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Growth performance of sandal wood (*Santalum album* L.) (An endangered medicinal tree) progenies under nursery conditions

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Abstract

The study was conducted to select superior progenies of *Santalum album* from predominant sandal growing areas in south India. The results of the nursery experiments revealed that the following two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) had found recording significantly higher collar diameter, height and volume index. Hence the integration of these progenies in the tree improvement programme would result in better wood production. The superiority of these two progenies due to juvenile superiority indicated that these two progenies are under strong limelight for immediate utilization and incorporation in the further breeding programme

Keywords: Nursery, sandal, growth, biometric attributes, progenies

Introduction

Sandal is considered as one of the most valuable tree in the world. Sandal (*Santalum album* L.) is Indigenous to peninsular India; its distribution estimated at about 17,432 ha is confined predominantly to the eleven states of India (Aparnapallavi, 2015) [2]. *Santalum album* L. is intimately associated with Indian culture and heritage and is acclaimed as the most precious and valuable among Indian forest trees (Manoj Kumar, 1994) [14]. The sandal is known for its oil which is pronounced as the most famous East Indian sandal wood oil which is produced from the heartwood of sandal on distillation mainly for perfumery industries and pharmaceutical industries (Shankaranarayana *et al.*, 1998) [26].

The demand for sandal is increasing, but the supply from forests has almost been stopped which resulting in wider gap between demand and supply. Due to this wider gap between the actual availability and the growing demand, the prices of sandal wood and the associated value added product have gone out steeply (Jeremy Luedi, 2017) [9]. Because of its demand and high value, live sandal tree in their natural habitats are ruthlessly felled and removed by smugglers (Manonmani, 1997) [15]. Due to its status (vulnerability) and availability, this species is under thread and need to conserve.

The genetic variations are being utilized for improvement of sandal tree with reference to fast growth, heart wood and sandal oil content (Venkatesan *et al.*, 1995). Better growth, quality and adaptability can be achieved through careful selection of the best species (Kjaer and Foster, 1996) [11]. Genetically board populations should therefore be maintained as a basis for present and future domestication. Genetic variation is important for the long term adaptation of species (Falk and Holsinger, 1991) [4]. *Santalum album* is the most attracted species among the *Santalum sp.* and they exhibited wider variations in its natural range of occurrence. However there is no systematic evaluation of *Santalum album* improvement programme in order to utilize the existing genetic variation, which warrants a systematic improvement programme in this species. Hence, there is an urgent need to identify potential genetic resources of *Santalum album*, this paper clearly explained on the superiority of the collected progenies for ex-situ conservation.

Materials and Methods

The experimental materials for this study consisted of 30 genotypes of *Santalum album* L. selected from various locations of South India viz., Tamil Nadu, Karnataka, Kerala and Andhra Pradesh. Nursery experiment was carried out at Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam (11°19'N, 76°56'E), 300 m.a.m.s.l., 800 mm, pH 7.1) during 2015-2017.

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Nursery experiment

A known quantity of seeds were sown in the raised beds (10 x 1 m size) and covered with sand and straw. The nursery bed was irrigated twice a day. After germination healthy seedlings were pricked out and transplanted into the poly bags of size 15 cm x 25 cm filled with standard potting mixture of soil, sand and FYM in the ratio of 2: 1: 1. *Alternanthera sessilis* is planted along with the sandal seedlings as primary host in nursery.

Experimental design and treatment

The nursery experimental trail was laid out using a Completely Randomized Block Design with 30 progenies for 3 replications. *Alternanthera sessilis* is planted along with the

sandal seedlings as primary host in nursery. Observation with respect to plant height, collar diameter and number of leaves were taken at every one month interval.

Estimation of biometric attributes

The biometric observations made in every 30 days interval (30, 60, 90, 120, 150 and 180 days) were used for all the statistical analysis. The growth attributes were recorded on twenty five randomly selected seedlings from each treatment in each replication. The following observations viz., plant height, collar diameter and number of leaves were made in one month interval. From the observations recorded, the following parameters viz. Sturdiness quotient and volume index were derived.

i.	Plant height	:	The length of individual shoot was measured from the ground collar region to the apex of the leading shoot and expressed in cm.
ii.	Collar diameter	:	Collar diameter was measured at the time of height measurement with the help of digital caliper and observations were recorded. It was expressed in mm.
iii.	Number of Leaves	:	The visual number of leaves was counted and expressed in numbers

(Ritchie, 1985)

iv. Sturdiness quotient

The sturdiness quotient was calculated as per the formula given below (Ritchie, 1985)

$$\text{Sturdiness Quotient} = \frac{\text{Height (cm)}}{\text{Collar Diameter (cm)}}$$

v. Volume index

Volume index was arrived by using the formula (Hatchel, 1985; Manavalan, 1990)

$$V. I. = (\text{Collar diameter})^2 \times \text{Height (cm)}$$

Results

Observations on four biometric traits viz., plant height, collar diameter and number of leaves were measured at six growth periods viz., 30 DAS, 60 DAS, 90 DAS, 120 DAS, 150 DAS and 180 DAS. Sturdiness quotient and volume index were calculated using the primary data. The data were analyzed and the results are presented hereunder.

