STUDIES ON SEED SOURCE AND NURSERY MANAGEMENT REGIME IN INDIAN SANDALWOOD (*Santalum album* L.)

SHWETHA, V. R.
PAMB 0058

DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
UNIVERSITY OF AGRICULTURAL SCIENCES
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By
SHWETHA, V. R.
PAMB 0058

UNIVERSITY OF AGRICULTURAL SCIENCES
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DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
COLLEGE OF AGRICULTURE, GKVK, BENGALURU
UNIVERSITY OF AGRICULTURAL SCIENCES BANGALORE

CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON SEED SOURCE AND NURSERY MANAGEMENT REGIME IN INDIAN SANDALWOOD (*Santalum album* L.)"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY in FORESTRY AND ENVIRONMENTAL SCIENCE** to the University of Agricultural Sciences, Bangalore is a record of *bona fide* research work carried out by **Ms. SHWETHA, V. R., ID. No. PAMB 0058** during the period of her study in University under my guidance and supervision. The thesis has not previously formed the basis for award of any degree, diploma, associateship, fellowship or other similar titles.

Place: Bengaluru
Month & Year: December, 2023

(M. MAHADEVAMURTHY)
Major Advisor

Approved by

Chairman : ______________________
(M. MAHADEVAMURTHY)

Members : 1. ______________________
(R. KRISHNAMURTHY)

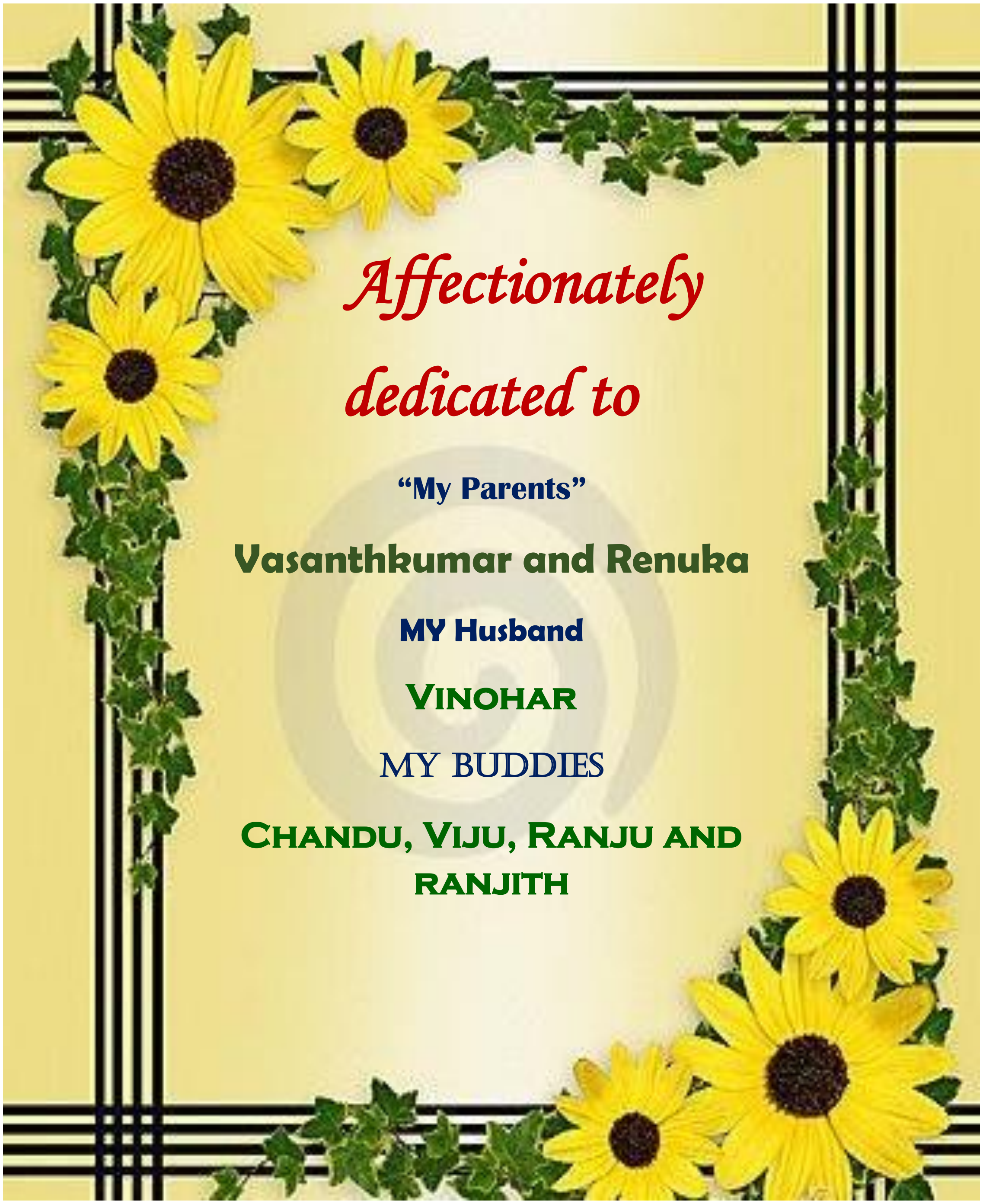
2. ______________________
(R. SIDDARAJU)

3. ______________________
(B.S. LALITHA)

4. Raghu H.B
(H.B. RAGHU)

____

External Examiner
(B.N. SATHISH)
Associate Professor
Dept. of Forest products & Utilization
College of Forestry, Ponnampet-581401



Affectionately dedicated to

“My Parents”

Vasanthkumar and Renuka

MY Husband

Vinohar

MY BUDDIES

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Bengaluru
December, 2023 ***(Shwetha, V.R.)***

STUDIES ON SEED SOURCE AND NURSERY MANAGEMENT REGIME IN INDIAN SANDALWOOD (*Santalum album* L.)

SHWETHA, V. R.

ABSTRACT

A study was conducted to identify the potential seed sources from different regions of Karnataka and to develop nursery management regime for sandalwood. Seeds were collected from seven different locations of Karnataka (S1-Bevinahally; S2-Doranalu; S3-Gottipura; S4-Gungaraghatti; S5-Muddenahally; S6-Narasapura; S7-Tavarekere) and to compare S8-Marayoor seeds were procured from Kerala Forest Research Institute. Seed source S8 (68.66%) displayed the highest germination. Among the Karnataka seed sources S3-Gottipura (51.67%) recorded the highest germination and growth parameters. To improve the germination of Gottipura seed source, three distinct priming methods were employed, *viz.*, biopriming with *Pseudomonas fluorescens* and *Trichoderma viride*, nutripriming with varying concentrations of KNO_3 and $MnSO_4$, and hydropriming with double distilled water. Nutriprimimg with $MnSO_4$, at 0.4M concentration for 3 days, yielded optimal germination (84.00%), and hydroprimimg yielded lowest germination of all priming methods. Next step in nursery management regime is selecting suitable container and optimizing potting media for quality stocking production. Different types and sizes of container and potting media were evaluated. Out of 20 combinations studied 30 cm x 20 cm poly bag, in combination with a potting media soil, rice husk, and farmyard manure in 2:1:1 ratio, consistently recorded superior seedling growth. The assessed growth attributes, were significantly enhanced with this specific combination. Later growth attributes of the species was evaluated with six different host species (*Crotalaria juncia*, *Mimosa pudica*, *Casuarina equisetifolia*, *Cajanus cajan*, *Crotalaria retusa* and *Alternanthera sessilis*). Host species *Crotalaria retusa* recorded the highest growth attributes. Economic viability of the the treatments was also assessed. These series of experiments collectively offer a holistic framework for Indian sandalwood nursery management regime.

December, 2023

Dept. of Forestry and Environmental Science
UAS, Bangalore-65

M. MAHADEVAMURTHY
(Major Advisor)

ಭಾರತೀಯ ಶ್ರೀಗಂಧದ (*ಸ್ಯಾಂಟಲಮ್ ಆಲ್ಬಮ್ ಎಲ್.*) ಬೀಜಮೂಲ ಮತ್ತು ಸಸ್ಯಕ್ಷೇತ್ರ ನಿರ್ವಹಣೆಯ ಕುರಿತ ಅಧ್ಯಯನ

ಶ್ವೇತಾ ವಿ.ಆರ್.

ಪ್ರಬಂಧ ಸಾರಾಂಶ

ಕರ್ನಾಟಕದ ವಿವಿಧ ಪ್ರದೇಶಗಳಿಂದ ಸಂಭಾವ್ಯ ಬೀಜ ಮೂಲಗಳನ್ನು ಗುರುತಿಸಲು ಮತ್ತು ಭಾರತೀಯ ಶ್ರೀಗಂಧದ ಸಸ್ಯಕ್ಷೇತ್ರ ನಿರ್ವಹಣೆಯನ್ನು ಅಭಿವೃದ್ಧಿಪಡಿಸಲು ಈ ಅಧ್ಯಯನವನ್ನು ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು. ಕರ್ನಾಟಕದಿಂದ ಏಳು ವಿವಿಧ ಸ್ಥಳಗಳಿಂದ ಬೀಜಗಳನ್ನು ಸಂಗ್ರಹಿಸಲಾಗಿತ್ತು ಅವುಗಳೆಂದರೆ; ಎಸ್1–ಬೇವಿನಹಳ್ಳಿ, ಎಸ್2–ದೊರಣಾಳು, ಎಸ್3–ಗೊಟ್ಟಿಪುರ, ಎಸ್4–ಗುಂಗರಗಟ್ಟಿ, ಎಸ್5–ಮುದ್ದೇನಹಳ್ಳಿ, ಎಸ್6–ನರಸಾಪುರ, ಎಸ್7–ತಾವರೆಕೆರೆ ಮತ್ತು ತುಲನೆಗಾಗಿ ಎಸ್8–ಮರೆಯೂರು ಬೀಜಗಳನ್ನು ಕೇರಳ ಅರಣ್ಯ ಸಂಶೋಧನಾ ಸಂಸ್ಥೆಯಿಂದ ಸಂಗ್ರಹಿಸಲಾಗಿತ್ತು. ಮರೆಯೂರು ಬೀಜಮೂಲವು (ಶೇ.68.66%) ಅತ್ಯಧಿಕ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆಯನ್ನು ತೋರಿದ್ದು, ಕರ್ನಾಟಕದ ಬೀಜಮೂಲಗಳಲ್ಲಿ ಎಸ್3–ಗೊಟ್ಟಿಪುರ (ಶೇ.51–67%) ಬೀಜಮೂಲ ಅತ್ಯಧಿಕ ಮೊಳಕೆಯೊಡೆದಿದೆ. ಪರೀಕ್ಷಿಸಿದ ಎಲ್ಲಾ ಬೆಳವಣಿಗೆಯ ನಿಯತಾಂಕಗಳಲ್ಲಿ ಗೊಟ್ಟಿಪುರ ಬೀಜಮೂಲವು ಕರ್ನಾಟಕದ ಬೀಜಮೂಲಗಳಲ್ಲಿ ಉತ್ತಮವೆಂದು ತಿಳಿದುಬಂದಿದೆ. ತದನಂತರ ಗೊಟ್ಟಿಪುರ ಬೀಜಮೂಲದಲ್ಲಿ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆಯನ್ನು ಹೆಚ್ಚಿಸಲು ಮೂರು ವಿಭಿನ್ನ ಪ್ರೈಮಿಂಗ್ ವಿಧಾನಗಳನ್ನು ಬಳಸಲಾಯಿತು, ಅವುಗಳೆಂದರೆ ಸ್ಯೂಡೋಮಾನಾಸ್ ಫ್ಲೂರೊಸೆನ್ಸ್ ಮತ್ತು ಟ್ರೈಕೋಡರ್ಮಾ ವಿರೀಡೆ ಬಳಸಿ ಬಯೊಪ್ರೈಮಿಂಗ್, ಪೊಟ್ಯಾಷಿಯಂ ನೈಟ್ರೇಟ್ ಮತ್ತು ಮ್ಯಾಂಗನೀಸ್ ಸಲ್ಫೇಟ್ ಬಳಸಿ ನ್ಯೂಟ್ರಿಪ್ರೈಮಿಂಗ್ ಮತ್ತು ಡಬಲ್ ಡಿಸ್ಟಿಲ್ಡ್ ನೀರನ್ನು ಬಳಸಿ ಹೈಡ್ರೊ ಪ್ರೈಮಿಂಗ್ ಮಾಡಲಾಗಿತ್ತು. ಅವುಗಳಲ್ಲಿ ಮೂರು ದಿನಗಳವರೆಗೆ 0.4M ಸಾಂದ್ರತೆಯಲ್ಲಿ ಮ್ಯಾಂಗನೀಸ್ ಸಲ್ಫೇಟ್ ನ್ಯೂಟ್ರಿಪ್ರೈಮಿಂಗ್ ಉತ್ತಮ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆ (ಶೇ.84%) ನೀಡಿದೆ ಮತ್ತು ಹೈಡ್ರೊಪ್ರೈಮಿಂಗ್ ಎಲ್ಲಾ ಪ್ರೈಮಿಂಗ್ ಗಳಲ್ಲಿ ಅತೀ ಕಡಿಮೆ ಫಲಿತಾಂಶ ನೀಡಿದೆ. ನರ್ಸರಿ ನಿರ್ವಹಣೆಯಲ್ಲಿ ಮುಂದಿನ ಹಂತ ಉತ್ತಮವಾದ ಧಾರಕ ಮತ್ತು ಗುಣಮಟ್ಟದ ಮಡಿಕೆ ಮಾಧ್ಯಮ ಗುರುತಿಸುವುದು. ಒಟ್ಟು 20 ಸಂಯೋಜನೆಗಳಲ್ಲಿ ವಿವಿಧ ಗಾತ್ರದ ಧಾರಕ ಮತ್ತು ಮಡಿಕೆ ಮಾಧ್ಯಮಗಳನ್ನು ಅಧ್ಯಯನ ಮಾಡಲಾಗಿತ್ತು. ಅವುಗಳಲ್ಲಿ 30 ಸೆಂ.ಮೀ × 20 ಸೆಂ.ಮೀ ಪಾಲಿಬ್ಯಾಗ್ ಮತ್ತು 2:1:1 ಅನುಪಾತದ ಮಣ್ಣು, ಭತ್ತದ ಹೊಟ್ಟು ಮತ್ತು ಹೊಲದ ಗೊಬ್ಬರ ಸಂಯೋಜನೆ ಉತ್ತಮ ಬೆಳವಣಿಗೆ ನೀಡಿದೆ. ತದನಂತರ ಶ್ರೀಗಂಧ ಸಸಿಗಳ ಬೆಳವಣಿಗೆಯ ಮೇಲೆ ಅತಿಥೇಯ ಸಸಿಗಳ ಪರಿಣಾಮವನ್ನು ಅಧ್ಯಯನ ಮಾಡಲಾಯಿತು. ಆರು ವಿಭಿನ್ನ ಜಾತಿಯ ಅತಿಥೇಯ ಗಿಡಗಳಲ್ಲಿ (ಕ್ರೊಟಲೇರಿಯಾ ಜಂಕ್ಷಿಯಾ, ಮೈಮೊಸಾ ಪುಡಿಕಾ, ಕ್ಯಾಸುರಿನ ಈಕ್ವಿಸಿಟಿಪೊಲಿಯಾ, ಕಾಜಾನಸ್ ಕಜಾನ, ಕ್ರೊಟಲೇರಿಯಾ ರೆಟ್ಯುಸ ಮತ್ತು ಆಲ್ಟರ್ನೆಂಥರಾ ಸೆಸಿಲಿಸ್) ಕ್ರೊಟಲೇರಿಯಾ ರೆಟ್ಯುಸವು ಅತ್ಯಧಿಕ ಬೆಳವಣಿಗೆಯನ್ನು ನೀಡಿದೆ. ಕೊನೆಯಲ್ಲಿ ಎಲ್ಲಾ ಉಪಚಾರಗಳ ಆರ್ಥಿಕ ಕಾರ್ಯಸಾಧ್ಯತೆಯನ್ನು ಕೂಡ ಅಂದಾಜಿಸಲಾಗಿದೆ. ಈ ಅಧ್ಯಯನವು ಒಟ್ಟಾರೆಯಾಗಿ ಭಾರತೀಯ ಶ್ರೀಗಂಧದ ಸಸ್ಯಕ್ಷೇತ್ರ ನಿರ್ವಹಣೆಗೆ ಉತ್ತಮ ಅಡಿಪಾಯವಾಗಿದೆ.

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ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಜಿ.ಕೆ.ವಿ.ಕೆ ಬೆಂಗಳೂರು–65

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

I INTRODUCTION

Forest nurseries play a vital role in the successful establishment of forest plantations. Owing to the large-scale demand for quality forest plants coupled with the shortage of quality planting materials, it has become imperative that tree nurseries should also be managed professionally to produce the desirable quality nursery stock. Raising good quality seedling requires technical skills, careful planning for all the major components such as the collection of quality seed, seed pre-treatment, appropriate growing media and containers, nursery hygiene and protection (Mohanan and Sharma, 2005). An adequate attention in developing healthy nursery planting stock will ensure their better establishment and survival in field. These plants will also give higher productivity in the long run than those plants which are produced through unscientific nursery practices (Chaturvedi and Jain, 1994). Even though, forest tree seedling production system has been revolutionized in many countries, it is still in its infancy in India and largely depended upon conventional methods for planting material production of many forest tree species. Among forest nurseries sandalwood nurseries are gaining importance these days.

Sandalwood (*Santalum album* L.) is one of the hemi parasitic plants in the family Santalaceae and the genus *Santalum.* It is most celebrated tree species of the tropics and is often regarded as the paragon of Indian timbers. It is an evergreen tree attaining 10-15 m height and 1-2 m girth at full maturity when it reaches the age of 60-80 years (Ghosh *et al.*, 1985; Jain *et al.,* 1999). The tree flourishes well from sea level up to 1200 m altitude in regions with different soil types and varying climatic conditions with an annual precipitation of 600-1600 mm. Its bark is reddish brown to dark brown in colour, smooth in young trees, becoming rough with deep vertical fissures as the tree matures. Leaves are opposite, decussate, flowers unscented, straw yellow coloured turning to deep purplish brown on maturation and occurs in axillary or terminal cymose panicles. Flowering generally occurs twice a year from March to May and September to December. The fruit is single seeded succulent drupe, purplish black when mature (Srinivasan *et al.*, 1992).

It is a highly polymorphic species (Kulkarni, 1995) and morphological studies have shown that the trees vary significantly in leaf length and width, colour of the heartwood and in oil content (Kushalappa, 1983; Bagchi and Veerendra, 1985; Kulkarni, 1995). Distribution of genus *Santalum* in the tropical region is between 30°N and40°S, from India in the West to Juan Fernandez Islands in the East and from Hawaiian Archipelago in the North to New Zealand in the South. It comprises of 16 species (Hamilton and Conrad, 1990; Barret and Fox, 1997) and all of them are xylem tapping root hemi-parasites with highly valued aromatic heartwood. Four *Santalum* species namely *S. spicatum*, *S. acuminatum*, *S. morrayanum* and *S. lanceolatum* are native to Western Australia. Among the *Santalum* species, *Santalum album* has the highest oil content (6-7%) while *S. spicatum* (2%) and *S. laneolatum* (3-5%) yield poorly scented wood and low-quality oil (Barret and Fox, 1997).

