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Assessment of Root-Shoot Growth of Tree Seedlings Raised in Conventional Container Type and Air-prune Pots

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Abstract: The experiment investigated the effects of different growing environments on various shoot and root characteristics of six tree species, including *Terminalia bellirica*, *Tecomella undulata*, *Terminalia arjuna*, *Azadirachta indica, Syzygium cumini*, and, *Madhuca longifolia* over a period twelve months. The seedlings of 30 days growth were transplanted into four container environments: black polybags kept on cemented floor (C1), white polybags kept on nursery floor (C2), black polybags kept on nursery floor (C3), and airpots (C4), using a factorial completely randomized design with four replications. There were significant differences for various traits except root-shoot ratio. After one year of growth, *Terminalia arjuna* continued to show superior growth in height (67.36 cm) while *Terminalia bellerica* for collar diameter (8.62 mm). However, the reverse trend was observed for tap root length and diameter. The seedling fresh (79.65 g/seedling) and dry (33.37 g/seedling) biomass was highest for *Syzygium cumini*. *Maduca longifolia* produced the lowest seedling growth and biomass except tap root diameter in *Tecomella undulata*. The container environment (C3) showed the maximum values for root shoot growth and biomass production due to higher production of lateral roots. Quality assessments indicated that the good root shoot ratio and sturdiness quotient (SQ) were obtained for *Syzygium cumini* in air-prune pots; and *Terminalia bellerica* in air-prune pots. The maximum Dickson's quality index (DQI) was observed for S5C3 followed by S4C3 and S5C2. Besides, root shoot ratio and SQ, DQI was significantly maximum for the seedling grown in black polybags kept on nursery floor.

Keywords: Forest tree seedling, Container type, Air-prune pots, Root-shoot growth

Forest cover plays a pivotal role in maintaining ecological balance, particularly in a biodiversity-rich country like India. According to the Forest Survey of India (FSI 2021), the total forest cover in India spans 713,789 square kilometres, accounting for 21.71% of the country's geographical area. Additionally, trees outside forests contribute another 95,748 square kilometres, or 2.91%, resulting in a combined forest and tree cover of 24.62%. Despite this, the forest and tree cover in some regions, such as Punjab, remains critically low. In Punjab, forest and tree cover constitutes only 3.67 and 2.26%, respectively, of the state's total geographical area, which is very low by 33% minimum forest cover recommended by the National Forest Policy (1988) for well being of human life and ecological sustainability. This alarmingly low forest cover in Punjab has sparked significant ecological concerns, prompting a series of afforestation efforts led by the state forest department, non-governmental organizations (NGOs), and local communities.

Despite these efforts, environmentalists and NGOs have raised concerns about the poor survival rates of out-planted saplings, attributing the issue to inadequate nursery practices that result in low-quality seedlings. Surveys of forest department nurseries revealed that 30-40% of tree stock, aged 1 to 3 years, exhibited severe root deformities, including multiple or rudimentary taproots, fewer fibrous roots, and girdled roots. Saplings also demonstrated irregular stem thickness and leaning central leaders, with destructive analysis revealing coiled and kinked roots, which could impede long-term establishment. These deformities are a major concern, as a well-developed root system is essential for sapling survival and successful establishment in the field (Grossnickle 2005).

Poor root quality significantly hinders a tree's ability to adapt post-transplantation, underscoring the need for improved nursery management practices to ensure successful reforestation and afforestation efforts. A healthy root system is not only vital for nutrient and water uptake but also serves as a foundation for sapling sturdiness and growth. Previous studies have shown that factors such as species selection, the rooting environment, and post-planting care play critical roles in seedling survival and establishment (Hirons and Percival 2012). Furthermore, advancements in nursery practices, particularly the shift toward container nurseries in the 1970s, have allowed for greater control over seedling production by enabling nurseries to optimize cultural practices (Dumroese et al 2016). These containerized systems, however, have introduced new challenges, particularly in root development, as the confined growing space can lead to issues such as root circling, girdling, and kinking, which compromise the sapling's ability to establish itself in the field (Gilman and Kempf 2009). Container design, growing medium composition, and root pruning are crucial factors that influence the development of healthy seedlings in nurseries. Research indicates that containers designed to encourage the formation of fibrous root systems are more effective at promoting nutrient uptake and overall tree establishment (Arnold and McDonald, 2006). Root pruning, a key nursery practice, fosters a more robust lateral root system, enhancing the sapling's ability to absorb nutrients and water post-transplantation (Gilman and Wiese 2012). However, improper pruning techniques can lead to undesirable root deformities, which may negatively impact long-term growth and survival in unmanaged site conditions. This study assessed the seedlings of different forest tree species grown in different containers including nursery polythene bags air-prune pots for root-shoot growth, seedling biomass characteristics and quality of seedlings after 12 months of transplanting.