i. Plant height

The plant height in *Santalum album* progenies were observed to increase with increase in number of days of observation. Among the 30 progenies evaluated, significant differences were observed for this parameter. Plant height of 30 progenies at 30 DAS had ranged from 4.02 cm (FCRISA 20 (Sirsi)) to 6.78 cm (FCRISA 16 (Mysore)). At 60 DAS, the plant height ranged from 6.43 cm (FCRISA 30 (Anantapur)) to 10.89 cm (FCRISA 16 (Mysore)). The general mean was 8.45 cm. Nine progenies viz., FCRISA 16 (Mysore) (10.89 cm), FCRISA 2 (Tirupattur) (10.53 cm), FCRISA 24 (Kanthaloor) (9.99 cm), FCRISA 19 (Chikkamagaluru) (9.65 cm), FCRISA 3 (Salem) (9.63 cm), FCRISA 22 (Marayoor) (9.19 cm), FCRISA 23

(Nachivayal) (8.85 cm), FCRISA 8 (Coimbatore) (8.81 cm) and FCRISA 7 (Sathyamangalam) (8.78 cm) recorded significantly higher plant height compared to grand mean. The plant height at 90 DAS ranged from 10.62 cm (FCRISA 30 (Anantapur)) to 14.52 cm (FCRISA 19 (Chikkamagaluru)). The general mean for this period was 12.59 cm. At this stage, the following eight progenies viz., FCRISA 16 (Mysore) (15.22 cm), FCRISA 2 (Tirupattur) (14.51 cm), FCRISA 19 (Chikkamagaluru) (14.52 cm), FCRISA 17 (Shivamogga) (14.31 cm), FCRISA 22 (Marayoor) (13.79 cm), FCRISA 13 (Sirumalai) (13.37 cm), FCRISA 27 (Thrissur (KFRI)) (13.22 cm) and FCRISA 21 (Hassan) (13.14 cm) recorded significantly higher plant height compared to grand mean. At 120 DAS, the plant height significantly varied and ranged from 14.17 cm (FCRISA 30 (Anantapur)) to 18.85 cm (FCRISA 16 (Mysore)). At 150 DAS, plant height ranged from 16.59 cm (FCRISA 20 (Sirsi)) to 22.28 cm (FCRISA 16 (Mysore)). Five progenies viz., FCRISA 16 (Mysore) (22.28 cm), FCRISA 2 (Tirupattur) (20.86 cm), FCRISA 15 (Bengaluru) (20.15 cm), FCRISA 22 (Marayoor) (20.03 cm) and FCRISA 7 (Sathyamangalam) (19.76 cm) recorded significantly higher plant height compared to general mean (18.71 cm). The plant height differed significantly among different progenies of *Santalum album*. At 180 DAS, the plant height ranged between 20.60 cm (FCRISA 30 (Anantapur)) and 26.28 cm (FCRISA 16 (Mysore)). The average height of plant recorded was 23.29 cm. At this stage only two progenies viz., FCRISA 16 (Mysore) (26.28 cm) and FCRISA 2 (Tirupattur) (24.68 cm) recorded significantly higher value for this character (Table 1).

Considering six growth periods into account, two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) revealed consistently higher plant height.

Table 1: Variation for plant height (cm) in *Santalum album* under nursery evaluation

S. No.	Name of the Progeny	Plant height (cm)					
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS
1	FCRISA 1 (Tiruvannamalai)	4.26	8.65	12.73	15.95	19.43	23.33
2	FCRISA 2 (Tirupattur)	6.31*	10.53*	14.51*	16.59*	20.86*	24.68*
3	FCRISA 3 (Salem)	4.76	9.63*	12.05	14.74	18.30	22.45
4	FCRISA 4 (Trichy)	5.55*	8.03	12.19	15.23	18.93	23.31
5	FCRISA 5 (Mettur)	5.78*	8.67	11.44	15.65	18.63	23.01

