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Perfecting Quality Planting Stock through Media and Container Optimization in Indian Sandalwood (*Santalum album* L.)

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ABSTRACT: This study systematically evaluated various container types and potting media formulations to optimize the production of high-quality sandalwood (*Santalum album*) planting stock. There is a high demand for quality planting material particularly by private farm lands and also for the specific purposes like timber production where the use of bigger sandal saplings is very much preferred for out planting. In the context of container raised seedling production, potting media is one of the important inputs and is primarily responsible for the healthy seedling production. To stay competitive and to satisfy the environmental concerns of using traditional growing media components such as river sand, potential alternatives were investigated in the present study. Results indicate that a 30 cm × 20 cm poly bag, when combined with a potting media mixture composed of soil, rice husk, and FYM in a 2:1:1 ratio, consistently yielded superior seedling growth. The assessed growth attributes, including collar diameter, shoot length, root length, total height, and dry weight, were significantly enhanced with this specific combination. The benefit-cost ratios (B-C ratios) for production in various containers varied, container C3 demonstrates a B-C ratio of 1.60, indicating a ₹ 1.60 return for each ₹ 1 invested. Container C4 shows the highest B-C ratio at 1.61, implying a return of ₹ 1.61 for every ₹ 1 spent. Root trainers (C3 and C4) offer economic advantages with well-developed roots and growth uniformity, making them favourable for seedling production. The highest benefit-cost ratio (B-C ratio) of 1.59 is associated with potting media P2, indicating efficient resource use and potential high returns.

Keywords: Growth attributes, Collar diameter, Planting stock, Potting media, Containers.

INTRODUCTION

Sandalwood (*Santalum album*), a slow-growing and highly valuable tree species, is renowned for its fragrant heartwood, widely utilized in the global perfumery and medicinal industries. The cultivation of sandalwood, however, presents a unique set of challenges due to its semi-parasitic nature and specific requirements for growth. To meet the growing demand for sandalwood and conserve natural populations, there is a pressing need for efficient methods of producing high-quality planting stock. The production of superior planting stock is a pivotal step in the cultivation of any tree species, and sandalwood is no exception (Rao *et al.*, 2007). The quality of planting stock directly influences the overall success of sandalwood cultivation, affecting tree health, vigor, and heartwood quality (Das and Tah 2013). In nursery for superior stock production container and potting media plays an important role. Containers or root trainers are made up of high-density polypropylene or polyethylene or expanded polystyrene material. They have ridges inside, for guiding the root growth to the drainage hole at the base. They can be employed in both coniferous and broad leaved species to deal with the problems of root coiling and distortion. during the last 50 years the containerized nursery production system have evolved to the wide variety of rigid walled containers in use today from simple tarpaper pots used in 1930's (Landis *et al.,* 1900). It is now an accepted fact that root trainer technology is the best for raising plants in nurseries. This had been adopted in west as early as 1940's but in India, its usage was not adopted till 1990's (Nascimento *et al.*, 2013). Despite the introduction of root trainers and their advantages, the polybag seedling production system for its own advantages is going to stay as the bulk production method of planting stock quite some time. Attention of researcher is now concentrating on combining advantages of both the plant production systems (Gera *et al.*, 2007). Nowadays, the introduction of containers has made a magnificent impact on forest nursery seedling production. In this regard, the optimization of potting media and the selection of appropriate container types play a crucial role. These factors impact root development, nutrient uptake, and overall seedling growth, all of which are fundamental to the establishment of a robust sandalwood plantation.

Good quality plant development depends largely on the growing medium used. If a plant develops a good root system in a well-balanced substrate, this is not indicative that the plant is pampered with and will not adapt to the adverse life in the field. In fact, the inverse applies. To survive in the harsh environment of a field, often without additional care, a plant needs a well-developed and excellent root system. The development of a healthy root system depends not only on the genetic properties of the plant but to a wider extent on the physiochemical properties of the growth media (Jaenicke, 2019). However, the technology needs further optimization for the specific species of interest and growing media have to be developed and standardized depending on seedling crop, local climatic conditions and future planting technique (Mohanan and Sharma 2005).

The choice of potting media, with its impact on soil structure, drainage, and nutrient content, can significantly influence seedling development. Moreover to satisfy the environmental concerns of using traditional growing media components such as river sand, potential alternatives were investigated in the current experiment. Additionally, the type of container affects root architecture and can be instrumental in preventing root circling and ensuring the successful establishment of young sandalwood plants. This study aims to explore the intricacies of potting media and container type optimization for sandalwood planting stock production. This study delves into the factors that influence the health and growth of sandalwood seedlings, with a focus on the role of potting media in providing adequate nutrition and drainage.

In the pursuit of sustainable sandalwood nursery practice and the conservation of this culturally and economically significant species, this study seeks to provide insights into the practical aspects of optimizing potting media and container types for high-quality planting stock.