MATERIAL AND METHODS

Experimental site and plant material: The study was carried out at Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana, Punjab, India (30°54' N latitude and 75°48' E longitude, 247 m amsl). Twelve-month-old tree seedlings of *Terminalia bellirica*, *Tecomella undulata*, *Azadirachta indica*, *Terminalia arjuna*, *Syzygium cumini* and *Madhuca longifolia* were used for study. The nursery seedlings were bare-rooted and were subjected to corrective pruning to remove any root defects prior to planting in the containers. The potting media comprised volumetric proportions of soil:vermicompost (3:1; v/v). The pots were tapped 3-4 times while filling of the media to ensure uniform bulk density throughout its finite volume.

Cultural practices: The one-month-old seedlings of uniform size (4-5 inch length) were planted in four containers, *i.e.* black polybags kept on hard floor (C1), white polybags kept on nursery floor (C2), black polybags kept on nursery floor (C3) and air-prune pots (C4). The polythene bags are having size of 8×6 inches and experiment was in the factorial completely randomized design with 4 replications with a plot size of 5 seedlings per treatment. The experiment was initiated on August 2022. The pots were filled with loam soil : sand : farm yard manure in equivalent volumetric ratios by gentle tapping while filling the media mixture to ensure uniform bulk density and similar compaction levels. The rooted seedlings of uniform age (one-month-old) were transplanted into polythene bags and air-prune pots. The pots were kept under 50% shade net ensuring only 50% of the sunlight light transmittance during first week of May till end of June. During rest of the year, the pots were kept under open sun ensuring uniform sunlight and gaseous exchange with the surrounding air. The pots were irrigated as and when required in August-September, and thereafter the frequency of irrigation was reduced once per week (October-February) due to low temperature. The pots were irrigated daily with the rise in temperature (March-July) ensuring thorough wetting of the pot volume at nearly 100% saturation. The weed growth in pots was controlled by periodic hand weeding. The seedlings were uniformly supplemented with recommend doses of fertilizers.

Growth and biomass measurements: The various observations were recorded during September 2023 on 12-months after transplanting of seedling in the pots to monitor the growth rate. Shoot growth was assessed in terms of seedling height, number of leaves and branches, fresh weight and dry weight of the shoots. The collar diameter was measured with a digital vernier caliper gently placed 1 cm above the collar region. The observations pertaining to root characteristics were categorised as root length and diameter of main tap root and number of first-order lateral roots (FOLR, with diameter ~1-2 mm) and second order lateral roots (SOLR, with diameter < 1mm). Further, fresh and dry biomass of the root system was also calculated to assess the variability in dry matter accumulated due to type of pots. The characteristics defining the quality of seedlings were also assessed by determining the root-to-shoot ratio, sturdiness quotient (SQ), and Dickson's quality index (DQI).

Statistical analysis: The statistical analysis was carried out using SPSS software version 21.

RESULTS AND DISCUSSION

The tree species and container types significantly affected seedling growth and biomass, but no significant effect was observed for the ratio of root-to-shoot biomass (Table 1). The container size had larger effects on seedling growth and biomass production of seedlings except root weight than genotype of seedlings. There was significant interaction between tree species and container types for all the trait of the seedlings used in the study.

