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Seed Source Variation in Seed Traits, Germination and Seedling Growth Attributes of Sandalwood (*Santalum album* L.)

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Abstract: *Santalum album* is indigenous to peninsular India and popularly known as Indian Sandalwood. In this study, we evaluated total six different sandalwood seed sources under nursery condition including seed morphology at College of Forestry, NAU, Navsari, Gujarat. There was a significant variation in seed morphological attributes, seed germination and other attributes *viz.,* Mean daily germination, Peak value of germination, Germination value and Germination rate index and Mean germination time. Seedling growth measured at 90 days after transplanting also resulted in significant variation among the seed sources under nursery. Idukki (Kerala) and Bengaluru (Karnataka) sources showed superiority for seed size, germination and seedling growth attributes under Navsari climatic conditions; conversely, Surat and Dharwad sources showed poor germination. Therefore, Idukki and Bengaluru sources can be used for large scale seedling production as well as for further selection and evaluation at field condition.

Keywords: Hemiparasite, Nursery attributes, Sandalwood, Seed morphology, Seed source

Sandalwood, a generic term used for species of Genus *Santalum,* is a hemi-parasitic genus renowned for its fragrant wood. It includes 15 extant species and 14 varieties and one extinct species *i.e., Santalum fernandezianum* (Harbaugh and Baldwin 2007). Among several species of *Santalum*, *S. album* (Indian Sandalwood), *S. spicatum, S. austrocaledonicum, S. insulare, S. lanceolatum, S. macgregorii* and *S. yasi* are commercially important ones (Durai 2021). *S. album* is indigenous to peninsular India distributed from Nasik to Northern Circars (Madras Presidency) downwards, and occurs in the dry deciduous forest of Deccan plateau at the edge of Western Ghats and Kalrayan and Shevaroy Hills of Tamil Nadu. *S. album* stands out from other sandalwood species for its highly valued oil and wood making. It is the second most expensive wood in the world after *Dalbergia melanoxylon* (African blackwood). The most economical parts of a sandalwood tree are heartwood of root and stem; therefore is most valued for its fragrant heartwood. Santanol content is most responsible for its aroma. Sandalwood oil is commonly used in the perfumery industries and pharmaceutical uses in medicines (Arunkumar et al., 2012, Arunkumar et al., 2016) and there is great global and domestic demand for sandalwood oil.

Thus, farmers, private agencies, state forest departments started growing sandalwood plantations in large scale across India including non-traditional sandalwood areas *viz.,* Andhra Pradesh, Telangana, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan and other parts. Currently, the area under sandalwood in farmlands has grown dramatically to an estimated 30,000 ha in 2019, with the majority of the plantings taken place in Gujarat and Karnataka (Pallavi 2015). Considering the future financial benefits of growing sandalwood, farmers have started cultivation of Sandalwood from the last 10 years. With the help of Gujarat Forest Department, more than 670 farmers raised about 3.3 lakhs Sandalwood seedlings under Agroforestry and Vrukshkheti schemes (Singh 2021, Rathore et al., 2021). Hence, there was a demand for quality planting materials for large scale plantation programs. Then, identification of good seed source is very crucial and screening of good seed sources provides information on nature and magnitude of variability present in planting material (Suma and Balasundaran 2007, Gunaga et al., 2015, Arunkumar et al., 2012, Bhuva et al., 2024). With this context, a study comprising six distant seed sources including Gujarat was started to understand the seed trait variability and its performance on germinability and growth under nursery condition in the Navsari climatic situation of southern Gujarat.

MATERIAL AND METHODS

The present study was carried out at Navsari Agricultural University (NAU), Navsari, Gujarat [20° 55' 21.18'' N and 72° 54' 29.24'' E with an altitude of 9 meter above the mean sea level during 2023-24. Seeds were collected from six different seed sources- one from Kerala, three from Karnataka and two from Gujarat (Table 1). Since species is under IUCN threat category (Arunkumar et al., 2016), the geo co-ordinates of selected locations are not given. Collected seeds were cleaned and characterized for seed morphological observations in the laboratory.