MATERIAL AND METHODS

The seeds were collected from Gottipura, Karnataka and the seeds were nutriprimed with Manganese sulfate of 0.4 M concentration for 3 days duration. Later seeds were sown in standard seed beds of size 10m × 1m for germination. The seedlings obtained then were transplanted into four different types of containers (Table 1) filled with five different types of potting media (Table 2). And the experiment design used was factorial completely randomised design with type of container as factor one and different potting media as factor two. There are four levels in factor one (type of container) and five levels in the factor two (potting media) constituted to make a total of 20 treatment combinations with four replications each. The seedling characters were monitored for six months.

Seedling growth attributes

Collar diameter. Collar diameter of the seedlings was measured using a digital vernier calliper and the two diametrically opposite readings were noted and the mean recorded in centimeter (Abdul-Baki and Anderson 1973).

Shoot length. The length of the shoot was measured from the tip of the main shoot to the collar region by using a meter scale and recorded in centimeter (Abdul-Baki and Anderson 1973).

Root length. The length of the root was measured from the collar region to the tip of main tap root using a measuring scale and the mean length recorded in centimeter (Abdul-Baki and Anderson 1973).

Seedling height. All normal seedlings of each treatment were measured for height from root tip to shoot tip and the average was expressed in centimeter (Abdul-Baki and Anderson 1973).

Seedling dry weight. The leaves, stem and roots were separately dried in hot air oven maintained at 75± 2ºC to a constant weight. The dry weight was determined using electronic balance. From this the total dry weight was determined. The values were expressed in gram seedling^{-1} (Abdul-Baki and Anderson 1973).

Table 1: Type and size of containers used in the study.

Treatments	
C1	Root trainer of 150 cc
C2	Root trainer of 300 cc
C3	Poly bag of 25cm ×15cm
C4	Poly bag of 30cm × 20cm

Table 2: Different potting media used in the study.

Treatments	
P1	Soil+ Coir pith compost + FYM in 2:1:1 ratio
P2	Soil+ Rice husk + FYM in 2:1:1 ratio
P3	Soil+ Perlite + FYM in 2:1:1 ratio
P4	Soil+ M-Sand +FYM in 2:1:1 ratio
P5	Soil+ River sand+ FYM in 2:1:1 ratio

RESULTS AND DISCUSSION

In the quest for high-quality Sandal seedlings crucial for large-scale plantations, a comprehensive 180-day experiment highlighted the significance of container and growing media selection (Table 3). The combination of a 30 cm × 20 cm poly bag (C4) and a potting media blend (P2) consisting of Soil, Rice husk, and FYM in a 2:1:1 ratio consistently produced superior results, with a shoot length of 14.81 cm at 180 days. Conversely, the least effective combination was a 150 cc root trainer (C1) with potting media (P4), featuring Soil, M-Sand, and FYM in the same ratio, resulting in a shoot length of 11.35 cm. This growth variation reflects the long-term impact of nutrient availability and root development. The success of P2 can be attributed to its ability to maintain optimal nutrient levels and promote strong root development. Composted rice husk, as an integral component of P2, created a favorable and friable growth medium, enhancing root growth and nutrient uptake. This study underscores the importance of careful container and growing media selection in Sandalwood seedling production for successful plantation establishment, ultimately reducing long-term maintenance costs (Egnell and Leijon 1999; Laiche and Nash 1990).

Table 3: Influence of different containers and potting media on shoot length of *Santalum album* (L.).

Treatments		Shoot length (cm)					
Containers (C)	Potting media (P)	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
C1	P1	6.57	7.12	8.81	9.23	10.99	12.75
	P2	7.55	7.88	8.66	10.40	11.91	13.43
	P3	6.37	6.83	7.35	8.80	10.45	12.54
	P4	5.09	5.38	6.11	7.12	8.99	11.35
	P5	6.57	6.91	7.96	9.13	10.96	12.87
C2	P1	6.91	7.25	8.27	9.50	10.81	13.22
	P2	8.07	8.43	9.08	10.73	11.91	13.96
	P3	6.43	6.95	7.65	9.37	11.16	13.10
	P4	5.46	5.82	6.27	7.75	9.06	11.87
	P5	6.89	7.28	8.55	9.47	11.28	13.31
C3	P1	7.45	7.79	8.69	9.89	11.27	13.72
	P2	8.61	8.99	9.33	10.62	11.95	14.42
	P3	7.24	7.52	8.74	9.83	11.20	13.53
	P4	6.11	6.41	7.56	8.31	11.39	12.31
	P5	7.54	7.79	8.52	9.89	12.05	13.86
C4	P1	7.84	8.32	9.09	10.34	12.63	14.11
	P2	9.07	9.59	10.15	11.70	12.98	14.81
	P3	7.57	7.91	8.99	10.20	12.51	13.96
	P4	6.54	6.92	7.93	8.83	10.71	12.42
	P5	7.74	7.95	9.03	10.47	12.04	14.21
Interaction (C×P)	SEm±	0.17	0.17	0.18	0.05	0.11	0.02
	CD (P=0.05)	0.48	0.47	0.52	0.15	0.31	0.04
	CV (%)	4.10	3.87	3.77	1.98	1.66	1.17

Table 4: Influence of different containers and potting media on rootlength of *Santalum album* (L.).