Shoot characteristics: The seedling height ranged from 31.3 cm (*A. indica* grown in C4) to 83.08 cm (*T. arjuna* in C3), while the root-collar diameter varied from 4.64 mm (*S. cumini* in C4) to 10.19 mm (*T. arjuna* in C3) as presented in Table 2. Number of leaves and branches varied from 11.75 (*T. arjuna* in C4) to 68.67 (*T. bellerica* in C3), and from 1.33 (*S. cumnini* in C4) to 4.33 (*T. arjuna* in C3), respectively. These findings illustrate the pronounced impact of various growing containers on the height development of the tree seedlings, highlighting the importance of selecting appropriate cultivation conditions for optimal growth. The study order of S6C4 > S3C4 > S5C4 > S1C1 > S2C4 >S1C3 > S5C1. The mean maximum mean root-to-shoot ratio was obtained for air-prune pots (0.84) and *S. cumini* (0.72). A small sturdiness quotient (SQ) indicates a sturdy seedling with higher chance of survival under field conditions. For those air-prune pots seedlings, *i.e. M. longifolia* (S6C4; 4.03), *A. indica* (S3C4; 4.52), *S. cumini* (S5C1; 5.11) and *T. bellerica* (S1C1; 5.59) seedlings showed the good SQ values (SQ < 6.0). Remaining seedlings grown in different container type are somewhat susceptible to some environmental or cultural damages due to having higher SQ, *i.e.* >6.0 value, thought their growth was higher in terms of shoot or root growth. Dickson's quality index (DQI) is one of the important parameter used to assess the seedling vigour at minimum 60 days of age. However, in the present study, the seedling were evaluated at the age of 12 month after transplanting, the maximum DQI was observed for S5C3 (4.54) followed by S4C3 (4.05) and S5C2 (3.72). Besides root shoot ratio, DQI

Table 2. Effect of genotype and container type on shoot growth in forest tree seedlings

Species		Container	Seedling height (cm)	Collar diameter (mm)	Number of leaves	Number of branches
Terminalia bellirica (S1)		C1	51.29	8.05	41.08	1.83
		C2	55.57	8.66	52.39	2.53
		C3	62.42	9.11	68.67	2.17
		C4	60.75	8.66	60.83	1.58
		Mean	57.51	8.62	55.74	2.03
Tecomella undulata (S2)		C1	61.00	8.47	21.25	1.50
		C2	57.43	6.61	23.50	3.17
		C3	61.94	9.65	41.56	3.26
		C4	45.94	7.14	30.36	2.56
		Mean	56.58	7.97	29.17	2.62
Azadirachta indica (S3)		C1	66.71	6.41	28.83	1.50
		C2	62.25	6.32	29.33	2.42
		C3	71.08	8.07	33.11	2.47
		C4	31.11	6.04	14.67	1.58
		Mean	57.79	6.71	26.49	1.99
Terminalia arjuna (S4)		C1	71.56	7.88	22.25	2.67
		C2	70.72	9.15	30.92	3.39
		C3	83.08	10.19	44.92	4.33
		C4	44.08	6.72	11.75	1.75
		Mean	67.36	8.49	27.46	3.04
Syzygium cumini (S5)		C1	45.61	8.10	51.19	3.58
		C2	60.87	8.19	42.94	2.44
		C3	62.47	8.77	53.00	3.69
		C4	40.39	4.64	21.78	1.33
		Mean	52.34	7.43	42.23	2.76
Madhuca longifolia (S6)		C1	58.67	5.59	30.47	3.22
		C2	57.92	6.65	25.75	2.08
		C3	59.31	7.28	33.25	3.83
		C4	28.44	5.00	12.67	1.61
		Mean	51.09	6.13	25.54	2.69
CD (p=0.05)	Tree species		4.48	1.01	3.92	1.01
	Container type		5.17	1.23	4.70	1.23
	Species × Container		7.67	1.47	7.41	2.47

confirmed that all species and growing containers differed significantly in terms of shoot growth. Seedlings raised in black polybags placed on the nursery floor showed the highest values, suggesting that the container and environment significantly impacted growth. These findings align with earlier studies on the impact of container types and growing environments on seedling growth. Venkatesh et al. (2002) reported that *Acacia nilotica* seedlings grown in large size black polythene bags exhibited more shoot length, leaf count and collar circumference. Similarly, Malik and Shamet (2009), Ferdousee et al. (2010) observed that the large size and bottom-hole polybags, significantly influenced seedling growth metrics in nurseries. Oliet et al. (2005) and Grossnickle and South (2014) confirmed that container size significantly affects the early growth and root morphology of tree species. Grossnickle and South (2014) discussed the significance of container design and size directly affects the root morphology and overall seedling vigor, supporting the claims made also by Malik and Shamet (2009).

