at various research organizations, apprehension of low heartwood production with low oil content and scanty and insignificant scientific investigation serve as a caution to farmers who wish to cultivate sandalwood in nontraditional areas (1). Nonetheless, literature suggests the climatic and edaphic suitability of sites for sandalwood cultivation in Uttar Pradesh and its adjoining areas and also highlights the involvement of research institutes, NGOs, CBOs and farmers (1). The Fragrance and Flavour Development Centre (FFDC), Kannauj and ICAR-CAFRI, Jhansi, Uttar Pradesh are promoting sandalwood plantation in the region. However, reported scientific agroforestry-tree data are very limited.

Heartwood formation in sandalwood trees generally starts around 8-12 years of age, but what activates this process has not been very well understood (4). Certain factors, generally relating to stress, such as gravelly dry soil, insolation and elevation (500 m–700 m), seem to provide a favourable environment for the formation of heartwood. The oil yields range between 1.6 % and 3.6 % from trees of girth size of 47 cm-82 cm grown in homogenous conditions, whereas 1.0 % to 2.9 % oil content was reported for trees of girth classes grown in non-traditional areas such as Rajasthan, Maharashtra, Punjab and Odisha (12, 23). The oil content may vary according to girth class, age and location. Few studies have reported heartwood formation at the fourth year, sixth year, seventh year and tenth year and also reported no heartwood formation in 13 % to 20 % of 10-14 years old trees (1, 16, 18, 19, 24).

Therefore, a field survey was conducted in Bundelkhand with the following objectives: 1) Identification and location of sandalwood agroforestry systems in the region, 2) To study the growth and development of the stand and 3) To study heartwood formation and wood oil content in the trees. In this part of the study, standing trees in the identified plantation were measured for biometric data to estimate biomass production, heartwood formation, oil content, carbon sequestration and oxygen production to assess the potentiality of sandalwood in agroforestry systems of Bundelkhand.

Materials and Methods

The hot semi-arid to sub-humid Bundelkhand region lies between 23°10' and 26°30' North latitude and 78°20' and 81°40' East longitude. The region covers a geographical area of around 70000 km^2 in Central India, which includes seven districts of Uttar Pradesh (Banda, Chitrakoot, Hamirpur, Jalaun, Jhansi, Lalitpur and Mahoba) and seven districts of Madhya Pradesh (Chhatarpur, Datia, Damoh, Panna, Sagar, Tikamgarh and Niwadi). The region falls under semi-arid zone is most degraded ecosystems characterized by undulating and rugged topography coupled with underdeveloped agricultural system. The major soils of the region are sandy, sandy loam, laterite, red and black soils. They are poor in fertility and have low water holding capacity. The average annual rainfall in the Bundelkhand region is 876 mm.

A sandalwood-based agroforestry system scouting survey was conducted in the Bundelkhand region to determine cultivation potential in the region during the year 2015-2016. The survey found a well-established 15-year-old private sandalwood plantation having trees of different age gradations in Deligaon village, in Jhansi district, Uttar Pradesh, India. The study team interacted with the farmer and obtained the information about the site characteristics, establishment, care and management of the plantation. The biometric data of the standing trees were recorded and 20 trees were identified and marked for harvesting. The identified trees were felled by leaving a 15 cm stump above ground level. The stump along with roots was uprooted by using JCB, an earth moving machine. The roots, stump, trunk wood, branch wood and leaves were sorted for weighing. The heartwood was separated from the sapwood by splitting logs and heartwood samples were drawn for oil content analysis. Pulverized 50 g heartwood samples, drawn from each tree, were fed into a Soxhlet apparatus for distillation and estimation of oil content.

The standing tree total volume was estimated using the allometric model $V= \pi (D/2)^2 \times H$, where V is the volume of the tree (m^3), D is the diameter at breast height (DBH; m) and H is the height (m) of the tree (25). The diameter (D) of the tree was measured by using a tree caliper and the height of the tree was measured using poles marked in meters and decimetres. The aboveground biomass (AGB) was calculated by multiplying estimated tree volume by the average wood density of sandalwood (940 kg m^{-3}). The below-ground biomass (BGB) was calculated by multiplying AGB by factor 0.26. The sum of AGB and BGB constitutes the total tree biomass (26).