6	FCRISA 6 (Hasanur)	5.23	8.45	12.46	16.24	19.08	22.74
7	FCRISA 7 (Sathyamangalam)	6.21*	8.78*	12.21	15.95	19.76*	24.07
8	FCRISA 8 (Coimbatore)	4.04	8.81*	12.20	15.72	18.78	23.43
9	FCRISA 9 (Maruthamalai)	5.17	8.44	12.13	15.18	17.48	23.44
10	FCRISA 10 (Mettupalayam)	5.67*	8.71	11.71	14.24	17.68	23.76
11	FCRISA 11 (Amaravathi)	4.78	7.45	11.07	15.09	18.33	23.03
12	FCRISA 12 (Dindugal)	5.73*	8.44	12.39	15.23	18.95	23.26
13	FCRISA 13 (Sirumalai)	4.69	8.47	13.97*	14.65	18.17	21.97
14	FCRISA 14 (Kalakad)	4.29	8.26	11.95	15.62	17.84	22.92
15	FCRISA 15 (Bengaluru)	5.07	7.89	12.22	16.31	20.15*	23.86
16	FCRISA 16 (Mysore)	6.78*	10.89*	15.22*	18.85*	22.28*	26.28*
17	FCRISA 17 (Shivamogga)	4.23	7.34	14.31*	16.65*	18.48	24.20
18	FCRISA 18 (Kodagu)	5.68*	7.55	13.09	15.65	19.15	22.90
19	FCRISA 19 (Chikkamagaluru)	5.43*	9.65*	14.52*	16.94*	19.33	23.26
20	FCRISA 20 (Sirsi)	4.02	6.81	10.94	14.28	16.59	22.98
21	FCRISA 21 (Hassan)	4.78	7.83	13.14*	16.60*	18.38	23.02
22	FCRISA 22 (Marayoor)	5.37*	9.19*	13.79*	16.76*	20.03*	24.19
23	FCRISA 23 (Nachivayal)	4.97	8.85*	11.21	15.31	17.36	23.06
24	FCRISA 24 (Kanthaloor)	6.23*	9.99*	12.89	14.92	18.41	24.05
25	FCRISA 25 (Chinnar)	4.47	7.43	11.89	14.64	17.87	23.80
26	FCRISA 26 (Thrissur (KAU))	5.83*	7.04	12.74	15.89	19.04	23.05
27	FCRISA 27 (Thrissur (KFRI))	4.95	8.32	13.22*	15.49	18.06	22.77
28	FCRISA 28 (Chittoor)	5.20	8.69	12.57	15.41	17.62	22.43
29	FCRISA 29 (Tirupathi)	4.76	8.17	12.30	16.66*	19.17	22.75
30	FCRISA 30 (Anantapur)	4.11	6.43	10.62	14.17	17.15	20.60
	Mean	5.15	8.45	12.59	15.69	18.71	23.29
	SEd	0.11	0.16	0.28	0.37	0.42	0.51
	CD (0.05)	0.21	0.33	0.55	0.73	0.85	1.03

(*Significant at 5% level)

ii. Collar diameter

The collar diameter differed significantly due to progenies at different periods of observation. At 30 DAS, collar diameter ranged between 0.073 cm (FCRISA 17 (Shivamogga)) and 0.166 cm (FCRISA 16 (Mysore)). At 60 DAS, collar diameter ranged from 0.126 cm (FCRISA 4 (Trichy)) to 0.187 cm (FCRISA 16 (Mysore)). At 90 DAS, collar diameter ranged from 0.213 cm (FCRISA 20 (Sirsi)) to 0.423 cm (FCRISA 16 (Mysore)). The collar diameters at 120 DAS ranged between 0.517 cm (FCRISA 9 (Maruthamalai)) and 0.739 cm (FCRISA 16 (Mysore)). The average collar diameter recorded was 0.614 cm. At 150 DAS, the collar diameter ranged from 0.637 cm (FCRISA 30 (Anantapur)) to 1.011 cm (FCRISA 16 (Mysore)). The average collar diameter recorded was 0.812

cm. At 180 DAS, the collar diameter significantly varied and ranged from 0.912 cm (FCRISA 20 (Sirsi)) to 1.212 cm (FCRISA 16 (Mysore)). Seven progenies viz., FCRISA 16 (Mysore) (1.212 cm), FCRISA 2 (Tirupattur) (1.149 cm), FCRISA 25 (Chinnar) (1.104 cm), FCRISA 17 (Shivamogga) (1.088 cm), FCRISA 29 (Tirupathi) (1.083 cm), FCRISA 5 (Mettur) (1.074 cm) and FCRISA 12 (Dindugal) (1.061 cm) recorded significantly higher collar diameter compared to general mean (1.014 cm) (Table 2).

Considering all the growth periods into account, two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) registered significantly higher collar diameter consistently.

Table 2: Variation for collar diameter (cm) in *Santalum album* under nursery evaluation