In India, the distribution of sandal is mainly in the Deccan plateau; with a total extent of 9600 km^2 of which Karnataka and Tamil Nadu cover 8200 km^2. In Kerala, it occurs sporadically in the deciduous forests up to 900 m elevation. The estimated global demand of sandalwood is approximately 5000–6000 tones year^{-1} and that of its oil is 100 tones year^{-1}. However, the production of sandalwood had declined from 3176 t year^{-1} in 1960–1965 to 1500 t year^{-1} in 1997–1998 and eventually to 500 t year^{-1} in 2007 and 100 t year^{-1} in 2011–2012 (Dutt and Verma, 2020).

Though, *Santalum album* (L.) holds immense economic and ecological significance as a high-value timber species and a source of precious essential oil. However, its natural populations have faced severe threats due to overexploitation and habitat degradation, leading to a significant decline in its availability. To counteract this trend and ensure sustainable sandalwood production, it becomes crucial to investigate and optimize seed source selection and nursery management regimes. The selection of appropriate seed sources plays a pivotal role in determining the genetic diversity and quality of sandalwood seedlings (Rao *et al.*, 2007). The genetic variation within and among populations can influence important traits such as growth rate, heartwood formation, and oil content. Though the area under sandal is more in Karanataka, plantation growers of Karnataka source seeds from Marayoor Therefore, in this study seeds from seven different source of Karnataka were collected and compared with the novel Marayoor source. Identifying superior seed sources can enhance the overall productivity and adaptability of cultivated sandalwood stands.

Furthermore, the nursery management regime significantly affects the growth, survival, and health of sandalwood seedlings during their critical early stages. Factors such as substrate composition, irrigation practices, and shading, fertilization and pest control strategies directly influence the establishment and performance of sandalwood seedlings. Optimizing these management practices can enhance seedling quality, increase survival rates, and accelerate growth, thereby reducing production costs and maximizing yields.

Seed dormancy is the most limiting factor for seed germination and thus it causes prolongation in the seed germination. The seeds of sandalwood are impermeable to water and oxygen thus inhibits the germination of the seed. Various other factors also cause seed dormancy like mechanically resistant seed coats, rudimentary and physiological immature embryo, morphologically mature and physiological immature embryos (Das and Tah, 2013). Hence, there is a need to enhance the seed germination by breaking the seed dormancy through various presowing seed treatments. Since presowing treatments in this species is extensively studied, but germination improvement methods like priming are seldom studied in forest species. However, different methods using conventional vegetative plant propagation methods like semi hardwood cuttings and air layering are not successful. Hence, a systematic study is needed to study the effect of different priming methods in sandalwood to break the seed dormancy and ensure superior quality seedlings, and supply of quality planting material to promote the cultivation of sandalwood.

There is a 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 outplanting. 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. In this context, composted coir pith and

and rice husk are reported to be an ideal medium in potting mixture having similar physical properties as that of sand (Das and Tah, 2013).

Though the polythene bags are conventionally used for large-scale seedling production of forest plantation species, there exist some important limitations with these including root coiling, less fibrous root formation, poor aeration, the bulkiness of the potting medium, requirement for a large nursery area and difficulty in transportation. The use of root trainers as containers can address these problems to a great extent. Root 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. They are made in various shapes and sizes, either individually as single cells or in aggregates as blocks. Optimum container size depends on factors such as size of the seedling desired, type of growing media and length of the growing season. Advantage of containers over seedbed is that root coiling of seedlings can be avoided.

Karnataka Forest Department (KFD), the largest producer of sandal seedlings in Karnataka has been resorting to other types of planting materials for mass production. Among these, root trainer grown seedlings has received wider acceptance in view of their better root growth and mass production of uniform planting materials. At present, both the poly bag and root trainer techniques are being practiced by the state forest departments. Root trainer grown seedlings has more prominent tap root system that will increase the resource accusation potential of the plant (Dutt and Verma, 2020).

Studying all possibilities of materials to raise the quality stock and providing right knowledge to the farmers further increase the sandal population.

Currently most of the world demand of sandalwood is supplied from Australia using *S. spicatum* known as Australian sandalwood. High economic value of sandal wood provides sufficient incentives to farmers for growing this tree on a commercial scale. The gap between demand and supply is so wide that the prices of sandal wood and oil are currently extremely high. In accordance with that, increasing trend of sandalwood plantation establishment in Australia, India, Sri Lanka, China, and other tropical countries is been observed (Xiaojin *et al.*, 2011).

However, the plantation sector lacks the information on establishing superior plantations, which is identified as a great risk when considering their profit maximising goal. Without the information such as nursery techniques, host suitability, plantation establishment, growth rates and oil characteristics, managers of sandalwood plantations might face difficulties in achieving the expected outcomes. Along with that the seeds of sandalwood have inherent morphophysiological dormancy, low and prolonged germination and poor establishment of seedlings. Optimization of potting media, host introduction time at nursery stage is the major concern. Forest nurseries play a vital role in successful establishment of plantations. Production of quality planting materials ensure faster establishment and influence the subsequent growth and yield of the crop.

However, despite the economic potential and ecological importance of Indian sandalwood, studies specifically focusing on seed source selection and nursery management in this species are limited. Existing research in this area primarily pertains to other tree species, leaving a significant knowledge gap regarding the unique requirements and characteristics of Indian sandalwood propagation.

There is need to bring considerable refinement in the present package of materials and processes involved in sandal seedling production. This study will address to the most cardinal issues of quality sandal seedling production such as the wastage of valuable seeds, long duration of nursery period, no uniformity of the growth and quality of seedlings etc. Hence, the following objectives were framed:

1. To assess and compare the different sandal seed sources from Karnataka with the Marayoor seed source.
2. To elucidate the effect of different priming treatments on seed germinability in sandal.

3. To select the suitable container type and optimize the potting mixture for the production of quality planting stock in sandal.
4. To study the effect of host plant on the growth attributes of sandal.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Sandalwood (*Santalum album* L.), commonly known as Indian sandalwood, is a valuable and revered tree species renowned for its fragrant heartwood, which is a prized ingredient in various cultural, religious, and commercial applications. Managing nurseries for sandal is a crucial step in ensuring the sustainable cultivation and conservation of this species. The nursery management regime plays a pivotal role in the successful growth and development of sandalwood saplings, facilitating their eventual transplantation into the main plantation area. This introduction explores the essential components and principles of an effective nursery management regime for *Santalum album*, focusing on optimal environmental conditions, appropriate propagation techniques, and crucial factors influencing the growth and vitality of sandalwood seedlings. Effective nursery management sets the foundation for a healthy and sustainable sandalwood plantation, contributing to the preservation of this iconic species and its valuable contributions to various industries worldwide.

2.1 Distribution of the species

The genus *Santalum* comprises of about 16 known species (Hamilton and Conrad, 1990) out of which fifteen species is extant and one is extinct (Harbaugh and Baldwin, 2007).

The genus is characterized by the members of obligate hemi-root parasitic species. *S. album* is known to grow luxuriantly in Western Ghats mainly in the dry regions (deciduous forests) of peninsular India stretched from Vindhya Mountains to the southwards, in the regions of Mysore and Tamil Nadu. Its distribution in deciduous forests is restricted to an area of 9600 km^2, and the states of Karnataka and Tamil Nadu covers more than 90% of the total natural population of sandalwood in India (Rocha *et al.,* 2014).

2.1.1 Botanical description

Santalum album is a medium sized tree, grows upto 8-12 m in height and 2.5 m in girth (Ma *et al.*, 2006). It is a cross-pollinating tree species known to flower twice a year. The leaves are thin, glabrous, elliptic-ovate or lanceolate in shape. It bears flowers of purplish or reddish colour, terminal or axillary in position arranged in panniculate cyme inflorescence. The flowers are small and stalked and show architecture for self-pollination but possess self-incompatibility and therefore display out-breeding (cross-pollination). The fruits are fleshy drupe bear single seed, globose and obovoid in shape. The tree possesses drooping branches with smooth gray-brown bark and reaches maximum heartwood formation at the age of 30 years (Burdock and Carabin, 2008).

2.1.2 Importance of the species

The heartwood is astringent and bitter and therefore used in drugs, medicines and aromatherapy (Dikshit and Hussain, 1984). Traditionally, sandalwood is known for processing antiseptic, antipyretic, antibacterial, antifungal, diuretic, expectorant, stimulant properties (Srinivasan *et al.*,1992).

Commonly the oil is used as a remedy for treating cold, bronchitis, piles, scabies, fever, UTI and several types of inflammations. It is also a demulcent, diuretic, mild stimulant, carminative and digestive agent (Burdock and Carabin, 2008, Kumar *et al.*, 2012).

Essential oil is used as an antiviral, anti-carcinogenic and anti-tumor. The α-santalol, in particular, cures neuroleptic problems and is chemopreventive (Kim *et al.*, 2006), anti-hyperglycemic and antioxidant (Misra and Dey, 2013), cytotoxic (Matsuo and Mimaki, 2012), anti-ulcer (Ahmed *et al.*, 2013), anti-cancer (Kaur *et al.*, 2005, 2011, Santha *et al.*, 2013), antimicrobial (Ashok and Jayaprakash, 2012, Santha and Dwivedi, 2015). The compound urs-12-en-3β-yl palmitate isolated from bark acts as insect growth inhibitor (Shankaranarayana *et al.*, 1980).

2.1.3 Economic importance

A growing sandal tree under natural conditions can put up an increment of 1 kg of heartwood/year and a girth of one cm/year (Venkatesan, 1980; Rai, 1990). The heartwood and oil content vary with locality and from tree to tree, and increase with girth and age of the tree. Oil percentage is higher in the heartwood of root as compared to stem and hence the tree is invariably harvested by uprooting (Ananthapadmanabha, 2000).

Market trend indicates that sandal heartwood prices have increased from Rs. 365/ton in 1900 to Rs. 6.5 lakhs/ton in 1999-2000 and to Rs. 37 lakhs/ton in 2007. India has suffered a substantial decline in sandalwood production from 3176 tons/year during 1960-65 to 1500 tons/year in 1997-98, and to 500 tons/year in 2007 (Jain *et al.,* 2003). Oil production has also declined from 60 tons/year during 1981-1994 to 40-50 tons/year during 1999-2000 (Gairola *et al.*, 2007).

Global demand for sandalwood is about 5000- 6000 tons/year and that of oil is 100 tons/year (Joshi and Arun Kumar, 2007). Out of this, nearly 70-80 per cent is met from Karnataka (Rao *et al.,* 2007). Sandalwood oil is an important constituent of many food products worldwide. It is used to flavor alcoholic and non-alcoholic beverages, dairy products, candies, gelatins and puddings under a maximum allowed consumption of 90 ppm (Burdock and Carabin, 2008; Brand *et al.,* 2012).

The heartwood is hard and possesses oil-textured grains which provide durability to the wood and makes a fine material for carving delicate and intricate designs of high market value. The unscented sapwood is used for making agarbattis and turnery items (Kumar *et al.,* 2012).

The essential oil possess sweet, persistent fragrance, thereby acquires high demand as fixative in perfumery. It easily blends with other floral scents to enhance their fragrances, provides stability and persists for long duration. The oil is also known to be commonly used in woody, wood-floral and oriental-floral bases. The attributes of sandalwood oil i.e. aroma and fragrances are due to α- and β- santalols (Diaz-Chavez *et al.,* 2013).

The powdered wood is used in medicine and in cultural and religious practices in many Asian and Arabian countries. The powdered sapwood and heartwood are also used in preparing incense or joss sticks (Subasinghe, 2013).

2.1.4 Threats

The sandal genetic resources in the country are threatened by variety of biotic and abiotic factors including logging of the trees, poaching, large-scale changes in land-use and poor natural regeneration (Srinivasan *et al.*, 1992). The sandal area is declining drastically due to over exploitation, poor seed germination, poor regeneration and failure of artificial regeneration (Jeeva *et al.,* 1998). Most of the existing sandal populations are not dense. They are devoid of large girth class trees due to illicit felling, hacking, forest fire and encroachments (Surendran *et al.,* 1998). Since much of the sandal wealth and natural sandal bearing areas have been lost, the remaining sandal trees are to be protected effectively and natural sandal bearing areas are to be preserved (Swaminathan *et al.*, 1998).

Umashankar *et al.* (2000) reported decline in the genetic diversity of natural population of sandal due to indiscriminate extraction. Sandal was a nationally protected resource in India. Despite the protection status the natural resources of sandal are being indiscriminately exploited, perhaps because of its extremely high export value. It has been extensively harvested and more intensively so in the latter half of this century (Meera *et al.,* 2000; Nageswara Rao *et al.,* 2002). Extensive extraction of heartwood has severely decimated the natural stands of the tree in the forests and has rendered many populations fragmented.

In India, though sandal is distributed all over the country, nearly 90 per cent of its natural production is in Karnataka and Tamil Nadu and to some extent in Kerala and Andhra Pradesh. Until 2002, state governments had monopoly control over all sandal resources including those on private land. But, this monopoly has neither deterred illegal and indiscriminate felling by smugglers and poachers nor has it helped conserve the species in its natural habitat. Sandalwood smuggling is the major problem in all the states where sandal grows (Viswanath *et al.,* 2009).

Though seed germination is generally profuse, population density is poor due to abiotic and biotic interferences. In view of the high price it fetches, live sandal trees in their endemic habitats have been ruthlessly felled and removed by smugglers. These activities have selectively removed trees possessing large dimensions and quality heartwood, resulting in narrowing of the gene pool leaving population of trees with mostly sapwood. The magnitude of illicit removals has been so intense that sandal has now been enlisted as a “vulnerable‟ species by (International Union for Conservation of Nature) IUCN (Annapurna *et al.*, 2004).

2.1.5 Nursery management in sandal

Sandal wood seedlings are completely autotrophic in the initial growth stage using seed derived nutrients, but later get attached to host plants for essential mineral nutrients. In nature more than 300 species act as hosts for sandalwood (Neil, 1990). Success of *S. album* nursery is based on the seed quality, seed pre-treatments, applications of fungicides and nematicides, nature of soil and provision of shade, type of attached hosts etc. Healthy sandalwood nurseries can be accomplished by the following procedures.

1. Sandal wood requires sandy to rocky soils with an ideal altitude, rainfall and temperature ranges between 700-1200 m, 600 to 1600 mm and 10-35°C respectively for better growth. The plant will grow better in moist, fertile, iron-rich clay soils, but growth will be inhibited in waterlogged areas (Radomiljac, 1998).

2. Naturally sandal wood plants regenerate by means of seeds or root suckers, but propagation method faces many problems due to dormancy period, less viability of seeds, hard seed coat and loss of viability during storage. GA_3 (Gibberellic acid) or water treatment will enhance seed germination rates by imbibition of GA_3 or water by seed coats.

3. Seedlings should be transplanted along with short-term primary host in the nursery stage and with long-term secondary host in the field. Selected host plants (short term host, intermediate host and long-term host) will provide nutrients and protect from the sun, the wind and grazing (Srimathi and Kulkarni 1995; Radomiljac *et al.,* 1999; Annapurna *et al.*, 2004).

2.1.6 Problems in sandal cultivation

In the early stages of seedling development sandalwood derive nutrition from their relatively large seed reserves and later, the formation of host attachment becomes critical for seedling survival and growth (Barrett and Fox, 1997). Failure of regeneration efforts is one of the main causes of sandal depletion. Failure of artificial regeneration is due to poor understanding of the host parasite relationship and edaphic factors (Surendran *et al.,* 1998).

The selection of appropriate hosts is vital to ensure successful sandal plantation establishment (Radomiljac *et al.,* 1999). The hemi parasitic nature of sandal is not fully understood and silvicultural techniques to establish it are not fully known. Intriguingly, despite the large host range of the majority of parasitic plants, many of them also show high level of host preference. Impact of hosts on parasite communities not only depends on parasitized but also when parasitism occurs and sandalwood is no exception. Being a hemi parasite the silvicultural requirements of sandal are unique and there is no adequate understanding of the same.

2.2 Variations in seed morphological characteristics and oil content

Kaura *et al.* (1998) studied the seed morphology (seed length and 20 seed weight) and oil content in *Azadirachta indica* (Neem) of five provenances of northern and western India. Maximum average oil content was observed in trees from Hisar provenance. Seed oil content in most of the provenances was not consistently and significantly correlated with morphological parameters of seeds.

Kaushik and Vir (2000) observed significant variability in individual fatty acids in 60 neem seed samples collected from different provinances of the Rajasthan state. The palmitic acid ranged from 16 to 34 per cent, stearic acid from 6 to 24 per cent, oleic acid from 25 to 58.9 per cent, and linoleic acid from 6 to 17 per cent.

Uniyal *et al*. (2002) have undertook the provenance survey of *Grewia oppositijolia* Roxb. to identify suitable seed sources for the production of quality seedlings for mass afforestation in agroforestry systems in Central Himalaya. Significant (p = 0.05) variations were recorded for seed characters among provenances. Elevational range of seed source exhibited significant (p = 0.05) positive correlation with seed length, thickness and weight thus indicating that some of these phenotypic variations may also have genetic base within the natural range of distribution. On an average, the provenances Chilledi, Simswara and Malsi were found to be the best on the basis of seed morphological characters.

Ginwal *et al.* (2005) found significant seed source variations in seed morphology (colour, size and weight), seed germination (viability, germination percent, germination energy, germination value) and seedling growth parameters (survival percentage, seedling height, collar diameter, leave/plant, and seedling biomass). The seed source of Chhindwara (M. P.) was found to be the best source in comparison to others in *Pongamia pinnata* species.

Kaushika *et al*. (2007) assessed the variability in seed traits and oil content of 24 accessions of *Jatropha curcas* which were explored from different agroclimatic zones of Haryana. They reported significant differences in seed size, 100-seed weight and oil content between accessions. Maximum seed weight was recorded in seeds collected from IC-520602 and the least weight was recorded in IC-520587. Oil variability ranged from 28.00 per cent in IC-520589 to 38.80 per cent in IC-520601.

Fandohan *et al*. (2010) highlighted the variability in tamarind seed size across the climatic conditions. They observed that seeds collected from Guineo-Congolian region showed the highest values for length, width and weight, followed by seeds from the Sudano-Guinean region and then from the Sudanian region.

Singh *et al*. (2010) investigated the provenance variation in seed and seedling attributes of *Quercus glauca*. They noticed significant differences in morphological and seedling attributes with populations. The altitude of seed source showed significant inverse correlation with seed length, seed weight and seedling weight. But altitude showed significant positive correlation with percentage germination and root collar diameter of seedlings.