Root characteristics: The effect of the genotype and container type on root characters of seedling was significant (Table 3). The root length and diameter varied from 29.33 cm (*A. indica* in C2) to 47.25 cm (*T. bellerica* in C3), and from 5.52 mm (*S. cumini* in C4) to 11.31 mm (*T. arjuna* in C3), respectively. In term of number of first order and second order lateral roots were significantly affected with the container type and varied from 6.08 (*T. bellerica* in C4) to 28.17 (*S. cumini* in C4), and from 10.61 (*T. undulata* in C4) to 52.92 (*S. cumini* in C3), respectively. The seedling of *S. cumini* showed lower diameter with higher number of first and second order laterals roots. Root length and diameter showed opposite trend with shoot length and diameter. The colour of the containers has significant difference on seedlings root growth. Approximately 20-30% more root length and number of lateral roots in black polybags kept in nursery floor than white polybags kept in nursery floor except *S. cumini* and *M. longifolia*; however, root diameter does not have any significant effect of colour of container. Similar to these results, best seedling growth and morphology of *Hevea brasiliensis* roots was observed in larger containers (Salisu et al., 2018). Amal and Mohamed (2010) explored that large and container and black colour had better root development and better growth in *Eucalyptus camaldulensis* seedlings. Vieira et al. (2019) concluded that shoot and root growth of *Agave angustifolia* seedlings had significant growth differences due to container size, shape, and growing media composition.

Biomass characteristics: The fresh and dry biomass of shoot and root in forest tree seedlings grown in the containers C3 were highest than C1, C2 and C4 (Table 4). Fresh shoot and root biomass varied from 21.05 g/seedling (*A. indica* grown in C4) to 59.52 g/seedling (*S. cumini* grown in C3), and from 8.64 g/seedling (*M. longifolia* in C4) to 33.41 g/seedling (*S. cumini* in C3), respectively. The minimum dry shoot and root weight was observed in *M. longifolia* seedling grown in C4 (5.38 and 3.01 g/seedling). However, the maximum dry shoot and root weight was 26.43 g/seedling for *T. undulata* and 13.83 g/seedling for *A. indica* grown in C3 containers, respectively. *Terminalia bellerica*, *T. undulata* and *A. indica* did not show any significant differences. The attributes of the biomass varied significantly among the different tree species, while, no significant differences were observed for root fresh and dry weigh. Growing container significantly affects seedling biomass. In contrast, there were no discernible variations in dry weight of the roots and shoots when seedlings grown in transparent and black polybags (Nayanakantha et al., 2018). Tsakaldimi et al. (2005) studied the effect of container type on the root growth and morphology of *Quercus ilex* and *Pinus pinea*, and concluded that deeper and larger containers promoted greater root depth, better anchorage, and increased survival rates in the field, mirroring the observations of Nayanakantha et al. (2018) regarding the importance of container size and type.

Seedling quality characteristics: Owing to the interaction between tree species and container type, we evaluated the integrated effect of treatments on the seedling quality characteristics, *i.e.* root-to-shoot ratio (Fig. 1), sturdiness quotient (Fig. 2) and Dickson's quality index (Fig. 3). Significant differences were observed for tree species, container and their interactions (Fig. 1-3). The root-to-shoot biomass ratios ranged from 0.47 to 1.03, and followed the

Table 1. Analysis of variance for growth and biomass production of forest tree seedlings

Factors	Seedling growth				Seedling fresh biomass		
	Height (cm)	Collar diameter (mm)	Root length (cm)	Root diameter (mm)	Shoot weight (g)	Root weight (g)	Root-to-shoot ratio
Species (S)	10.67***	4.61***	4.12**	3.80**	2.56***	2.59***	0.94 ns
Container (C)	14.63**	6.88**	5.11***	7.30***	6.76**	1.53***	1.54 ns
S×C	9.92***	3.19**	2.63***	2.48***	4.34***	1.64*	0.78*

Note: ns: non-significant. *, ** and *** indicate significant effects at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively was significantly maximum (3.33) in C3 container type.