S. No.	Name of the Progeny	Collar diameter (cm)					
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS
1	FCRISA 1 (Tiruvannamalai)	0.093	0.178*	0.321	0.622	0.775	0.930
2	FCRISA 2 (Tirupattur)	0.143*	0.184*	0.384*	0.673*	0.909*	1.149*
3	FCRISA 3 (Salem)	0.076	0.158	0.279	0.563	0.854*	0.992
4	FCRISA 4 (Trichy)	0.092	0.126	0.295	0.602	0.805	0.972
5	FCRISA 5 (Mettur)	0.164*	0.161	0.291	0.649*	0.871*	1.074*
6	FCRISA 6 (Hasanur)	0.127*	0.179*	0.342*	0.647*	0.792	0.970
7	FCRISA 7 (Sathyamangalam)	0.082	0.176*	0.284	0.523	0.741	0.941
8	FCRISA 8 (Coimbatore)	0.113*	0.168	0.295	0.622	0.868*	1.054
9	FCRISA 9 (Maruthamalai)	0.078	0.155	0.307	0.517	0.750	0.966
10	FCRISA 10 (Mettupalayam)	0.092	0.156	0.314	0.664*	0.831	1.024
11	FCRISA 11 (Amaravathi)	0.132*	0.149	0.299	0.674*	0.801	0.957
12	FCRISA 12 (Dindugal)	0.099	0.163	0.361*	0.655*	0.916*	1.061*
13	FCRISA 13 (Sirumalai)	0.074	0.146	0.318	0.567	0.677	0.964
14	FCRISA 14 (Kalakad)	0.151*	0.166	0.301	0.635	0.769	0.946
15	FCRISA 15 (Bengaluru)	0.093	0.159	0.356*	0.593	0.767	0.979
16	FCRISA 16 (Mysore)	0.166*	0.187*	0.423*	0.739*	1.011*	1.212*
17	FCRISA 17 (Shivamogga)	0.073	0.156	0.303	0.633	0.885*	1.088*
18	FCRISA 18 (Kodagu)	0.091	0.173*	0.371*	0.628	0.758	0.961
19	FCRISA 19 (Chikkamagaluru)	0.154*	0.167	0.347*	0.638	0.813	0.990

20	FCRISA 20 (Sirsi)	0.094	0.151	0.213	0.566	0.779	0.912
21	FCRISA 21 (Hassan)	0.105	0.188*	0.317	0.618	0.800	0.996
22	FCRISA 22 (Marayoor)	0.078	0.158	0.366*	0.602	0.773	0.972
23	FCRISA 23 (Nachivayal)	0.147*	0.173*	0.274	0.544	0.840	1.019
24	FCRISA 24 (Kanthaloor)	0.077	0.151	0.347*	0.553	0.880*	1.022
25	FCRISA 25 (Chinnar)	0.102	0.167	0.305	0.641	0.714	1.104*
26	FCRISA 26 (Thrissur (KAU))	0.081	0.155	0.365*	0.623	0.860*	1.096
27	FCRISA 27 (Thrissur (KFRI))	0.133*	0.169*	0.342*	0.588	0.759	0.946
28	FCRISA 28 (Chittoor)	0.084	0.137	0.349*	0.631	0.839	1.013
29	FCRISA 29 (Tirupathi)	0.074	0.177*	0.312	0.639	0.891*	1.083*
30	FCRISA 30 (Anantapur)	0.081	0.153	0.291	0.561	0.637	1.029
Mean		0.105	0.163	0.322	0.614	0.812	1.014
SEd		0.002	0.003	0.007	0.014	0.020	0.022
CD (0.05)		0.004	0.006	0.016	0.028	0.040	0.045

(*Significant at 5% level)

iii. Number of leaves

At 30DAS, number of leaves varied from 6.67 (FCRISA 5 (Mettur), FCRISA 7 (Sathyamangalam) and FCRISA 27 (Thrissur (KFRI)) to 8.67 (FCRISA 23 (Nachivayal)). The average number of leaves recorded was 7.44. Four progenies viz., FCRISA 23 (Nachivayal) (8.67), FCRISA 10 (Mettupalayam) (8.33), FCRISA 15 (Bengaluru) (8.33) and FCRISA 17 (Shivamogga) (8.00) recorded significantly higher value for number of leaves compared to general mean. At 60 DAS, number of leaves varied from 9.00 (FCRISA 9 (Maruthamalai)) to 11.67 (FCRISA 16 (Mysore)). The average number of leaves recorded was 9.82. At 90 DAS, the number of leaves varied from 12.00 (FCRISA 8 (Coimbatore) and FCRISA 15 (Bengaluru)) to 14.67 (FCRISA 16 (Mysore) and FCRISA 17 (Shivamogga)). The average number of leaves recorded was 13.36. Eight progenies viz., FCRISA 16 (Mysore) (14.67), FCRISA 17 (Shivamogga) (14.67), FCRISA 2 (Tirupattur) (14.33), FCRISA 12 (Dindugal) (14.33), FCRISA 20 (Sirsi) (14.33), FCRISA 21 (Hassan)

(14.33), FCRISA 24 (Kanthaloor) (14.33) and FCRISA 30 (Anantapur) (14.33) were recorded significantly higher number of leaves compared to general mean (13.36). At 120 DAS, the number of leaves ranged between 14.00 (FCRISA 18 (Kodagu)) and 19.33 (FCRISA 16 (Mysore)). The average number of leaves recorded was 15.86. At 150 DAS, the number of leaves varied from 17.33 (FCRISA 18 (Kodagu), FCRISA 24 (Kanthaloor) and FCRISA 25 (Chinnar)) to 21.33 (FCRISA 16 (Mysore)). The average number of leaves recorded was 18.51. At 180 DAS, number of leaves ranged between 19.33 (FCRISA 13 (Sirumalai)) and 24.33 (FCRISA 16 (Mysore)). Four progenies viz., FCRISA 16 (Mysore) (24.33), FCRISA 30 (Anantapur) (23.33), FCRISA 2 (Tirupattur) (22.33) and FCRISA 3 (Salem) (22.33) were recorded significantly higher value for number of leaves compared to general mean (21.23) (Table 3).