Ghosh and Singh (2011) described changes in the characteristics of Jatropha seeds and seedlings by collecting seeds from six regions (geographic regions) of India and 4-6 provenances in each region. They found that all the traits of the seeds and seedlings of *Jatropha curcas* were significantly different from region to region. Among the six zones, sub humid to humid eastern, south eastern uplands, semi-arid lava plateaus and central highlands showed maximum seed length, seed weight, oil content and plant height. All seed and seedling characters were lowest for humid western Himalayan zone. Among the 32 provenances, Danikundi, Pendra road, Nainpur and Indore-1 provenances showed better seed and seedling characters.

A thorough and extensive wild germplasm exploration survey was undertaken and 50 high yielding candidate plus trees (CPTs) of *Pongamia pinnata* (L.) Pierre from 11 locations in an area spread of 150,000 km^2 for evaluating genetic association and variability in seed and growth characters (Rao *et al.*, 2011). There were significant differences in seed morphology *viz*., seed length, seed width, 100 seed weight and oil content.

Twenty seed sources of *Pongamia pinnata* were collected from Konkan region of Maharashtra from different agro-climatic zones. The pod length (14.50 mm to 69.69 mm), avg. pod weight (2.80 g to 7.64 g) varied significantly. Similarly, seed length, seed weight and oil content varied significantly (Raut *et al*., 2011).

Shankar *et al.* (2012) studied morphological variations of fruits and seeds of *Prunus nepaulensis* Steud in Meghalaya, India. The ripe fruits were collected from seven trees in three provenances on Shillong plateau. The fruits and seeds were measured for nine morphological traits. Mawlai scored better than Nongstoin and Kshaid provenances with respect to the highest mean values of weight, length and diameter of fruits and seeds. However, the differences among the three provenances with respect to the mean quantities of pulp content were not significant. Tree-to-tree variation was more significant than provenance variation.

Pavithra *et al.* (2013) carried out a provenance variation study by collecting 232 candidate plus trees of *Pongamia pinnata* from selected agro-ecological zones of southern peninsular India and reported significant variations ($P < 0.01$) for pod and seed traits across zones and provenances within zones. The southern dry and transition zone of Karnataka showed the highest mean value for all the pod and seed traits.

Kumar and Singh (2014) selected 28 candidate plus trees from the states of Jharkhand, West Bengal and Bihar in Eastern India and nine seed parameters were measured and their genetic values. They observed significant genetic differences in all the seed characteristics among the different candidate plus trees of *J. curcas*. The seeds collected from Baghmundi district of West Bengal recorded the highest seed morphological characters.

Munasinghe and Wansapala (2015) showed morphological characteristics of seeds of *Madhuca longifolia* (length, width and the weight) that differed significantly in four agro-climatic zones. Similarly, the oil content (50.07-53.85 %) was also significantly different for four agro-climatic zones. Whereas, Oleic, Linoleic, Palmitic and Steric were the predominant fatty acids in all the four agro-climatic zones. Based on the results they conceded that percentages of four prominent fatty acid types varied considerably among the four agro-climatic zones showing the effect of locality on the fatty acid composition. Oil content and the fatty acid composition were not correlated with the studied geographical factors however, there could be impact of other environmental conditions.

Tiwari and Dhuria (2018) studied the variability in pod and seed characteristics of *Albizia procera* in Chhattisgarh. They discovered that highly significant differences among provenances in all studied parameters except pod thickness. The highest variation among provenances in seed traits were observed in seed weight and seed length while seed thickness had the lowest variation. Significant variations were recorded in all the studied parameters. The extent of variation in pod length and seed width was higher as compared to pod width, seed thickness, seed length and number of seeds per pod, high heritability was recorded in pod length (46.01 %), seed width (67.74 %) and seed thickness (45.00 %) thus suggesting that there is scope for considerable genetic gain.

Prabakaran *et al*. (2019) confirmed the existence of substantial genetic variation that could be utilized for genetic resource conservation in gene bank and further tree improvement programmes in *Azadirachta indica* by screening the thirty-four Plus Trees for morphological and biochemical characters.

2.2.1 Variation in oil yield and fatty acid profile

Chakraborty *et al*. (2009) concluded that the fatty acid profile of oil extracted from *Terminalia* was found to be comparable with similar seed oils attempted for biodiesel production. They reported that *Terminalia* oil contained 32.8 per cent palmitic acid, 31.3 per cent oleic acid, and 28.8 per cent linoleic acid. The calorific value and kinematic viscosity of *Terminalia* oil were e 37.50 MJ/kg and 25.60 cSt, respectively.

Borges *et al*. (2011) demonstrated that it is possible to develop a fast fatty acid methyl esters content estimation from viscosity measures in biodiesel samples. This method is suitable for the determination of methyl ester contents considering different sources of vegetable oils.

Callophyllum inophyllum provenances exhibited significant periodic variations in oil content and fatty acid profile and as a result altered the quality of fatty acid methyl esters (biodiesel). Higher temperatures at fruit development seemed to increase the oil content and the amount of saturated fatty acids. In contrast, higher mean annual rainfalls and lower seasonal temperatures seemed to have induced lower oil contents and higher unsaturated fatty acids causing lower CPs and CFPPs (Hathurusingha, 2011).

Aabd *et al*. (2013) examined the variability in yield and fatty acid composition of argan seed oil (*Argania spinosa* L.) in four provenances. Twenty genotypes were preselected and assessed for fatty acid composition over 3 years (2008–2010). The results revealed variations in seed oil content (51.83–57.50 %). Total saturated fatty acids percentage (C14:0, C16:0, C18:0, C20:0) ranged from 19.53 to 20.29 per cent with lower percentage in Had Dra and Biougra than other provenances. However, the concentration of total unsaturated fatty acids ranged from 79.56 to 80.29 per cent, with a higher percentage of monounsaturated fatty acid (C16:1, C18:1, C20:1) (47.60 %) in Aoulouz and a higher percentage of polyunsaturated fatty acid (C18:2, C18:3) (35.53 %) in Biougra provenance.

Khamchum *et al.* (2013) detected five fatty acids as palmitic, stearic, oleic, linoleic and behenic through GC and estimated by NIRS in *P. pinnata*. These results showed that the highest content was linoleic acid followed by oleic, behenic, and stearic acids. Palmitic acid was within the smallest content range. High amounts of unsaturated fatty acid as oleic (C18:1) and linoleic acids (C18:2) indicated that *P. pinnata* oil is very useful for biodiesel production.

Rahangdale *et al*. (2014) analyzed the fatty acid composition in seeds of *Pongamia pinnata*, representing different agro climatic regions of Madhya Pradesh and revealed that, the major fatty acid was oleic acid (54.33 -65.90 %), followed by linoleic acid (11.03-19.57 %), palmitic acid (9.07-18.90 %) and stearic (2.47-9.13 %).

Jaysankar *et al*. (2016) analyzed the oil percentage of 49 species belonging to 25 families collected from various parts of Andaman and Nicobar. Out of the 45 species, maximum oil percentage (62 %) was estimated from *Cerbera manghan* followed by *Mesua ferrea* (61 %).

Palanikumaran *et al*. (2016) studied the seed, oil quality as well as fatty acid profile of *Calophyllum inophyllum* L. Among the progenies, only one progeny *viz*., FCRICI 14 consistently expressed superiority in all seed characteristics *vi*z., pod length (3.95 cm), pod width (3.42 cm), seed length (2.71 cm), seed width (2.35 cm), 100-seed weight (536.26 g), germination per cent (73.00 %), germination value (5.11), peak value (3.06) and oil content (55.60 %). Three progenies *viz*., FCRICI 14 (Honnavara, Karnataka), FCRICI 2 (Nagapattinam, Tamil Nadu) and FCRICI 17 (Bhatkal, Karnataka) recorded higher oil content of 55.60, 52.33 and 51.43 per cent, respectively. The analysis of fatty acid composition revealed that the major fatty acid was oleic acid (56.42-68.25 %) followed by palmitic acid (8.23-18.42 %) and stearic acid (6.23 - 8.23 %).

Rengasamy *et al*. (2017) reported that the highest *Artocarpus heterophyllus* seed oil was about 19.8 per cent obtained from microwave oven process using methanol as solvent and the biodiesel production was successfully conducted using methanol with sodium hydroxide as a catalyst.

2.2.2 Physico-chemical properties of seed oil

Sandal seeds were evaluated for their physico-chemical and fatty acid profiles. Since, *Santalum spicatum,* the Australian sandalwood is generally used as a source of Ximenynic acid. This work has established the superiority of *S.album* seeds over *S. spicatum* with respect to Ximenynic acid content. Gas-Chromatography-Mass Spectrometry analysis of the fatty acid profiles of six samples of *Santalum album* (L.)

recorded higher percent of Ximenynic acid as compared to *Santalum spicatum*. Therefore, *S. album* seed oil can be used as a potential source of intermediate income for farmers besides being a natural source of an anti-ageing ingredient (Vasundhara *et al.*, 2023)

Akpan *et al.* (2006) revealed that characterization analysis of tested parameters included specific gravity, refractive index, acid value, saponification value and iodine value for both crude and refined castor oil produced. They were within the ASTM standard specifications. In fact, the iodine value obtained (84.8 g I_2 100 g^{-1}) for the refined oil indicated that the oil could certainly be used as lubricant, hydraulic brake fluid and protecting coatings.

Ahmad *et al*. (2009) compared the fuel properties of transesterified pongamia oil chemically known as methyl esters (biodiesel) with biodiesel standards of American Standard Testing Methods. The fuel properties of pongamia biodiesel (100 %) had specific gravity of 0.92, kinametic viscosity @ 40 ºC, 7.53, flash point 90 ºC, sulfur contents wt. per cent 0.0084, pour point 6 ºC, cloud point 4 ºC, distillation (initial boiling point) 215, and cetane number 53 and were near to high-speed diesel.

Fan *et al.* (2009) reported that characterization of produced biodiesel showed that it met the ASTM D 6751 with respect to the kinematic viscosity at 40 ºC, acid number, flash point, water and sediment, cold soak filtration test, oxidation stability, free and total glycerin *et*c.

Devi *et al*. (2012) analyzed the physico-chemical properties of rubber seed oil for the potentiality for the production of biodiesel and found that it had efficient biodiesel resources which met the ASTM standards for biodiesel.

Ong *et al*. (2013) concluded that *Jatropha curcas* , *Sterculia foetida and Ceiba pentandra* seed oil was suitable for biodiesel production after confirming the properties of the biodiesel produced that fulfilled the ASTM 6751 and EN 14214 biodiesel standards.

Kumar and Suresh Kumar (2016) extracted the seed oil from *Manilkara zapota* (25 and 30 %) and derived biodiesel through transesterification process using an alkaline catalyst. The composition of fatty acids and physico-chemical properties of the biodiesel derived were estimated and compared with EN14214 biodiesel standards and found that the new biodiesel *M. zapota* methyl ester met the EN14214 biodiesel standards.

2.3 Seed priming

Seed priming is one among the key technologies to achieve seed enhancement through rapid germination of seeds and optimizing the seedling establishment after planting in the field. It is a controlled seed hydration treatment during which the metabolic activity is enhanced, but suspended before radicle protrusion. Different priming treatments includes, soaking seeds in water (hydropriming) or nutripriming ($CaCl_2$, $CaSO_4$ or NaCl etc.) or the other chemicals and biological agents (biopriming) prior to germination. Priming inducts a specific physiological condition in plants through the treatment of priming agents. The efficiency of seed priming depends on many factors and is strongly depend on the plant species and therefore the method of priming varies. The success of priming depends on physico-chemical factors like osmoticum and water potential, priming agent, duration of treatment, light, temperature, aeration and the seed condition (Hussain *et al.,* 2006, Varier *et al.,* 2010).

The reduction in leakage of metabolites (Styer and Cantliffe, 1983), rise in synthesis ribonucleic acid and protein (Fu *et al.,* 1988), the expression of β-tubulin (De Castro *et al.*, 1995) and nuclear DNA synthesis within the radicle cells of seeds (Saracco *et al.*, 1995; Liu *et al.,* 1997), faster embryo growth (Dahal *et al.*, 1990), nuclear replication (Lanteri *et al.,* 1993), and minimal chromosomal damage (Sivritepe and Dourado, 1995) are promoting effectors of seed priming.

A more uniform endogenous GA concentration may help to synchronize endosperm weakening, embryo cell elongation, and reserve mobilization (Sung *et al.,* 2008). Ethylene may directly influence speed and rate of germination. Seed priming, commonly synchronize individual seed germination (Taylor and Harman, 1990).

Re-drying of the seeds to their original moisture content, following seed priming is an inevitable step which can otherwise do harm to the primed seeds (Thomas *et al.*, 2000) thereby affecting the seed quality (Parera and Cantliffe, 1992). Improper seed re-drying may cause reduction in the lag time of imbibition affecting seed germination (Heydecker and Coolbear, 1977; Brocklehurst and Dearman, 1983). Re-drying must be attained slowly to take care of the benefits obtained during priming.

Priming is reported to initiate the repair and reactivation of pre-existing mitochondria and to initiate the biogenesis of latest ones (Sun *et al.*, 2011). It is going to thus afford a better level of energy over a brief time to sustain final germination (Nascimento *et al.,* 2013). The increase in germination by priming could also be related to a change in phytohormone biosynthesis and signaling. Priming has increased gibberellins and abscisic acid ratio (El- Araby *et al.*, 2006), and this might cause direct effect on a priming impact in organic phenomenon pattern (Schwember and Bradford, 2010).

The increased germination rate and uniformity of germination achieved through priming are often attributed to metabolic repair occurring during imbibition (Burgass and Powell, 1984) or could due to the buildup of germination enhancing metabolites (Basra *et al.,* 2005). Nowadays, seed priming is a commercially used simple and efficient process to accelerate the seed germination and to improve seedling uniformity in many crops (Halmer, 2003; Taylor and Harman, 1990). Additionally, plants can gain resistance to abiotic stress after treatment with several natural or synthetic compounds like Butenolide, Selenium, $CuSO_4$, $ZnSO_4$, KH_2PO_4, ethanol and Chitosan (Demir *et al*., 2012).

Moreover, seed priming aids to synthesize proteins that play crucial role during germination in several plant species (Gallardo *et al.,* 2001). Furthermore, the rapid and uniform germination through seed priming also can be attributed to stimulation of antioxidant activities (Chiu *et al.,* 2002; Afzal *et al.,* 2012).

In addition, seed priming gives abiotic stress tolerance to plants (Ashraf and Foolad, 2005; Patade *et al.,* 2009). Seed priming benefits mainly from the activation of enzymes related to endosperm utilization (Habib *et al.,* 2010), mobilization of storage proteins and changes in hormonal balance (Iqbal and Ashraf, 2013).

2.3.1 Biopriming and nutripriming

The study investigated hydro and osmopriming effects on germination and seedling performance. Osmopriming with 5% PEG-6000 for 2 days showed the highest germination (79%), a 42 (%) increase. Longer durations (6–8 days) or hydropriming had minimal impact. Enhanced growth post-osmopriming correlated with elevated β-amylase, carbohydrate, and fat content, and reduced electrical conductance. Osmopriming is a cost-effective method to improve Santalum album L. seed germination and seedling growth for quality planting material, with potential applications in stress resistance (Debta *et al.*, 2023).

Trichoderma viride, Trichoderma harziaum and *Pseudomonas fluorescens* are different bio-control agents frequently used for biopriming treatment. Several scientists have investigated the utilization of beneficial micro-organisms within the priming medium to regulate disease proliferation during priming itself (Warren and Bennet, 1999).

Seed biopriming is one among the foremost suitable techniques for the appliance and subsequent establishment of bacterial antagonists within the spermospheres and rhizospheres (Jeffries *et al*., 2003). Beneficial soil microbes and their association greatly influences the plant health and soil fertility. It is considered as a safer, cheaper and simply applicable method for biological control (El-Mougy and Abdel-Kader, 2008). It has potential advantages over seed coating (Muller and Berg, 2008) because of the very fact that biopriming aid in establishing the bacteria within the seed which attributes to the higher stability and time period of the seeds.

The biopriming which integrates disease control is used recently as an alternative method for controlling many seed and soil borne pathogens (Begum *et al.,* 2010). The concept of sustainable agriculture has given more importance for the utilization of rhizospheric bacteria to assist plants for easy nutrient uptake and solubilisation of fixed nutrients like phosphorus (Hayat *et al.*, 2010).

There are different methods used for explaining biopriming varying with the temperature and duration for soaking the seeds (Miche and Balandreau, 2001; Gholami *et* *al.*, 2009; Abuamsha *et al.*, 2011; Sharifi and Khavazi, 2011; Sharifi *et al*., 2011; Carrozzi *et al.*, 2012; Firuzsalari *et al.*, 2012; Saber *et al*., 2012; Kasim *et al*., 2013; Reddy, 2012). Many researchers have also surface disinfected the seeds prior to soaking into the bacterial suspension.

Chitra and Jijeesh, 2019 studied impacts of nutripriming, osmopriming, hydropriming, and biopriming on germination and seedling characteristics of *Santalum album*. The result indicated that the sandal seeds subjected to biopriming with *Pseudomonas fluorescens* at 100(%) for 8 days and the seeds subjected to chemical priming with 0.8 M of Manganese sulphate for 3 days recorded the highest germination of 88 per cent among the 52 priming treatment combinations. The germination percent exhibited by the seeds subjected to chemical priming at 0.4 M, 0.6 M and 1 M of manganese sulphate for 3 days were on par with the germination percentage of seeds subjected to biopriming with *Pseudomonas fluorescens* at 25(%), 50(%) and 75(%) for 8 days. Besides, the higher germination per cent showed by biopriming treatments over control, the seeds subjected to biopriming for 4 days at different concentrations were on par with the best treatment.

2.3.2 Hydropriming

The seed priming method in which the seeds are soaked in distilled or normal water to initiate the pre-germination activities suspending prior to radicle emergence is named as hydropriming. The seeds after a specific period of hydration are dried back to the original moisture under shade conditions (Mc Donald, 2000) or by induced air under shade (Bennett and Waters, 1987). The seeds after soaking are to be dried because storing of partially dried seeds will result in more harmful effects to the seeds (Thomas *et al*., 2000).

Hydropriming is the simplest and easiest among the seed priming techniques since it depends on soaking in pure water and re-drying to original moisture content before sowing. The protoplasm of seeds subjected hydropriming have a lower viscosity and exhibit increased permeability to water and nutrients and also withstand dehydrating forces (Thomas *et al*., 2000).

The advantage of hydropriming is the augmentation of physiological and biochemical processes happening in seeds even when the germination is suspended by low osmotic potential and negligible matric potential of the imbibing medium (Rodríguez *et al.*, 2015). Increase in the seedling growth correlated with higher water intake by primed seeds is the main feature of hydropriming (Yagmur and Kaydan 2008). Fujikura *et al.* (1993) reported the hydropriming as an easy and cheap method and consistent with seedling establishment. Abebe and Modi (2009) also reported that hydropriming is a major seed treatment technique for quick germination and uniform seedling establishment.

A study in Barley by Su-juan *et al.* (2012) identified that hydropriming can improve rate of germination, length of coleoptile and root, dry mass accumulation and seedling vigour index. It had been observed as the most successful method for improving seed germination in Onion (Caseiro *et al*., 2004).