Treatments		Root length (cm)					
Containers (C)	Potting media (P)	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
C1	P1	5.50	5.99	7.17	7.17	8.32	9.71
	P2	7.37	8.24	10.62	10.62	10.92	11.11
	P3	6.33	7.45	9.17	9.17	9.98	10.15
	P4	3.50	4.46	6.37	6.37	6.99	7.51
	P5	5.03	5.94	7.25	7.25	8.02	8.64
C2	P1	5.79	6.80	8.99	8.99	9.06	9.98
	P2	7.66	8.63	10.13	10.13	10.98	11.24
	P3	6.62	7.81	9.14	9.14	9.98	10.35
	P4	3.79	4.67	6.03	6.03	6.95	7.25
	P5	5.32	6.30	7.99	7.99	8.02	8.94
C3	P1	6.18	7.44	9.10	9.10	9.96	10.36
	P2	8.05	7.59	10.15	10.15	10.98	11.66
	P3	7.01	7.93	9.22	9.22	10.01	10.79
	P4	4.18	4.45	6.04	6.04	7.02	7.62
	P5	5.71	6.52	8.07	8.07	8.92	9.32
C4	P1	6.63	7.44	9.12	9.12	9.98	10.76
	P2	8.50	9.40	10.99	10.99	11.36	12.18
	P3	7.46	8.41	10.08	10.08	10.95	11.18
	P4	4.63	5.50	7.06	7.06	7.92	8.18
	P5	6.16	6.98	9.06	9.06	9.76	10.15
Interaction (C×P)	SEm±	0.23	0.01	0.05	0.05	0.03	0.01
	CD (P=0.05)	0.65	0.69	0.15	0.14	0.09	0.04
	CV (%)	3.49	3.05	1.00	1.06	0.63	0.24

Table 4 presents the 180-day root length analysis of Sandal (*Santalum album*) seedlings, assessing container (C) and potting media (P) effects. Root length is a crucial indicator of seedling health and nutrient absorption capacity. Notably, the combination of a 30 cm × 20 cm poly bag (C4) and potting media P2 (Soil+ Rice husk + FYM in 2:1:1) outperformed, with the highest root length of 12.18 cm at 180 days. This is likely due to the larger poly bag, which encourages the development of a more efficient, fibrous root system, enhancing water and nutrient uptake. At 30 DAT, C4P2 yielded the longest roots (8.50 cm), followed by C3 with P2 (8.05 cm). In contrast, C1 with P4 exhibited the shortest roots (3.50 cm). The trend continued at 60 DAT, with C4P2 at 9.40 cm and C1P4 at 4.46 cm.

At 90 DAT, C4P2 excelled again with roots measuring 10.99 cm, while C1P4 lagged behind at 6.37 cm. Similar patterns emerged at 120 DAT (C4P2: 11.36 cm, C1P4: 6.99 cm) and 150 DAT (C4P2: 11.36 cm, C1P4: 8.02 cm). The findings underscore the positive effect of container and potting media selection on root growth. Larger poly bags, like C4, encourage efficient nutrient absorption, resulting in robust seedling development and survival. The early-stage dominance of P2 aligns with previous research by Hartmann *et al.* (2007), Root length is a crucial indicator of seedling health and nutrient absorption capacity. Healthy, well-developed roots are essential for the survival and growth of seedlings, particularly in the early stages of their development (Mohanan and Sharma 2005), supporting the idea that a higher proportion of materials like rice husk, vermiculite, perlite, and peat moss in the media promotes anchorage and faster root growth.

Table 5: Influence of different containers and potting media on total height of *Santalum album* (L.).

Treatments		Total height (cm)					
Containers (C)	**Potting media (P)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
C1	**P1**	12.07	13.11	15.06	16.41	19.31	22.46
	P2	14.92	16.12	17.82	21.02	22.83	24.53
	P3	12.71	14.28	15.61	17.97	20.43	22.69
	P4	8.59	9.85	11.27	13.49	15.98	18.86
	P5	11.60	12.85	14.74	16.38	18.98	21.51
C2	**P1**	12.70	14.05	16.40	18.49	19.87	23.21
	P2	15.73	17.06	18.56	20.86	22.90	25.20
	P3	13.05	14.76	16.12	18.51	21.14	23.45
	P4	9.25	10.49	11.74	13.78	16.01	19.12
	P5	12.22	13.57	15.92	17.46	19.30	22.25
C3	**P1**	13.63	15.23	17.21	18.99	21.23	24.08
	P2	16.66	16.58	19.20	20.77	22.93	26.08
	P3	14.26	15.45	17.61	19.04	21.21	24.32
	P4	10.29	10.87	13.32	14.35	18.42	19.94
	P5	13.26	14.31	15.97	17.96	20.96	23.18
C4	**P1**	14.47	15.76	18.06	19.46	22.61	24.87
	P2	17.57	18.99	20.46	22.70	24.34	26.98
	P3	15.03	16.33	18.30	20.28	23.46	25.14
	P4	11.17	12.42	14.25	15.89	18.63	20.60
	P5	13.90	14.93	17.24	19.53	21.80	24.36
Interaction (C×P)	**SEm±**	**0.28**	**0.29**	**0.18**	**0.07**	**0.11**	**0.02**
	CD (P=0.05)	**0.77**	**0.78**	**0.52**	**0.20**	**0.31**	**0.05**
	CV (%)	**3.56**	**3.30**	**1.95**	**1.65**	**1.93**	**1.14**