The amount of carbon dioxide absorbed by the trees was calculated using the formula, $CO_2 = C \times 3.67$, where CO_2 is the total carbon dioxide absorption in the trees (kg $tree^{-1}$) and C is the amount of carbon in the tree biomass (for tropical trees, it is 0.47 or ~0.5). A stoichiometric conversion ratio 3.67 based on the molecular weight of CO_2 to C (44/12), was used to convert woody biomass carbon (C) to CO_2 (27, 28). Quantification of amount of oxygen released during tree growth was estimated by an atomic weight-based conversion of carbon absorbed by the tree: O_2 released from the tree (kg $tree^{-1}$) = C sequestration (kg $tree^{-1}$) × 32/12 (29).

Results

The studied plantation was established in the year 2000 using seedlings brought from Mysuru and planted at 3 m x 3 m spacing. The plantation was managed through the application of 200 g of 19:19:19 NPK fertilizer once a year and by irrigating once a week during the summer season using a tanker in the early stage of establishment. The height of the harvested trees ranged between 4.3 m to 12.2 m, with an average height of 7.3 m. The average girth was 53.8 cm, with an equivalent DBH of 17.2 cm. The girth of the harvested trees ranged between 33.3 cm to 68.6 cm. The volume of the trees (m^3 $tree^{-1}$) varied from 0.04 m^3 to 0.45 m^3 with an average tree volume of 0.19 m^3. The above ground biomass ranged from 35.7 to 424.1 kg $tree^{-1}$ and the below ground biomass of trees ranged from 9.3 to 110.3 kg $tree^{-1}$. The total biomass varied from 44.9 kg $tree^{-1}$ to 534.4 kg $tree^{-1}$ with an average tree total biomass of 220.7 kg $tree^{-1}$ (Table 1). The range of heartwood content of the harvested trees was

Table 1. Growth parameters of 20 harvested trees: height, diameter at breast height (DBH), volume of trees, aboveground biomass (AGB), belowground biomass (BGB), carbon content, CO_2 absorption and O_2 release from the trees

Tree number	Height (m)	DBH (cm)	Volume (m^3)	AGB (kg $tree^{-1}$)	BGB (kg $tree^{-1}$)	TB (kg $tree^{-1}$)	Carbon (kg $tree^{-1}$)	CO_2 (kg $tree^{-1}$)	Oxygen (kg $tree^{-1}$)
1	6.2	13.8	0.09	87.2	22.7	109.8	54.9	201.5	146.4
2	4.3	10.6	0.04	35.7	9.3	44.9	22.5	82.5	59.9
3	5.9	21.3	0.21	197.6	51.4	249.0	124.5	456.9	332.0
4	6.9	17.2	0.16	150.7	39.2	189.9	94.9	348.4	253.2
5	8.2	19.8	0.25	237.3	61.7	299.0	149.5	548.7	398.7
6	7.2	15.9	0.14	134.4	34.9	169.3	84.7	310.7	225.8
7	6.6	11.8	0.07	67.8	17.6	85.5	42.7	156.9	114.0
8	8.2	20.7	0.28	259.4	67.4	326.8	163.4	599.8	435.8
9	7.1	16.5	0.15	142.7	37.1	179.8	89.9	330.0	239.7
10	8	17.8	0.20	187.1	48.7	235.8	117.9	432.7	314.4
11	7.2	17.3	0.17	159.1	41.4	200.5	100.2	367.8	267.3
12	6.8	19.7	0.21	194.8	50.7	245.5	122.7	450.5	327.3
13	4.3	12.3	0.05	48.0	12.5	60.5	30.3	111.0	80.7
14	5.8	18.5	0.16	146.6	38.1	184.7	92.3	338.8	246.2
15	11.3	21.9	0.43	400.1	104.0	504.1	252.1	925.1	672.2
16	7.9	16	0.16	149.3	38.8	188.1	94.1	345.2	250.8
17	7.1	17.3	0.17	156.9	40.8	197.7	98.8	362.7	263.6
18	7.8	16.1	0.16	149.3	38.8	188.1	94.0	345.1	250.8
19	12.2	21.7	0.45	424.1	110.3	534.4	267.2	980.6	712.5
20	6.2	13.8	0.09	87.2	22.7	109.8	54.9	201.5	146.4
Total	**139.0**	**326.2**	**3.5**	**3328.2**	**865.3**	**4193.5**	**2096.7**	**7695.1**	**5591.3**
Average	7.3	17.2	0.2	175.2	45.5	220.7	110.4	405.0	294.3
Range (min)	4.3	10.6	0.0	35.7	9.3	44.9	22.5	82.5	59.9
Range (max)	12.2	21.9	0.5	424.1	110.3	534.4	267.2	980.6	712.5
Std. deviation	1.8	3.2	0.1	98.2	25.5	123.7	61.9	227.1	165.0
CV (%)	25.3	18.9	56.1	56.1	56.1	56.1	56.1	56.1	56.1
Kurtosis	2.20	-0.70	1.88	1.89	1.89	1.89	1.89	1.89	1.89
Skewness	1.02	-0.26	1.19	1.20	1.20	1.20	1.20	1.20	1.20