However, Pereira Kikuti (2008) reported that even though priming increases the speed of germination and uniformity of seedling emergence in cauliflower yield was not affected. Hydropriming treatment for 48 and 24 hours significantly increased the germination percentage, seedling weight and vigour indices compared to control in *Aegle marmelos* (Singh, 2017). Hydropriming in chickpea resulted in three to four times increase in root and shoot length to control seedlings in drought condition (Kaur *et al*., 2002) which can be attributed to the faster roots and shoots resulting in vigorous plants and thus better drought tolerance (Amzallag *et al*., 1990; Cayuela *et al*., 1996; Lee-suskoon *et al*., 1998).

In wheat, hydropriming caused significant improvement in germination and early growth. In wheat, hydropriming was found to be effective in improving the seeding vigour (Jafar *et al*., 2012). Daniel *et al*. (1984) hydroprimed lettuce seed in water at 15°C in the dark for various durations and revealed that the hdropriming for 20 h increased germination up to 86 % in lettuce seeds.

Moradi and Younesi (2009) reported that both hydropriming and osmopriming increased the percentage and mean time of emergence in sorghum seeds at sub-optimal temperature of 15°C. Seed treatment for 12 and 24 h had a positive and significant effect on emergence percentage and rate. Hydropriming for 36 h did not have specific effect on these factors. Amooaghaie (2011) reported that seedlings from hydroprimed seeds had a higher root and shoot growth compared to the seedlings from control. Li *et al*. (2011) from their laboratory experiment on hydropriming of the seeds of pyrethrum concluded that it has significantly reduced the mean germination time and increased the germination percentage. Consistent with Srivastava *et al*. (2010), hydropriming was the foremost suitable priming technique in mustard.

Shah *et al*. (2012) also suggested hydropriming as an efficient seed priming technique for enhancing the vigour and nutrient uptake in mung bean. Similarly, Umair *et al*. (2012) also proved that hydropriming significantly increased the seed yield of mung and also enhanced the antioxidant enzyme activities. Venudevan and Srimathi, 2013 also presented hydro priming as probably the most cost-effective priming method of seed priming. Duration of the hydropriming treatment is decided by controlling the seed imbibition and therefore the hydrated seeds.

2.4 Effect of potting media on sandal seedlings

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, 1999). 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)**.**

Prajapathi and Tandel (2021) studied 12 INM treatments of different organic, inorganic, biofertilizers and their combinations application along with control for sandal wood growth and biomass. Among different integrated nutrient management treatments, seedling height, collar diameter, number of leaves per plant, fresh and dry weight of shoot, leaves and whole plant were recorded. Fresh and dry weight of root and root length were registered maximum in vermi-compost at 50 g seedling−1. The seedlings without integrated nutrient treatment were poorest for all parameters under study. However, root: shoot ratio was noted maximum in vermi-compost at 25 g seedling−1.

Abirami *et al.*, 2010 studied the effect of twenty-one different growing media on seedling growth and vigour index of Nutmeg. The growing media soil: Coir dust: Sand: Vermicompost in equal ratio showed the best seedling characteristics.

An experiment was conducted by AI- Menaie *et al.* (2010) to investigate the effect of 1: 1: 1, 2:1:1 and 3:1:1 mixtures of Sand: Peat moss and Potting soil (humus) on the growth of *Cassia nodosa* and *Cassia fistula* seedlings, both species of cassia showed better growth and development in the media containing the three components in equal proportion. Growing media of 70% forest soil + 15% humus + 15% pumice or creek sand gave best results of seedling growth parameters in Crimean juniper (*Juniperus excels*a) (Gulcu *et al.*, 2010).

Yadav *et al.* (1982) investigated the growth of root system and dry weight of *Tectona grandis* in fifteen different potting media. Each media was filled in 25 polythene bags (6″x13″), which were placed in shade and transferred after 4 weeks to sunlight. After six months, results revealed that maximum dry weight of seedling (2.28 gm) was found in pure black natural soil while minimum (0.13 gm) in sand. Maximum root length (35.60 cm) observed in medium having equal amount of black natural soil and sawdust. Shoot length was more (8.75 cm) in pure sawdust than in pure black natural soil (6.0 cm). Combination of sawdust with black natural soil produced more shoot length (3.75 cm) than with sand (3.5 cm).

Syam, 1988 stated that higher germination noticed in vermiculite growing medium for teak seed germination then sand and the seedlings grown in that medium recorded better tap root growth and dry matter production. This may be due to the increased water absorption retention qualities of exfoliated vermiculite thereby increasing the amount of available water to seeds.

Bahuguna and Lal (1996) reported that overall performance of nursery seedlings of *Mallotus phillipinensis* was better in growing media Soil: Sand: FYM (1: 1: 1). Chapman (1997) reported that seedling growing in old sawdust are equal in quality to those produced in Perlite. Therefore, aged sawdust could be considered a logical alternative to Perlite where old Sawdust is not available fresh sawdust could be composted. Rose and Haase (1998) studied the effect of six different growing media on Douglas fir (*Pseduotsuga menziesii*) and concluded that the seedlings grown in peat were significantly better performing in comparison to those grown in Ecotech coir: Vermiculite: Perlite (2: 1: 1), Ecotone coir: Peat moss: Vermiculite: Perlite (1: 1: 1: 1) or Lignocell coir: Vermiculite: Perlite: (2: 1: 1). Shrivastava *et al.* (1998) concluded that Compost, Sand and Soil in the ratio of 2: 1:2 is the best potting mixture for raising Eucalyptus hybrid seedlings in root trainers. Bhardwaj *et al.* (1986) reported that soil, sand and FYM in equal proportion is the best potting medium for optimum germination and seedling growth of *Pinus roxburghii.*

The growing medium exerts significant influence on all the seedling growth aspects of Chilgoza pine (*Pinus gerardiana* Wall.), dry root weight, number of leaves, Shoot-root ratio, total dry weight, plant height, collar diameter, dry shoot weight and quality index were the best in medium of Chilgoza forest soil: Sand: Moss: FYM in the ratio of 1:1:1:1 (Malik and Shamet, 2009). A similar study was conducted by Juliana *et al.* (2009) to determine *the Lagestroemia floribunda* seedling growth performance in terms of leaf area, number, total dry mass and relative growth rate using three different growing media. The results depicted that the in Alluvial soil seedlings showed greatest proportion of dry mass in roots.

Aklibasinda *et al.* (2011) conducted a study to determine the effect of different growing media on scotch pine (*Pinus sylvestris*) seedling growth parameters such as collar diameter, seedling length, root length and number, dry root and shoot and dry biomass and the results revealed that the best growth attributes were shown by the media of 10% rice hulls to 90% peat material. Japanese cedar (*Cryptomeria Japonica*) seedlings when raised in root trainers with different growing media, for thirty-month-old seedlings, the maximum survival was recorded in Soil: Sand: FYM, 1:1:1 and the media, Peat moss + Vermiculite, 1:1 recoded maximum seedling height, shoot and root fresh weight (Khan *et al.*, 2011)**.**

Qaisar *et al.* (2009) studied the effect of different growing mediums on Silver fir (*Abies pindrow*), growing media composed of Peat moss + Vermiculite in the ratio of 1:1 recorded the best seedling height, collar diameter, fresh weight and height increment. Qaisar *et al.* (2009) while evaluating growing media for quality seedling stock production in *Cedrus deodara* using root trainers observed that Soil: Sand: FYM: Dalweed in the ratio of 1: 2: 3:1gave the best results. Annapurna *et al.* (2007) conducted an experiment on the growth of seedlings of sandalwood at Institute of Wood Science & Technology (Bengaluru, Karnataka), result revealed that significantly the best seedling growth in term of total dry weight (1.16 g) with potting medium consisting of sand and compost (25:75) at the age of seven months. An investigation conducted by Sofi and Bhardwaj (2007) showed that potting mixture (Soil: Sand: FYM) in the ration of 1: 1:3 is the best for *Cedrus deodara* for getting the best seedling quality.

A medium consisting of Sand: Soil: Compost: Burnt rice husk: Charcoal in the ratio of 25:15:50: 5:5 favoured the development of *Santalum album* L. in terms of collar diameter, root and shoot dry weight, total dry weight and quality index (Annapurna *et al.*, 2005). *Casurina eqisetifloia* seedling growth at five-month age in terms of height, collar diameter, total, and root dry weight and quality index were observed to be the best in mixture consisting of Sand: Soil: Compost: Burnt rice husk: Charcoal in the ratio of 30: 10: 50: 5: 5. (Rathore *et al.,* 2004). Various experiments have been carried out to check the efficiency of FYM, soil and sand composites in different ratios as effective growth media. Kannur and Devar (2003) studied the influence of growing media on seedling growth of *Tectona grandis* (Teak) and observed that soil, sand and FYM in the ratio of 1:1: 2 gave maximum growth and biomass followed by an equal proportion mixture. Tiwari and Saxena (2003) reported that *Dalbergia sissoo* seedling growth in potting mixture of Soil: Sand: FYM in the ratio of 1: 2: 2 and 1: 2: 1 indicated high growth, dry weight and quality index. *Mallotus phillipinensis* showed better growth in Soil: Sand: FYM (1: 1: 1) reported by Bahuguna and Lal (1996). The seedlings of plants like *Dendrocalamus strictus, Gmelina arborea, Dalbergia sisso*, *Acacia catechu* and *Bombax ceiba* were raised successfully in root trainers using soil, sand and FYM/compost in the ratio of 1: 2: 2 and 1: 1: 3 (Khedkar and Subramanian, 1996). The performance of *Albizia* and *Acacia species* were found to be best in the mixture of Soil: Sand: FYM in the ratio of 1: 1: 2 (Luna and Chamoli, 2006).

Bali *et al.* (2013) standardized the growing media for the optimum condition for germination and seedling growth of *Terminalia bellirica.* This experiment revealed that maximum germination, seedling height recorded maximum in silt loam soil and FYM combination. Nutrient composition of rice husk ash was analysed by Hashim *et al.* (1996) and Frimpong-Manso *et al.,* (2011) and recorded that Si- 80.26 (%), P-0.38 (%), K- 1.28 (%) and Mg-0.21 (%). Headlee *et al.* (2014) and Douds *et al.* (2006) analysed physical and chemical properties of vermiculite and quoted that, it possesses cation exchange properties; thus, it can hold more moisture.

2.5 Effect of planting container on sandal seedlings

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. 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.,* 2001). Nowadays, the introduction of containers has made a magnificent impact on forest nursery seedling production. The root trainer technology application offers large number of healthy and uniform sized planting stock with superior quality.

Mohanan and Sharma (2005) illustrated the principles behind the root trainer technique: (1) this technique provide ambient condition for the rapid development of primary roots and subsequent root system (2) this will induce early natural pruning of primary tap root and also lead to the production of multiple secondary tap roots (3) maintain acute angle of secondary and tertiary root tips, and its subsequent pruning, so as to keep downward movement to attain massive network of root system. These facilitate the better performance in the field level by the extensive root system and more resource use potential (Khedkar, 1999). Mohanan (2000) further reported that the root trainer grown plants have more disease resistance and disease management is easier. Studies revealed that the root trainer seedlings have quick establishment of mycorrhiza in roots.

Malik and Shamet (2009) conducted an experiment on refinement of container type and revealed that maximum plant height, collar diameter, dry shoot weight, vigour index, dry root weight, shoot-root ratio, total biomass and quality index resulted when seedlings were raised in polybags of 20x10 cm proved best for most of seedling growth parameters than obtained in 275 cc root trainers. An experiment was conducted by Qaisar *et al.* (2009) on Silver fir (*Abies pindrow*) seedlings raised in four different root trainers i.e. 100,150, 250 and 300 cc. The results showed that the root trainers of 300 cc capacity gave maximum height, collar diameter and dry shoot and root weight when the growth of seedlings was recorded after two years and six months of sowing. Singh, (2018) conducted a study on the influence of root trainers cell volume and seedling density and composition of growing media in relation to morphological biomass and seedling quality parameters of four-month old planting stock of *Acacia catechu*, *Azadirachta indica* and *Pongamia pinnata*. Results showed that a cell volume of 90 cc was not sufficient for proper seedling growth of *Acacia catechu* and *Azadirachta indica*. However, a clear-cut superiority of 300 cc cell volume was evident for *Acacia catechu*.

Gera *et al.* (2003) compared 150 and 300 cc root trainers were compared with the conventional nursery production system by raising seedlings of *Acacia catechu*, *Albizia lebbeck, Azadirachta indica* and *Pinus roxburghii* on the basis of costs input and benefit output, a seedling raised in root trainer has better height, collar diameter and seedling quality parameters. Similarly, Venkatesh *et al.* (2002) conducted an experiment on *Acacia nilotica* in which the container of 300 cc size registered superiority over 150 cc size polythene bags. In yet another study, Saxena (1997) compared the growth performance of *Gmelina arborea, Acacia catechu, Dalbergia sissoo and Bombax ceiba* seedlings for root trainer's vs polythene bag and observed increased height and survival percent in root trainers over polythene bags in all species.

Annapurna *et al.* (2004) conducted a study on containers type and size effect on growth and quality of *Santalum album* L. in which maximum collar diameter was recorded in root trainer of volume 150 mL whereas maximum height was recorded in 600 mL also highest total dry weight, shoot and root dry weight were recorded in root trainers of 600 mL followed by 270 and 300 mL. Rathore *et al*. (2004) reported that at the age of 3 months seedlings of *Casuarina equisetifolia* raised in 300 cc single cell root trainers have the maximum growth parameter. Comparative study on the quality of bamboo seedlings in root trainers and polybags kept on the mounted angle showed the seedlings raised in 300 cc root trainers had superior quality parameter in comparison to same size polythene bag (Gera *et al.,* 2007). Similarly, Luna and Chamoli (2006) showed that in *Albizia procera, Eucalyptus tereticornis and Acacia catechu* seedlings raised in 300 cc root trainer produced maximum biomass than 200 cc and 150 cc containers.

In Teak, Khedkar (1999) reported that teak plantation raised in root trainer technology showed interesting performance as it developed multiple tap root, also growth of root trainer teak plants was better and faster as compared to stump planting in the field. Khedkar and Subramanian (1997) reported that quality of teak raised in root trainer of 150 cc volume were sturdier, healthier and were had more collar girth than the stump origin plants. Teak seedling also developed numerous adventitious roots in the root trainers which would help in faster establishment.

Gera and Ginwal (2002) reported that assessment of seedling after one and a half year of planting *Dalbergia sissoo* showed root trainer (150 cc) raised seedlings performed better in all parameters except collar girth.

Dominguez-Lerena *et al.* (2006) reported that 300-400 cc container produced largest plants of *pinus pinea* seedling, which will increase growth following outplanting. Verma *et al.* (2018) reported that largest sized polybags 20 × 15 cm and 25 × 15 cm provided more favourable root environment which helps in enhanced growth and vigour of

Prosopis cineraria seedlings. Ferraz and Engel (2011) stated that 100 cm^3 and 150 cm^3 root trainers shown most cost effective when compared with *pinus wallichinana* seedling raised in 300 cm^3 root trainers. Luna and Chamoli (2006) concluded that 300 cc root trainer produced maximum biomass compared to 200 cc and 150 cc container in *Albizia procera. Eucalypts tereticornis* and *Acacia catechu* seedlings. Ginwal *et al.* (2001) reported the root trainers 300 cc cell volume is the best size of root trainer for *Acacia nilotica*, but when there is a limitation and the objective is to raise more number of seedlings per unit area of the nursery space, the hiko tray 150 cc volume is equally good.

Ginwal *et al*. (2001) used multivariate approach to find out the ideal size/ volume and type of root trainer for raising. *Dalbergia sissoo* seedlings. Root trainers consisted of Hiko trays (90 cc, 150 cc and 300 cc), book type (200 cc) and single cell bullet (290 cc) were tried for 3 months in the nursery for two consecutive years. Seedlings so raised were planted in the field conditions. Performance of 150 cc Hiko trays was adjudged the best container to raise seedling for planting in field conditions while 300 cc Hiko trays performed well in nursery. According to them larger quantity media and bigger container is not necessarily a catalytic factor for better performance of seedlings in field conditions. Ferraz and Engel (2011) stated that the increase in root trainer size provided expressive gains in the height of seedling, stem diameter, leaf area, shoot, root dry matter and quality index. Root trainer of 300 cc provided seedling characteristics greater than those produced in the other root trainer, making it possible to reduce by 70 days the production time of the seedlings. Plastic pots of size 4000 mL showed maximum seedling height, collar diameter and seedling survival rate as compared with 1600 mL poly bag and root trainer of 350 mL in *Terminalia bellarica* (Bali *et al.*, 2013).

Similarly, Farhana *et al.* (2010) in a comparative growth analysis of *Albizia procera* seedlings grown in polybags, nursery bed and root trainers observe that, seed germination and seedling growth when assessed for shoot length, root length, collar diameter, total dry matter production and leaf number, seedling developed in polybags of 23 x 15 cm size were the best performers in respect to germination and other growth parameters. However, root-shoot ratio was higher in root trainers in comparison to any other treatment.

2.6 Effect of host plants on sandal seedlings

Hemiparasites such as sandal are not totally nutritionally dependent on their hosts, since they possess chlorophyll, but require water, minerals and physical support from their host at varying levels depending upon the species. They acquire some or all of their water, carbon and nutrients via the vascular tissue of the host's roots or shoots. They access their host resources through a key organ called the haustorium, which provides a physical as well as a physiological bridge between the parasite and the host, directing the host's resources to the parasite and functioning at multiple stages in the parasitism (Kuijt, 1969). Balasubramanian *et al.* (2023) conducted experiment in Tamil Nadu (India) to study the early growth performance of sandal tree with different host plants (*Alternanthera sessilis*, *Sesbania grandiflora* and Casuarina) under drip irrigation system. The five treatments, viz., T1 - Sandal + *Alternanthera sessilis*, T2 - Sandal + *Sesbania grandiflora*, T3 - Sandal + *Alternanthera sessilis* + *Sesbania grandiflora*, T4 - Sandal + Casuarina and T5 - Sandal (Without host) were studied with four replication in randomized block design. Growth was measured in terms of height and basal diameter at the time of planting and eight months later. Best growth of sandal was recorded in case of combined hosts *Alternanthera sessilis* + *Sesbania grandiflora*.

Padmanabha *et al.* (1988) reported that sandal raised with *Annonus squamosa* performed well at Srinivasapura (Karnataka). Germination of Sandal seeds are found profuse from the bird droppings in the forest floor as well as in the village yards & bunds of the agricultural fields. Sandal is also found growing wild in some farmlands, homesteads and wastelands in Hirbundh block of Bankura District. This indicates the potential of growing the tree in the farmlands. The hemi–parasitic nature of sandal is not fully understood and silvicultural techniques to establish it are not fully known.

Padmanabha *et al.* (1988) reported that sandal plants established haustorial connections with the secondary hosts (*Pongamia*). Though sandal plants can survive without host, their experiment has proved beyond doubt that the host plants are absolutely necessary for the better growth of sandal plants. Very slow growth of sandal and the long rotation period is another disincentive for sandal cultivation. It is important to determine if high early stem growth is positively correlated to high future *Santalum album* heartwood production, as if so, the intermediate host is an extremely important silvicultural component being effective during the early phase of plantation growth.

