Effect of container type and size on the growth and quality of seedlings of Indian sandalwood (*Santalum album* L.)

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Summary

Studies were carried out to determine the effects of container type and size on the growth and quality of seedlings of Indian sandalwood (*Santalum album* L.), an over-exploited hemi-root parasite. Three types of container, viz. root trainers (150, 270, 300, 450 and 600 mL), polythene bags (polybags) (600, 1000 and 1500 mL) and plastic containers (1000 mL) were used with a potting medium that consisted of sand, soil, compost, burnt rice husk and charcoal in the ratio of 5:3:10:1:1. *Cajanus cajan* was used as a primary host in all treatments.

Survival and overall growth of sandalwood seedlings 6 mo old, in terms of height, collar diameter, seedling biomass and root–shoot ratio, were best in root trainers, and next best in plastic containers. Among the root trainers, the 600 mL size was optimum for most of the parameters of seedling quality, including height (20.4 cm), total dry weight (3.06 g), shoot dry weight (1.66 g), root dry weight (1.41 g) and quality index (0.37). This size was followed by the 270 and 300 mL root trainers. Despite the large size of the polybags (600–1500 mL), seedling growth in these was poor. Root coiling and poor root development affected root dry weight (0.13–0.39 g) and the quality index (0.03–0.05).

Good quality seedlings >20 cm high, >3.0 mm in collar diameter and with an 0.3 quality index can be produced in 6 mo in 600 mL root trainers. Most of the parameters of seedling quality (seedling height, collar diameter, seedling biomass and quality index) of seedlings grown in 270 mL block-type root trainers were comparable with those of seedlings in 1000 mL plastic containers. This result encourages further reduction in container size from 600 mL to 270 mL by better managing nutrition and screening for better primary hosts.

Keywords: seedling growth; quality; containers; container grown plants; planting stock; *Santalum album*; *Cajanus cajan*

Introduction

Indian sandalwood (*Santalum album* L.) is a hemi-root parasite, highly prized for its fragrant wood and oil. Over-exploitation and illicit felling has resulted in a great decline in the population of sandalwood in natural habitats, and it is considered a threatened species (Meera *et al*. 2000). Production of sandalwood has fallen from 4000 t during 1997 to 1000 t during 2000, and prices of sandalwood have increased from Rs 0.16 million t^{-1} during 1990–1991 to Rs 0.65 million t^{-1} during 1999–2000 (Ananthapadmanabha 2000). While the remaining natural resource cannot meet international demand for sandalwood and oil in a sustainable manner, it is an important gene resource for India and Indonesia. Plantations based upon it are a potential source of the wood and oil.

The genetic and physical quality of planting stock greatly influences survival, growth and productivity of the subsequent crop. In this paper, the expression 'quality of seedling' integrates genetic (seed source), morphological (seedling height, collar diameter, sturdiness and root–shoot ratio) and physiological (nutrition and root growth potential) characteristics. These attributes when taken together ultimately determine seedling performance.

Traditional nursery practice entails raising seedlings in polythene bags (polybags) using soil, sand and farmyard manure (FYM) as a potting medium. Such mixtures may produce seedlings with good shoot development but poor root systems (Miller and Jones 1995). In India, *S. album* seedlings are conventionally raised in polybags of 1500 mL capacity (13 cm x 30 cm size) using a potting mixture of sand:soil:FYM in a 2:1:1 ratio, with *Cajanus cajan* as a pot host. This produces a plantable seedling 30 cm high with dark brown stem in 6–8 mo (Rai 1990). Problems commonly associated with this conventional practice are the bulk, poor nutritional status and poor aeration of the medium, limited root fibrosity, root coiling, and difficulty in maintaining and managing the host. A consequence is poor survival in the nursery and field. These problems can be addressed by the use of a balanced potting mixture, by using an optimum type and size of container, by applying supplementary nutrition and by choosing the best primary host species. In Western Australia, black plastic containers 180 mm high and 100 mm diameter (1500 mL), have been used with a potting medium of sand:peat:perlite in the ratio of 3:2:2 for the production of *S. album* seedlings in 5–6 mo, using *Alternanthera nana* as a primary (pot) host (Radomiljac 1998).

