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Influence of Secondary Host tree on Growth, Heartwood Initiation and Oil content of Twelve Year-old of Sandalwood Plantations at Eastern dry zone of Karnataka, in Peninsular India

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ABSTRACT: This study investigates the influence of different secondary hosts on sandalwood in Eastern dry zone of Karnataka's Chikkballapur and Kolar Districts in peninsular India. It assesses how sandalwood's growth, heartwood development, and oil production are linked to secondary hosts. Focusing on twelve-year-old trees in Chikkballapur, the clear bole height of sandalwood showed notable increases when associated with hosts like *Sesbania grandiflora* and *Casuarina equisetifolia* (1.86 m). Notably, sandalwood trees with *Emblica officinalis* as hosts displayed elevated heartwood content (23.05%) and the highest heartwood oil concentration (2.16%). Stem volume was highest under the host of *Sesbania grandiflora* (7.57 dm³). Studying a thirteen-year-old sandalwood trees in Kolar district, those linked with *Morus alba* hosts exhibited the tallest clear bole height (2.54 m) and the greatest stem volume (22.93 dm³). In terms of heartwood composition, sandalwood trees associated with *Emblica officinalis* showcased high percentages (43.32%). Additionally, sandalwood trees with *Emblica officinalis* as hosts exhibited a notably high oil content (3.40%), while those with *Moringa oleifera* hosts had the lowest oil content (0.44%). In conclusion, this research underscores the significant impact of secondary hosts on sandalwood's growth, heartwood development, and oil production. The findings offer valuable insights for the cultivation and management of sandalwood, ultimately enhancing its economic and cultural importance. The effect of secondary hosts on sandalwood heartwood, and oil content formation was less explored. With the analogy of the study concluded with formation of heartwood and oil content was highly correlated with effect from secondary hosts.

Keywords: Semi-root parasite, Sandalwood, heartwood, oil content and clear bole height.

INTRODUCTION

The Indian Sandalwood tree (*Santalum album* L.) holds immense commercial value as one of the world's most prized timbers and sought-after oils. Its historical significance traces back to ancient times, making it one of India's earliest traded commodities with other nations (Rai and Sarma 1990). Referred to as the "Dollar earning parasite," this native species is renowned for its economic contributions (Krishnappa, 1972; Durairaj and Kamraj 2013). The Sandalwood tree is indigenous to the Indian sub-continent's peninsular region and can be found across various states, covering an extensive area of 9040 km^2. The majority of its habitat lies in Karnataka and Tamil Nadu, earning it the name "East Indian Sandalwood" (Ramaswamy, 1956; Gairola *et al.,* 2008). Thriving in dry deciduous forests, these evergreen trees can grow up to 20 meters tall with a girth of up to 2.5 meters (Sen Sarma, 1982). Surprisingly, the species is adaptable to diverse agroclimatic conditions and can survive at altitudes of up to 5000 meters above sea level (Troup, 1921; Annapurna *et al.,* 2006). Although Sandalwood prefers deep red soil, it can be found in various soil types, tolerating a wide range of rainfall (500 – 3000 mm) and temperatures (0°C-38°C). During its growth stages, the tree requires partial shade initially and then thrives in full sunlight, accompanied by a modest amount of water. It takes around seven years for Sandalwood to mature and bear fruits, with the prized heartwood becoming noticeable after ten years of development (Pullaiah and Swamy 2021).

Sandalwood tree is intimately associated with human civilization since time immemorial and is a part of Indian culture and heritage (Srinivasan *et al.,* 1992). *Santalum album* is designated as the 'state tree of Karnataka'. Mysuru is praised as a sandalwood shrine (Gandhada Gudi), while Karnataka is known as the state of sandalwood (Adkoli, 1977). The majority of religions, especially Hinduism and Buddhism Worship Indian sandalwood. The sole largest market category for Indian sandalwood is comprised of goods and uses

intended for ceremonial, ritual and religious functions. Every facet of human life involves the usage of sandalwood, particularly in Indian culture and civilizations where it is necessary from birth to cremation. These days' sandalwood is used for different purposes in different parts of the world. In Europe and North American markets, the essential oil from wood is consumed as fine perfumes, body care products and in pharmaceutical preparation. Similarly, in China, Japan and Republic of Korea sandal is used for solid furniture, carvings, traditional medicines and religious uses; for attars funeral pyres and chewing tobaccos in India; and for customary uses in the Middle East (Thomson, 2020).