It was also reported that sandal requires a primary host at nursery stage, secondary long term host and permanent host in the field (Annapurna *et al.,* 2006). Padmanabha *et al.,* (1988) and Nagaveni and Vijayalakshmi (2004) concluded that host is necessary for good growth of Sandalwood plants and further they categorized host plants as good, medium and poor from pot culture studies based on growth, biomass, nutrient level and haustorial connections etc.

Plant Haustoria are the root modifications of parasitic plants that penetrate the host tissues to connect with xylem, phloem or both for nutrient uptake and growth improvement. The parasitic plants may be a facultative/obligate parasite, stem/root parasite or hemi/holoparasite. Meristematic glandular haustorium, a unique character of Santalaceae family establishes connections with host roots within 30 days after seed germination (Nagaveni and Srimathi, 1985).

Formation of haustoria is more or less confined to younger roots and they arise from external layers of rootlets, unlike lateral rootlets, which are formed deep in its tissues. The establishment of connection and histological changes that take place during contact have been explained in detail by Barber (1906 and 1907, and Bhatnagar 1965).

Barber (1907) made a number of observations on the structure of the haustoria beginning with the formation of cushion like bodies from sandal roots to complete penetration inside the host root and establishing intimate attachment between them. The haustorial connection proceeds in two stages, in the first stage, ruptures and then penetration of the host root till it reached the woody portion. In the next stage, a channel of communication between haustoria and vessels of the sandal root is formed.

Rama Rao (1911) in his experiments on extent of root parasitism found that sandal seedlings were incapable of growing beyond one year without haustoria. It has been noticed that the roots of sandal had travelled a length of nearly 40 m and attacked the roots of a large *Pterocarpus marsupium* tree.

Number, size and shape of sandal wood plant haustoria are dependent on the nature of attached host plants. Leguminous plants induced numerous large sized haustoria, while the no host sandal wood roots developed small sized non-specific haustoria. However, sandal wood developed bell-shaped haustoria on the roots of *Tithonia diversifolia* composed of meristematic peripheral hyaline body and central penetration peg with an ellipsoidal disc at the end (Tennakoon and Cameron, 2006).

Srimathi and Sreenivasaya (1962) mentioned that the spectacular increase in the rate of growth of the Sandal was related to the increase in number and size of chromosomes and the endopolyploidy was associated with most of the secretion of glands as well as haustoria. Sandalwood haustorium-host plant interface composed of parenchymatous tissue with scattered vascular elements supported selective cross-membrane transport between xylem tissues of the host and parasite than massive flow of nutrients through vascular elements.

Sandalwood plant haustorium consist a collapsed layer on the outer side of meristematic region of the hyaline body and inter collapsed layer between the vascular core and intrusive tissue initiated at the time of vascular gland penetration to the host stele (Zhang *et al.,* 2012; Yang *et al.,* 2014).

Nagaveni and Vijayalakshmi (2007) studied the differential response in the haustorial formation and growth of sandalwood plant in respect to different host. Rocha *et al.* (2014) conducted anatomical studies of haustoria with host *Casuarina* reveals that vascular connections between the host and the sandalwood tree became so close that the host and the parasitic root became almost a single physiological unit catering to the nutritional requirement of sandalwood tree.

On the basis of selective power of Sandal root haustoria, Rama Rao (1911), classified the hosts as good, moderate and bad and also mentioned these haustoria could attach with good host extensively and with bad host very sparingly. The unidirectional flow of nutrients from host to the parasitic sandal due to maintenance of higher osmotic pressure in the tissue of sandal as compared to the host tissue was observed.

Parthasarathi *et al.* (1974) mentioned that the haustorium absorbs potassium, calcium, magnesium, iron, copper and zinc from the soil due to possession of cation exchange capacity in sandal roots at a level comparable to those of many hosts. Srinivasan *et al.* (1992) concluded that sandal depends on its host for its supply of amino acids. But total nitrogen in sandal leaves was found to be influenced by the nature of host plant.

Rao (1933) reported that the osmotic pressure in the tissues in sandal is higher compared to that in the tissues of the host plant. This ensures unidirectional flow of nutrient from host to the parasitic sandal. The cation exchange capacity of the white succulent root in the young seedling of sandal was, however, reported to be at a slightly low level.

Alternanthera used as a better pot host in the nursery stage decreases the nutrient deficiency related mortality and loss of plants in the field. Association with leguminous secondary hosts (*Sesbania formosa, Acacia trachycarpa* and *Acacia ampliceps*) improved total N, C, P, K, Na, fructose and malic acid contents in sandalwood xylem sap (Radomiljac, 1998).

Vigna unguiculata (L.) used as a better annual primary host under nursery conditions increased total chlorophyll content, performance index, sturdiness quotient, shoot-root ratio and Dicksons quality index (Ramya, 2010).

Annapurna *et al.* (2006), *Mimosa pudica* (L.) proved as the best host, significantly enhancing growth and nutrient status (NPK) of *S. album* seedlings. The primary host *Cajanus cajan* as an effective species for nourishing sandal in nursery has been reported by many authors like Taide *et al.* (1994).

According to Nagaveni and Vijaylaskshmi (2003) there are 300 species which can be parasitized by sandal in nature, starting from grasses to other sandal. But it is evident that the growth patterns are different in case of different hosts. Hosts may also be preferred if they are available as a resource for longer period for e.g. a preference for woody perennials over herbaceous annuals.

Annapurna *et al.* (2006) has reported that *C. cajan* as a traditional primary host has several disadvantages, such as its fast growth, high level of competition with sandal seedlings for light and nutrients, susceptibility to fungal attacks, insect pests and also the requirement for intensive management.

Morphological analysis, total biomass estimation, seedling quality analysis, xylem solute estimation, chlorophyll fluorescence analysis, chlorophyll estimation, anatomical and morphological studies of haustoria etc. of sandalwood host plant associations were reported in the previous studies and detected 'leguminous plants as better hosts' (Radomiljac, 1998; Tennakoon and Cameron, 2006; Ramya, 2010).

Rocha *et al.* (2014) conducted anatomical studies of haustoria with host *Casuarina* reveals that vascular connections between the host and the sandalwood tree became so close that the host and the parasitic roots became almost a single physiological unit catering to the nutritional requirement of sandalwood tree. Their study with ^{32}P radio tracer technique suggested that the host plants need not be present in the same pit of sandalwood tree as it can extend its root to distance of 1.5 to 3 m to form haustoria on neighboring plants.

Sudhakar *et al.* (2014) conducted experiment for two decades on Indian Sandalwood to standardize nursery technology. They prescribed *Casuarina* as the best host followed by *Terminalia, Albizia, Dalbergia* and *Pongamia*. They also opined that Sandalwood can take up elements like Ca, S and P directly from soil and a small fraction of these is obtained from host.

Das and Tah (2014) conducted experiment in different soil environment of South West Bengal both in nursery and field condition after transplantation of sandalwood saplings with different hosts singly & in combination of hosts and found that Arhar (*Cajanus cajan*) is the best host followed by Arhar & Tulsi (*Ocimum sanctum*) combination followed by Tulsi singly though sandalwood plants survive without host but the girth & height growth is much better with the hosts.

Viswanath (2014) suggested the best growth of sandalwood was recorded with Mango host under intensively managed condition and least was with Amla host under slightly less intensively managed conditions. Their study also revealed that under managed conditions in agroforestry, it is possible to attain mean annual increment in excess of 4 cm in a year.

Singh *et al.* (2014) found that height, collar diameter, crown size, clear bole and survival of *S. album* trees were greater with *Citrus aurantium* as compared to *Casuarina equisetifolia* and *Punica granatum* hosts.

Ashokan and Krishnambika (2007) emphasized the growing demand and the dwindling supply of sandalwood, there exist great potential for raising sandal not only in forest area but also in-home garden and other agroforestry system.

Chauhan and Aggarwal (2007) explained the growth which is extensively used in the forestry sector to provide prediction about the growth and yield of plantation which maximizes the revenue and other benefits. In nature, the establishment and survival of sandal trees is entirely dependent on other woody plants in its vicinity which serve as hosts.

Santalum album (L.) growth and heartwood contents of S. album trees aged 6 years cultivated on farm land in association with *Citrus aurantium, Punica granatum* and *Casuarina equisetifolia* as host species, were studied to identify the most suitable host. Survival, height, collar diameter, crown size and clear bole of *S. album* trees were greater when grown with *C. aurantium* than the other two hosts (Singh *et al.*, 2014).

The best sandalwood seedling height was attained by the plants grown with *Desmodium triflorum* up to the 24th week and then the plants grown with *Mimosa pudica* attained the same height. The best root collar diameter growth and the highest number of leaf whorls were produced by the plants grown with *M. pudica and D. triflorum* respectively. Control experiment and the fertliser treatment produced poor results. (Subasinghe, 2013).

Lu *et al.* (2014) in China tested the effects of two non-N_2-fixing (*Bischofia polycarpa* and *Dracontomelon duperreranum*) and two N_2-fixing hosts (*Acacia confusa* and *Dalbergia odorifera*) on the growth characteristics and nitrogen (N) nutrition of *Santalum album* and observed the significantly higher biomass production of shoot, root and haustoria, N and total amino acid in *S. album* grown with the two N_2-fixing hosts.

Deepa and Yusuf (2015) examined the morphological and anatomical features along with biochemical parameters of sandal haustoria developed with the roots of five host species from leguminous (*Mimosa. pudica, Clitoria ternatea*, *Capsicum pubescens* and *Arachis glabrata*) and non-leguminous (*Vetiveria zizanioides*) plants. The plants attached with the roots of *Mimosa pudica* showed better growth (total chlorophyll, protein and carbohydrate content) compared to sandal plants attached with other hosts.

Doddabasawa *et al.* (2020) investigated the parasitism ecology of sandalwood under natural population in the semi-arid tropics, covering the north-eastern dry zone of Karnataka, India. Sandalwood was found to parasitize on nine different tree species belonging to four families dominated by Leguminosae (six tree species), and the maximum associations occurred with *Acacia nilotica*. It was found to be the best host among tree species followed by *C. siamea.*

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present investigation titled **'Studies on seed source and nursery management regime in Indian Sandalwood (*Santalum album* L.)'** was aimed at the comprehensive studies on quality planting stock production of sandal. In order to produce quality planting stock, selection of seed source is very important. After careful selection of the best seed source from Karnataka, seeds were subjected to different methods of priming to enhance germination. After conducting germination studies different type and size of containers and potting media was evaluated. Since sandal is a hemi root parasite different host species are evaluated in nursery condition. The flow of series of experiments is given in Plate 1.

3.1 Study area

The present study was conducted at Department of Forestry and Environmental Science, University of Agriculture Sciences, Bangalore, Karnataka. The nursery set up for the study was established at Kurudi village of Gowribidanur Taluk during the period 2021 to 2023. Geographically, the area is located at 755 m above mean sea level at 13°64'N latitude and 77°37'E longitude. The area experiences a warm climate with distinct rainy season. The soil of the experimental site is red soil with sand mix. The soils and sub soils are porous and extremely well drained.

3.2 Seed collection

Though the area under sandal is more in Karnataka, seeds for plantation development are exclusively sourced from Marayoor, Kerala. Therefore, to assess and compare whether any of the seed sources from Karnataka are potential enough to use as plantation rising material, seeds were collected from seven different locations of Karnataka (Plate 2) during October-November 2021 (Table 1) and Marayoor seeds were procured from Kerala Forest Seed Centre a division of Kerala Forest Research Institute, Thrissur, Kerala. The evaluation of fruit lot at Kerala Forest Research Institute, seed centre recorded moisture content of 7.89 (%) in fresh fruits and the average number of seeds per kg was 6000 and seed size ranged from 0.2 to 1.2 cm in diameter. After collection fresh fruit weight

Table 1: Geographical information of seed sources

Sl. No.	**Location**	**District**	**Latititude Longitude**	**Altitude (m)**	**Ann. rainfall (mm)**	**Avg. Temp. (^{0}C)**	**Soil type**
S1	Bevinahally	Bengaluru Rural	13°30'20.2"N 77°29'10.6" E	755	747	28	Clay loam
S2	Doranalu	Chikkamagalore	13°40'44.7" N 75°50'04.1" E	680	914	24	Red sandy loam,
S3	Gottipura	Bengaluru Rural	13°05'59.1" N 77°50'41.8" E	875	857	25	Red loamy and lateritic soil
S4	Gungaraghatti	Dharwad	15°31'37.8" N 74°56'37.7" E	720	786	28	Well drained loamy sand over gravel
S5	Muddenahally	Chikkaballapur	13°24'12.0" N 77°41'27.6" E	993	808	28	Red loamy
S6	Narsapura	Koppal	15°37'32.3"N 76°09'17.2"E	639	172	31	Black clayey soil
S7	Tavarekere	Tumakur	13°47'49.7" N 76°48'15.6" E	802	638	28	Clalyey soil
S8	Marayoor	Idukki	10°16'34.5" N 77°24'58.0" E	989	983	28	Red loam and lateritic soil

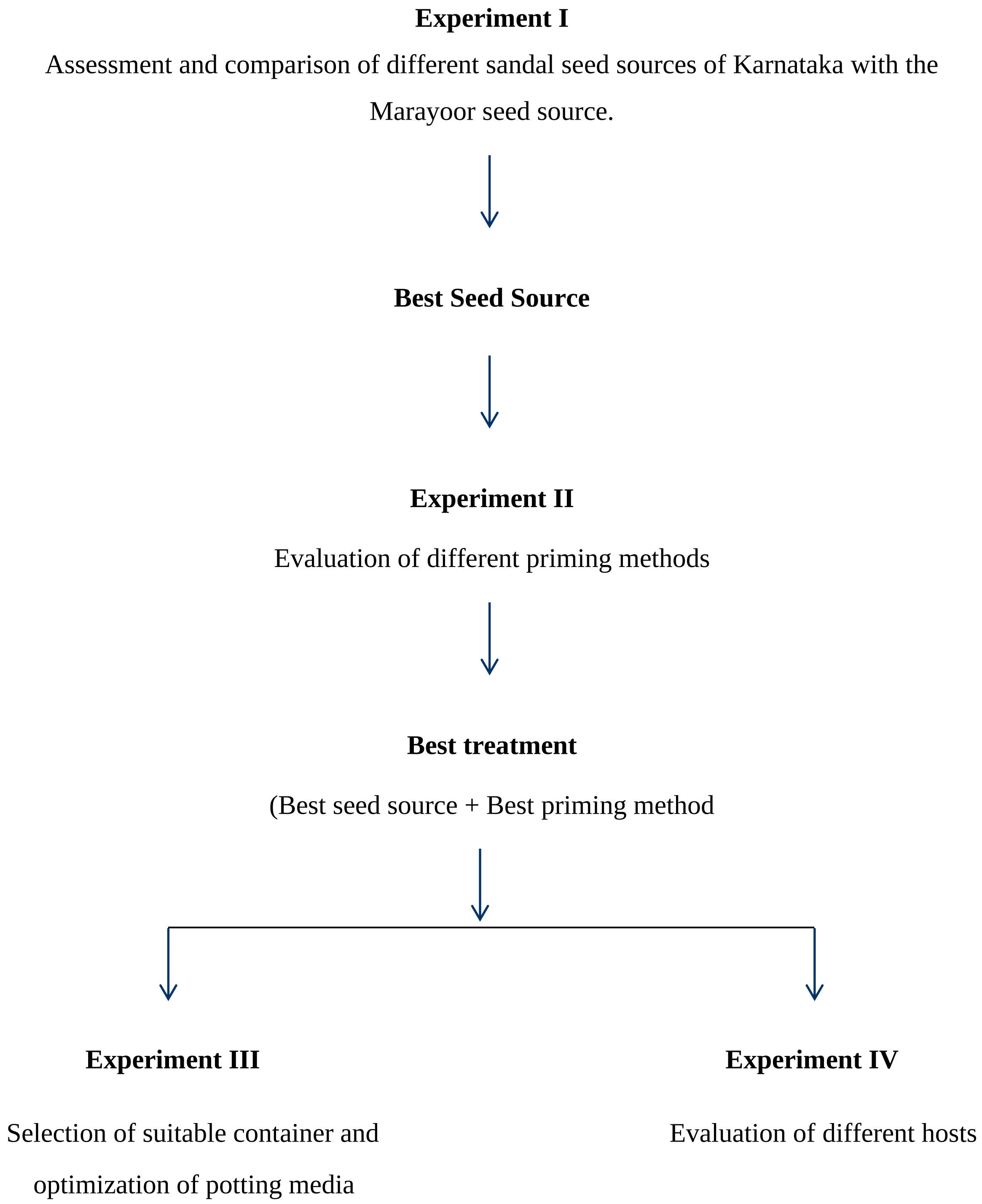


Plate 1: Flow chart of the experiment

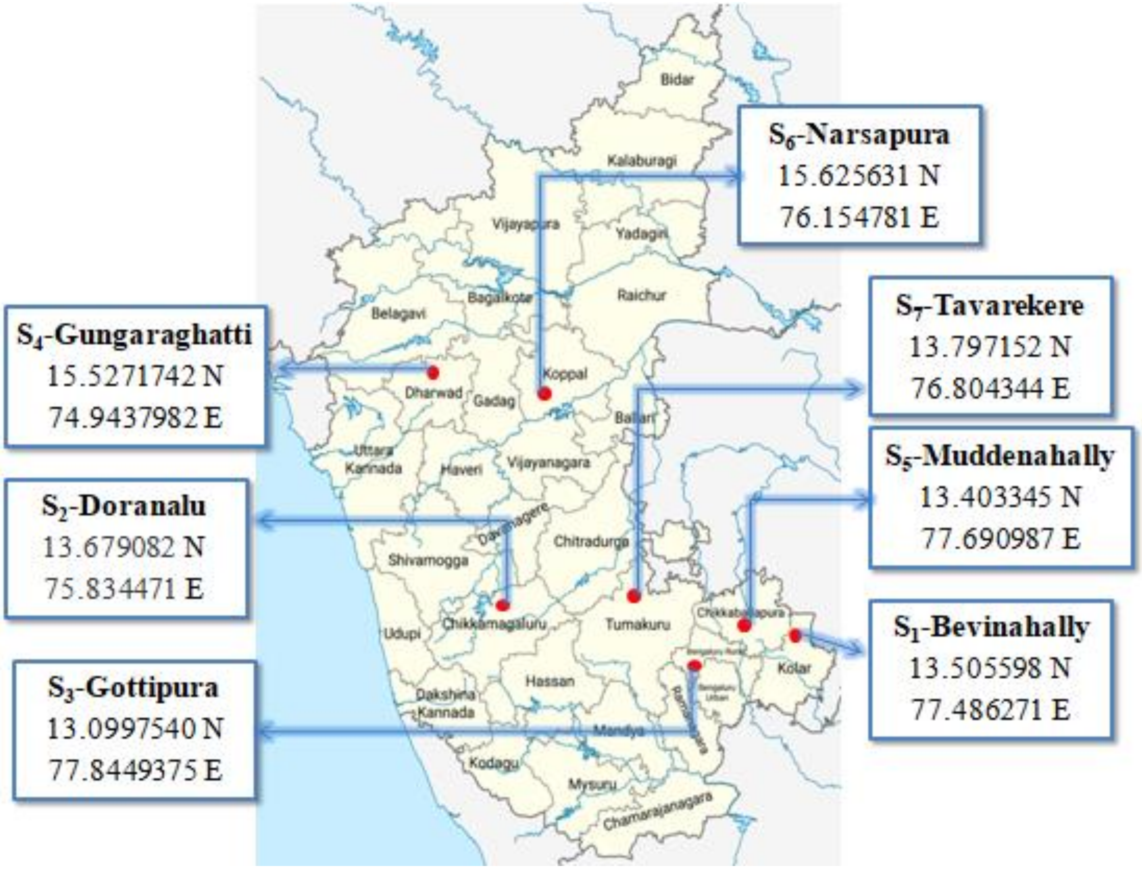


Plate 2: Geographical location of the seed sources

was measured and fruits were soaked in water for depulping. Depulped seeds were shade dried and pretreated with 1000 ppm GA_3 for 24 hours.