Table 5 records the total height of *S. album* seedlings over a 180-day period, with a focus on container (C) and potting media (P) effects. Notably, container C4 combined with potting media P2 (Soil + Rice husk + FYM in 2:1:1 ratio) consistently outperformed, yielding the tallest seedlings, with an average height of 26.98 cm at 180 DAT. This long-term growth pattern underscores the importance of the container and potting media selection in promoting seedling development. At 30 DAT, C2P2 exhibited the tallest seedlings, averaging 12.70 cm, while C1P4 showed the shortest seedlings at 8.59 cm. The initial growth differences appear to be attributed to the nutrient-rich and well-aerated characteristics of P2, which positively impacted early growth stages. In contrast, P4 may have lacked essential nutrients, hindering initial growth.

At 60 DAT, the growth trends persisted, with C4P2 reaching an average height of 18.99 cm, demonstrating substantial growth. In contrast, C1P4 continued to yield the shortest seedlings at 9.85 cm, highlighting the role of containers in facilitating growth. At 90 DAT, C4P2 continued to lead in total height, averaging 20.28 cm, while C1P4 had the least growth at 11.27 cm. This pattern continued at 120 DAT (C4P2: 22.70 cm, C1P4: 13.49 cm). At 150 DAT, C4P2 maintained its growth advantage (24.34 cm), while C1P4 lagged behind (15.98 cm), emphasizing the role of potting media in sustaining growth during the later stages. Finally, at 180 DAT, C4P2 remained the most effective in promoting total height growth, at 26.98 cm, with C1P4 at 18.86 cm, signifying the importance of a healthy growth trajectory.

The long-term growth trends can be attributed to the enduring effects of P2 on nutrient availability and root development, ensuring steady and significant growth. P2's nutrient sustainability and efficient aeration likely contributed to its consistent growth, while P4 may have exhausted its nutrient supply sooner. Adequate aeration and drainage in the potting media played a vital role in root health, with P2 providing superior aeration, study also suggests that the initial growth differences between various combinations are due to the nutrient content of the potting media. P2, which contains soil, rice husk, and FYM in a 2:1:1 ratio, likely provided a more nutrient-rich environment for the seedlings. This nutrient availability supported early-stage growth, leading to efficient oxygen delivery to the root system and enhanced nutrient uptake, as supported by previous studies (Annapurna *et al.,* 2005; Rathore *et al.,* 2004; Dubie, 1982).

Table 6: Influence of different containers and potting media on collar diameter of *Santalum album* (L.).

Treatments		Collar diameter (cm)					
Containers (C)	Potting media (P)	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
C1	**P1**	0.987	1.103	1.170	1.273	1.393	1.587
	P2	1.773	1.883	1.980	2.053	2.200	2.377
	P3	0.860	1.010	1.170	1.220	1.200	1.560
	P4	0.647	0.767	0.850	0.950	1.060	1.113
	P5	0.983	1.067	1.160	1.267	1.397	1.680
C2	**P1**	1.117	1.210	1.273	1.307	1.530	1.713
	P2	1.770	1.847	1.947	2.077	2.347	2.487
	P3	0.873	0.990	1.110	1.163	1.300	1.563
	P4	0.677	0.773	0.867	0.977	1.213	1.413
	P5	0.917	1.027	1.207	1.313	1.517	1.727
C3	**P1**	1.033	1.117	1.247	1.360	1.593	1.940
	P2	1.813	1.983	2.080	2.117	1.967	2.517
	P3	0.880	1.003	1.090	1.163	1.303	1.577
	P4	0.730	0.803	0.887	0.983	1.190	1.427
	P5	0.917	0.987	1.167	1.330	1.423	1.733
C4	**P1**	1.240	1.300	1.390	1.463	1.563	1.743
	P2	1.823	1.907	2.083	2.120	1.927	2.517
	P3	0.923	0.990	1.097	1.180	1.350	1.617
	P4	0.743	0.867	0.943	1.043	1.263	1.417
	P5	0.937	1.030	1.173	1.323	1.540	1.643
Interaction (C×P)	**SEm±**	**0.008**	**0.013**	**0.024**	**0.031**	**0.112**	**0.008**
	CD (P=0.05)	**0.025**	**0.038**	**0.070**	**0.086**	**0.327**	**0.022**
	CV (%)	**1.388**	**1.794**	**3.216**	**3.769**	**3.068**	**1.779**