Further, all these seed lots were used for assessing seed germination and seedling growth at Nursery in the NAU Campus. Study site belongs to typical tropical warm climate characterized by fairly hot summer, moderately cold winter and warm humid monsoon. Generally, monsoon commences in the second week of Jun and ends in Sept with mean annual rainfall from 1200 to 1500 mm. During experimental period from Apr 2023 to Mar 2024, maximum rainfall occurred during July with 1030 mm, followed by Jun (306 mm) and Sept (289mm); while, maximum temperature ranged from 29.5 to 36.0 ºC and minimum temperature ranged from 14 to 26.9 ºC. The minimum and maximum relative humidity recorded was 62 and 93 per cent, respectively. These data were collected from the Agricultural Meteorological Cell, Department of Agricultural Engineering, N.M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat.

Morphometric variation in seed traits such as seed length, seed thickness, seed weight and test weight (hundred seed weight) was measured using all the six seed sources in the laboratory. For each seed source, total two hundred fifty seeds *i.e.,* five sample containing fifty seeds each were used. For germination study, five repetitions containing 100 seeds each (N= 500 per source) for six seed sources were sown on nursery bed by following completely randomized design by maintaining uniform growing condition under mini-polytunnel in the nursery. Prior to sowing, seed were subjected to common pre-sowing treatment with GA_3 @ 500 ppm for 24 hours uniformly for all the seed sources. Seed beds were drenched with Carbendazim (Bavistin), before seed sowing (Lekshmi 2024). The numbers of seeds germinated on each day were counted. Emergence of plumule above the soil was taken as germinated. Based on daily germination count, day of first germination and day of last germination was recorded. Further, daily germination count was used to determine the germination percentage and other germination parameters such as mean daily germination (MDG), Peak Value (PV), germination value (GV), germination rate index (GRI) and mean germination time (MGT) using standard formulae (Czabator 1962, Orchard 1977, Esechie 1994, Thakur et al., 2017).

To assess the seedling growth, germinated seeds from germination experiment (different seed sources wise) were transplanted into polybags of size 4x8cm containing potting mixture of soil, sand and FYM (well decomposed) in the ratio 2:1:1. Pigeon pea (*Cajanus cajan* L.) was grown as a host plant (Lekshmi 2024). Total five repetitions, each containing 25 seedlings, were used and then seedlings were arranged in completely randomized design under shade net condition. Growth observation such as plant height, collar diameter and number of leaves per plant was recorded and growth at 90 days after transplanting was reported.

Statistical analysis: All the data were subjected to CRD and DMRT analysis was also performed by following Gopinath et al. (2020).

RESULTS AND DISCUSSION

Variation in seed traits: There was a significant variation among six seed sources for seed length (7.18 to 7.87 mm), seed width (6.56 to 7.01 mm), seed weight (0.15 to 0.19 g) and 100 seed weight (14.24 to 18.69 g). Seed width was slightly lesser than seed length indicating oval shape. Among all the seed sources, seeds collected from Idukki, Bengaluru and Dharwad sources recorded to be bigger in size having more length, width and weight, while seeds collected from local sources *viz.,* Surat and Junagadh showed smaller seeds (Table 1). Similar to the present study, Madhuvanthi et al. (2024) reported variability in seed weight between individuals as well as populations of *S. album*, where the Idukki population recorded maximum seed weight and was minimum in Mysore population. Earlier studies on *S. album* showed that seed length varied 6.02 to 7.9 mm, seed width from 6.00 to 8.42 mm seed weight from 0.16 to 0.19 g. (Manonmani and Vanangamudi 2002, Annapurna et al., 2005, Shwetha et al., 2024)