3.2.1 Assessment and comparison of different sandal seed sources of Karnataka

Before sowing seeds, the initial seed quality parameters *viz.*, seed length, seed width, fruit weight and seed weight were measured. Electrical conductivity of the seeds was also measured and the biochemical parameters like total carbohydrates, total protein and seed oil content were measured. Later the oil extracted from the seed was assessed for its physicochemical properties and fatty acid profiling was also done.

3.2.2 Electrical conductivity of seed leachates

To measure the electrical conductivity, the leachate after soaking was filtered. Five mL of the leachate was diluted to final volume of 25 mL with distilled water and the electrical conductivity was determined using a conductivity meter. The EC was expressed as dS cm^{-1} (Chitra and Jijeesh, 2019).

3.2.3 Biochemical assay of seeds

The methodology for determination of biochemical constituents like total carbohydrate, protein and oil content is given in the following sections.

3.2.3.1 Total carbohydrate (Anthrone reagent method)

Reagents

1. **Sulphuric acid 95 (%):** To 95.9 mL of sulphuric acid 4.1 mL of distilled water was added to make up to 100 mL.
2. **Anthrone reagent:** Two hundred mg anthrone was dissolved in 100 mL of ice cold 95 per cent sulphuric acid. Fresh reagent was prepared each time.

Preparation of sample

About 200 mg of sample with 10 mL of 80 (%) ethanol was boiled on a boiling water bath. After cooling the supernatant solution was filtered through Whatman No. 10

filter paper in a volumetric flask. The residue was re-extracted with 10 mL 80 (%) ethanol as described above for 1 hour and supernatant was separated again. Finally the residue was boiled with 10 mL double distilled water and the clear solution was collected. All the supernatants were pooled and the volume was made up to 50 mL.

Preparation of standard curve

The glucose (100 mg) was dissolved in 100 mL of distilled water to prepare standard. Working standard was prepared by dissolving 10 mL of above stock solution to 100 mL with distilled water. From the above solution, 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of standards corresponding to 20, 40, 60, 80 and 100 µg of glucose were taken in test tubes. Volumes were made up to 1 mL and this was followed by addition of 4 mL of anthrone reagent. Mixture was heated in boiling water bath for 8 minutes. After cooling, absorbance was read at 630 nm using photometer to prepare standard curve.

Assay

Seeds of one gram from each treatment was taken and powdered. Total sugars were extracted from the powdered material using 80 per cent aqueous ethyl alcohol (10 mL /g). The extract (0.2 mL) was taken in a test tube and kept in a water bath to completely evaporate the solvent. Then one mL of water was added to dissolve the sugars and 4 mL of anthrone reagent was added from a burette. The green colour developed was measured in a spectrophotometer (ELICO SL 159) at 630 nm with suitable blank. The optical density values were referred to a glucose standard curve and expressed in mg/g. (Yemm and Wilis, 1954)

3.2.3.2 Total protein

Principle

Organic nitrogen digested with sulphuric acid in the presence of catalyst was converted to ammonium sulphate. Ammonium liberated by making the solution alkaline is distilled into a known volume of standard acid, which is then back titrated. Protein per cent calculated by multiplying the nitrogen present by the factor 6.25 (Chitra and Jijeesh, 2019).

Reagents

1. **Boric acid solution 2 (%):** 2 g of boric acid dissolved in some distilled water. The solution then transferred to a 100 mL volumetric flask and made up to the mark.
2. **NaOH 40 (%):** 40 g of sodium hydroxide pellets dissolved in distilled water. The solution then transferred to a 4000 mL volumetric flask and made up to the mark.
3. **HCl 0.1 N:** 8.33 mL of fuming HCl dissolved in 1000 mL distilled water.
4. **Mixed indicator:** Prepared by mixing methyl red 0.2 (%) and bromocresol green 0.2 (%) in a 1:2 ration (v/v) respectively.
5. **Digestion mixture:** Anhydrous sodium sulphate and copper sulphate.
6. **Concentrated sulphuric acid (H_2SO_4).**

Digestion

Sample (0.5g) was weighed into the digestion tubes of the Gerhardt digester in duplicate and two heaped spatulas each of sodium and copper sulphate were added to each tube. Concentrated sulphuric acid of 25 mL was also added and samples digested until the contents of the tubes were turned to green in color. Each of the digested materials dissolved in distilled water and transferred into a 100 mL volumetric flask and then made up to the mark.

Distillation

Samples of 10 mL each were transferred into the distillation tube of the automatic Gerhardt unit and 20 mL of 2 per cent boric acid to which 3-4 drops of the mixed indicator was added. Then the mixture was placed with 40 per cent NaOH and distilled water to facilitate operation. Distillation was done for 5 minutes and the ammonia collected and trapped by the boric acid was observed. The boric acid turned from reddish pink to green as it collected the ammonia.

Titration

The green colored boric acid was titrated against the 0.1 N HCl until its color turned pink. A blank was run simultaneously and the titer values obtained were incorporated in the equation below to obtain the per cent nitrogen present in the sample which in turn multiplied by the factor 6.25 to obtain the per cent protein (Bremner, 1960)

$$\text{Protein (g/100 g)} = \frac{\text{Titration value x normality of HCl x 0.014 x 6.25}}{\text{Weight of sample (g)}} \text{ x } 100$$

3.2.4 Seed oil assessemnt

Seeds weighing five gram in three replications were pulverised to powder in a pestle and mortar and transferred to an extraction thimble. The thimble was then placed in a Soxhlet apparatus to which sufficient quantity of solvent petroleum ether (40-60°C boiling points) was added and heated until eight siphonings were completed. Then, the extraction flask with siphonings was taken out and placed in a hot-air-oven maintained at 60^0C to evaporate the petroleum ether completely. The entire extraction process was carried out in Soxhlet apparatus (Akpan *et al.,* 2006).

$$\text{Oil content (\%)} = \frac{\text{Weight of oil (g)}}{\text{Weight of seed (g)}} \times 100$$

3.2.5 Physico- chemical characterization of oil

3.2.5.1 Estimation of acid value of seed oil

The oil sample of one gram was dissolved in 50 mL of neutral solvent (Isopropyl alcohol) in 250 mL conical flask. A few drops of phenolphthalein indicator was added and then the contents were titrated against 0.1 N KOH and shaken constantly until the appearance of pink color which persist for 15 seconds. From the amount of alkali added, the amount of free fatty acid present in the oil was calculated in milligrams of KOH required to neutralize the free acids present in one gram of oil (Jayaraman, 1981).

$$\text{Acid value} = \frac{\text{Titrate value} \times \text{Noramality of KOH} \times 56.1}{\text{Weight of sample}} \text{ mg KOHg}^{-1}$$

3.2.5.2 Estimation of iodine value of oil

To a clean and dried iodine flask 0.3 g of oil was transferred and then 10 mL of chloroform, 25 mL of IBr were added and mixed well. A blank was prepared without adding the sample. All flasks were kept in a dark place for about 30 minutes with shaking of samples for every five minutes. Then, each flask was added with 50 mL of water and 10 mL of 10 % KI solution Then the solution in the flask was titrated against a standard sodium thiosulphate solution using 2 mL of starch indicator till the appearance of blue colour to colourless as an end point (Jayaraman, 1981).

$$\text{Iodine value} = \frac{(V_1 - V_2) \times N \times 126.9}{W \times 1000} \times 100 \quad \text{g I}_2\ 100\ \text{g}^{-1}$$

Where,

V_1 = Volume of $Na_2S_2O_3$ used for blank

V_2 = Volume of $Na_2S_2O_3$ used for oil

N = Normality of $Na_2S_2O_3$

W = Weight of oil in grams

3.2.5.3 Determination of saponification value of oil

A gram (with precision of three decimals) of oil was added to a 250 mL clean round bottom flask and then 10 mL of ethanol/ether mixture (2:1 v/v), 25 mL of 0.5 N alcoholic KOH were added. The mixture was then refluxed for an hour and the contents were cooled down. Simultaneously, another flask without adding oil was processed as blank. The solutions were then titrated against 0.5 N HCL using phenolphthalein as an indicator. The difference between the titration value of the blank and the flask containing oil was calculated. The amount of KOH used by 1 g of oil during the process of heating was calculated and reported as saponification value (Jayaraman, 1981).

$$\text{Saponification value} = \frac{(A - B) \times N \times 56.1}{W} \quad \text{mg KOHg}^{-1}$$

Where,

A = Volume of HCL used for blank

B = Volume of HCL used for oil

N = Normality of HCL

W = Weight of sample in grams

3.2.5.4 Determination of viscosity of oil

Viscosity of oil was determined using U-VISC 110 Kinematic viscometer. The measurement was done as per ASTM D445. The viscosity was determined by the modified ubbelohde viscometer. The viscometer was calibrated with standard viscosity liquid; samples were filtered through whatman filter paper No.1. The temperature of the viscometer was set to 40 ºC and the samples were taken in the viscometer cups and placed into a sampling holder. The viscosity was determined by the system and the value was noted down (Jayaraman, 1981).

3.2.5.5 Determination of density of oil

The density of oil was determined by density meter (Anton paar DMA^{TM} 35) which works by measuring the oscillation of a glass tube that contains the sample. About 10 mL of the sample was taken into a beaker. The density of the sample was measured by suction of sample into the portable density meter. The density of the sample was displayed on the density meter and the results were noted down (Jayaraman, 1981).

3.2.5.6 Specific gravity

The actual weight of the empty specific gravity bottle is determined and followed by weight of water and the sample i.e. sandalwood seed oil. It is expressed as the ratio of density of the sample to the density of water at the specified temperature (Ong *et al.,* 2013).

3.2.5.7 Refractive index

Refractive Index is the ratio of the velocity of light (of specific wavelength) in air to the velocity in the substance of sample. Refractive Index may also be defined as the Sine of the angle of incidence divided by the Sine of the angle of refraction, as light passes from air into the sample. Refractive Index is a fundamental property used in conjunction with other properties to characterize hydrocarbons and their mixtures. To determine refractive index of the oil, accurate to one unit in the fourth decimal place, ABBE’s Refractro meter with a monochromatic (sodium) light source is used. This method applies to refractive indices in the range between 1.33 and 1.60 (Ong *et al.*, 2013).

3.2.5.8 Determination of fatty acid profile

The fatty acid composition of the oil was determined by gas chromatography mass spectroscopy (GCMS).

Esterification protocol (Method: BF$_3$- Methanol)

About 40 µL of the kernel oil was placed into 10 mL centrifuge tubes and 2mL of esterification mixture (Boron trifluoride in methanol) was added. The tubes were reacted at 60ºC for 1 hour 30 minutes with mixing for 5 seconds for every 20 minutes. Then, 2 mL of saturated sodium bicarbonate solution along with 1 mL of distilled water and 1 mL of n-hexane and the tubes were mixed well and the extracts were removed for GC analysis.

Procedure

Profiling of fatty acids using gas chromatography mass spectroscopy (GCMS)-QP 2020 SHIMADZU Fatty acid methyl esters (FAME) were analysed in GC-MS by using a QP 2020 SHIMADZU gas chromatograph QP 2020 SHIMADZU equipped with a 30 m × 0.32 mm with 0.25 µm film thickness fused with silica capillary column. The temperature programmes for the column was 60ºC in the beginning and further up to a final temperature of 240ºC. The carrier gas was helium 1 mL/min with injector temperature of 240°C, rap rating 60 ºC to 220ºC @ 15ºC, 220ºC to 240ºC @ 3ºC, hold time @ 240ºC for 5 minutes, ion source-heating at 230°C. Chromatograms were recorded in the data station by using LC solutions software.

The fatty acids were identified by comparing the spectra available with NIST-2017 library. The individual fatty acid (%) was estimated by the following formula (Fan *et al.*, 2009).

$$\text{Individual fatty acid (\%)} = \frac{\text{Peak area of individual}}{\text{Total peak area}} \times 100$$

3.3 Germination studies

The evaluation was conducted in a nursery setting to provide controlled environmental conditions and eliminate potential variations due to site-specific factors. The nursery bed was prepared by adding well rotten and pulverized farmyard manure to the soil and firmly leveled (Plate 3). The soil was uniformly mixed with well decomposed and pulverized farmyard manure before sowing. Standard nursery bed of 10×1m was then prepared and 100 pre-treated (1000 ppm GA_3) seeds per replication were sown (Plate 4). The nursery beds were watered regularly on daily basis. Daily germination counts were recorded until germination was completed. The biomass observations were recorded for growth and biomass of sandal seedlings. Five plants randomly were pulled out from each replication to record the root and dry biomass related parameters. The experiment was conducted in completely randomized design with three replications for each seed source.

3.3.1 Germination and its attributes

3.3.1.1 Germination percentage

The number of seedlings produced in each replication was counted, and average was expressed in per cent (Czabator, 1962).

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seed sown}} \times 100$$

3.3.1.2 Mean Daily Germination (MDG)

The mean daily germination is calculated as the cumulative percent of full seed germination at the end of germination test, divided by the number of days from sowing to the end of the test (Czabator, 1962).

3.3.1.3 Peak Value of germination (PV)

Peak value of germination actually denotes the speed of germination, which is the maximum mean daily germination, recoded at any time during the period of test (Czabator, 1962).

Plate 3: Nursery bed preparation for sowing *Santalum album* (L.) seeds.

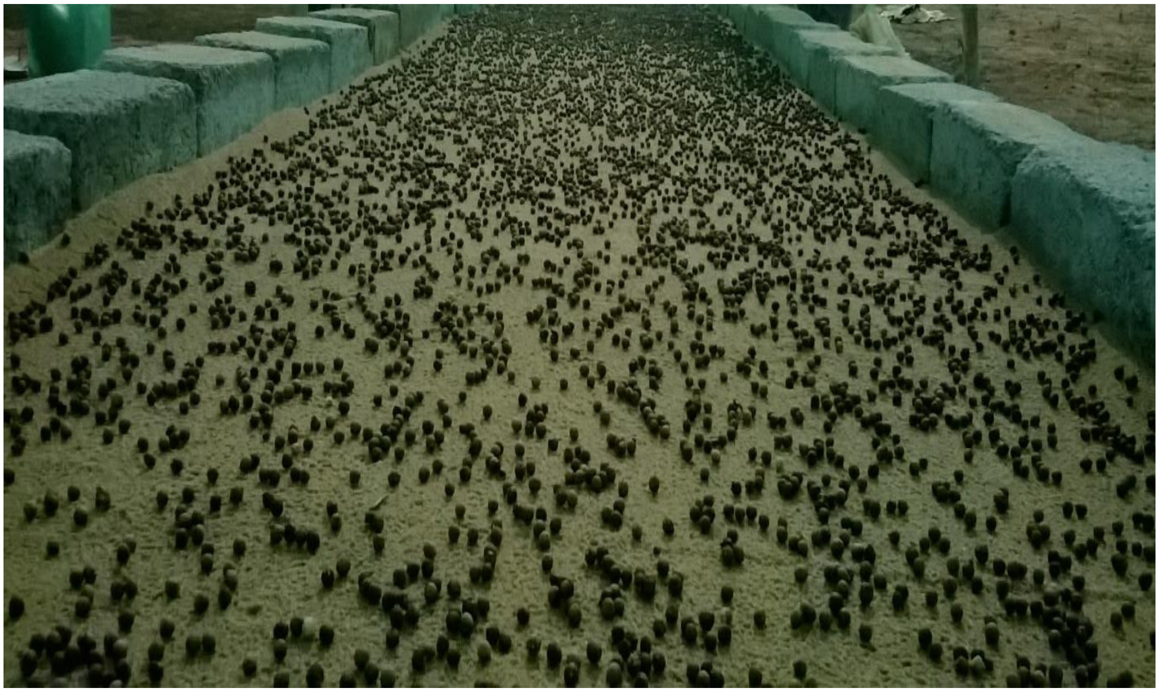


Plate 4: Sowing of seeds after treatment in nursery bed

3.3.1.4 Germination Value (GV)

The Germination Value (GV) was calculated using the following formula suggested by (Czabator, 1962).

GV = Mean daily germination x Peak value of germination

3.3.2 Seedling growth attributes

The following seedling characters were recorded

3.3.2.1 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).

3.3.2.2 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).

3.3.2.3 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).

3.3.2.4 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).

3.3.2.5 Seedling dry weight

The leaves, stem and roots were separately dried in hot air oven maintained at 75± 2°C 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).

3.3.2.6 Vigour Index

In the case of seeds sown in the nursery bed, the germinated seedlings were grown in the field up to one month. At the end, 10 seedlings from each replication were uprooted to measure the total dry weight. Vigour index (VI) was computed using the following formula and expressed as whole number (Abdul-Baki and Anderson, 1973).

$$\text{Vigour index} = \text{Germination (\%)} \times \text{Total dry weight (g)}$$

3.3.3 Physiological Observations

At the end of 30, 60 and 90 days after transplanting, six seedlings per replication were randomly selected to take physiological observations. Physiological attributes calculated using the below formulae:

3.3.3.1 Leaf Area Ratio (LAR)

Leaf area ratio as a measure of leaf area to the weight of the whole plant (Radford, 1967), it is expressed in cm^{2}g^{1}

$$\text{LAR} = \frac{\text{Leaf Area}}{\text{Plant dry weight}}$$

3.3.3.2 Leaf Weight Ratio (LWR)

It is the ratio of leaf dry weight to the plant dry weight. It is the measure of leafiness of the plant on a weight basis. It is expressed in g kg^{-1} (Radford, 1967).

$$\text{LWR} = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$$

3.3.3.3 Specific Leaf area (SLA)

It is the ratio assimilating area to its dry weight and expressed in cm^{2} mg^{-1} (Kvet *et al.*, 1971).

$$\text{SLA} = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

3.3.3.4 Specific Leaf Weight (SLW)

It is the ratio of leaf dry weight to its area of assimilating surface and expressed as below (Kvet *et al.,* 1971).

$$\text{SPW} = \frac{\text{Leaf dry weight}}{\text{Leaf area}}$$

3.3.4 Dickson Quality index (DQI) (Dickson *et al.*, 1960)

$$Quality\ index = \frac{Total\ dry\ weight\ of\ seedlings\ (g)}{\frac{Height\ of\ seedling(cm)}{Diameter\ of\ seedlings\ (mm)} + \frac{Shoot\ dry\ weight\ (g)}{Root\ dry\ weight\ (g)}}$$

3.3.4.1 Sturdiness Quotient (SQ)

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

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

3.3.4.2 Bio Volume Index (BVI)

Bio Volume Index was calculated by using the formula (Manavalan, 1990)

$$\text{BVI} = (\text{Collar diameter})^{2} \times \text{Height of seedling (cm)}$$

3.4 Effect of different priming treatments on seed germinability in sandal.

The best seed source (among Karnataka sources) emerged from experiment- I was used for this experiment. The sandal seeds were subjected to three priming methods *viz.*, Bio, Nutri and Hydro priming. Bio- inoculants *viz., Pseudomonas fluorescens*, and *Trichoderma viride* were used for biopriming. For nutripriming of sandal seeds $MnSO_4$ and KNO_3 solutions were used in different concentrations. And double distilled water was used for hydropriming.