5-30 kg tree^{-1} (Table 2). The sapwood content was around 20-60 kg tree^{-1}. The roots which had highest oil content, weighed in the range between 15 to 45 kg tree^{-1}. It was found that, all the harvested trees contained heartwood (Fig. 1). The oil content of the trees ranged from 1.7 % to 4.0 %. Individual tree level variation in biometric parameters was relatively high, as the coefficient of variation (CV) was more than 18 % for DBH and over 25 % for tree height (Table 1).

Table 2. Yield parameters of the 20 harvested trees

Parameters	Estimates
Number of trees felled	20
Age of trees (years)	15
Total estimated wood volume (m^3)	3.5
Total aboveground biomass (kg)	3328.2
Total belowground biomass (kg)	865.3
Total biomass (kg)	4193.5
Total carbon (t ha^{-1})	2096.7
Total carbon dioxide absorption (kg)	7695.1
Total oxygen released (kg)	5591.3
Range of heartwood yield (kg tree^{-1})	5.0- 30.0
Range of sapwood yield (kg tree^{-1})	20.0 - 60.0
Range of root weight (kg tree^{-1})	15.0 - 45.0
Range of oil content estimated (%)	1.7-4.0
Total sap wood powder produced (kg)	200
Prevailing heartwood price (₹ kg^{-1})	6500

Discussion

The Bundelkhand region experiences extreme weather, with soaring summer temperatures reaching 50 °C and chilling winter temperatures dropping to a minimum of 2 °C. The dominant soil types of the region are Vertisols and Alfisols. Therefore, the establishment of tree crops in the region faces considerable challenges. Since sandalwood is a hardy plant and reportedly occurrs naturally in the region, it poses limited hindrance to its introduction into the agroforestry system in the region. Therefore, farmers have started cultivating sandalwood in their farms, despite having limited information on the harvestable heartwood. The fact of the matter is the high cost involved in protecting matured trees (1).

The range of heartwood extracted from harvested trees was 5 kg tree^{-1}-30 kg tree^{-1}. The results indicate tree-level variation in the heartwood production and some trees exceeded the reported growth of 15 kg of heartwood tree^{-1} in 12 years (12). Heartwood formation varies from tree to tree under natural conditions and there is no fixed age for heartwood initiation (30). The heartwood weight of 32 Indian sandalwood trees, aged 16 years, in Kununarra, Australia, varied between trees, with the largest trees containing 24 kg–30 kg (19). The observed growth rate of trees in the study was on par with that of the best sandalwood-growing regions of the country (Karnataka, Tamil Nadu and Kerala), as seedlings are obtained from Mysuru, Karnataka. The source of planting material is another factor that controls growth and development. The girth and age of a tree have a greater influence on the heartwood and oil content of trees than other factors (26). The oil content of the heartwood ranged from 1.7 % to 4.0 %, which indicates good-quality oil, as the wood oil content varies from 1.0 % to 8.0 % depending on the age of the tree, girth, soil, climatic and genetic factors (16, 31). There are reports indicating that the concentration of essential oil within the heartwood of mature sandalwood ranges from 0.5 % to 5 % (32). There are research gaps regarding the optimum age for tree harvesting, heartwood yield, factors affecting yield, age of heartwood initiation and the relationship between tree girth and heartwood content in managed and farm grown plantations (10). The value of a sandalwood tree is largely determined by the weight of its heartwood and the concentration and composition of the oil (8). The weight of the heartwood is invariably dependent on the size of the tree (10).