Variation in seed germination: Seeds collected from Surat source resulted in poor and irregular seed germination (1 to 3%); hence, this source was dropped from germination and growth studies. Germination experiment shows that seed source influenced the seed germination and its attributes in Sandalwood. Seeds started germinating 21 days after sowing and completed within 52 days. Shwetha et al. (2024) and Annapurna et al., (2005) also reported variation in initiation of seed germination and time of seed germination varied from 16 to 31 days and 15 to 28 days, respectively. Periodic germination showed a significant variation among five seed sources (Table 2) and it varied from 1.40 to 24.20 per cent at 30 days and 7.20 to 45.00 per cent at 70 days after sowing. Similarly, other germination attributes such as germination rate index also showed significant variation among seed sources (Table 3). Mean germination time show the average days to achieve maximum germination ranged from 33 (Mysore) to 43 (Dharwad). Such information is ideal for selection of better seed source(s). Shwetha et al. (2024) observed variation in germination among seven seed sources from Karnataka and one from Kerala (Marayoor). Out of these, Marayoor (Idduki, Kerala), Gungaraghatti (Dharwad, Karnataka) and Gottipura (Bengaluru, Karnataka) performed better than other sources. In present study Idukki and Bengaluru sources proved better germination; in contrast, Dharwad and Junagadh sources resulted in lower germination. Better performance of seed sources could be

due to greater genetic diversity and nature of adaptability (Suma and Balasundaran 2007). It is also evident that provenances and individual genotypes behave differently for germination and attributes including seedling growth. Erstwhile studies confirm that variation in germination traits can be attributed by seed sources. As per review, the germination varied from 4.00 to 80.33 per cent (Manonmani and Vanangamudi 2002, Annapurna et al., 2005, Batabyal et al., 2014, Madhuvanthi et al., 2024 and Shwetha et al., 2024). Interestingly, the range of germination (7.20 to 45.00%) recorded in the present study also falls under this range. Apart from genetic factors, seed germination is also influenced by

Table 1. Variation in seed traits among six seed sources of Sandalwood

Seed sources	Seed length (mm)	Seed width (mm)	Seed weight (g)	Test weight (g)
Idukki (Kerala)	7.87^{a}	6.96^{ab}	0.19^{a}	18.69^{a}
Mysore (Karnataka)	7.18^{c}	6.56^{d}	0.16^{d}	15.88^{c}
Bengaluru (Karnataka)	7.60^{b}	7.01^{a}	0.17^{cd}	16.69^{bc}
Dharwad (Karnataka)	7.87^{a}	6.83^{bc}	0.18^{ab}	17.58^{ab}
Junagadh (Saurashtra, Gujarat)	7.47^{b}	6.91^{abc}	0.17^{bc}	16.10^{c}
Surat (South Gujarat)	7.61^{b}	6.78^{c}	0.16^{d}	14.21^{d}
Mean	7.60	6.84	0.17	16.53
CD (P<0.05)	0.17	0.16	0.016	1.37
CV (%)	1.67	1.74	6.95	6.35

Treatments with same letters are not significantly different

Table 2. Variation in seed germination at different time intervals among six seed sources of Sandalwood

Seed sources	Seed germination (%)				
	30 DAS (G30)	40 DAS (G40)	50 DAS (G50)	60 DAS (G60)	70 DAS (G70)
Idukki (Kerala)	13.60^{b} (21.62^{b})	20.60^{bc} (26.98^{bc})	27.80^{b} (31.75^{b})	30.20^{b} (33.30^{b})	31.60^{b} (34.18^{b})
Mysore (Karnataka)	16.80^{b} (24.08^{b})	25.40^{bc} (30.17^{b})	27.80^{b} (31.76^{b})	28.40^{b} (32.15^{b})	31.40^{b} (34.03^{b})
Bengaluru (Karnataka)	24.20^{a} (29.36^{a})	36.40^{a} (37.08^{a})	39.20^{a} (38.74^{a})	41.40^{a} (10.03^{a})	45.00^{a} (42.12^{a})
Dharwad (Karnataka)	1.40^{d} (6.58^{d})	3.80^{d} (10.78^{d})	5.40^{d} (13.14^{d})	6.60^{d} (14.64^{d})	7.20^{d} (15.33^{d})
Junagadh (Saurashtra, Gujarat)	8.60^{c} (16.40^{c})	16.40^{c} (23.59^{c})	21.20^{c} (27.29^{c})	22.20^{c} (28.40^{c})	22.60^{c} (28.33^{c})
Mean	12.92	20.52	24.28	25.76	27.56
CD (P<0.05)	4.41	4.49	3.91	3.41	3.44
CV (%)	17.05	13.32	10.38	8.82	8.46