Two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) registered significantly higher number of leaves consistently over the different growth periods.

Table 3: Variation for number of leaves in *Santalum album* under nursery evaluation

S. No.	Name of the Progeny	Number of leaves					
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS
1	FCRISA 1 (Tiruvannamalai)	7.00	10.33*	13.33	16.00	19.33*	21.67
2	FCRISA 2 (Tirupattur)	7.67	10.33*	14.33*	18.67*	20.33*	22.33*
3	FCRISA 3 (Salem)	7.00	9.33	13.33	14.67	19.33*	22.33*
4	FCRISA 4 (Trichy)	7.67	9.67	13.00	16.33	17.67	20.67
5	FCRISA 5 (Mettur)	6.67	9.67	12.67	16.33	19.67*	21.33
6	FCRISA 6 (Hasanur)	7.33	10.33*	13.33	16.33	18.67	21.33
7	FCRISA 7 (Sathyamangalam)	6.67	9.67	12.67	14.67	18.33	20.67
8	FCRISA 8 (Coimbatore)	7.00	10.00	12.00	14.33	18.00	21.00
9	FCRISA 9 (Maruthamalai)	7.33	9.00	13.33	15.67	18.00	20.33
10	FCRISA 10 (Mettupalayam)	8.33*	9.67	12.33	15.33	17.67	20.67
11	FCRISA 11 (Amaravathi)	7.33	9.33	13.67	16.33	19.33*	22.00
12	FCRISA 12 (Dindugal)	7.33	10.33*	14.33*	16.33	19.33*	20.67
13	FCRISA 13 (Sirumalai)	7.33	9.33	13.33	15.33	17.67	19.33
14	FCRISA 14 (Kalakad)	7.67	9.33	13.67	16.33	19.33*	21.67
15	FCRISA 15 (Bengaluru)	8.33*	10.67*	12.00	15.67	17.67	21.33
16	FCRISA 16 (Mysore)	7.33	11.67*	14.67*	19.33*	21.33*	24.33*
17	FCRISA 17 (Shivamogga)	8.00*	9.67	14.67*	15.33	17.67	20.00
18	FCRISA 18 (Kodagu)	7.33	9.67	13.00	14.00	17.33	20.67
19	FCRISA 19 (Chikkamagaluru)	7.67	9.33	12.33	16.67*	19.33*	22.33
20	FCRISA 20 (Sirsi)	7.33	10.67*	14.33*	15.33	17.67	21.00
21	FCRISA 21 (Hassan)	7.33	10.67*	14.33*	14.67	18.33	20.33
22	FCRISA 22 (Marayoor)	7.67	9.33	12.33	16.33	17.67	20.67
23	FCRISA 23 (Nachivayal)	8.67*	9.67	13.33	15.33	18.33	21.33
24	FCRISA 24 (Kanthaloor)	7.33	9.33	14.33*	15.67	17.33	20.33
25	FCRISA 25 (Chinnar)	7.67	9.67	12.67	14.67	17.33	20.33
26	FCRISA 26 (Thrissur (KAU))	7.33	9.33	13.67	16.00	18.33	21.67
27	FCRISA 27 (Thrissur (KFRI))	6.67	9.33	13.33	15.33	19.33*	21.33
28	FCRISA 28 (Chittoor)	7.00	10.33*	12.67	16.33	18.00	20.67

29	FCRISA 29 (Tirupathi)	7.67	9.67	13.33	15.67	17.67	21.33
30	FCRISA 30 (Anantapur)	7.67	9.33	14.33*	16.67*	19.33*	23.33*
Mean		7.44	9.82	13.36	15.86	18.51	21.23
SEd		0.16	0.19	0.22	0.32	0.40	0.45
CD (0.05)		0.32	0.39	0.45	0.63	0.80	0.91

(*Significant at 5% level)

iv. Sturdiness quotient

Sturdiness quotient differed significantly due to progenies over six growth periods studied. At 30 DAS, the sturdiness quotient ranged from 28.41 (FCRISA 14 (Kalakad)) to 80.91 (FCRISA 24 (Kanthaloor)). At 60 DAS, sturdiness quotient ranged from 41.65 (FCRISA 21 (Hassan)) to 66.16 (FCRISA 24 (Kanthaloor)). The average sturdiness quotient recorded was 52.10. Eleven progenies viz., FCRISA 24 (Kanthaloor) (66.16), FCRISA 4 (Trichy) (63.73), FCRISA 28 (Chittoor) (63.43), FCRISA 3 (Salem) (60.95), FCRISA 16 (Mysore) (58.24), FCRISA 22 (Marayoor) (58.16), FCRISA 13 (Sirumalai) (58.01), FCRISA 19 (Chikkamagaluru) (57.78), FCRISA 2 (Tirupattur) (57.23), FCRISA 10 (Mettupalayam) (55.83) and FCRISA 9 (Maruthamalai) (54.45) were recorded significantly higher value compared to general mean. At 90 DAS, sturdiness quotient ranged between 34.32 (FCRISA 12 (Dindugal) and FCRISA 15 (Bengaluru)) and 47.24 (FCRISA 17 (Shivamogga)). The average sturdiness quotient recorded was 39.38. At 120 DAS, the sturdiness quotient ranged from

