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Impact of Sowing Time on Sandalwood (*Santalum album*) Seedling Growth in Sub-Tropical Zone

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Abstract: The aim of the study was to determine the appropriate sowing time for sandalwood seeds at Punjab Agricultural University, Ludhiana, India. Dried sandalwood seeds collected from Marayoor, Kerala were used in the study. Sandalwood seeds were treated for 16 to 24 hours with 0.05 % gibberellic acid and sown at 24 different dates throughout the year. Seeds sown in April showed superiority in all germination and growth parameters followed by August, 1st September and 15th March. The highest germination percentage (77.5), germination value (2.56), survival percentage (63), plant height (22.5 cm) and collar diameter (0.22 cm) were witnessed in 15 April sown seeds. Lowest plant height (4 cm) and collar diameter (0.07 cm) were in the December sown seeds which were at par with November and January. Sturdiness quotient and volume index was also higher in April sown seeds. Extreme temperatures, whether winter or summer affected germination and growth of sandalwood. The study concludes that period from 15th March to end April as well as August and September is suitable for sandalwood seed sowing.

Keywords: Climatic conditions, Germination behavior, Month of sowing, Sandalwood growth

Santalum album L., often known as East Indian White Sandalwood is widely recognised across the world for its aromatic heartwood and immense therapeutic value. The genus, Indian sandalwood has the highest oil (6-7%) and santalol content. It is one of the slow-growing tropical trees that are being cultivated on a large scale for plantations. Sandalwood cultivation poses a significant challenge in obtaining high-quality stock. The essential oil market is predicted to reach USD 197 million by the end of 2026 (Global Sandalwood Oil Markets Report, 2020). Unfortunately, its production in its natural habitat (Karnataka and Tamil Nadu) has declined dramatically in recent years, due to indiscriminate exploitation, especially for its high export value, coupled with poor regeneration, disease, and changes in land-use patterns and is listed as a "vulnerable" tree species by the IUCN (Kumar et al., 2019). Sandalwood heartwood is prized for carving, while its oil is used extensively in attars, perfumes, cosmetics, medicinal products, and flavored tobacco (Chavan et al., 2024). The natural distribution of *S. album* spans an estimated 9,000 km², with about 90% of this area concentrated in Karnataka, Tamil Nadu, Madhya Pradesh, and select regions of Kerala. Smaller populations also exist in semi-arid areas of Maharashtra, Telangana, and parts of Uttar Pradesh (Madhuvanthi et al., 2024). Recently, commercial plantations have been expanding into non-traditional areas such as Andhra Pradesh, Telangana, Maharashtra, Gujarat, Assam, and Punjab (Durai et al., 2022). Therefore, to expand cultivation and bridge the gap between demand and supply that can reduce pressure on the wild population, it is now proposed to introduce sandalwood cultivation in northern India.

Optimizing the sowing time is important because every seed needs a specific climate or season to take out maximum resources from the soil (Sumathi and Srimathi 2013) and varies from species to species. The ability of a viable seed to germinate is controlled by a series of factors, including inherent causes of germination and external conditions. Sandalwood seeds take around 4–8 weeks to complete germination or reach the transplanting stage and it is an erratic, low-yield and time-consuming process. Seasonal temperature fluctuations is an important factor in determining seed germination and species in different locations exhibit different germination behaviors in response to temperature fluctuations (Liu et al*.,* 2013). Extreme temperatures give rise to oxidative damage in seeds; low temperatures reduce seed germination percentage, extend the first germination time and inhibit early seedlings growth (Fu et al*.,* 2017). High temperatures up-regulate abscisic acid biosynthesis genes and down-regulate catabolism genes. When seeds are exposed to favourable temperature conditions, changes in this phytohormone favour and seed germination (Sumathi and Srimathi 2013). Due to the constant change in climatic conditions in Punjab, it is very difficult to choose an appropriate time for sowing sandalwood seeds because these are vulnerable to climate change. Sowing and transplanting times affect not only seedling growth after germination but also the germination process itself. The

success of a sandalwood plantation is directly influenced by raising quality seedlings, which further depends on optimum timing.