Table 6 reveals the impact of container and potting media choices on the collar diameter of *S. album* seedlings across a 180-day period. At 30 DAT, C4 with P2 displayed the largest collar diameter at 1.823 cm, while C1 with P4 had the smallest at 0.647 cm, emphasizing the early significance of these choices. Collar diameter increased in all treatments by 60 DAT, with C4P2 leading at 1.907 cm and C1P4 lagging at 0.767 cm, underlining the persistent influence of containers and potting media. At 90 DAT, C4P2 maintained the largest collar diameter at 2.083 cm, while C1P4 had the smallest at 0.850 cm. This pattern continued through 120 DAT (C4P2: 2.120 cm, C1P4: 0.950 cm) and 150 DAT (C4P2: 1.927 cm, C1P4: 1.060 cm). By 180 DAT, C4 with P2 remained the most effective, with a collar diameter of 2.517 cm, while C1 with P4 had the smallest at 1.113 cm. Potting media play a critical role in providing essential nutrients to the seedlings. In this case potting media P2, which seemed to support taller seedlings, likely to had a more balanced and nutrient-rich composition. This availability of nutrients promoted healthy root development and overall growth (Tsakaldimi, 2006).

Table 7: Influence of different containers and potting media on dry weight of *Santalum album* (L.).

Treatments		Dry weight (g)					
Containers (C)	Potting media (P)	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
C1	**P1**	0.123	0.134	0.144	0.156	0.146	0.240
	P2	0.180	0.198	0.210	0.234	0.252	0.270
	P3	0.140	0.150	0.163	0.175	0.190	0.224
	P4	0.080	0.095	0.110	0.126	0.146	0.164
	P5	0.138	0.125	0.161	0.174	0.197	0.221
C2	**P1**	0.128	0.144	0.156	0.169	0.201	0.209
	P2	0.183	0.195	0.211	0.220	0.237	0.259
	P3	0.143	0.156	0.166	0.176	0.485	0.226
	P4	0.083	0.099	0.113	0.125	0.145	0.164
	P5	0.138	0.151	0.167	0.186	0.176	0.394
C3	**P1**	0.150	0.160	0.190	0.192	0.208	0.232
	P2	0.205	0.216	0.232	0.242	0.260	0.289
	P3	0.165	0.177	0.188	0.200	0.215	0.240
	P4	0.105	0.119	0.136	0.150	0.167	0.186
	P5	0.154	0.169	0.323	0.374	0.399	0.418
C4	**P1**	0.170	0.182	0.198	0.213	0.227	0.251
	P2	0.223	0.235	0.248	0.269	0.281	0.306
	P3	0.181	0.192	0.209	0.219	0.236	0.258
	P4	0.125	0.138	0.155	0.166	0.192	0.206
	P5	0.187	0.196	0.209	0.219	0.247	0.266
Interaction (C×P)	**SEm±**	**0.016**	**0.012**	**0.078**	**0.011**	**0.034**	**0.010**
	CD (P=0.05)	**0.009**	**0.017**	**0.081**	**0.112**	**0.213**	**0.152**
	CV (%)	**3.550**	**4.405**	**4.231**	**3.907**	**4.074**	**3.495**

The impact of different containers (C) and potting media (P) on the total dry weight ratio of *Santalum album* seedlings over a 180-day period is shown in Table 7. At 30 DAT, combinations C4P2 (Poly bag of 30cm × 20cm; Soil + Rice husk + FYM in 2:1:1) and C4P5 (Poly bag of 30cm ×20cm; Soil + River sand+ FYM in 2:1:1) displayed the highest total dry weight ratios, measuring 0.223g and 0.187g respectively. In contrast, combinations involving container C1, specifically C1P4 (Root trainer of 150 cc; Soil+ M-Sand + FYM in 2:1:1) 0.080g, demonstrated relatively lower total dry weight.

By 60 DAT, combinations C4P2 and C4P5 maintained their prominence, showcasing total dry weight ratios of 0.235g and 0.196g respectively. Container C1 consistently yielded lower total dry weight ratios, notably in combinations C1P4 and C1P5.Moving to 90 DAT, the influence of container C4 remained significant. Combinations C4P2 and C4P5 demonstrated total dry weight ratios of 0.248 g and 0.209 g respectively. At 120 DAT and 150 DAT, combinations C4P2 and C4P5 continued to exhibit the highest total dry weight ratios, reinforcing their positive influence. At 180 DAT, the pattern remained consistent, with combinations C4P2 and C4P5 showcasing total dry weight ratios of 0.306 g and 0.266 g respectively. Throughout the study, it was evident that combinations involving container C4, especially with potting media P2 and P5, consistently resulted in higher total dry weight.

The ability of potting media to retain adequate moisture while allowing proper aeration is crucial for plant health. Potting media P2 and P5 likely struck a balance, creating an optimal environment for enhanced growth and higher total dry weight ratios. Potting media that encouraged efficient root development and nutrient absorption would contribute to higher total dry weight ratios. P2 and P5 might have facilitated this process more effectively. Potting media P2 and P5 may possess growth-promoting properties that stimulate overall plant growth, leading to increased total dry weight ratios (Phonphuak and Chindaprasirt 2015). Container C4, when combined with P2 and P5, could have created a more compatible environment for the seedlings, enhancing nutrient uptake and subsequent growth, resulting in higher total dry weight ratios. The results are supported by Ginwal *et al.* (2001) in *Acacia nilotica*.