The present study supports the assertion of Singh *et al* (2024) that tree seedlings grown in air-pruning containers and found that air-pruning improved root architecture, resulting in better root-to-shoot ratios and increased survival rates in field conditions. Sharma et al. (2017) observed the use of air-pruning containers on the growth of *E. camaldulensis* seedlings and concluded that seedlings grown in air-pots had superior root systems, including increased lateral root development and reduced root circling. This enhanced root structure promoted better shoot growth and increased plant stability post-transplantation. The seedling grown in air-pruning containers had a well-structured and well developed fibrous root system (Mariotti et al., 2015). Chiatante et al. (2015) explored the use of air-pruning containers in enhancing the growth of *Populus alba* and *Pinus halepensis* seedlings and findings showed that air-pruning containers produced seedlings with more

Table 3. Effect of genotype and container type on root growth in forest tree seedlings

Species		Container	Root length	Root diameter	FOLR	SOLR
Terminalia bellirica (S1)		C1	43.56	9.18	10.81	35.67
		C2	35.22	9.16	12.58	29.44
		C3	47.25	9.73	16.83	43.25
		C4	37.41	8.46	6.08	24.25
		Mean	40.86	9.13	11.83	33.15
Tecomella undulata (S2)		C1	30.08	6.77	11.33	19.00
		C2	32.33	6.75	12.17	10.61
		C3	42.00	7.54	18.31	25.53
		C4	35.87	5.59	12.28	23.75
		Mean	35.07	6.66	13.52	19.72
Azadirachta indica (S3)		C1	31.83	7.45	7.10	22.00
		C2	29.33	8.18	9.67	21.21
		C3	40.00	8.95	11.25	20.17
		C4	30.43	6.89	10.22	22.67
		Mean	32.90	7.87	9.56	21.51
Terminalia arjuna (S4)		C1	36.31	9.85	17.31	50.67
		C2	37.00	10.50	27.72	46.33
		C3	42.00	11.31	22.25	61.25
		C4	31.48	7.01	21.67	28.67
		Mean	36.70	9.67	22.24	46.73
Syzygium cumini (S5)		C1	33.58	8.93	22.78	36.97
		C2	37.88	8.82	26.17	50.92
		C3	38.46	9.38	28.17	52.92
		C4	36.41	5.52	22.00	38.39
		Mean	36.58	8.16	24.78	44.80
Madhuca longifolia (S6)		C1	30.04	7.15	6.83	23.81
		C2	32.22	7.05	6.64	25.42
		C3	32.78	8.56	10.58	23.25
		C4	29.42	7.05	7.11	16.11
		Mean	31.12	7.45	7.79	22.15
CD (p=0.05)	Tree species		3.22	1.05	1.99	9.26
	Container type		3.61	1.29	2.44	11.34
	Species × Container		6.23	2.58	2.88	12.54