Information on the seasonal germination of sandalwood seeds in northern conditions is lacking as this has been introduced in north India recently. Keeping in view the economic potential of the species as well as the tremendous increase in the number of farmers willing to take up sandalwood cultivation for diversification, the study was planned to study the germination behaviour of *Santalum album* seeds during different months.

MATERIAL AND METHODS

The experiment was conducted at Punjab Agricultural University, Ludhiana, India during the year 2021 (January 21-December 21). The study area is situated at 247 m above mean sea level and lies at 30° 45` N latitude and 75° 40` E longitude.

Climate: The experimental area is situated in the central part of Punjab. Generally, weather conditions are sub-tropical to tropical, with long dry spells from late September to early June and an effective wet season from July to September. May and June are the hottest months, whereas December and January are the coldest months. Frost occurrences are not common. On average, the site receives an annual rainfall of 704 mm, which is not evenly distributed and most of which is received from July to September (75–80%). From meteorological data (Fig. 1), mean monthly minimum and maximum temperatures as well as relative humidity were calculated in the study region.

Pre sowing seed treatment: Sandalwood seeds were soaked in 500 ppm gibberellic acid (GA_3) to break the dormancy and enhance seed germination. To prepare a 500 ppm GA_3 solution, 1 g of GA_3 was weighed in a glass beaker and dissolved in a few drops of alcohol. Water was then added gradually, and the mixture was stirred thoroughly to make a final volume of 2 liters.

Germination bed preparation: Germination beds were prepared with a 2:1:1 mixture of sand, FYM, and soil. More proportion of sand provides good drainage, aeration, and disinfection against microorganisms, which protects the viability of seeds. This same mixture of materials was used to create four different beds, each with 50 seeds.

Transplanting stage: Transplanting was done in the evenings when the temperature was low. The ideal stage for pricking was observed to be a 2-4 leaf stage. Seedlings were pricked out and planted in 8 x 12 inch polybags after being treated with Bavistin. Then, plants were kept in the shade for 5–6 days to avoid transplanting shock. Host plants (pulses: gram, moong, arhar) were sown along with sandalwood seedlings in every polybag after one week of transplanting.

Germination Parameters

Germination percentage: The germination percentage of the seeds was calculated as the ratio between the total number of sown seeds and the number of germinated seeds after the germination period had passed**.**

Germination energy (GE): The per cent germination energy was number of total seeds those had germinated when the peak of germination was achieved that means number of highest seed germinated in a period of 24 hours.

$$GE\ (\%) = \frac{\text{Number of seeds germinated up to the time of peak germination}}{\text{Total number of seeds sown}} \times 100$$

Germination value (GV): Seed germination is a measure of speed and completeness of seed germination with a single