Note: Values in the parenthesis are arc-sine transformed; DAS = Days After Sowing; Treatments with same letters are not significantly different

Table 3. Variation in seed germination attributes among five seed sources of Sandalwood

Seed sources	MDG	PV	GV	GRI	MGT
Idukki (Kerala)	0.51^{b}	0.17^{b}	0.09^{b}	0.98^{b}	35.94^{b}
Mysore (Karnataka)	0.50^{bc}	0.19^{b}	0.10^{b}	1.07^{b}	33.03^{b}
Bengaluru (Karnataka)	0.77^{a}	0.29^{a}	0.22^{a}	1.53^{a}	33.08^{b}
Dharwad (Karnataka)	0.12^{d}	0.06^{c}	0.01^{c}	0.19^{d}	43.22^{a}
Junagadh (Saurashtra, Gujarat)	0.40^{c}	0.16^{b}	0.07^{bc}	0.69^{c}	35.99^{b}
CD (P<0.05)	0.11	0.08	0.06	0.18	4.74
CV (%)	18.13	34.80	49.41	15.69	9.91

Note: MDG = Mean daily germination; PV= Peak value of germination; GV= Germination value; GRI = Germination rate index and MGT = Mean germination time; Treatments with same letters are not significantly different

Table 4. Variation in seedling growth at 90 days after transplanting across five seed sources of Sandalwood

Seed sources	Shoot height (cm)	Basal diameter (mm)	Number of leaves
Idukki (Kerala)	20.44[a]	1.82[a]	11.42
Mysore (Karnataka)	14.82[b]	1.43[b]	8.76
Bengaluru (Karnataka)	19.97[a]	1.85[a]	11.01
Dharwad (Karnataka)	17.34[ab]	1.74[a]	12.98
Junagadh (Saurashtra, Gujarat)	15.75[b]	1.76[a]	11.34
Mean	17.66	1.72	11.10
CD (P<0.05)	3.30	0.28	NS
CV (%)	12.42	10.80	16.78

several factors like viability, dormancy, season of seeding, seed maturation, tree age, and other extrinsic factors (Schmidt 2000, Gunaga et al., 2007, Gunaga and Vasudeva 2009).

Variation in seedling growth: Seedling growth attributes recorded at 90 days after transplanting showed significant variation among five seed sources, where Idukki and Bengaluru seed sources showed superiority over Mysore source. Plant height varied significantly from 14.82 to 20.44 cm, whereas collar diameter varied from 1.43 to 1.85 mm (Table 4), however, seed source did not influence on the number of leaves at 90 days of growth in the nursery. This result is compliance with the investigation of Shwetha et al., (2024) on Sandalwood, where superior performance of Marayur (Kerala) and Gottipura (Karnataka) sources on seedling growth and biomass was observed. Variation attributed for growth among seed sources is mainly due to genetic factors, followed by physiological functions and local environment (Schmidt 2000, Gunaga et al., 2007, Gunaga and Vasudeva 2009). Alike other studies, both Idukki and Bengaluru seed source also showed superiority under south Gujarat condition. Hence, these sources can be used for large scale seedling production as well as further tree improvement work.

CONCLUSION

Study concludes that different seed sources of Sandalwood used in the experiment resulted in significant variation for seed traits, germination and seedling growth attributes. Idukki (Kerala) and Bengaluru (Karnataka) seed sources showed superiority for seed size, germination and seedling growth attributes under Navsari climatic conditions. Therefore, these sources can be used for large scale seedling production as well as for further selection and evaluation at field condition. Further investigation may be required to address the problem of poor germination in local seed sources.

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AUTHOR'S CONTRIBUTION

Ms. Lekshmi as a master's student, she collected, analyzed the data, and prepared the thesis, Dr. Gunaga as a major guide, planned, designed, executed the experiment and synthesized the manuscript, Dr. Thakur and Dr. Huse helped in the nursery experiments as well as in the draft manuscript, and Dr. Garde helped in statistical analysis.

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