An individual growing tree can put an increment of 1.0 kg of heartwood per year and can attain a girth of over 1.5 meters (Rai and Sarma 1990). The heartwood of sandalwood trees is estimated to be fetching approximately 9 lakhs per tonne in the international market (Ananthapadmanabha, 2000). As per 2010 auction in Marayoor, Kerala, fifth class sandalwood tree was sold at rupees 7390 kg^{-1}. In the international market, sandalwood is fetching about US$2000 per kg of Sandalwood oil (Pullaiah and Swamy 2021). Nearly, 150 tonnes of Sandalwood oil is produced per annum worldwide (Goswami and Jagatpati 2018). Most of the Sandalwood demand in the world met through Australian Sandalwood (*Santalum spicatum*) (Pullaiah and Swamy 2021). However, over-exploitation, illicit felling of sandalwood trees has resulted in decline in population and genetic erosion (Annapurna *et al.,* 2006).

MATERIAL AND METHODS

The survey was undertaken in two locations at Chikkballapur and Kolar district of Karnataka. The basic information was collected with help of questionnaires. In each location/AF systems five trees were selected randomly for estimation of heartwood and oil content (Table 1 and 2).

Observation were recorded during the survey

— Name of the location
— Age of the tree (years)
— Name of the secondary host introduced
— Method of planting
— Spacing adopted (m)
— Growth parameters
— Percent heartwood formation
— Percent oil content

Site characteristics: Location, latitude, Altitude (m) longitude, Rainfall (mm), Temp and soil type are mentioned in Table 4 and 5

Canopy volume. Canopy volume was estimated using the following formula (Thorne *et al.,* 2002).

$$V = \frac{2}{3}\pi h\left(\frac{a}{2}\times\frac{b}{2}\right)$$

Where, h is the height of the canopy; a and b are spread of mid canopy at perpendicular axes.

Volume of the main stem. The main stem volume indicates the dry matter accumulation in the sandalwood tree and marketable yield. It was calculated considering the main stem as cylinder using the formula as a non-destructive observation.

$V = \pi r^2 h$

Where h is clear bole height and r is radius derived from tree girth

To estimate heartwood per cent and oil yield from the identified locations of Chikkballapur and Kolar district. Data from three replicates/ sample trees in each girth class was recorded. Girth at breast height (GBH) and height of the trees were recorded. The core sample from each tree was extracted using a Haglof increment borer. The core sample was extracted by using the bark, sapwood, transition region and heartwood percentage. The heartwood portion of the core sample used for oil content estimation and the collected core samples was collected at breast height level and its wrapped with blotting paper and kept in a desiccators.

From the core samples, bark thickness, sapwood radius, transition region and heartwood radius was estimated (by converting tree girth to tree diameter) accordingly percentage of heartwood has been calculated. Sandalwood oil was being estimated from the core samples using the method developed by Shankaranarayana *et al*. (1997). This non-destructive method has been found to be very convenient for quick screening of plants for their oil content from the standing trees. The heartwood portion was then cut into fine pieces using a blade. 100 mg of the sample was weighed on a weighing balance and then 100 ml of hexane (60-700 boiling points) was added to the 100 ml standard flask. The samples were kept aside for 18 hours with periodic shaking. The supernatant was taken in quartz cell and optical density at 219 nm (maximum) was measured by UV Spectrophotometer (Shimadzu-240). The mean values are worked out and the data expressed as mean ± SE. Statistical significance was determined using student t-test in Microsoft Excel 2010 at 95 per cent probability level ($P<0.05$).