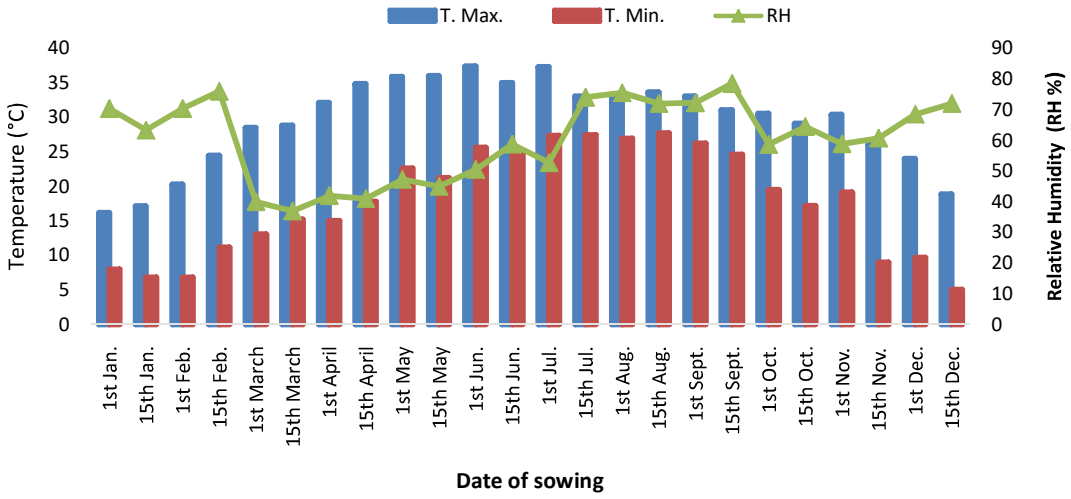

Fig. 1. Climatic conditions during different sowing times (January 21 to December 21)

figure which was calculated (Czabator 1962).

$$GV = PV \times MDG$$

Where, GV = Germination value

PV = Peak value of germination is the highest value of the cumulative germination per cent divided by the number of days since the start of the experiment.

Or

$$PV = \frac{\text{Cumulative germination per cent}}{\text{Days since sowing}}$$

MDG = Mean daily germination

Or

$$MDG = \frac{\text{Cumulative germination per cent at the end of the test}}{\text{Days since sowing to the end of test}}$$

Survival percentage:

$$\text{Survival percentage} = \frac{\text{No. of seedlings survived after 180 days}}{\text{No. of seeds sown}}$$

Growth Parameters

Seedling height (cm): The height of the seedling was recorded with the help of scale from the upper surface of soil filled in polythene bag to the shoot tip of the seedling.

Seedling collar diameter (mm): The seedling diameter at collar region of seedlings was measure from the collar region with the help of vernier caliper and expressed in millimeters.

Number of leaves: Fully opened leaves were considered as matured leaves and were counted visually in each seedling.

Quality Parameters

Sturdiness Quotient (SQ): SQ of the seedling was derived (Roller 1997).

$$SQ = \frac{\text{Height of seedling (cm)}}{\text{Collar diameter (mm)}}$$

Volume index (VI): VI was derived (Manavalan 1990).

$$VI = \text{Collar diameter}^2 \times \text{Height (cm)}$$

Statistical analysis: The data obtained from different observations were analyzed using the procedures of completely randomized design with CPCS1 software.

RESULTS AND DISCUSSION

Germination parameters: The effect of time of sowing on germination of sandalwood revealed highly significant variations in all parameters, *viz*. days taken to initiate germination, days taken to complete germination, germination percentage, germination value, germination energy and survival percent (Table 1). The seeds sown on 15th March, 1st April, 15th April, 1st May, 1st August, 15th August and 1st September recorded seed emergence (initial germination), 7-8 days earlier than that in 1st March and July months (27 to 31 days). Seeds took around 33 to 40 days to initiate germination in June and October, whereas more than 45 days in November, December and January. Similarly, fewer days (40 to 43) required to complete the germination of seeds in the period from 15th March to end April and in August and 1st September. In March and July, sown seeds took around 44 to 49 days to complete germination or reach the 2-4 leaf stage. Lastly, seeds sown in November, December and January took more than 60 days to complete germination or reach the transplanting stage. This may be due to varied temperature and weather conditions throughout the year as the availability of food reserves at an optimum temperature favours early initiation and completion of seed emergence. Extreme temperatures, whether high or low, both adversely affected the initiation and completion of germination, which explains the sensitivity of sandalwood seeds to temperature and weather conditions. At optimal conditions, the time taken for the initiation of sandalwood germination can only be influenced by the pretreatment of dormant seeds, but the variation in time taken for the completion of germination entirely depends upon environmental conditions. From March 15 to end April, and again in August and September, the average temperature in Punjab ranged from 24 to 30°C which suits germination, when it takes around 20 days to initiate and 43 days to complete germination. Batabyal et al. (2014) reported that in the Bankura district of West Bengal, where temperatures ranged from 10-48°C, sandalwood seeds took 15.66 days to initiate germination and 57.33 days to complete germination. More than 70% germination rate was recorded in sowing dates of 15th March, 1st April, 15th April, 1st May and September, whereas in November, December and January seeds germinated at a rate of less than 15%. With an increase in temperature, the rate of germination percentage increased from February to till 1st May and then again from July to September. Germination declined from September 15th to February as temperatures began to fall. The seeds sown on April 15th had the highest germination percentage followed by those in 1st September .The lowest germination percentage was t 0.5% in December, which might be due to low temperature. Baskin and Baskin (2014) predicted that the low germination of some species at low temperatures might be due to physiological dormancy. However, Mohapatra et al. (2019) recorded maximum germination percentage (55%) in May in Bubaneashwar, Orissa. Batabyal et al. (2014) recorded 44.66% germination in December month sown seeds in West Bengal. The findings indicate that sandalwood seeds prefer optimum temperatures for germination, which vary due to diverse climatic conditions across the country.