Containerised seedling production has been widely used since the early sixties. The practice improved seedling survival and management as compared to bare-root seedling production (Xuo and Gao 1984). The primary function of any container is to hold a discrete supply of growing medium, which in turn supplies water, air, mineral nutrients and physical support to the seedling. Apart from these functions, the containers must inhibit root spiralling and root coiling and encourage root pruning at the base of the cell, which favours a more fibrous root system (Jinks 1994).

Table 1. Details of type and size of containers used to see their effect on growth of seedlings

Treatment	Container (colour)	Volume (mL)	Diameter (cm)	Length (cm)	Length: diameter	Stocking (No. m^{-2})
C1	Root trainer (black)	150	5	10	2.00	400
C2	Root trainer (black)	270	7	10	1.43	160
C3	Root trainer (black)	300	7	14	2.00	204
C4	Root trainer (black)	450	6	23.5	3.92	278
C5	Root trainer (black)	600	7	24.5	3.50	204
C6	Polybag (white)	600	7	11	1.57	204
C7	Plastic container (black)	1000	11	11	1.00	83
C8	Polybag (white)	1000	8	16	2.00	125
C9	Polybag (white)	1500	10	16	1.60	100

Polythene bags are conventionally used for large-scale seedling production of forest plantation species. However, problems with them can include root coiling, less fibrous root formation, poor aeration, the bulk of the potting medium, a requirement for a large nursery area, and difficulty in transportation. The use of root trainers as containers can lessen these problems. Trainers are easy to fill and have fewer problems with weeds. They are easy to manage, avoid water-logging, produce comparatively uniform growth, and give high survival and better growth in the field (Josiah and Jones 1992). They are made in various shapes and sizes (Landis *et al*. 1990), either individually as single cells or in aggregates as blocks. Those with a volume of 50–100 cm^3 are adequate for most conifers, while a larger volume, 300 cm^3, is appropriate for many broadleaved species (Jinks 1994). Root trainers are used in India to produce high quality planting stock of several forestry species (Khedkhar and Subramanian 1996, 1997; Shrivastava *et al*. 1998; Ginwal *et al*. 2001, 2002).

In current forest nursery practices the concept of container size incorporates all dimensional aspects including volume, height, diameter and shape. Optimum container size depends on factors such as species, plant stocking in the nursery, size of the seedling desired, type of growing medium and length of the growing season (Jinks 1994; Sharma 1996). As sandalwood is parasitic, it requires a primary host at the nursery stage to assist growth (Rai 1990; Surata 1992; Barrett and Fox 1995; Fox *et al*. 1996; Radomiljac 1998; Fox 2000). It is therefore important to select the best size and type of container to accommodate both *S. album* and its primary host. There have been no systematic studies of the type and size of container for sandalwood. The present study aimed to determine the optimum container for the rapid large-scale production of quality seedlings of *S. album*.

Materials and methods

Seeds of *S. album* were collected during November 1998 from a clonal seed orchard (CSO) at Nallal, Bangalore, India. Depulped and dried seeds were graded and pre-treated with 0.05% gibberellic acid (w/v) for 16 h. Pre-treated seeds were sown in trays of sand for germination under shade in a nursery at Nagroor, Bangalore. The sand was watered daily. Seedlings 35–40 days old, at the two-leaf stage, were transferred to the containers to be tested (Table 1). The potting medium used was sand, soil, compost, burnt rice husk and charcoal in the ratio 5:3:10:1:1. In all the treatments, single superphosphate (SSP, 4.5 kg m^{-3}) and deoiled neemcake (10 kg m^{-3}) were added to enhance fertility of the potting medium. The cake is a residue after oil is extracted from the neem seed; the Indian Standards Institute has recommended its use as a manure (Anon. 1990). It not only provides nutrients and slows the loss of nitrogen by nitrification, but also controls soil-borne pathogenic fungi and pests (Korah and Shingte 1968; Schmutterer 1995). Indophil M-45™ (fungicide) and Phorate™ (nematicide), each at 0.25 kg m^{-1}, were used as prophylactic measures against soil-borne pathogens.