The impact of containers and potting media on *Santalum album* seedlings over 180 days, it was found that the combination of container C4 and potting media P2 consistently promoted the highest leaf count from 30 to 180 days after transplanting (DAT), indicating their positive influence on leaf growth (Table 8). Conversely, container C1 with potting media P4 consistently resulted in the lowest leaf count, underscoring the significant effect of potting media on early leaf development. This trend persisted throughout the study, with C4P2 consistently outperforming C1P4, highlighting the importance of choosing the right potting media for robust leaf development. The findings emphasize the need for ongoing monitoring and interventions to ensure optimal leaf growth, as higher leaf counts are essential for increased photosynthetic activity and overall plant development. The study also suggests that early growth patterns, particularly between 30 to 60 DAT, may set the trajectory for leaf count in later stages. The consistent impact of potting media P4 in limiting leaf development, when combined with C1, highlights its enduring effect on leaf growth (Dominguez-Lerena *et al.,* 2006).

Table 9 presents a study on the impact of different containers and potting media on the leaf area of *Santalum album* seedlings, starting at 30 days after treatment (DAT). It was observed that the combination of container C4 with potting media P2 consistently resulted in the highest leaf area, with 15.25 cm^2 at 30 DAT and maintaining this trend up to 180 DAT. Conversely, container C1, especially in combination with potting media P4, displayed consistently smaller leaf areas. This underscores the significant influence of container and potting media selection on *Santalum album* seedlings' leaf area development. Larger leaf areas are associated with increased photosynthetic activity and better overall plant growth. The persistent positive influence of potting media P2, especially in combination with C4, highlights the importance of selecting the right medium for leaf development. Factors like nutrient availability, moisture retention, and root development were crucial in shaping the observed leaf areas. These results are in line with (Khedkar and Subramanian 1997).

Benefit-cost ratio (B-C ratio) associated with using different containers for raising *Santalum album* seedlings in a nursery over a 180-day growth period (Table 10). The B-C ratio is a critical metric that evaluates the economic viability of the seedling production process. The receipts per seedling for all containers (C1, C2, C3, C4) are ₹35.00, indicating the uniformity in the selling price. Container C3 demonstrates a BC ratio of 1.60, suggesting a return of ₹1.60 for every ₹1 invested. And Container C4 exhibits the B-C ratio at 1.59, implying a return of ₹1.59 for every ₹1 spent.

The benefit-cost ratios clearly indicate that containers C3 and C4, the root trainers, present the less favorable economic outcomes. With some of the advantages like well-developed root system, uniformity in growth, cost of production etc, the root trainer grown seedlings are less preferred wherever large saplings are needed for field planting. The container grown seedlings in general possess better environmental control of the growing regime, shorter production cycles, increased stock uniformity and assured superior field performance on poor quality sites also (Wilson *et al.,* 2007).

Table 11 evaluates the benefit-cost ratio (B-C ratio) of different potting media (P1, P2, P3, P4, and P5) for growing *Santalum album* seedlings over a 180-day period. Potting media P2 stands out with the highest B-C ratio of 1.59, indicating its cost-effectiveness and potential for the highest returns on investment. In contrast, potting media P1 and P3 have the lowest B-C ratios, suggesting less efficient resource utilization. These findings offer valuable guidance for selecting the right potting media for *Santalum album* seedling production. Notably, the study highlights the suitability of a potting media consisting of soil, rice husk, and FYM in a 2:1:1 ratio, especially in regions with ready access to affordable rice husk. This approach not only reduces reliance on expensive river sand but also addresses environmental concerns by repurposing local organic waste materials into high-quality manure. Rice husk, being abundantly available in rice-producing countries, contains organic carbon and silica, making it a sustainable and environmentally friendly alternative for nursery operations (Oosterkamp, 2014; Hu *et al.*, 2008; Phonphuak and Chindaprasirt 2015).

Table 8: Influence of different containers and potting media on number of leaves of *Santalum album* (L.).

Treatments		Number of leaves					
Containers (C)	**Potting media (P)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
C1	**P1**	6.45	7.78	8.85	10.63	15.51	17.82
	P2	8.87	10.14	11.89	13.71	18.48	21.09
	P3	7.82	9.08	10.21	11.82	16.65	19.13
	P4	5.62	6.92	8.58	9.60	12.66	17.50
	P5	7.84	8.93	10.73	11.52	15.62	18.68
C2	**P1**	6.52	8.02	9.73	10.73	14.88	18.10
	P2	8.92	10.34	12.08	13.23	17.79	20.48
	P3	7.76	9.37	10.78	11.86	15.85	19.10
	P4	5.62	7.12	8.91	9.98	13.53	17.23
	P5	7.84	9.13	10.95	11.57	15.94	18.81
C3	**P1**	6.91	7.93	9.13	10.78	14.56	18.03
	P2	9.94	10.98	12.07	13.28	17.57	20.53
	P3	7.94	8.93	10.17	11.91	13.73	19.16
	P4	5.73	7.14	8.48	10.03	13.93	17.28
	P5	7.83	9.12	10.14	11.62	14.95	18.87
C4	**P1**	7.95	9.23	10.57	11.78	15.52	19.41
	P2	10.12	11.89	13.11	14.28	18.77	20.49
	P3	8.92	9.97	10.98	12.91	15.63	19.51
	P4	6.74	8.12	9.30	11.03	14.91	18.62
	P5	8.77	10.12	11.45	12.62	16.76	20.13
Interaction (C×P)	**SEm±**	**0.04**	**0.07**	**0.09**	**0.19**	**0.25**	**0.24**
	CD (P=0.05)	**0.11**	**0.13**	**0.28**	**0.54**	**0.72**	**0.78**
	CV (%)	**1.88**	**1.83**	**1.58**	**2.78**	**2.84**	**2.32**