RESULTS AND DISCUSSION

Sandalwood, a semi-root parasite, relies on suitable hosts at different life stages: primary, secondary, and tertiary. Secondary host plants play a pivotal role during the exponential growth phase, influencing sandal plant establishment, heartwood development, and oil content. The impact of various secondary host plants on sandalwood's features was examined across two locations in Karnataka. The interaction encompassed sandal clear bole height, tree girth, main stem volume, heartwood composition, and oil content.

This study was focused on the influence of secondary host trees on twelve-year-old sandalwood trees in Chikkballapur and Kolar district. The Chikkballapur district results, presented in Table 1 and Fig. 1, revealed significant variations. Sandalwood clear bole height was notably greater with *Sesbania grandiflora* (1.86 m) and *Casuarina equisetifolia* (1.86 m), comparable to *Dalbergia latifolia* (1.84 m), *Melia dubia* (1.76 m), *Murraya koenigii* (1.71 m), and *Manilkara zapota* (1.66 m). *Mangifera indica* (1.48 m) and *Emblica officinalis* (1.50 m) displayed lower heights, akin to *Grevillea robusta* (1.50 m) and *Morus alba* (1.63 m).

Similar findings emerged from Bilas *et al.* (2018) study, indicating that *Citrus aurantium*, *Casuarina equisetifolia*, and *Punica granatum* enhanced various parameters of *S.album* trees. Another investigation by Srikantaprasad *et al.* (2022) showcased improved growth of secondary host trees, encompassing height, canopy spread, volume, stem girth and volume in sandalwood cultivation within the northern dry zone of Karnataka. Among ten identified secondary hosts, *Sesbania grandiflora* exhibited the most substantial tree girth (22.58 cm), while *Murraya koenigii* and others showed relatively lower girths (18.17–19.17 cm). The volume of the main sandalwood stem was maximized by *Sesbania grandiflora* (7.57 dm^3), followed by *Casuarina equisetifolia* (6.21 dm^3) and *Melia dubia* (6.05 dm^3), with *Mangifera indica* yielding the least (3.95 dm^3).

Emblica officinalis demonstrated significantly high heartwood content (23.05%), surpassed by *Sesbania grandiflora* (17.05%) and *Melia dubia* (16.41%). In contrast, *Manilkara zapota* exhibited the lowest heartwood content (8.00%), akin to *Casuarina equisetifolia*, *Murraya koenigii*, *Mangifera indica*, and *Dalbergia latifolia*. Regarding oil content in sandalwood heartwood, *Emblica officinalis* had the highest (2.16%), whereas *Dalbergia latifolia* had the lowest (0.37%), similar to *Manilkara zapota* and *Murraya koenigii* (0.38 and 0.40%) respectively. This trend was mirrored in Srikantaprasad *et al.* (2022) study, which indicated that secondary hosts like *Prosopis juliflora* and Mango supported heartwood initiation. Previous studies by Argal *et al.* (2018); Felker (2009) also endorsed the role of secondary hosts in enhancing survivability and early heartwood formation under challenging conditions.

Table 1: Influence of host trees on growth, heart wood initiation and oil content on twelve-year-old sandalwood trees at Chikkballapur district.

Sr. No.	Secondary host plants	Sandal clear bole height (m)	Tree girth (cm)	Volume of main stem (dm^3)	Heart wood content (%)	Oil content (%)
1.	*Morus alba*	1.63	21.27	5.86	15.83	1.80
2.	*Emblica officinalis*	1.50	20.33	4.94	23.05	2.16
3.	*Murrayakoenigii*	1.71	18.17	4.52	9.50	0.40
4.	*Sesbania grandiflora*	1.86	22.58	7.57	17.05	1.00
5.	*Grevillea robusta*	1.50	20.70	5.10	13.66	1.14
6.	*Dalbergia latifolia*	1.84	19.17	5.37	11.26	0.37
7.	*Casuarina equisetifolia*	1.86	20.50	6.21	8.16	0.89
8.	*Mangifera indica*	1.48	18.27	3.95	11.03	0.96
9.	*Manilkara zapota*	1.66	19.00	4.79	8.00	0.38
10.	*Melia dubia*	1.76	20.75	6.05	16.41	1.07
	S.Em ±	**0.068**	**0.58**	**0.27**	**1.55**	**0.10**
	C D @ 5 %	**0.203**	**1.73**	**0.8**	**4.97**	**0.33**