One week after transplanting *S. album* seedlings from the sand trays to the containers (Table 1), *Cajanus cajan* seeds were sown in the containers — the aim was to get one plant of each species per container. Host plants were pruned initially after 30 days, and subsequently at intervals of 15 days for the duration of the study, 20 June – 19 December 1999. A total of 100 seedlings was used in each treatment, arranged in four replicates each of 25 seedlings and in a completely randomized design (CRD).

Growth data

Seedling height, collar diameter and survival were recorded after 3, 4 and 6 mo. A 'sturdiness quotient' (SQ) (Roller 1977) was calculated by dividing seedling height (cm) by collar diameter (mm).

At the termination of experiment, three randomly-selected seedlings from each replicate were carefully uprooted without disturbing the root system and washed in running tap water. The seedlings were cut at the root collar and dried separately at 80°C in paper bags in a hot air oven for biomass estimation. The dry shoots and roots were weighed using a top pan electronic balance. The root:shoot dry weight ratio was calculated for each plant. A quality index was calculated (Dickson *et al*. 1960):

$$\text{Quality Index } (QI) = \frac{s}{(h/d) + (t/r)},$$

where s = seedling dry weight (g); h = height (cm); d = diameter (mm); t = top dry weight (g); and r = root dry weight (g).

Table 2. Effect of type and size of container on the seedling height and collar diameter of *Santalum album* at ages 3, 4 and 6 months

Treatment	Age at assessment					
	3 months		4 months		6 months	
	Height (cm)	Collar diameter (mm)	Height (cm)	Collar diameter (mm)	Height (cm)	Collar diameter (mm)
C1	11.7±1.3	2.2±0.5 b	14.1±2.1 b	2.7±0.4 c	18.3±2.5 ab	3.3±0.6 c
C2	11.5±1.9	2.0±0.3 ab	13.3±2.2 a	2.6±0.4 bc	17.7±2.4 ab	2.8±0.5 b
C3	11.3±2.0	1.9±0.3 ab	13.9±2.3 ab	2.4±0.4 b	18.8±2.4 b	2.7±0.6 ab
C4	11.1±2.2	1.7±0.4 a	13.7±4.3 ab	2.2±0.3 a	20.0±4.3 b	2.7±0.9 ab
C5	11.5±1.2	1.9±0.2 ab	14.6±2.0 ab	2.4±0.4 b	20.4±4.4 b	2.8±0.6 b
C6	11.6±2.0	2.0±0.4 b	14.5±1.9 b	2.4±0.4 b	18.4±4.5 ab	2.8±0.7 b
C7	11.8±1.2	2.1±0.4 b	14.3±1.5 b	2.1±0.3 a	17.1±2.3 ab	2.5±0.4 ab
C8	11.8±1.7	2.3±0.5 b	14.1±2.0 ab	2.7±0.7 c	19.8±1.8 b	2.4±0.4 a
C9	11.0±1.4	1.8±0.4 ab	13.5±1.8 ab	2.6±0.5 bc	16.8±1.3 a	2.5±0.4 ab
lsd*	NS	0.3	0.4	0.2	1.9	0.3

± = Standard deviation (SD); lsd = least significant difference at α = 0.05; Values with the same letter within columns are not significantly different at α = 0.05

Table 3. Effect of type and size of container on the various growth parameters of *Santalum album* at age 6 months