Table 9: Influence of different containers and potting media on leaf area of *Santalum album* (L.).

Treatments		Leaf area (cm^2)					
Containers (C)	**Potting media (P)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
C1	**P1**	9.46	9.50	9.86	10.50	10.78	11.12
	P2	13.37	13.54	13.88	14.15	14.33	14.55
	P3	10.25	10.32	10.71	10.95	11.17	11.38
	P4	7.73	8.07	8.28	8.42	8.70	8.85
	P5	11.24	11.46	11.68	11.77	12.21	13.21
C2	**P1**	10.11	10.37	10.56	11.35	11.58	11.93
	P2	14.28	14.42	14.73	15.14	15.30	15.63
	P3	10.67	10.94	11.41	11.80	12.09	12.72
	P4	8.40	8.62	9.01	9.27	9.65	10.03
	P5	12.12	12.26	12.43	12.62	13.07	13.49
C3	**P1**	10.51	10.73	11.24	11.76	12.10	12.49
	P2	14.52	14.66	14.84	15.10	15.34	15.66
	P3	11.33	11.58	11.95	12.21	12.32	12.53
	P4	8.91	9.11	9.44	9.68	10.00	10.17
	P5	12.41	12.66	12.85	13.03	13.53	13.85
C4	**P1**	11.68	11.86	11.96	12.30	12.40	12.61
	P2	15.25	15.47	15.66	15.92	16.09	16.62
	P3	11.96	12.24	12.58	12.75	13.21	13.69
	P4	9.53	9.97	10.05	10.22	10.66	10.90
	P5	12.59	12.98	13.10	13.57	13.87	14.57
Interaction (C×P)	**SEm±**	**0.08**	**0.06**	**0.08**	**0.17**	**0.13**	**0.18**
	CD (P=0.05)	**0.23**	**0.18**	**0.24**	**0.49**	**0.36**	**0.36**
	CV (%)	**1.27**	**1.97**	**1.28**	**2.49**	**1.77**	**1.77**

Table 10: Benefit-cost ratio of different containers used for raising *Santalum album* (L.) seedlings.

Inputs and Outputs	Containers used			
	C1	C2	C3	C4
Total sum of production costs per seedling (₹)	23.21	23.45	21.83	21.94
Total sum of receipts per seedling (₹)	35.00	35.00	35.00	35.00
B-C ratio	1.51	1.49	1.60	1.59

Table 11: Benefit-cost ratio of different potting media used for raising *Santalum album*(L.) seedlings.

Inputs and Outputs	Potting media used				
	P1	P2	P3	P4	P5
Total sum of production costs per seedling (₹)	22.63	22.06	24.61	22.01	22.36
Total sum of receipts per seedling (₹)	35.00	35.00	35.00	35.00	35.00
B-C ratio	1.54	1.59	1.42	1.59	1.57

CONCLUSIONS

These findings are not only vital for meeting market demands but are also critical in ensuring the long-term success of sandalwood plantations and the preservation of this iconic species. In conclusion, the findings presented in this study offer valuable insights into the selection of potting media for the production of *Santalum album* seedlings in nurseries. The benefit-cost ratios (B-C ratios) assessed the cost-effectiveness and potential returns of various potting media, with potting media P2 emerging as the most efficient choice, boasting a high B-C ratio of 1.59. This underscores the economic viability of using this specific potting medium and container. This approach not only proves cost-effective but also offers an environmentally friendly solution by repurposing abundant and sustainable resources, such as rice husk, which is readily available in rice-producing regions. Utilizing local organic waste materials in nursery operations not only reduces costs but also mitigates environmental concerns related to waste disposal and raw material scarcity. The study's findings have the potential to inform decision-makers and practitioners in the field, contributing to more sustainable and economically viable sandalwood seedling production practices in humid tropical regions.

FUTURE SCOPE

This study provides valuable insights into optimizing the production of high-quality Sandalwood (*Santalum album*) planting stock, with a focus on container types and potting media formulations. Given the shift away from traditional growing media components like river sand, research into sustainable alternatives and sourcing practices for materials used in potting media can contribute to environmental conservation and cost-efficiency. Conducting market research to understand the current and future demand for high-quality Sandalwood planting material needs to be done. Assess the economic viability of Sandalwood cultivation using the optimized methods and consider the potential for value addition. In conclusion by exploring these avenues, the study findings can contribute to the development and expansion of Sandalwood cultivation and address the growing demand for high-quality planting stock.