Maximum germination energy was obtained in April and

1st September, sown seeds which were statistically at par. Germination energy and germination value showed similar results to germination percentage. Among different months, a statistically significant germination percent was on 15th April and in 1st September, and the minimum germination value was obtained in the months of January, February, November and December and was due to the optimum temperature during seed germination, which enabled the accumulation of higher photosynthates, which affected germination energy and germination value. Mohapatra et al. (2019) reported that seeds sown without seed coat in the month of May in sand recorded higher germination capacity (70%), and germination energy (41.50%) in Bhubanashewar, Orissa, than sowing seeds in April, May, and June.

The highest plant percentage was obtained from sowing dates in April, 15th August and 1st September, and the minimum in November, December and January. Survival percent was highest in April and 1st September, closely followed by 15 March and 15 August respectively. A portion of these early-germinating juvenile seedlings were observed damaged or killed by severe frost and cold in December and January. The extreme summer also recorded the lowest plant percent, which might be due to higher temperatures that could have caused the mortality of weaker seedlings due to heat shock. Gulcu et al. (2010) observed a reduction in the germination rate, retardation of growth, and heterogeneous physical structure of the surviving seedlings due to environmental variations.

Overall, highest significant values were obtained for seeds sown on March 15, April 1, April 15, May 1, and both August and September in almost all germination parameters. This may be due to the high ambient temperature and relative humidity, as well as the seeds' better adaptation to the April climatic conditions in Punjab. Moreover, better performance in these months can be credited to better internal and external conditions of seed. On contrary, southern part of the

Table 1. Germination parameters of sandalwood sown at twenty four dates of sowing (January 21 to December 21)

Treatments (Date of sowing)	Days taken to initiate germination	Days taken to complete germination	Germination percent	Germination value	Germination energy	Survival percent
1.1.21	59.01	64.20	10.50	0.03	19.34	2.50
15.1.21	47.02	61.03	10.50	0.03	18.39	1.50
1.2.21	44.02	58.10	30.01	0.24	32.55	10.00
15.2.21	40.04	56.20	46.02	0.51	42.69	17.50
1.3.21	31.02	53.10	51.50	0.88	44.70	48.50
15.3.21	20.01	43.46	72.01	2.09	52.56	61.00
1.4.21	21.01	41.21	71.50	2.27	55.53	63.00
15.4.21	21.41	43.04	77.50	2.56	56.17	63.00
1.5.21	20.09	43.10	75.50	1.98	51.36	59.50
15.5.21	27.02	49.05	65.03	1.52	51.67	58.00
1.6.21	38.00	54.20	25.51	0.17	30.31	20.75
15.6.21	33.01	53.01	44.52	0.80	38.92	37.50
1.7.21	28.00	46.20	45.50	0.87	39.78	38.50
15.7.21	27.08	44.53	59.54	1.65	46.99	56.00
1.8.21	22.00	41.06	61.52	1.72	50.46	60.50
15.8.21	20.05	40.08	65.04	2.15	48.14	61.00
1.9.21	23.00	45.07	74.03	2.48	54.37	63.00
15.9.21	24.00	48.01	54.52	1.61	44.98	42.00
1.10.21	37.02	52.31	51.51	0.68	46.99	40.00
15.10.21	40.01	57.12	38.50	0.23	39.49	13.50
1.11.21	54.04	60.67	26.05	0.16	30.64	7.00
15.11.21	55.04	61.23	13.08	0.04	20.26	5.00
1.12.21	61.91	63.09	6.51	0.01	14.37	1.20
15.12.21	64.90	65.21	0.56	0.00	8.13	1.00
CD (p=0.05)	1.71	2.71	1.82	0.16	19.34	2.07