Treatment	Sturdiness quotient (SQ)	Total dry weight (g)	Shoot dry weight (g)	Root dry weight (g)	Root:shoot ratio	Quality index
C1	5.6±0.2 a	1.55±0.50 bc	0.84±0.35 bc	0.71±0.17 bc	0.91±0.24 b	0.23±0.05 d
C2	6.2±0.7 a	1.96±0.39 c	1.20±0.26 c	0.76±0.14 bc	0.68±0.09 ab	0.25±0.06 d
C3	7.1±0.4 bc	1.87±0.32 c	1.11±0.10 c	0.76±0.20 bc	0.67±0.10 ab	0.22±0.05 d
C4	7.5±0.5 c	1.12±0.19 b	0.59±0.20 b	0.53±0.01 b	1.00±0.38 b	0.13±0.01bc
C5	7.2±0.2 bc	3.08±0.54 d	1.66±0.28 d	1.41±0.26 d	0.86±0.05 b	0.37±0.06 e
C6	6.7±0.2 b	0.49±0.17 ab	0.34±0.12 ab	0.15±0.01 a	0.45±0.15 a	0.05±0.01 ab
C7	6.9±0.3 bc	1.85±0.54 c	0.96±0.14 c	0.89±0.42 c	0.92±0.34 b	0.23±0.08 d
C8	8.4±0.7 d	0.30±0.04 a	0.18±0.03 a	0.13±0.01 a	0.73±0.07 b	0.03±0.00 a
C9	6.8±0.8 b	0.97±0.11 b	0.58±0.05 b	0.39±0.01 ab	0.66±0.07 ab	0.12±0.03 ab
lsd*	0.7	0.65	0.37	0.33	0.28	0.09

± = Standard deviation (SD); lsd = least significant difference at α = 0.05; Values with the same letter not significantly different at α = 0.05

Results

The height of sandalwood seedlings 3 mo old did not differ significantly among treatments (container type and size), whereas for collar diameter significant differences were evident from the third month onwards (Table 2). At 3 mo of age, the largest collar diameter was 2.3 mm in the C8 treatment (1000 mL polybag). This was on par with 2.2 mm in C1 (150 mL root trainer), 2.1 mm in C7 (1000 mL plastic container) and 2.1 mm in C6 (600 mL polybag). The pattern was similar at 4 mo, when C8 again had the greatest collar diameter (2.7 mm). This was on par with C1, C2 (270 mL root trainer) and C9 (1500 mL polybag).

At 6 mo all the recorded parameters, viz: height, collar diameter, sturdiness quotient, shoot dry weight, root dry weight, total dry weight, root–shoot ratio and quality index showed significant differences among the treatments (Tables 2 and 3). Among the different types of containers used, survival and overall growth of seedlings 6 mo old was better in root trainers, followed by the plastic container and finally polybags (Table 2 and 3; Figs 1–7).

Among root trainers, maximum collar diameters of 2.2 mm, 2.7 mm and 3.3 mm were recorded in C1 (150 mL) at 3, 4 and 6 mo, respectively, whereas maximum heights of 14.6 mm and 20.4 mm were recorded in C5 (600 mL) at 4 and 6 mo age (Table 2). The greatest total dry weight (3.1 g), shoot dry weight (1.7 g) and root dry weight (1.4 g) were recorded in C5, followed by C2 (270 mL) and C3 (300 mL). The root:shoot ratio was highest in C4 (1.0), which was on par with C1 (0.9). Quality index, an indicator of overall seedling performance, was greatest in C5 (0.37) followed by C2 (0.25), C1 (0.23) and C3 (0.22).

The plastic containers (1000 mL; C7) proved better than polybags. Seedlings produced in C7 had total dry weight of 1.8 g, shoot dry

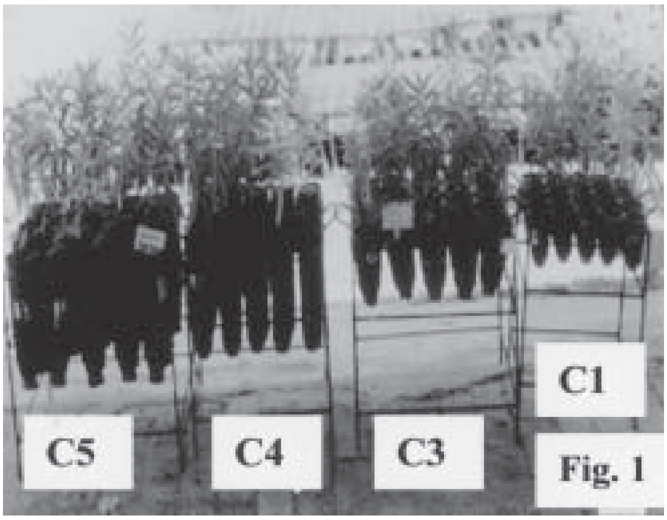

Figure 1. Six-month-old *Santalum album* seedlings in single-cell root trainers (l – r: C5 (600 mL), C4 (450 mL), C3 (300 mL) and C1 (150 mL))