3.4.1 Seed sampling

The sandal seed lot was thoroughly mixed to improve the homogeneity and the seeds were quarter divided four times. Seeds were randomly selected from the seedlot to conduct various priming treatments.

3.4.2 Seed priming methods

The seeds were surface sterilized using 0.1(%) Mercuric chloride for 5 minutes and thoroughly washed to remove the traces.

3.4.2.1 Biopriming

The priming agents selected for the present study was *Pseudomonas fluorescens*, and *Trichoderma viride*. For the study 20 g of the powder formulations of the bioinoculants @ 108 CFU mL^{-1} is said to produce 100% concentration for 50 sandal seeds. Hence, the ratio of powder formulations to the number of seeds to be primed was taken in the ratio 2:5. The biopriming of seeds were carried out at four different concentrations of the powder formulations *viz.*, 25, 50, 75 and 100% for 1, 2, 3, and 4 days duration (Plate 7). During the treatment distilled water was added to make up the volume of priming solution sufficient to suspend the seeds within it. The glass bottle with seeds and powder formulation was covered with aluminum foil. The seeds were stirred at regular interval to prevent the powder formulation from hardening.

3.4.2.2 Nutripriming

The seeds were primed using KNO_3 at different molar concentrations, (0.5M, 1.0M, 1.5M and 2.0M) for 1, 2, 3 and 4 days of duration. Similarly, seeds were primed at 0.2 M, 0.4 M, 0.6 M and 0.8 M concentrations of $MnSO_4$ for same duration. The $MnSO_4$ and KNO_3 were thoroughly dissolved in water to obtain a homogenous solution, required concentrations of both the solutions were calibrated and seeds were soaked in it. The glass bottles with seeds and priming solution was covered with an aluminum foil.

Plate 5: Covering nursery bed with polythene sheet after sowing for moisture retention

Plate 6: Germinated seeds in the nursery bed

3.4.2.3 Hydropriming

In order to hydroprime, the seeds were soaked in double distilled water for the same duration. Five hundred seeds weighing 70 to 90 g were hydroprimed with water. The seeds were transferred to a glass bottle and covered with aluminum foil.

3.4.3 Post priming process

The primed seeds were separated from the priming agents and thoroughly washed with distilled water thrice and dried with Whatman filter paper in shade at 25°C till the seeds achieved the moisture level prior to priming. The re-dried seeds were sown in nursery bed and covered with polythene sheet for moisture retention (Plate 5). And the experiment design used was factorial completely randomised design with priming agent concentration as factor one and priming duration as factor two. There are four levels in factor one (Priming agent concentration) and four levels of the factor two (priming duration) for each bio priming agent constituted to make a total of 16 treatment combinations with four replications each (Table 2). Germination parameters were recorded for each treatment (Plate 6).

Table 2: Priming agent concentration and duration used in the study

Sl. No.	Priming method	Priming agent	C-Concentration (%)	D-Duration (Days)
1	Biopriming	*Pseudomonas fluorescens*	25	1
			50	2
			75	3
			100	4
		Trichoderma viride	25	1
			50	2
			75	3
			100	4
2	Nutripriming	KNO_3	0.5	1
			1.0	2
			1.5	3
			2.0	4
		$MnSO_4$	0.2	1
			0.4	2
			0.6	3
			0.8	4
3	Hydropriming	Distilled water	-	4

3.5 Optimization of potting media and type of container

To satisfy the environmental concerns of using traditional growing media components such as river sand, potential alternatives were investigated in the current experiment. The best seed source and the best priming method obtained from experiment I and experiment II respectively were used for this experiment. The seeds were sown in standard seed beds of size 10 m x 1 m for germination. The seedlings obtained then were transplanted into four different types of containers (Table 3) filled with five different types of potting media (Table 4). 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 and recorded.

Table 3: 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 x15cm
C4	Poly bag of 30 cm x20cm

Table 4: Different potting media used in the study

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

Plate 7: Preparing sandal seeds for biopriming with powder formulation of bioagents

3.6 Influence of host plant on the seedling characteristics of Sandal

The best seed source and the best priming method obtained from experiment I and experiment II respectively were used for this experiment. Seeds were sown in standard seed beds of size 10m x1m for germination. The seedlings obtained then were transplanted into polybag with six different host species (Table 5; Plate 8&9). The sandal seedlings maintained without host served as control for this experiment. The experiment design used is completely randomized design with three replications for each host species; seedling and host growth parameters were recorded.

Table 5: Different host species raised with *Santalum album* (L.) for the study

Sl. No.	Treatments	
1	H0	No host
2	H1	*Crotalaria juncia*
3	H2	*Mimosa pudica*
4	H3	*Casuarina equisetifolia*
5	H4	*Cajanus cajan*
6	H5	*Crotalaria retusa*
7	H6	*Alternanthera sessilis*

3.6.1 Host relationship parameters

3.6.1.1 Host Use Efficiency (HUE)

The ratio between the *S. album* shoot dry weight (DW) and the host shoot DW was termed `host use efficiency' (HUE) (Radomiljac *et al.*, 1999).

3.6.1.2 Host Root Extension (HRE)

The total root biomass utilised by the *S. album* shoot includes its own roots as well as the host root system. The ratio between this total root DW and the DW of the *S. album* shoot is termed as host root extension (HRE) (Radomiljac *et al.*, 1999).

3.6.1.3 Host Root Support (HRS)

The total biomass supported by the host root includes its own shoot as well as the roots and shoot of *S. album*. The ratio between the root DW of the host and the total of the host shoot and *S. album* root and shoot DW is termed as the host root support (HRS) (Radomiljac *et al.*, 1999).

3.7. Statistical analysis

The experimental data thus obtained during the course of investigation were subjected to statistical analysis by applying the technique of one-way and two-way analysis of variance (ANOVA) to test the significance of overall differences among the treatments by using statistical software SPSS (Statistical package for social sciences).

RESULTS AND DISCUSSION

IV RESULTS AND DISCUSSION

This chapter deals with the results and discussion obtained comparing the selected seed sources of Karantaka with the Marayoor seed source, effect of different priming methods on seed germination and optimization of potting media and type of container suitable for raising sandal seedlings. An attempt was also made to select ideal host to raise the quality planting stock of sandal. The information obtained from the study is described under the following headings.

4.1 Assessment and comparison of different Sandal seed sources of Karnataka.

4.2 Effect of different priming treatments on seed germinability in Sandal**.**

4.3 Selection of suitable planting container and optimization of potting media for quality planting stock production

4.4 Influence of host plant on the seedling characteristics of Sandal.

4.1 Assessment and comparison of different Sandal seed sources of Karnataka.

Seeds were collected from seven different sources of Karnataka, and to compare, the seeds from Marayoor were collected from Kerala Forest Research Institute, Thrissur, Kerala. Seeds were assessed for initial seed physical quality parameters, seedling characters and overall quality of the seedlings.

4.1.1 Seed physical quality parameters

Seed physical quality affects germination rate and uniformity, which are critical for establishing a healthy and uniform crop stand. High-quality seeds with good physical attributes ensure a higher and more consistent germination rate, leading to uniform crop growth and maturity. The parameters measured include 100 fruit weight (g), 100 seed weight (g), seed length (mm), and seed width (mm). The study involved analyzing seeds from eight different seed sources from S1 to S8. Table 6 presents the results of the influence of seed source on various initial seed quality parameters in *Santalum album* (L.).

Table 6. Influence of different seed source on initial seed physical quality parameters in *Santalum album* (L.)

Seed Sources	100 Fruit weight (g)	100 Seed weight (g)	Seed length (mm)	Seed width (mm)
S1	68.47	17.07	7.50	6.64
S2	65.58	16.83	7.64	6.55
S3	68.51	17.10	7.45	6.46
S4	67.08	17.97	7.37	6.46
S5	60.54	16.58	7.44	6.28
S6	61.40	17.9	7.48	6.44
S7	61.96	16.92	7.72	6.46
S8	-	17.89	7.65	6.57
SEm±	**0.97**	**0.34**	**0.13**	**0.09**
CD (p=0.05)	**2.94**	**NS**	**NS**	**NS**
CV (%)	**2.58**	**3.45**	**3.06**	**2.44**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6-Narsapura, S7- Tavarekere, S8- Marayoor

The results show variations in the measured parameters across the different seed sources. For instance, 100 Fruit weight ranged from 60.54 g (Muddenahally-S5) to 68.51 g (Gottipura-S3), indicating differences in the size and weight of the fruits produced by the respective seed sources. Similarly, 100 seed weight varied between 16.58 g (Muddenahally-S5) and 17.97 g (Gungaraghatti-S_4), indicating variations in the weight of individual seeds. Seed length and seed width were also measured to assess the physical characteristics of the seeds. Seed length ranged from 7.37 mm (Gungaraghatti-S4) to 7.72 mm (Taverekere-S7), while seed width varied from 6.28 mm (Muddenahally-S5) to 6.64 mm (Bevinahally-S1).

Only in 100 fruit weight measurement significant difference was observed between different seed sources, but with respect to seed parameters like 100 fruit weight, seed length and seed width no significant differences were found showing the similarity in the physical quality parameters of seeds collected from different sources. Sandal is a well-established species with limited natural genetic variability. Cultivated varieties of *Santalum album* might have undergone selection and breeding, leading to relatively consistent seed traits across different seed sources. As a result, the genetic differences influencing seed weight and length among the seed sources may be minimal. Sindhuveerendra *et al.* (1998) also reported similar findings.

Table 7. Changes in the electrical conductivity and biochemical composition of sandal seeds with respect to different seed source

Seed Sources	Electrical conductivity (dS cm^{-1})	Total carbohydrate (mg g^{-1})	Total protein (mg g^{-1})	Oil content (%)
S1	0.83	1.03	0.041	41.11
S2	0.88	1.01	0.042	38.21
S3	0.52	1.61	0.073	31.51
S4	0.8	1.23	0.048	41.21
S5	0.68	1.42	0.051	36.22
S6	0.73	1.23	0.049	41.11
S7	0.71	1.35	0.051	35.12
S8	0.50	1.63	0.074	29.11
SEm±	**0.01**	**0.01**	**0.001**	**0.81**
CD (p=0.05)	**0.02**	**0.02**	**0.003**	**2.58**
CV (%)	**1.95**	**1.05**	**2.953**	**2.31**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

The seeds collected from different sources might have been harvested at a similar stage of maturity. Seed maturity can influence seed weight and size, and when seeds are collected at a similar developmental stage, it can result in uniform seed characteristics. If the parent plants used for seed production were relatively homogeneous in their traits, this could lead to consistent seed quality among the different sources. Different seed sources might experience varying levels of interactions with these biological factors, impacting their development and resulting seed quality (Rawat and Bakshi, 2011).

4.1.2 Electrical conductivity and biochemical parameters

The parameters measured include Electrical Conductivity (dS cm^{-1}), Total Carbohydrate (mg g^{-1}), Total Protein (mg g^{-1}), and Oil content (%). Table 7 shows the changes in electrical conductivity and biochemical composition of sandal seeds from different seed sources. The results show that across the different seed sources, Electrical conductivity (EC) which explains the degradation of cell membrane system values ranged from 0.50 dS cm^{-1} (Gottipura-S8) to 0.88 dS cm^{-1} (Doranalu-S2), indicating differences in the electrical conductivity levels of the seeds. Electrical conductivity (EC) is a direct indicator of cell membrane integrity and permeability. Variations in EC values reflect differences in the integrity of the cellular membrane system, which is influenced by factors such as seed maturity, hydration status, and environmental stress. Similar findings were reported by Ghosh and Singh (2011).

Seeds with lower EC values (Marayoor-S8) typically exhibit better cell membrane integrity, indicating lower leakage of ions and solutes. This could result from factors like optimal seed maturity at harvest, efficient seed hydration, and reduced exposure to stress such as high temperatures or pathogenic infections. Higher EC values (Doranalu-S2) may arise due to compromised cellular membranes, possibly linked to suboptimal maturity at harvest Fandohan *et al*. (2010) also reported similar findings. Seed sources (Marayoor-S8 and Gottipura-S3) may possess genetic traits that promote higher accumulation of carbohydrates and proteins during seed development. These genetic factors can impact the activity of enzymes and metabolic pathways involved in biosynthesis, leading to variations in the composition of these key biochemical constituents. These findings are in line with Singh *et al*. (2010).

Total Carbohydrate values varied between 1.01 mg g^{-1} (Doranalu-S2) and 1.63 mg g^{-1} (Marayoor-S8), indicating variations in the carbohydrate content of the seeds. Similarly, Total Protein values ranged from 0.041 mg g^{-1} (Bevinahally-S1) to 0.074 mg g^{-1} (S8), indicating differences in the protein content. The variations in total carbohydrate, total protein, and oil content among different seed sources are indicative of genetic diversity and metabolic differences. Genetic variability can influence the synthesis and accumulation of biochemical compounds within the seeds. Kumar and Singh (2014) reported similar findings in *Jatropha* species.

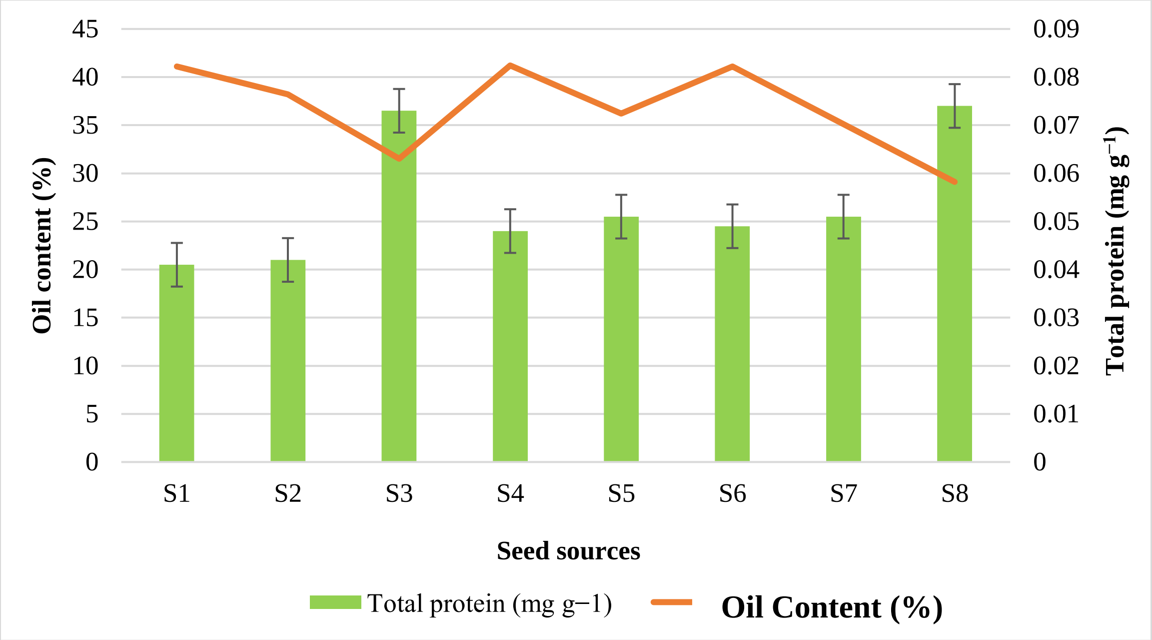


Fig. 1: Relationship between oil content and total protein in seeds of *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

Oil content varied between 41.1(%) Doranalu-S2 to 29.11 (%) Marayoor-S8, indicating differences in the oil content of the seeds. The seed source S3-Gottipura seed source yielded oil of 31.51(%), whereas the oil content of S1-Bevinahally and S6-Narasapura seed source was as high as 41.11 per cent. A trend was observed between the total protein content and oil content of the seed sources (Fig. 1). In the seed sources where protein content was found more, in such seed sources lower oil content was observed. Kaushik *et al*. (2007) observed that the crude protein content negatively correlates with oil content confirming that protein content in seeds depends on their oil content, the higher the amount of oil, the lower the protein content. The reason for this negative correlation might be due to plants having limited resources available for seed development, including energy, nutrients, and metabolic precursors. There is a trade-off between allocating resources towards protein synthesis, which requires nitrogen and other essential nutrients, and oil accumulation, which requires carbon and energy. When resources are directed towards one, they are not available in the same abundance for the other (Raut *et al*., 2011).

Table 8. Comparison of seed oil physico-chemical properties of the Marayoor (S8) versus Karnataka seed sources (S1-S7)

Sl. No.	Description	Check (S8)	Average (S1-S7)
1	Specific gravity	0.901	0.912
2	Refractive Index	1.398	1.478
3	Viscocity (Pa.s)	3.6×10^{-2}	3.5×10^{-2}
4	Freeze point (^{0}C)	-10.50	-10.50
5	Acid Value (mg KOH g^{-1})	4.581	4.240
6	Saponification Value (mg KOH g^{-1})	158.0	171.0
7	Iodine value (g I_2 100 g^{-1})	92.00	93.00

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.3 Physico-chemical properties of seed oil

The physico-chemical properties of seed oil is crucial to understad its fundamental composition for assessing their usability and applications across multiple sectors. Analysis of the physico-chemical properties of *Santalum album* seed oil, comparing the (S8-Marayoor) against average of all seven Karnataka sources (S1 to S7) is provided in Table 8. The specific gravity, a fundamental property indicating the density of the oil, is slightly lower in the S8-Marayoor (0.901) than the average of all seven Karnataka sources (0.912), suggesting a potential variation in composition or purity. On the other hand, the refractive index, a measure of light bending through the oil, significantly differs, with the (S8-Marayoor) (1.398) showing a notable deviation from the average of all seven Karnataka sources (1.478).

The viscosity of the (S8-Marayoor) sample (3.6×10^{-2} Pa.s) aligns closely with the average viscosity (3.5×10^{-2} Pa.s), indicating consistent flow behavior between the check value and the average. The freeze point remains consistent at -10.50°C for both the check and the average, suggesting uniformity in the ability of oil to solidify at this temperature. However, in terms of chemical properties, the check (S8-Marayoor) sample exhibits a higher acid value (4.581 mg KOH g^{-1}) compared to the average (4.240 mg KOH g^{-1}), indicating a potentially higher degree of free fatty acids.