country favors December and January months for sowing sandalwood nursery due to existing vast difference in the weather and climatic conditions. The internal conditions include food reserve, completion of the ripening process, less dormancy, and the external conditions include congenial temperature and climatic conditions. Kamondo et al. (2014) also suggested that sandalwood seeds should be sown in a mixture of sand and fertile soil at temperatures between 25°C and 40°C, and high humidity. The results are in conformity with Mohapatra et al. (2019) and Madhuvanthi et al. (2024).

Growth parameters: Different seedling growth parameters, *viz*. seedling height, collar diameter, and number of leaves, were significantly influenced by the date of sowing. Data for seedling height, collar diameter, and number of leaves were recorded at 90 and 180 days after transplanting (DAT) (Table 2). The plant height in *Santalum album* was found to increase as the number of days increased. Among the 24 sowing dates evaluated, significant differences were observed for this parameter. Plant height at 150 DAT, the plant height ranged from 3.6 cm (15th December) to 17.6 cm (1st April). At 180 DAT, the plant height ranged from 4.0 cm (15 December) to 22.5 cm (15 April). April-sown seeds had a significantly higher value, which could be attributed to the growing season as the temperature and relative humidity remained favourable for growth due to the increased photosynthetic surface, whereas December-sown seeds performed poorly due to the dormant period. Higher and lower temperatures during the vegetative period reduced plant height. The adverse effect of summers on plant height was also studied by Sumathi and Srimathi (2013).

The collar diameter also differed significantly at different periods of observation. Higher collar diameter can be attributed to the availability of starch and stored material under optimal conditions. At 90 DAT, collar diameter ranged from 0.064 cm (1 January) to 0.120 cm (15th April). The collar diameter at 120 DAT ranged between 0. 071 cm (15th

Table 2. Growth parameters of sandalwood sown at different dates of sowing

Treatments	Height (cm)		Collar diameter (mm)		Number of leaves		Sturdiness quotient (180 DAT)	Volume index (cm^3) (180 DAT)
Date of sowings	90 DAT	180 DAT	90 DAT	180 DAT	90 DAT	180 DAT		
1.1.21	4.13	9.20	0.64	1.21	7.00	14.0	7.60	0.01
15.1.21	5.38	10.00	0.71	1.19	5.00	14.0	8.30	0.15
1.2.21	6.50	12.80	0.74	1.37	6.00	13.0	9.40	0.24
15.2.21	6.38	15.50	1.00	1.63	9.00	13.1	9.50	0.41
1.3.21	6.88	19.50	1.08	1.77	10.0	14.2	11.00	0.62
15.3.21	9.63	20.10	1.13	1.83	16.0	13.1	11.10	0.67
1.4.21	11.38	21.40	1.15	2.09	10.0	19.4	10.40	0.95
15.4.21	11.13	22.50	1.20	2.23	13.0	15.1	10.30	1.15
1.5.21	9.75	19.50	1.08	1.95	12.0	17.0	10.30	0.76
15.5.21	8.88	19.40	1.04	1.82	10.0	14.0	10.60	0.65
1.6.21	5.00	11.40	0.74	1.50	5.00	14.0	7.60	0.26
15.6.21	6.00	12.30	1.02	1.38	12.0	12.0	8.90	0.23
1.7.21	8.75	13.40	1.04	1.53	10.0	13.2	8.80	0.32
15.7.21	10.13	15.00	1.04	1.67	14.00	14.1	9.00	0.42
1.8.21	9.00	16.00	1.09	1.74	11.00	14.1	9.20	0.49
15.8.21	10.00	19.00	1.07	1.89	11.00	14.0	10.1	0.69
1.9.21	9.38	21.00	1.06	1.94	12.00	13.3	10.8	0.80
15.9.21	8.75	18.50	1.03	1.70	10.00	13.1	10.9	0.54
1.10.21	7.50	13.80	1.08	1.51	6.00	13.4	9.10	0.32
15.10.21	6.25	10.50	1.02	1.60	11.00	10.2	6.60	0.27
1.11.21	5.75	9.50	0.92	0.99	10.00	10.1	9.60	0.09
15.11.21	4.75	7.10	0.68	0.93	5.00	9.00	7.70	0.06
1.12.21	3.75	6.00	0.68	0.74	5.00	10.2	8.10	0.03
15.12.21	2.38	4.00	0.67	0.73	5.00	9.00	5.50	0.02
CD (p=0.05)	0.74	1.30	0.06	0.17	1.12	2.48	1.00	0.16