Figure 2. Six-month-old *Santalum album* seedlings in 270 mL block-type root trainers

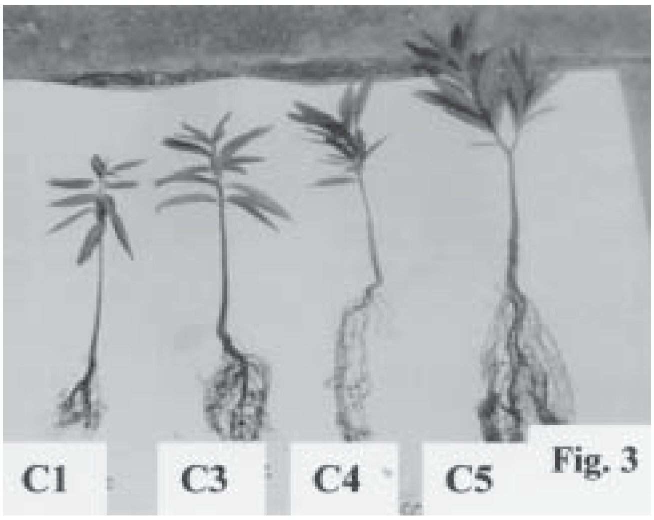

Figure 3. Six-month-old *Santalum album* seedling shoot and root systems (l – r: C1 (150 mL), C3 (300 mL), C4 (450 mL) and C5 (600 mL))

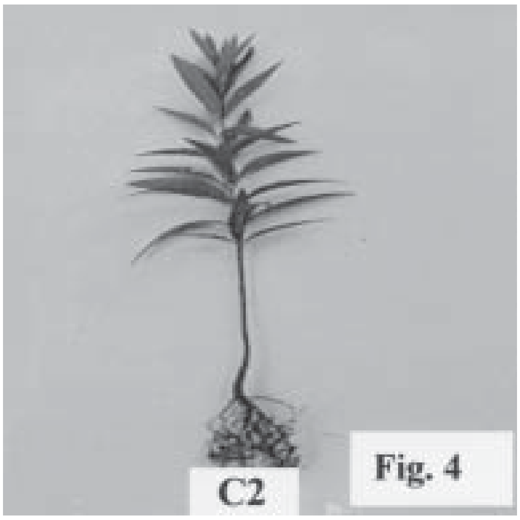

Figure 4. Six-month-old *Santalum album* seedling shoot and root system in 270 mL block-type root trainers

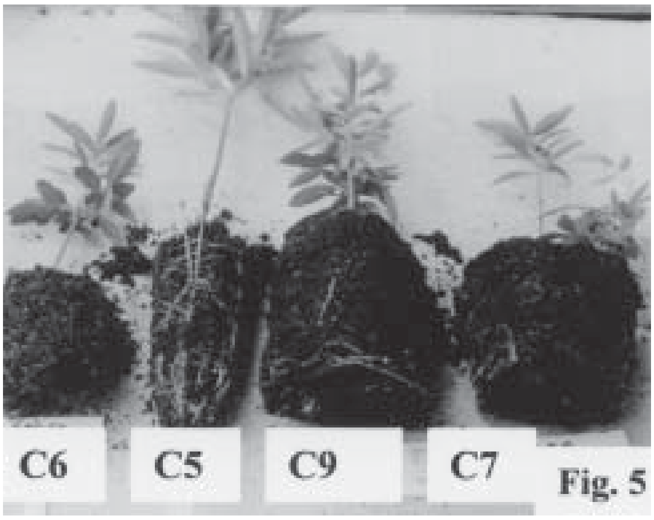

Figure 5. Six-month-old *Santalum album* seedlings in various types of containers (left to right: C6 (600 mL polybags), C5 (600 mL root trainer), C9 (1500 mL polybags) and C7 (1000 mL plastic container))