21.45 (FCRISA 10 (Mettupalayam)) to 30.50 (FCRISA 7 (Sathyamangalam)). At 150 DAS, the sturdiness quotient significantly varied and ranged from 20.68 (FCRISA 12 (Dindugal)) to 26.90 (FCRISA 30 (Anantapur)). The progenies of *Santalum album* exhibited significant variations for sturdiness quotient at 180 DAS also. The sturdiness quotient ranged from FCRISA 30 (Anantapur) (20.02) to FCRISA 7 (Sathyamangalam) (25.58). The progenies FCRISA 7 (Sathyamangalam) (25.58), FCRISA 20 (Sirsi) (25.20), FCRISA 1 (Tiruvannamalai) (25.09), FCRISA 22 (Marayoor) (24.89), FCRISA 15 (Bengaluru) (24.37), FCRISA 9 (Maruthamalai) (24.27), FCRISA 14 (Kalakad) (24.23), FCRISA 27 (Thrissur (KFRI)) (24.07) and FCRISA 11 (Amaravathi) (24.06) were recorded significantly higher sturdiness quotient value compared to general mean (23.04) (Table 4).

Considering all the growth periods into account, two progenies viz., FCRISA 7 (Sathyamangalam) and FCRISA 22 (Marayoor) registered significantly higher sturdiness quotient.

Table 4: Variation for sturdiness quotient in *Santalum album* under nursery evaluation

S. No.	Name of the Progeny	Sturdiness quotient					
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS
1	FCRISA 1 (Tiruvannamalai)	45.81	48.60	39.65	25.64	25.08*	25.09*
2	FCRISA 2 (Tirupattur)	44.13	57.23*	37.78	24.66	22.94	21.48
3	FCRISA 3 (Salem)	62.63*	60.95*	43.19*	26.19	21.42	22.63
4	FCRISA 4 (Trichy)	60.33*	63.73*	41.32*	25.30	23.52	23.98
5	FCRISA 5 (Mettur)	35.24	53.85	39.30	24.12	21.39	21.42
6	FCRISA 6 (Hasanur)	41.18	47.21	36.43	25.11	24.09	23.44
7	FCRISA 7 (Sathyamangalam)	75.73*	49.89	42.98*	30.50*	26.68*	25.58*
8	FCRISA 8 (Coimbatore)	35.75	52.44	41.37*	25.27	21.64	22.23
9	FCRISA 9 (Maruthamalai)	66.28*	54.45*	39.52	29.36*	23.30	24.27*
10	FCRISA 10 (Mettupalayam)	61.63*	55.83*	37.29	21.45	21.28	23.20
11	FCRISA 11 (Amaravathi)	36.21	50.00	37.03	22.39	22.88	24.06*
12	FCRISA 12 (Dindugal)	57.88*	51.78	34.32	23.25	20.68	21.92
13	FCRISA 13 (Sirumalai)	63.38*	58.01*	43.92*	25.84	26.82*	22.79
14	FCRISA 14 (Kalakad)	28.41	49.76	39.70	24.60	23.20	24.23*
15	FCRISA 15 (Bengaluru)	54.52	49.62	34.32	27.50*	26.27*	24.37*
16	FCRISA 16 (Mysore)	40.84	58.24*	35.97	25.50	22.03	21.68
17	FCRISA 17 (Shivamogga)	57.95*	47.05	47.24*	26.30	20.88	22.24
18	FCRISA 18 (Kodagu)	62.42*	43.64	35.29	24.92	25.26*	23.83
19	FCRISA 19 (Chikkamagaluru)	35.26	57.78*	41.85*	26.56	23.78	23.49
20	FCRISA 20 (Sirsi)	42.77	45.10	51.35*	25.22	21.29	25.20*
21	FCRISA 21 (Hassan)	45.52	41.65	41.45*	26.86*	22.98	23.11
22	FCRISA 22 (Marayoor)	68.85*	58.16*	37.68	27.83*	25.91*	24.89*
23	FCRISA 23 (Nachivayal)	33.81	51.16	40.90*	28.14*	20.67	22.63
24	FCRISA 24 (Kanthaloor)	80.91*	66.16*	37.15	26.98	20.92	23.53
25	FCRISA 25 (Chinnar)	43.82	44.49	38.97	22.84	25.03*	21.56
26	FCRISA 26 (Thrissur (KAU))	71.98*	45.42	34.91	25.51	22.14	21.03
27	FCRISA 27 (Thrissur (KFRI))	37.22	49.23	38.66	26.34	23.79	24.07*
28	FCRISA 28 (Chittoor)	61.90*	63.43*	36.03	24.42	21.00	22.14
29	FCRISA 29 (Tirupathi)	64.32*	46.16	39.43	26.07	21.52	21.01
30	FCRISA 30 (Anantapur)	50.74	42.03	36.49	25.25	26.90*	20.02
Mean		52.25	52.10	39.38	25.66	23.18	23.04
SEd		1.18	1.04	0.74	0.58	0.54	0.50
CD (0.05)		2.37	2.08	1.49	1.16	1.08	0.99