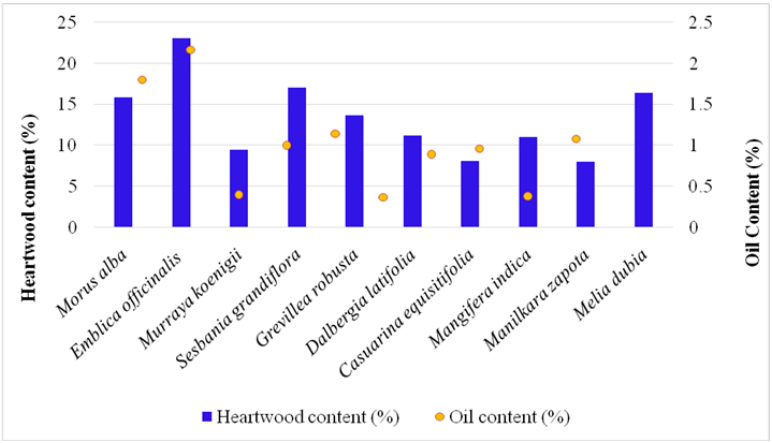

Fig. 1. Influence of host trees on growth, heart wood initiation and oil content on twelve-year-old sandalwood trees at Chikkballapur district.

The impact of host trees on the growth, heartwood, and oil content of thirteen-year-old sandalwood trees in Kolar district, the results were as follows:

The sandal clear bole height data were presented in Table 2. *Morus alba* demonstrated the highest sandalwood clear bole height (2.54 m), followed by *Moringa oleifera* and *Casuarina equisetifolia* (both at 2.00 m). Conversely, *Emblica officinalis* exhibited the lowest height (1.61 m), on par with *Swietenia mahogani*, *Mangifera indica*, *Syzygium cumini*, *Sesbania grandiflora*, *Murraya koenigii*, and *Psidium guajava* (ranging from 1.66 m to 1.95 m), in comparison to the remaining identified secondary host plants (Table 2 and Fig. 2). In terms of tree girth, significantly higher values were recorded for *Casuarina equisetifolia* (37.35 cm), followed by *Melia dubia* and *Morus alba* (both at 35.82 cm). The lowest tree girth was observed with *Psidium guajava* (21.42 cm).

Regarding the volume of the main sandalwood stem, *Morus alba* displayed the highest volume (22.93 dm^3), akin to *Casuarina equisetifolia* (22.27 dm^3). *Psidium guajava* exhibited the lowest stem volume, similar to *Swietenia mahogany* and *Emblica officinalis* (ranging from 8.98 dm^3 to 10.60 dm^3). Significantly higher heartwood content was recorded in *Emblica officinalis* (43.32%), comparable to *Casuarina equisetifolia* and *Morus alba* (41.85% and 40.65% respectively). *Psidium guajava* showcased the lowest heartwood content (4.33%). Similarly, higher oil content was found in sandalwood trees under the secondary host of *Emblica officinalis* (3.40%), whereas *Moringa oleifera* demonstrated the lowest oil content (0.44%), on par with the other secondary host, *Swietenia mahogani* (0.89%).

These outcomes align with the study conducted by Jain *et al.* (2003), where the author reported that essential oil content in *Santalum album trees* varies from 1 to 8 percent based on age, soil, climate, and genetic factors. Similarly, Mishra *et al.* (2018) revealed that sandalwood trees aged between 8 to 35 years, with girths ranging from 30 to 80 cm, exhibited oil content between 1.0 to 4.0 percent. As age increased, the percentage of heartwood and oil content also significantly increased**.**

Table 2: Influence of host trees on growth, heart wood initiation and oil content on thirteen-year-old sandalwood trees at Kolar district.