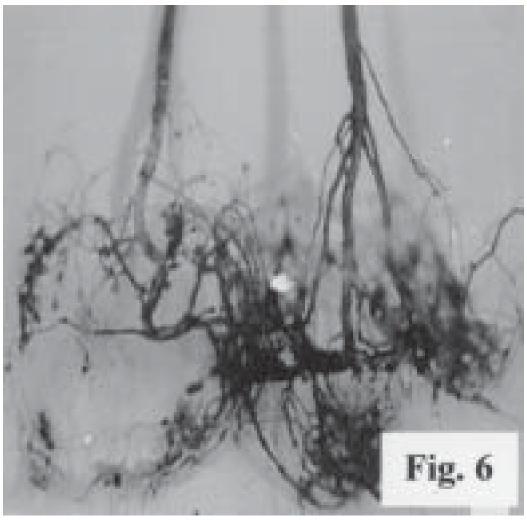

Figure 6. Close-up of root system of seedlings grown in 1000 mL plastic containers showing root coiling

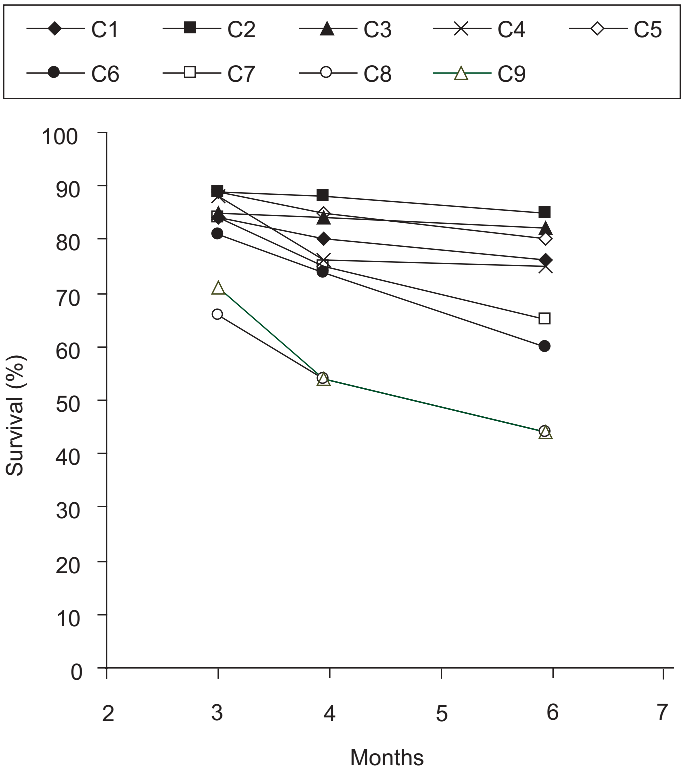

Figure 7. Effect of the type and size of containers on the survival of *Santalum album* seedlings at the age of 3, 4 and 6 mo

weight of 0.96 g, root dry weight of 0.89 g and quality index of 0.23; these values are comparable those of seedlings from the 270 mL and 300 mL root trainers. Root coiling was observed in plastic containers — a basic impediment to survival and satisfactory growth of seedlings (Fig. 6).

Survival and the growth of *S. album* seedlings in polybags was in general very poor (Fig.7). Among polybags, C9 (1500 mL) showed best growth, with a quality index of 0.12 as compared to C6 (600 mL) and C8 (1000 mL).

Among different types of containers, growth of *S. album* seedlings was better in black containers (root trainers and plastic containers) than in polybags. Among all the containers, 600 mL single-cell root trainers resulted in the best growth, followed by 270 mL block-type root trainers. Block-type root trainers are easier to handle, manage and transport than single-cell root trainers.