Note: FOLR - First order lateral root; **SOLR** - Second order lateral root

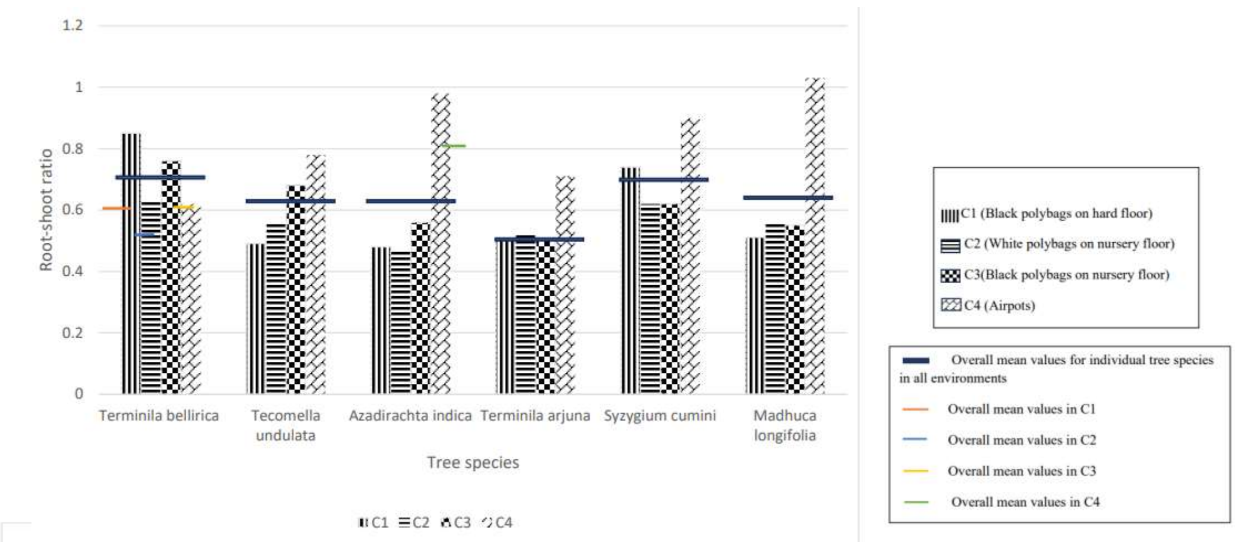

Fig. 1. Effect of container type on root-shoot ratio in forest tree seedlings

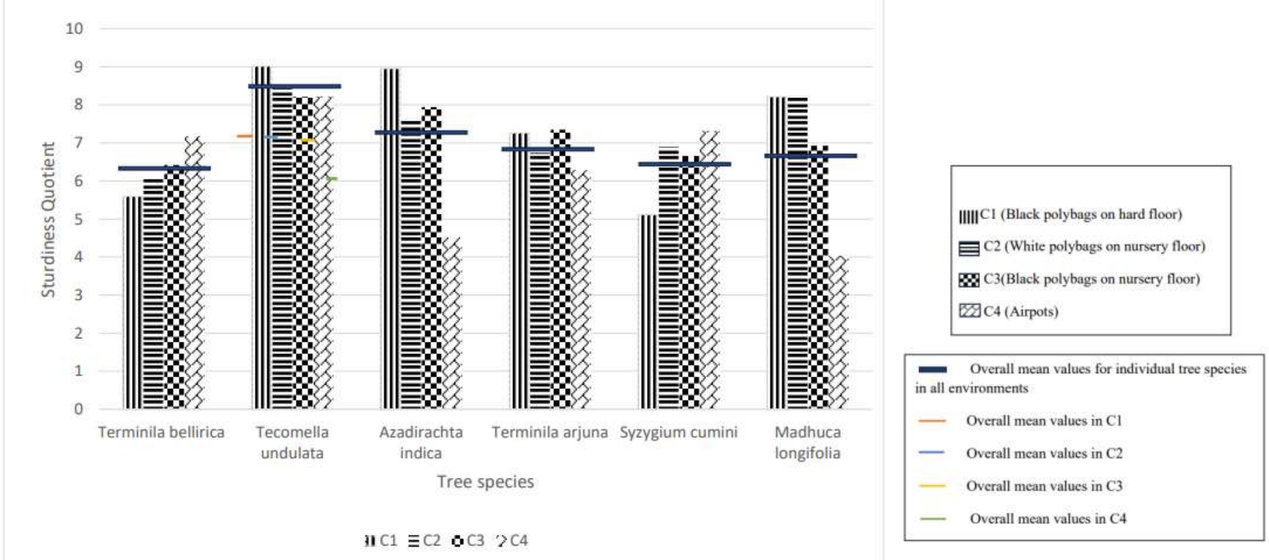

Fig. 2. Effect of container type on sturdiness quotient in forest tree seedlings

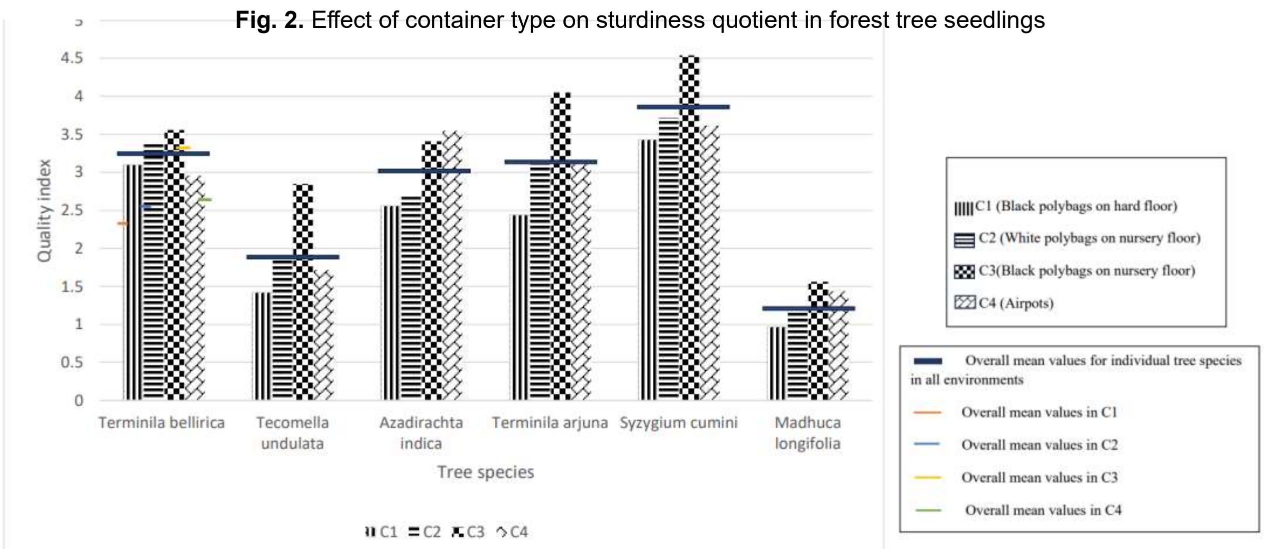

Fig. 3. Response of tree species on Dickson's quality index in forest tree seedlings

Table 4. Effect of genotype and container type on biomass production in forest tree seedlings

Species	Container	Fresh weight		Dry weight	
		Shoot	Root	Shoot	Root
Terminalia bellirica (S1)	C1	26.28	23.67	11.62	9.47
	C2	31.88	27.42	13.87	10.98
	C3	34.82	32.23	17.45	11.00
	C4	32.04	28.99	14.26	10.89
	Mean	31.26	28.08	14.30	10.59
Tecomella undulata (S2)	C1	43.60	14.01	11.97	4.53
	C2	44.59	16.73	15.36	5.73
	C3	56.97	20.09	26.43	7.30
	C4	27.15	14.82	9.51	6.99
	Mean	43.08	16.41	15.82	6.14
Azadirachta indica (S3)	C1	32.15	28.17	12.35	12.98
	C2	28.53	29.39	11.83	11.37
	C3	36.98	33.14	17.58	13.83
	C4	21.05	23.25	9.28	10.04
	Mean	29.68	28.49	12.76	12.06
Terminalia arjuna (S4)	C1	41.73	19.56	16.33	7.03
	C2	42.30	20.46	17.51	9.33
	C3	53.43	25.46	24.83	12.77
	C4	48.52	18.42	21.58	7.31
	Mean	46.50	20.98	20.06	9.11
Syzygium cumini (S5)	C1	48.46	18.07	22.62	6.61
	C2	52.84	25.35	22.39	10.89
	C3	59.52	33.41	26.22	13.08
	C4	50.79	30.16	18.77	12.88
	Mean	52.90	26.75	22.50	10.87
Madhuca longifolia (S6)	C1	26.16	10.36	7.29	3.03
	C2	28.18	10.95	6.80	4.54
	C3	35.15	15.61	9.46	4.60
	C4	22.98	8.64	5.38	3.01
	Mean	28.12	11.39	7.23	3.80
CD (p=0.05)	Tree species	7.44	NS	5.82	NS
	Container type	11.01	7.35	6.81	4.73
	Species × Container	18.03	9.71	10.62	NS

extensive and deeper root systems, increased root branching, and better overall plant health. The study emphasized that air-pruning prevented root deformities such as root circling, contributing to better transplant success. These studies further confirm the benefits of air-pruning containers, such as air-pots, on seedling root and shoot development. By promoting a well-structured and fibrous root system, air-pruning containers improve water and nutrient uptake, reduce root deformation (e.g., circling), and lead to better post-planting performance.

CONCLUSIONS

The study highlights the significant influence of container environments on root-shoot growth, biomass production, and seedling quality in six forest tree species. Seedling quality depends not only on height and diameter but also on attributes like leaf count, mini branches, and lateral roots. Superior growth was observed in *T. bellerica*, *T. arjuna*, and *S. cumini*, recommended for afforestation and roadside plantations. Black polybags (C3 container type) provided optimal conditions for growth, while air-prune pots (C4 container type) improved root-to-shoot ratios and sturdiness quotient (SQ). The study underscores the importance of container environment and species selection in nursery practices and need to explore for further research on long-term field performances of these tree saplings.

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