December) and 0.163 cm (15 March) followed by 150 and 90 DAT. The collar diameter was significantly low at 180 DAT, ranging from 0.07 cm (15 December) to 0.22 cm (15 April). Collar diameter results showed conformity with Chakarborty et al. (2021). The number of leaves also showed a statistically significant difference, fully opened leaves were counted as one, The number of leaves at were maximum at 180 DAT and ranged from 9 (November and December) to 19 (1st April) followed by 120 and 150 DAT.

The sowing period from 15th March to 1st May, August and September showed higher plant height, collar diameter and number of leaves compared to other months. Overall, superior plant heights of 22.5 cm and collar diameters of 0.22 cm were recorded for 15 April sown seeds at 180 days after transplanting, and lowest plant heights of 4 cm and collar diameters of 0.07 cm were observed in the month of December. Observations revealed that winter seed sowings produce low-quality seedlings and require more maintenance and protection during the harsh winter. Likewise, Krishnakumar et al. (2018) reported that the existence of variability in growth parameters was due to variability in weather and climatic conditions. The length of the growing season might be the core factor that affects maximum vegetative growth because a longer growing season provides more time for nutrient accumulation than a shorter growing season. The best sowing period is one that produces the healthiest nursery within the constraints of the local environment (Doddabasawa et al., 2021). It is evident from the data that all the germination parameters were statistically significant across different dates of sowing. This may be due to variations in weather and climate throughout the year.

Plant quality is a challenging parameter to characterize, and can be measured by morphological, physiological, and performance factors. The SQ and VI were used to evaluate seedling survival rate and growth performance Statistically significant results were obtained among treatments, at 180 days after transplanting, the highest SQ (11.1) was in March, which is statistically at par with April , May , 15th August, and September sown seeds. Large SQ ratios are often found in densely planted seeds on beds, which usually grow tall and slender (Huang et al., 2012). However, a smaller SQ ratio indicates a sturdy plant of better quality among container-grown seedlings. Apart from this, at 180 days after transplanting, the VI ranged from 0.013 to 1.153 cm^3. The highest volume index (1.153 cm^3) was also observed on April 15, which was statistically equal to April 1 (0.948 cm^3), followed by September and March sown seeds. SQ and VI measurements of seedlings in nurseries have a positive bearing on establishment in plantations (Krishnakumar et al., 2018).

CONCLUSIONS

Sowing period 15th March to end April, August and September were the best with regards to germination and growth parameters. The environmental conditions that prevailed during these months provided optimal conditions for reserve nutrient availability, which further helped in seedling establishment. The months of October to February, as well as June and July, were not ideal for seedling growth and germination behavior. However, the 15th of April sowing date outperformed the others.

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AUTHORS CONTRIBUTION

All authors made substantial contributions to the work: conception and design of the study .RIS Gill & B Singh: acquisition, analysis and interpretation of data; N Kaur & H Kaur: drafting of the manuscript; B Singh & A Singh: critical revision and improvement of the draft .

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