According to verified market reports (2025), the global sandalwood oil market was valued at USD 250 million in 2024 and is projected to reach USD 400 million in 2033. There is a huge demand from the personal care, aromatherapy and pharmaceutical industries and hence joint corporate-commercial ventures need to be encouraged for raising sandalwood plantations (33). Individual farmers with large land holdings are also establishing commercial plantations (33). The National Medicinal Plants Board and the National Horticultural Mission and the National AYUSH mission are providing financial assistance for sandalwood plantations (1, 33). For the protection of farm-grown trees from theft and smuggling, the Institute of Wood Science and Technology, Bengaluru, is developing microchip-based protection measures (1, 33). Many private growers have come up with the unique idea of protecting sandal plantations by erecting compound walls maintaining 24/7 watch and ward and deploying canine squad etc. Sandalwood production and supply in India remain very low and the country is importing wood and oil from Australia to meet its domestic demands.

By promoting sandalwood-based agroforestry systems in the water-scarce regions like Bundelkhand, the livelihood of farmers can be improved and the existing natural germplasm can be conserved. Further, the assurance of quality planting material availability from government nurseries and private nurseries may

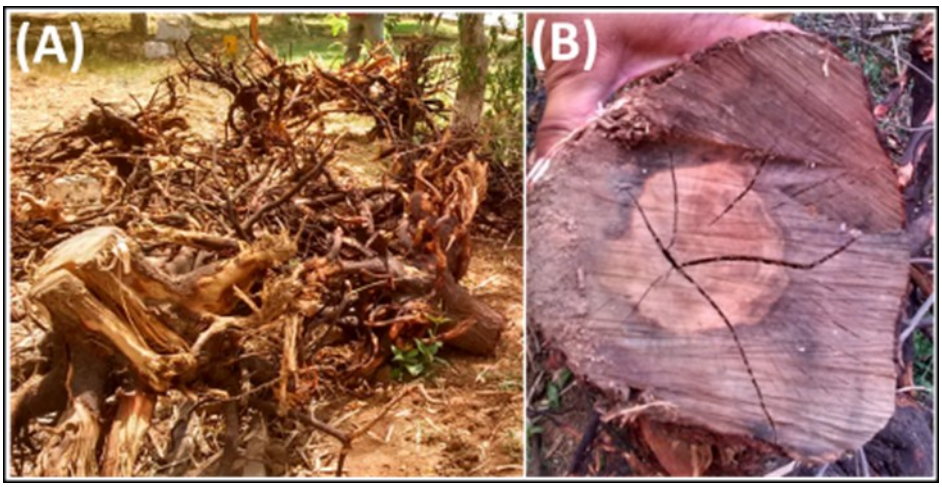

Fig. 1. Excavated roots from harvested trees (A) and stumps showing heartwood (B).

improve large-scale adoption of sandalwood plantations in the region. Additionally, changes in the country's high value tree crops policy regimes are needed to facilitate the cultivation of sandalwood (34). The National Agroforestry Policy is already in place in India and many state governments have come up with state agroforestry policies to promote sandalwood plantations in private lands. The Government of Karnataka enacted the Karnataka State Sandalwood Policy, 2022 and removed all existing restrictions on the sale of sandalwood in the open market.

Conclusion

Sandalwood can be cultivated in farm forestry and agroforestry systems in the semi-arid region of Bundelkhand to enhance farmers' income. Agroforestry and commercial plantations of sandalwood are needed to meet the present and future market demand for sandalwood and to conserve India's natural sandalwood forests. Though the Government of India is in the process of formulating a National Sandalwood Board and a Sandalwood Tree Act, there is a need to bring about uniform national laws pertaining to sandalwood cultivation and the protection of its natural habitats.