Sr. No.	Secondary host plants	Sandal clear bole height (m)	Tree girth (cm)	Volume of main stem (dm^3)	Heart wood content (%)	Oil content (%)
1.	*Emblica officinalis*	1.61	28.88	10.60	43.32	3.40
2.	*Mangifera indica*	1.78	32.59	15.11	28.97	2.47
3.	*Moringa olifera*	2.00	26.55	11.25	30.30	0.44
4.	*Morus alba*	2.54	35.82	22.93	40.65	2.45
5.	*Sesbania grandiflora*	1.94	31.08	14.99	30.47	2.58
6.	*Murrayakoenigii*	1.95	31.25	15.20	15.00	1.62
7.	*Psidium guajava*	1.95	21.42	7.24	4.33	1.17
8.	*Casuarina equisetifolia*	2.00	37.35	22.27	41.85	2.72
9.	*Syzygiumcumini*	1.80	32.71	15.52	31.55	2.48
10.	*Swietenia mahogani*	1.66	26.08	8.98	11.55	0.89
	S.Em ±	**0.12**	**0.99**	**1.24**	**1.76**	**0.22**
	C D @ 5 %	**0.37**	**3.17**	**3.97**	**5.28**	**0.65**

Table 3: List of predominant secondary hosts identified and their sample size of district in Kolar and Chikkballapur district.

Chikkballapur district				
Sr. No.	**Secondary host plants**	**Common Name**	**Age (Yrs)**	**Sample size**
1.	*Morus alba*	Mulberry	4.5	4
2.	*Emblica officinalis*	Amla	5	3
3.	*Murrayakoenigii*	Curry leaf	6	3
4.	*Sesbania grandiflora*	Chogache	3.5	3
5.	*Grevillea robusta*	Siveroak	4.5	3
6.	*Dalbergia latifolia*	Beete	5	3
7.	*Casuarina equisetifolia*	Beef wood	4.5	4
8.	*Mangifera indica*	Mango	5.5	3
9.	*Manilkara zapota*	Sapota	5	3
10.	*Melia dubia*	Hebbevu	6	3
Kolar district				
1.	*Emblica officinalis*	Amla	4	4
2.	*Mangifera indica*	Mango	5	3
3.	*Moringa olifera*	Mulberry	4.5	4
4.	*Morus alba*	Mulberry	5.5	3
5.	*Sesbania grandiflora*	Chogache	4.5	3
6.	*Murrayakoenigii*	Curry leaf	4	3
7.	*Psidium guajava*	Guava	5	2
8.	*Casuarina equisetifolia*	Beef wood	5.5	2
9.	*Syzygiumcumini*	Nerale	4.5	3
10.	*Swietenia mahogany*	Mahogany	4	3

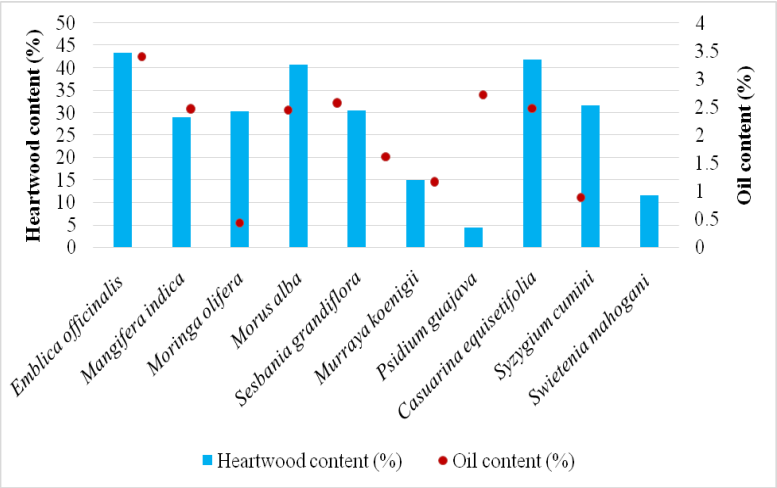

Fig. 2. Influence of host trees on growth, heart wood initiation and oil content on thirteen-year-old sandalwood trees at Kolar district.