(*Significant at 5% level)

v. Volume index

Volume index also differed significantly among progenies over six growth periods investigated. At 30 DAS, the volume

index ranged from 0.023 cm³ (FCRISA 17 (Shivamogga)) to 0.187 cm³ (FCRISA 16 (Mysore)). The average volume index recorded was 0.062 cm³. At 60 DAS, the volume index ranged

from 0.127 cm³ (FCRISA 4 (Trichy)) to 0.381 cm³ (FCRISA 16 (Mysore)). The average volume index recorded was 0.227 cm³. At 90 DAS, the volume index ranged between 0.496 cm³ (FCRISA 20 (Sirsi)) and 2.723 cm³ (FCRISA 16 (Mysore)). The average volume index recorded was 1.350 cm³. At 120 DAS, the volume index ranged from 4.363 cm³ (FCRISA 7 (Sathyamangalam)) to 10.293 cm³ (FCRISA 16 (Mysore)). At 150 DAS, the volume index significantly varied and ranged from 8.335 cm³ (FCRISA 13 (Sirumalai)) to 22.769 cm³ (FCRISA 16 (Mysore)). The progenies of *Santalum album* exhibited significant variations for volume index at 180 DAS also. The volume index ranged from 19.113 cm³ (FCRISA 20 (Sirsi)) to 38.604 cm³ (FCRISA 16 (Mysore)). FCRISA 16

(Mysore) (38.604 cm³), FCRISA 2 (Tirupattur) (32.583 cm³), FCRISA 25 (Chinnar) (29.008 cm³), FCRISA 26 (Thrissur (KAU)) (27.688 cm³), FCRISA 29 (Tirupathi) (26.683 cm³), FCRISA 17 (Shivamogga) (28.647 cm³), FCRISA 5 (Mettur) (26.541 cm³), FCRISA 12 (Dindugal) (26.184 cm³) and FCRISA 8 (Coimbatore) (26.029 cm³) progenies were recorded significantly higher volume index value compared to general mean (24.122 cm³) (Table 5).

Considering all the growth periods, two progenies viz., FCRISA 2 (Tirupattur) and FCRISA 16 (Mysore) registered significantly higher volume index consistently and proved superior.

Table 5: Variation for volume index (cm³) in *Santalum album* under nursery evaluation

S. No.	Name of the Progeny	Volume index (cm ³)					
		30 DAS	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS
1	FCRISA 1 (Tiruvannamalai)	0.037	0.274*	1.311	6.170	11.672	20.178
2	FCRISA 2 (Tirupattur)	0.129*	0.357*	2.139*	7.516*	17.246*	32.583*
3	FCRISA 3 (Salem)	0.027	0.240*	0.938	4.673	13.344*	22.092
4	FCRISA 4 (Trichy)	0.047	0.127	1.061	5.521	12.269	22.023
5	FCRISA 5 (Mettur)	0.155*	0.225	0.968	6.593*	14.131*	26.541*
6	FCRISA 6 (Hasanur)	0.084*	0.271*	1.457*	6.800*	11.966	21.396
7	FCRISA 7 (Sathyamangalam)	0.042	0.272*	0.985	4.363	10.840	21.314
8	FCRISA 8 (Coimbatore)	0.052	0.249*	1.062	6.081	14.149*	26.029*
9	FCRISA 9 (Maruthamalai)	0.031	0.203	1.144	4.057	9.831	21.873
10	FCRISA 10 (Mettupalayam)	0.048	0.212	1.155	6.278	12.211	24.914
11	FCRISA 11 (Amaravathi)	0.083*	0.165	0.990	6.855*	11.758	21.092
12	FCRISA 12 (Dindugal)	0.056	0.224	1.615*	6.533*	15.897*	26.184*
13	FCRISA 13 (Sirumalai)	0.026	0.181	1.412	4.711	8.335	20.417
14	FCRISA 14 (Kalakad)	0.098*	0.228	1.083	6.298*	10.550	20.511
15	FCRISA 15 (Bengaluru)	0.044	0.199	1.548*	5.734	11.852	22.868
16	FCRISA 16 (Mysore)	0.187*	0.381*	2.723*	10.293*	22.769*	38.604*
17	FCRISA 17 (Shivamogga)	0.023	0.179	1.314	6.670*	14.474*	28.647*
18	FCRISA 18 (Kodagu)	0.047	0.226	1.802*	6.172	11.001	21.149
19	FCRISA 19 (Chikkamagaluru)	0.129*	0.269*	1.749*	6.897*	12.779	22.797
20	FCRISA 20 (Sirsi)	0.036	0.155	0.496	4.574	10.065	19.113
21	FCRISA 21 (Hassan)	0.053	0.277*	1.320	6.340*	11.763	22.836
22	FCRISA 22 (Marayoor)	0.033	0.229	1.847*	6.073	11.967	22.854
23	FCRISA 23 (Nachivayal)	0.107*	0.265*	0.841	4.531	12.252	23.945
24	FCRISA 24 (Kanthloor)	0.037	0.228	1.552*	4.563	14.257*	25.120
25	FCRISA 25 (Chinnar)	0.047	0.207	1.106	6.015	9.110	29.008*
26	FCRISA 26 (Thrissur (KAU))	0.038	0.169	1.698	6.167	14.080*	27.688*
27	FCRISA 27 (Thrissur (KFRI))	0.088*	0.238*	1.547*	5.354	10.404	20.377
28	FCRISA 28 (Chittoor)	0.037	0.163	1.531*	6.134	12.403	23.017
29	FCRISA 29 (Tirupathi)	0.026	0.256*	1.198	6.803*	15.219*	26.683*
30	FCRISA 30 (Anantapur)	0.027	0.151	0.899	4.459	6.965	21.812
	Mean	0.062	0.227	1.350	5.974	12.519	24.122
	SEd	0.001	0.005	0.034	0.158	0.233	0.510
	CD (0.05)	0.003	0.010	0.069	0.315	0.466	1.021