Discussion

Survival and overall growth of *S. album* seedlings was best in root trainers, although they held a smaller volume of potting medium than plastic containers and polybags. This superiority may be due to the presence at the bottom of root trainers of a larger drainage hole (which resulted in better drainage, good aeration and aerial root pruning), and ridging on the sides of the container (which inhibited root coiling). These factors may be associated with greater secondary and tertiary root formation (enhanced root surface area) when compared with that of seedlings in plastic containers and polybags. Further, the organic-rich potting medium used in the study would have exhibited favourable physical and chemical properties (drainage, aeration, water holding capacity and nutrition) in root trainers. In polybags with inadequate drainage, however, the same medium may have hindered root growth and consequently shoot growth of seedlings.

Plastic containers came second to root trainers in the survival and growth of seedlings.

The colour and thermal conductivity of container materials have a direct bearing on heat absorption by containers and thus the temperature of the growing medium (Sharma 1996), so the interaction of type and colour of container and potting medium may produce differences in growth.

In general the greater the root trainer volume the better was the growth of *S. album* seedlings. A similar relationship has been reported between container volume and seedling height and biomass in *Pinus contorta* (Endean and Carlson 1975), and in *Grevillea robusta* (Misra and Jaiswal 1993). Increased seedling growth of 72–360% was observed in *Picea glauca*, *P. mariana* and *Pinus banksiana* when container volume was tripled (Sutherland and Day 1988).

The poor growth in 450 mL root trainers, compared to that in the 270 mL and 300 mL sizes, can be attributed to the high stocking (278 seedlings m^{-2}). Shoot height may be increased with increasing stocking as a result of greater competition for light, but in these circumstances stem diameter, and shoot and root weight, decrease as a consequence of reduced photosynthetically-active radiation in the lower crowns and lower water potential (Sharma 1996).

The overall growth of sandalwood seedlings was best in 600 mL root trainers with a diameter of 7 cm and a stocking of 240 plants m^{-2}. This was followed by growth in the 270 mL and 300 mL trainers (both with diameters of 7 cm) at stockings of 160 and 204 plants m^{-2} respectively. Similarly *Picea glauca* and *P. engelmani* seedlings grown in containers of 45–120 mL at higher stockings (64–1111 plants m^{-2}) had lower shoot and root weight, stem diameter and sometimes shoot height. Interaction between container volume and stocking was such that the effect of volume was evident only at stockings of <568 seedlings m^{-2} (Simpson 1991).

Seedling growth was better in 600 mL and 1500 mL polybags than in the 1000 mL polybag. This might be due to a greater ratio between length and diameter in the 1000 mL polybags (2.00) compared with the 600 mL (1.57) and 1500 mL (1.60).

Other workers have reported varied results regarding container size (length, diameter, ratio of length and diameter), stocking and volume of potting medium (Sharma 1996). Among eight sizes of polybags and three soil media tested, height, diameter and dry weight of *Pinus brutia* seedlings were better in 15 cm x 30 cm and 20 cm x 30 cm bags with sandy/clay soil at 2:1 ratio (Alkinany and Alwadi 1989a), whereas seedlings of *Eucalyptus camaldulensis* grew better in 25 cm x 30 cm and 30 cm x 30 cm bags with sandy loam and clay soil at 1:1 ratio (Alkinany and Alwadi 1989b).

Conclusion

Root trainers are the best containers, with compost as the major ingredient of the potting medium, for the production of good quality seedlings of *S. album.* For overall growth of seedlings, the 600 mL root trainers were best, followed by the 300 mL and 270 mL sizes. Since the 270 mL block-type root trainers have additional advantages, such as ease of handling and cost, they can be recommended for mass production of quality planting stock of sandalwood if used in conjunction with appropriate supplementary nutrition and a suitable primary host. Poor seedling growth and root coiling were encountered in polybags and plastic containers. Reducing the volume of organic matter (compost) in polybags and plastic containers may improve drainage and aeration, promoting better root development and overall growth. Though the design of experiment does not allow statistical evaluation of interactions between seedling stocking, potting medium, and container size (volume, length, diameter, ratio of length and diameter) and types, interaction was observed between these factors.

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