Table 4: Soil type, spacing and management practices followed in sandalwood trees and host plants in Kolar and Chikkballapur district of Karnataka.

Sr. No.	District	Location	Soil Type	Spacing adopted (m)		Management practices followed
				Sandal	Sandal to host	
1.	Kolar	Arahalli	Red soil	4×4	2×2	Irrigation, pruning, weeding
		Kolar	Red sandy	4×3	1v1	Pruning, drip irrigation, soil working
		Narasapura	Red clay soil	5×4	2×1	Pruning, soil working and weeding
		Malur	Red clay	4×4	1×1	Pruning, weeding, soil working
		Nalhal	Red	4×5	2×2	Pruning, irrigation
2	Chikkaballapur	Bevinahalli	Black soil	4×4	2×1	Pruning, weeding
		Gauribidanur	Clay loam	4×3	3×1	Pruning, organic fertilizer
		Kaiwara	Red soil	4×3	2×1	Pruning, weeding, soil working
		Chintamani	Red sandy	4×4	2×2	Pruning, weeding,
		Alagurki	Red clay	3×2	1×1	Pruning, irrigation
		Sidlaghatta	Black cotton	4×4	2×2	Irrigation, pruning, weeding

Table 5: Effect of locality factors on per cent oil content in sandalwood trees in Kolar and Chikkballapur districts of Karnataka.

Sr. No.	District	Location	Latitude (North)	Longitude (East)	Elevation (m)	Mean Annual Rainfall (mm)	Mean Annual Temperature (ºC)	
							Maximum	Minimum
1.	Kolar	Arahalli	13.16	78.12	844.50	739	32.02	26.60
		Kolar	13.13	78.12	842.14	744	31.50	25.67
		Narasapura	13.14	78.00	870.64	742	31.90	26.15
		Malur	12.99	77.94	908.81	723	31.67	27.08
		Nalhal	12.95	78.19	819.91	731	32.00	26.57
2.	Chikkaballapur	Bevinahalli	13.50	77.48	716.18	825	33.30	23.90
		Gauribidanur	13.61	77.51	684.12	809	32.15	24.15
		Kaiwara	13.35	77.99	905.79	814	32.67	23.65
		Chintamani	13.39	78.06	871.08	821	33.00	23.78
		Alagurki	13.53	77.940	824.02	810	31.92	22.67
		Sidlaghatta	13.40	77.87	898.72	807	31.50	22.55

CONCLUSIONS

This research examines how various secondary hosts affect sandalwood in Karnataka, India. The study evaluates sandalwood's growth, heartwood, and oil in relation to secondary hosts. Focusing on twelve-year-old trees in Chikkballapur, sandalwood's clear bole height increased notably with *Sesbania grandiflora* and *Casuarina equisetifolia* (1.86 m), akin to other hosts. *Emblica officinalis* had high heartwood (23.05%). In heartwood oil, *Emblica officinalis* showed the highest (2.16%), Investigating thirteen-year-olds in Kolar, *Morus alba* had highest clear bole (2.54 m) and also it had most stem volume (22.93 dm^3),The sandal having the host of Emblica *officinalis* had high oil (3.40%), hence the oil and heart wood content of the sandal is mainly depending on the host tree. The research

highlights secondary hosts' impact on sandalwood's growth, heartwood, oil, offering insights for cultivation and management, enhancing its economic and cultural value.

FUTURE SCOPE

Comprehensively investigating host tree species in different agroclimatic zones of Karnataka is necessary. Improving the core wood sample collection method using advanced techniques like ERT can enhance estimates of heartwood, sapwood, stress, and decay in trees. Evaluating suitable host trees for sandalwood through systematic examination is essential. Understanding the relationship between heartwood formation, age gradation, and host tree consistency across locations is crucial. Studying the physiological responses of secondary host plants under field conditions is imperative. Additionally, economically analyzing sandalwood-centered agroforestry across diverse agroclimatic zones in Karnataka is vital.

Conflict of Interest. None.

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