(*Significant at 5% level)

Discussion

Sandalwood is one of the oldest known perfumery and has 2000 years of uninterrupted history (Solanki *et al.*, 2014) [27]. Sandalwood is indigenous to India and endemic to few southern states with predominant occurrences in Karnataka and Tamil Nadu (Rai, 1990) [21]. The heartwood of sandalwood is most valued part which yields fragrance sandalwood oil. Sandalwood oil has profound utility in perfumery industries and for this purpose, the wood is priced heavily in international market. The limited distribution and increase demand in the international market attracted illegal felling. Which resulted in ruthless felling and removal of superior genetic resources and only the emaciated population is available in the country. This demanded holistic and

systematic tree improvement program through selection, evaluation and conservation. Significant differences were found among 30 progenies for growth characteristics viz., plant height, collar diameter, number of leaves, sturdiness quotient and volume index at nursery stage during six growth periods of evaluation. A plethora of researchers have already reported the existence of variability in growth parameters due to different genotypes at nursery stage and these differences vary with soil and climatic conditions (Krishnakumar *et al.*, 2017; Schmutterer, 1995) [12, 25]. Seedling growth in nursery and plantations greatly depend on seed characteristics of tree species as well as the genetic constitution which resulted in the different provenance of the same species exhibit variability in germination and growth characteristics at

nursery stage (Radwanski and Wickens, 1981) ^[20]. Sturdiness and growth of seedlings in nursery have a positive bearing on establishment of growth of seedlings in plantations (Jain and Dhar, 2008) ^[7]. In the current study also two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) have expressed superiority in growth characteristics particularly plant height, collar diameter, number of leaves, and volume index, thereby attest the earlier findings. Similar superiority of few genetic resources in *Santalum album* (Bagchi and Sindhuveerendra, 1991); *Acacia catechu* (Gera and Gera, 2006); *Callophyllum inophyllum* (Palanikumar et al., 2015) ^[19] were earlier reported lend support to the current investigation. A superfluity of workers reported the existence of significant differences and superiority of few provenances, seed sources and progenies in various tree species like *Acacia nilotica* (Padmini and Banerjee, 1986) ^[18]; *Eucalyptus camaldulensis* (Otegbeye, 1985) ^[17]; *Tecomella undulata* (Jindal et al., 1991) ^[10]; *Terminalia arjuna* (Srivastava et al., 1993) ^[28]; *Lagerstroemia* spp. (Jamaludheen et al., 1995) ^[8]; *Dalbergia sissoo* (Rawat and Nautiyal, 2007) ^[22]; *Pinus elliottii* var. *elliottii* (Vergara et al., 2011) ^[30]; *Leucaena leucocephala* (Sangram and Keerthika, 2013) ^[24]; *Jatropha curcas* (Anamikanath et al., 2014) ^[1] and *Pinus kesiya* (Ombir singh et al., 2015) ^[16] which also lend support to the current findings in *Santalum album*.

Conclusion

The combined analysis of variance revealed significant differences on morphological growth traits among the evaluated progenies of *Santalum album*. Among the 30 progenies evaluated under nursery, two progenies viz., FCRISA 16 (Mysore) and FCRISA 2 (Tirupattur) consistently expressed superiority for growth characteristics particularly plant height, collar diameter, number of leaves and volume index and these two progenies are under sharp focus.

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