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Authors' contributions

KBS was responsible for the conceptualization and drafting of the manuscript. MNR handled data curation and contributed to the writing and editing of the manuscript. PL and SBC conducted field investigations and collected data, while AKH was involved in editing the final version of the manuscript. ARU participated in field investigations and performed data analysis and ASK contributed through field investigations. ID assisted in editing the draft and RPD was engaged in both field investigations and data analysis. GV contributed to the editing of the manuscript and BN, AA, JVNSP provided supervision and conducted the literature review. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Yadav A, Singh S. Prospects and opportunities of sandalwood cultivation in Uttar Pradesh. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):45–7. https://iwst.icfre.gov.in/magazines.html
2. Gairola S, Aggarwal PS, Ravikumar GS. Status of production and marketing of sandalwood (*Santalum album* L.). In: Gairola S, Rathore TS, Joshi G, Arun Kumar AN, Aggarwal PK, editors. National seminar on conservation, improvement, cultivation and management of sandal. Bangalore: Inst Wood Sci Technol; 2008. p. 1–8.
3. Gunaga RP, Hanumantha M, Thakur NS, Hegde HT, Sankanur MS, Sondarva RL. Reproductive phenology and natural regeneration of Indian sandalwood: An ecological implication. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):67–8. https://iwst.icfre.gov.in/magazines.html
4. Divakara BN, Viswanath S, Nikhitha CU, Kumar S. Economics of *Santalum album* L. cultivation under semiarid tropics of Karnataka, India. For Res. 2018;7:223. https://doi.org/10.4172/2168-9776.1000223
5. Kumar R, Verma K, Kumar A, Bhardwaj AK. Potential for growing sandalwood (*Santalum album*) tree in salt affected soils. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):139–41. https://iwst.icfre.gov.in/magazines.html
6. Rathore TS, Rathore SS, Chauhan AK, Choudhary BR. Present scenario and prospects of sandalwood (*Santalum album* L.) cultivation in Rajasthan and Gujarat. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):41–4. https://iwst.icfre.gov.in/magazines.html
7. Banerjee M. Sandalwood - A case for private enterprise with government support: A scenario in Tamil Nadu. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):15–8. https://iwst.icfre.gov.in/magazines.html
8. Doran JC, Thomson L, Brophy JJ, Goldsack B, Bulai P. Variation in heartwood oil composition of young sandalwood trees in the south Pacific (*Santalum yasi*, *S. album* and F1 hybrids). Sandalwood Res Newsl. 2005;20:3–7.
9. Durai MV. Variations in growth, heartwood and oil content of commercial sandalwoods. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):119–23. https://iwst.icfre.gov.in/magazines.html
10. Viswanath S, Dhanya B, Rathore TS. Domestication of sandal (*Santalum album* L.) in India: Constraints and prospects. Asia-Pac Agrofor Newsl. 2009;34:9–12.
11. Arun Kumar AN, Joshi G, Mohan Ram HY. Sandalwood: History, uses, present status and the future. Curr Sci. 2012;103(12):1408–16.
12. Mishra B, Sandeep C, Arade A, Subbanna S, Viswanath S. Assessment of heartwood and oil content of *Santalum album* L. in natural and naturalized populations across contrasting edaphic conditions in India. Indian For. 2018;144(5):675–85.
13. Divakara BN, Prabuddha HR, Chaitra S. Heartwood estimation in standing trees of *Santalum album* L. In: Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2 (2):89–91.
14. McKinnell FH. Status of management and silviculture research on sandalwood in Western Australia and Indonesia. In: Hamilton L, Conrad CE, editors. Proceedings of the symposium on sandalwood in the Pacific. PSW-122. Honolulu: USDA For Serv; 1990. p. 19–25.
15. Jain SH, Angadi VG, Shankaranarayana KH. Edaphic, environmental and genetic factors associated with growth and adaptability of sandal (*Santalum album* L.) in provenances. Sandalwood Res Newsl. 2003;17:6–7.
16. Rai SN. Status and cultivation of sandalwood in India. In: Hamilton L, Conrad CE, editors. Proceedings of the symposium on sandalwood in the Pacific. Honolulu: USDA For Serv; 1990. p. 66–71.

17. Sandeep C, Gogoi R, Rahman R, Boruah RK, Viswanath S. Variation in heartwood and oil content of *Santalum album* L. in Assam and Karnataka. J Bioresour. 2016;3(1):80–8.