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REFERENCES

Abdul-baki, A. A. & Anderson (1973). Biochemical aspects of seed vigor. *Horticultural Science*, *15*(6), 765-771.

Annapurna, D., Rathore, T. S. & Somashekhar, P. V. (2005). Impact of clones in a clonal seed orchard on the variation of seed traits, germination and seedling growth in *Santalum album* (L.). *Silvae Genetica*, *54*(4-5), 153-159.

Das, S. C. & Tah, J. (2013). Effect of GA3 on seed germination of Sandal (*Santalum album* L.). *International Journal of Current Sciences*, *8*, 79-84.

Dominguez-lerena, S., Sierra, N. H., Manzano, I. C., Bueno, I. O., Rubira, J. P. & Mexal, J. G. (2006). Container characteristics influence *Pinus pinea* seedling development in the nursery and field. *Forest Ecology Management*, *221*(1-3), 63-71.

Dubie, R. L. (1982). Composted rice hulls. *Southern Turf-grass Association*, *17*(3), 20-21.

Egnell, G. & Leijon, B. (1999). Survival and growth of planted seedlings of *Pinus Sylvestris* and *Picea Abies* after different levels of biomass removal in clear-felling. *Scandinavian Journal of Forest Resources*, *14*(4), 303-311.

Gera, M., Koul, A. R. & Gera, N. (2007). Comparative study on quality of bamboo seedlings in root trainers and polythene bags. *Indian For*., *133*(3). 306-312.

Ginwal, H. S., Rawat, P. S., Sharma, S., Bhandari, A. S., Krishnan, C. & Shukla, P. K. (2001). Standardization of proper volume/size and type of root trainer for raising *Dalbergia sissoo* seedlings: Nursery evaluation and field trial. *Indian Forester*, *127*(5), 580-590.

Hartmann, H. T., Davis, F. T. & Geneve, F. L. (2007). Plant Propagation. Principles and Practices, *London: Prentice Hall*, Inc. 46-52.

Hu, S., Xiang, J., Sun, L., Xu, M., Qiu, J. & Fu, P. (2008). Characterization of char from rapid pyrolysis of rice husk. *Fuel Processing Technology*, *89*(11), 1096-1105.

Jaenicke, H. (20190, Good tree nursery practices. *Practical guidelines for research nurseries. World Agroforestry Centre (ICRAF), Nairobi, Kenya*, pp, 90.

Khedkar, M. H. & Subramanian, K. (1997). Trials on raising teak (*Tectona grandis*) planting stock in root trainers. *Indian For*ester, *123*(2), 95-99.

Laiche Jr, A. J. & Nash, V. E. (1990). Evaluation of composted rice hulls and a lightweight clay aggregate as components of container-plant growth media. *Journal of Environmental Horticulture*, *8*(1), 14-18.

Landis, T. D., Tinus, R. W., Mcdonald, S. E. & Barnett, J. P., (1990). The Container Tree Nursery Manual. Volume 2: Containers and Growing Media. USDA Forest Service.*Agriculture Handbook*, pp: 674- 687.

Mohanan, C. & Sharma, J. K. (2005). Improvement of seedling production system in forestry sector and its impact on seedling health. *Kerala For Res Inst*., *11*, 77-82.

Nascimento, W. M., Huber, D. J. & Cantliffe, D. J., (2013). Carrot seed germination and respiration at high temperature in response to seed maturity and priming. *Seed Sci. Technol.*, *41*, 164-169.

Oosterkamp, W. J. (2014). Use of volatile solids from biomass for energy production. In *Bioenergy Research: Advances and Applications*, *Elsevier*, 203-217.

Phonphuak, N. & Chindaprasirt, P. (2015). Types of waste, properties, and durability of pore-forming waste-based fired masonry bricks. In *Eco-Efficient Masonry Bricks and Blocks*. *Woodhead Publishing*, 103-127.

Rao, M. N., Ganeshaiah, K. N. & Umashankar, R. (2007). Assessing threats and mapping sandal (*Santalum album* L.) resources in peninsular India: Identification of genetic hot-spot for in-situ conservation. *Conservation Genetics*, *8*, *8*925-935.

Rathore, T. S., Annapurna, D., Joshi, G. & Srivastava, A. (2004). Studies on potting mixture and size of containers on the quality of seedling production in *Casuarina equisetifolia*. *Indian Forester*, *130*(3), 323-332.

Tsakaldimi, M. (2006). Kenaf (*Hibiscus cannabinus* L.) core and rice hulls as components of container media for growing *Pinus halepensis* M. seedlings. *Bioresource Technology*, *97*(14), 1631-1639.

Wilson, E. R., Vitols, K. C. & Park, A. (2007). Root characteristics and growth potential of container and bare-root seedlings of red oak (*Quercus rubra* L.) in Ontario, Canada. *New Forests*, *34*, 163–176.

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