18. Liu XJ, Xu DP, Yang ZJ, Zhang NN, Yang LJ, Deng HD, Zhang XY. Evaluation of growth and heartwood formation of young sandalwood plantations in Guangdong Province, south China. Sci Silvae Sin. 2012;48(5):108–15. https://doi.org/10.11707/j.1001-7488.20120517

19. Brand JE, Norris LJ, Dumbrell IC. Estimated heartwood weights and oil concentrations within 16-year-old Indian sandalwood (*Santalum album*) trees planted near Kununurra, Western Australia. Aust For. 2012;75:225–32. https://doi.org/10.1080/00049158.2012.10676406

20. Venkatesh L, Maheshnaik BL, Rathod R. Studies on sandalwood tree (*Santalum album* L.) based agroforestry system in Haveri district of Karnataka, India. Indian J Ecol. 2023;50(5):1602–7. https://doi.org/10.55362/IJE/2023/4102

21. Sreenivasaya M, Narayana N. Sandal seed, its oil and protein. J Indian Inst Sci. 1936;19:1–8.

22. Sinha RL. Sandal in Bundelkhand forest division, Uttar Pradesh. Indian For. 1961;87(10):590–7. https://doi.org/10.36808/if/1961/v87i10/24578

23. Bisht SS, Mamata R, Divyashree NG. Variability in yield and composition of oil from Indian sandalwood (*Santalum album* L.) trees grown in homogeneous conditions. Trop Plant Res. 2019;6(1):31–6. https://doi.org/10.22271/tpr.2019.v6.i1.006

24. Srimathi RA, Kulkarni HD, Venkatesan KR. Recent advances in research and management of sandalwood (*Santalum album* L.) in India. New Delhi: Associated Publishing Company; 1995.

25. Sureshbhai PJ, Thakur NS, Jha SK, Kumar V. Productivity and carbon sequestration under prevalent agroforestry systems in Navsari district, Gujarat, India. Int J Curr Microbiol Appl Sci. 2017;6(9):3405–22. https://doi.org/10.20546/ijcmas.2017.609.419

26. Chandana P, Lata MA, Aariff Khan MA, Krishna A. Climate change smart option and doubling farmer's income through *Melia dubia* based agri-silviculture system. Curr Sci. 2020;118(3):444–8. https://doi.org/10.18520/cs/v118/i3/444-448

27. Petersson H, Holm S, Ståhl G, Alger D, Fridman J, Lehtonen A, et al. Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass. For Ecol Manag. 2012;270:78–84. https://doi.org/10.1016/j.foreco.2012.01.004

28. Tripathi M, Joshi H. Carbon flow in Delhi urban forest ecosystems. Ann Biol Res. 2015;6(8):13–7.

29. Nowak DJ, Hoehn R, Crane DE. Oxygen production by urban trees in the United States. Urban For. 2007;33(3):220–6. https://doi.org/10.48044/jauf.2007.026

30. Srimathi RA, Kulkarni HD. Preliminary findings of the heartwood formation in sandal (*Santalum album* L.). In: Mathur NK, editor. Proceedings of second forestry conference. Dehra Dun: For Res Inst; 1980. p. 108–15.

31. Jain SH, Angandi VG, Shankaranarayana KH, Rajeevalochan AN, Theagarajan KS, Ragaswami CR. Identification of provenances of sandal in India for genetic conservation. In: Radomiljac AM, Ananthapadmanabha RM, Welbourn HS, Rao KS, editors. Sandal and its products. Canberra: ACIAR; 1998. p. 117–20.

32. Sindhu VHC, Anantha Padmanabha HS. The breeding system in sandal (*Santalum album* L.). Silvae Genet. 1996;45:188–90.

33. Ray PC, Mishra S. Need for a state sandalwood policy in Karnataka - A new vision. In: Singh MP, Shivakumar CM, Arun Kumar AN, et al, editors. Wood is good, grow more, use more, sandalwood. Bengaluru: Inst Wood Sci Technol; 2021;2(2):27–30. https://iwst.icfre.gov.in/magazines.html

34. Ramesha MN, Patil SL, Sridhar KB. Greening India perennially needs change in forest policy regime. Curr Sci. 2022;122(10):1125–6.

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