Saponification value and iodine value, of the check sample showcases a lower saponification value (158.0 mg KOH g^{-1}) compared to the average (171.0 mg KOH g^{-1}), implying differences in ester linkages and molecular weight of fatty acids. Similarly, the check sample presents a slightly lower iodine value (92.00 g I_2 100 g^{-1}) compared to the average (93.00 g I_2 100 g^{-1}), signifying a minor disparity in the degree of unsaturation. The variations in the seed oil properties could be attributed to environmental conditions and soil composition of that region. Variations in soil nutrients, water availability, and temperature can affect the growth and chemical composition of the plant, ultimately impacting the properties of the oil extracted from seeds grown in such soils (Kaushik *et al.*, 2007).

Table 9. Comparison of fatty acid profiling of the sandal seed oil of Marayoor (S8) seed source versus average of Karnataka seed sources (S1-S7)

Sl. No.	Fatty acid	Check –S8 (%)	Average S1-S7(%)
1	Palmitic acid	03.58	03.61
2	Palmitoleic acid	00.64	00.68
3	Stearic acid	01.61	01.69
4	Oleic acid	22.83	29.12
5	Linoleic acid	02.86	02.91
6	Linolenic acid	01.06	01.09
7	Stearolic acid	01.11	01.15
8	Ximenynic acid	61.38	68.41

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6-Narsapura, S7- Tavarekere, S8- Marayoor

4.1.4 Fatty acid profiling of sandal seed oil

The comparative analysis of fatty acid profiling between sandal seed oil from Marayoor (S8) and the average of all seven Karnataka seed sources (S1-S7) provides valuable insights into the differences in fatty acid composition. The results are presented in Table 9, a consistent presence of essential fatty acids such as palmitoleic acid, linoleic acid, linolenic acid, and stearolic acid in both samples, suggesting uniformity in these aspects across the regions studied. However, a substantial distinction is observed in the levels of oleic acid, a mono-unsaturated fatty acid. The Marayoor sample exhibits a significantly lower content of oleic acid (22.83%) compared to the average of Karnataka sources (29.12%), indicating potential variations in environmental or genetic factors influencing oleic acid synthesis. Similar finding were reported by Kumar and Singh (2014).

Ximenynic acid, a unique fatty acid, stands out with a substantial difference. The Marayoor sample demonstrates a notably lower percentage of Ximenynic acid (61.38%)

compared to the average of Karnataka sources (68.41%). The reason for variation in acid profiling is due to local stressors such as drought, pests, diseases, or pollutants can affect the fatty acid biosynthesis process. Marayoor and Karnataka may experience different stressors that influence the fatty acid composition (Kaushika *et al.*, 2007).

Table 10. Influence of different seed source on germination attributes of *Santalum album* (L.)

Seed Sources	TTIG (days)	TTCG (days)	MDG	PV	GV
S1	23.00	81.33	0.28	0.39	0.11
S2	31.00	86.33	0.22	0.25	0.05
S3	19.33	57.67	0.9	1.05	0.94
S4	20.67	69.33	0.37	0.40	0.14
S5	21.33	63.67	0.58	0.58	0.33
S6	24.00	61.00	0.49	0.40	0.20
S7	20.00	62.67	0.49	0.53	0.26
S8	16.67	51.67	1.33	1.86	2.47
SEm±	**0.77**	**0.99**	**0.02**	**0.03**	**0.04**
CD (p=0.05)	**2.34**	**2.98**	**0.07**	**0.09**	**0.11**
CV (%)	**3.08**	**2.56**	**2.46**	**2.82**	**2.17**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6-Narsapura, S7- Tavarekere, S8- Marayoor

4.1.5 Seed germination attributes

The germination attributes considered for the study are as follows Time Taken to Initiate Germination (TTIG), Time Taken to Complete Germination (TTCG), Mean Daily Germination (MDG), Peak Value of Germination (PV), and Germination Value (GV).

Table 10 shows the results of the effect of seed source on germination attributes of *S. album*. The early germination was observed in (S8) i.e., Marayoor source followed by (S3) Gottipura seed source, time taken to initiate germination in (Gungaraghatti-S4) was 20.67 days whereas it was 21.33, 24.00 and 20.00 days in S5 S6 and S7 respectively. TTIG was as low as 31 days in (Dornalu-S2). The time taken to complete germination was recorded 51.67 days in (S8) followed by (S3) which was 57.67 days.

Mean Daily Germination (MDG) represents the average number of seeds germinated per day. It ranged from 0.22 (Doranalu-S2) to 1.33 (Marayoor-S8), showing significant differences in the rate of mean daily germination. Among the different sources it was highest in Marayoor seed source (S8) followed by Gottipura seed source (S3). The seed source (S2) showed significantly low MDG throughout the treatment followed by (Bevinahally-S1). Peak value (PV) of germination varied between 0.25 (Doranalu-S2) and 1.86 (Marayoor-S8), indicating significant differences in the seed sources. The Marayoor seed source (S8) recorded highest PV followed by Gottipura seed source, the lowest PV was recorded in Doranalu seed source which was as low as 0.25.

Germination Value (GV) measures the speed at which germination occurs. GV values ranged from 0.05 (Doranalu-S2) to 2.47 (Marayoor-S8), indicating significant differences in the rate of germination among the seed sources. The germination value was recorded lowest 0.05 in (Bevinahally-S2) seed source. Variations in germination attributes can arise due to subtle genetic differences among the seed sources. Over generations, minor genetic variations accumulate, leading to differences in the timing of germination initiation and completion. Certain seed sources might possess genetic traits that confer an advantage in germination speed and vigor, explaining the observed early germination in Marayoor (S8) and Gottipura (S3) seed sources. These genetic differences could influence the physiological responses of seeds to environmental cues and affect germination rates (Divakara *et al.,* 2010).

Pavitra *et al.* (2013) inferred that each seed source originates from a distinct geographical location with unique environmental characteristics, including soil composition, climate, altitude, and microclimate. These conditions significantly influence seed development and germination behavior. Seed sources from regions with more favorable environmental conditions may experience quicker germination due to optimal nutrient availability, moisture levels, and overall environmental suitability. The relatively shorter time taken to initiate germination in Marayoor (S8) and Gottipura (S3) seed sources could be attributed to these favorable environmental factors.

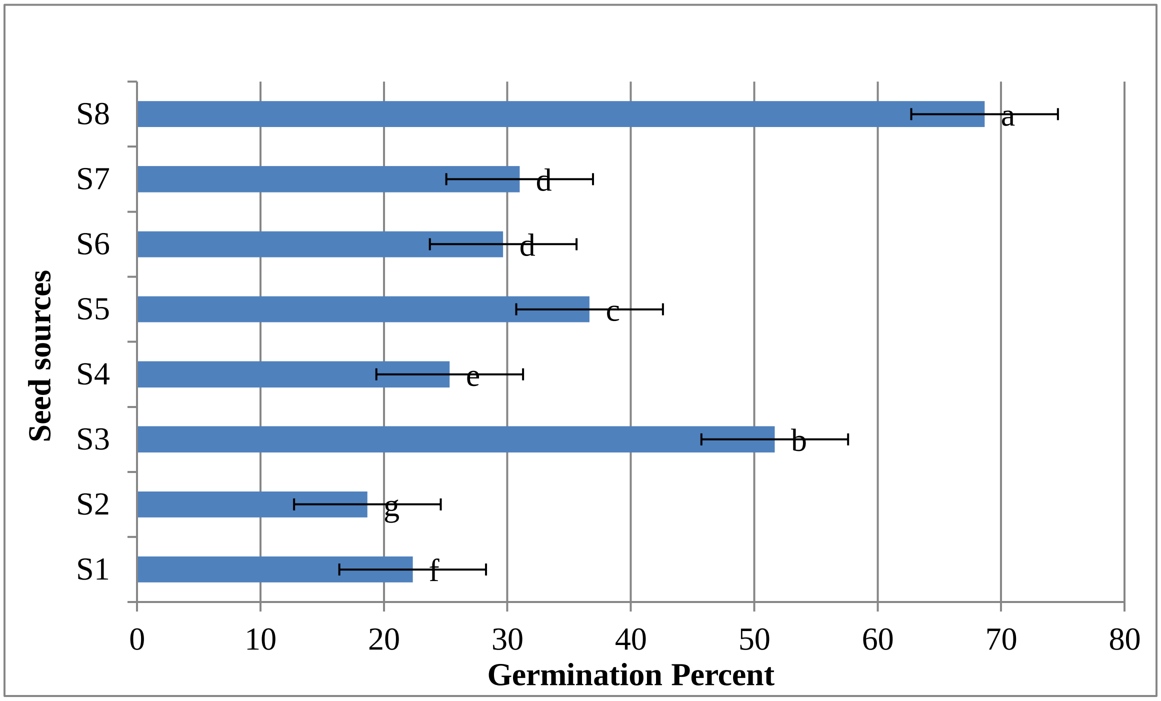


Fig. 2: Influence of Seed Source on the germination percentage of *Santalum album* (L.) (Bars with different letters are significantly different)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.6 Influence of seed source on germination per cent

The Fig.2 shows the influence of seed sources on germination percentages of *Santalum album*. The germination percentage varied among the seed sources, ranging from 18.67 (%) S2 to 68.66 (%) S8. Seed source S8 displayed the highest germination percentage (68.66%) followed by seed source S3 (51.67%). This indicates that seeds from this source have a higher probability of successful germination and early establishment when compared to other sources. On the other hand, seed sources S2 and S1 showed relatively lower germination percentages of 18.67 (%) and 22.33 (%), respectively. Electrical conductivity and oil content in the seed influenced the germination percentage. Negative trend was observed between germination percentage and electrical conductivity (Fig. 3). Similarly in the seed sources where oil content was found more, in such seed sources poor germination was observed (Fig. 4). These sources may have seeds with lower viability; potentially due to factors such as poor seed quality or storage conditions. The low germination percentages from these sources warrant caution when considering them for planting or reforestation projects, as they may result in lower plant establishment success (Jagadish, 2008).

Table 11. Influence of different seed source on shoot length of *Santalum album* (L.)

Seed Sources	**Shoot length (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
S1	6.22	7.80	8.61	9.78	11.29	12.65
S2	6.03	7.10	8.31	9.43	10.41	11.66
S3	8.05	9.49	10.71	12.46	14.26	16.55
S4	7.23	8.33	9.44	10.65	12.28	13.33
S5	7.57	8.59	9.83	11.36	13.79	15.74
S6	6.19	7.25	8.36	10.00	11.60	12.77
S7	7.29	8.31	9.44	10.67	11.78	13.53
S8	8.86	9.99	11.04	13.59	15.11	16.85
SEm±	**0.08**	**0.11**	**0.14**	**0.23**	**0.33**	**0.26**
CD (p=0.05)	**0.23**	**0.34**	**0.42**	**0.68**	**1.00**	**0.78**
CV (%)	**1.80**	**2.31**	**2.55**	**3.56**	**2.51**	**3.17**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6-Narsapura, S7- Tavarekere, S8- Marayoor

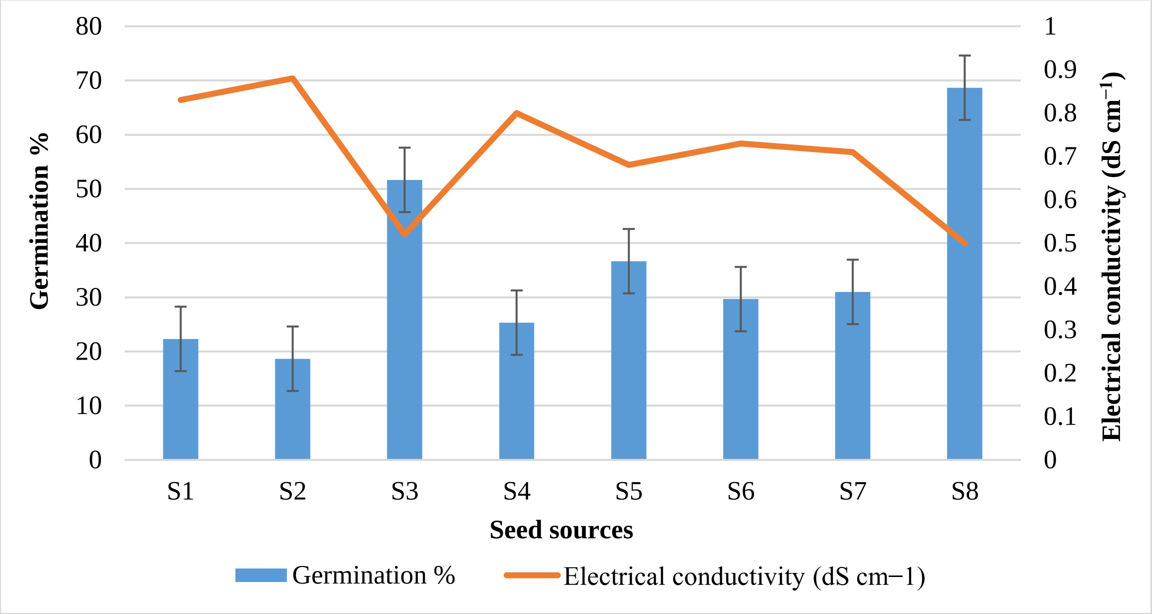


Fig. 3: Relationship between germination percentage and electrical conductiviy in *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

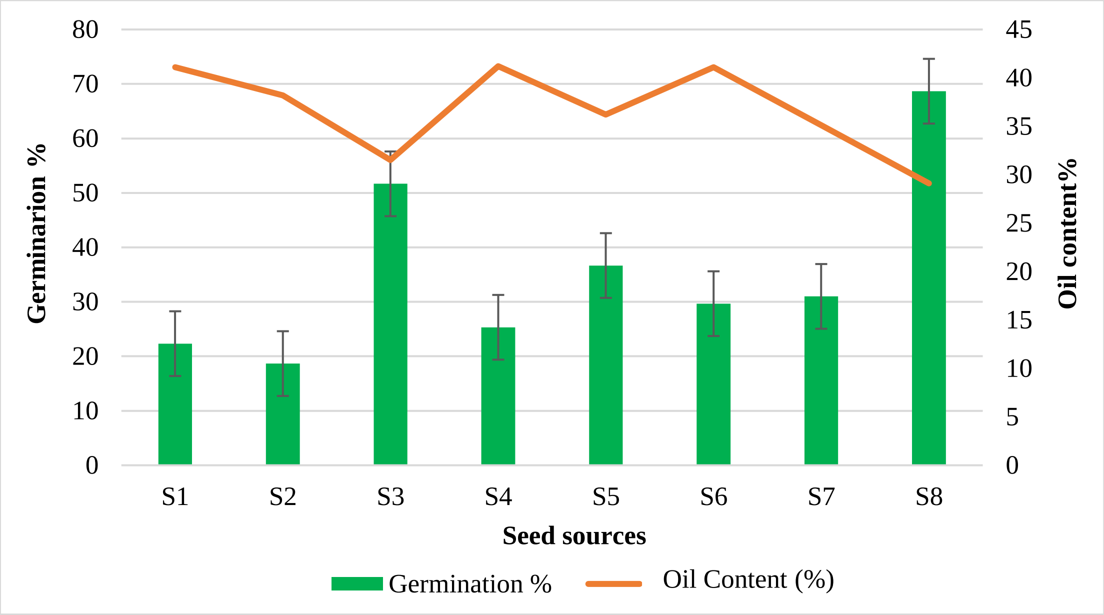


Fig. 4: Relationship between oil content and germination percentage in *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.7 Influence of seed source on shoot length

The seed sources influenced the seedling characteristics throughout the study period. Table 11 presents the results of the influence of different seed sources on the shoot length of *Santalum album* L. seedlings. The growth progression of seedlings from different seed sources over the 180-day period shows that, Marayoor seed source S8 recorded highest shoot length (8.86 cm). But among the Karnataka seed sources (Gottipura-S3) showed a steady increase in shoot length from 8.05 cm at 30 DAT to 16.55 cm at 180 DAT, indicating continuous growth over time. In contrast, seed source (Narasapura-S6) had shoot length measurements that increased from 6.19 cm at 30 DAT to 12.77 cm at 180 DAT.

Seed source S3 (8.05 cm) showed significant difference in shoot length compared to seed sources (Bevinahally-S1) (6.22 cm), S2 (6.03 cm), S6 (6.19 cm), and S7 (7.29 cm). Seed sources S4 (7.23 cm) and S5 (7.57 cm) do not exhibit much difference in terms of shoot growth at 30 DAT. Same trend continued at 60 DAT also. But seed source S3 (10.71 cm) shows significant difference in shoot length compared to seed sources S1 (8.61 cm) and S6 (8.36 cm). Seed sources S2 (8.31 cm) and S7 (9.44 cm) performance was not significant compared to S3 (Gottipura).

At 120 DAT seed source S3 (12.46 cm) shows a statistically significant difference in shoot length compared to seed sources S1 (9.78 cm) and S6 (10.00 cm), Seed sources S2 (9.43 cm) and S7 (10.67 cm) do not exhibit significant differences compared to seed source S3. Similar trend was observed in 150 days after transplantation. At 180 DAT Seed source S3 (16.55 cm) shows a statistically significant difference in shoot length compared to seed sources S1 (12.65 cm) and S6 (12.77 cm).

The complex interactions between genetic diversity, environmental conditions, climatic and edaphic factors, seed maturity, treatment practices, and potential biotic interactions collectively contribute to the observed variations in seedling attributes among different sandal seed sources. This comprehensive understanding of the factors influencing germination attributes is crucial for selecting optimal seed sources and developing effective cultivation strategies in sandalwood plantation establishment (Annapurna *et al.,* 2005).

Table 12. Influence of different seed source on root length of *Santalum album* (L.)

Seed Sources	**Root length (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
S1	4.32	5.06	5.93	6.89	7.98	8.97
S2	4.17	5.00	5.65	6.84	7.33	8.26
S3	6.24	7.15	8.40	10.25	11.08	12.26
S4	3.97	4.73	5.47	7.56	8.34	9.59
S5	3.98	4.69	5.38	6.96	7.77	9.04
S6	4.03	4.84	5.54	7.07	7.02	8.64
S7	4.39	4.93	5.54	7.04	7.51	8.76
S8	6.23	7.05	9.31	11.17	12.33	13.07
SEm±	**0.10**	**0.13**	**0.16**	**0.12**	**0.15**	**0.17**
CD (p=0.05)	**0.30**	**0.38**	**0.48**	**0.38**	**0.46**	**0.52**
CV (%)	**3.72**	**3.02**	**3.30**	**2.70**	**3.02**	**3.03**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.8 Influence of seed source on root length

Sandal being a hemi parasitic plant the root length measurement is crucial to understand the ability of the seed sources to produce good quality seeds**.** The results on influence of different seed source on the root length of *Santalum album* (L.) are presented in Table 12. Seed source Gottipura (S3) showed highest root length of 6.24 cm at 30 DAT, indicating strong initial root growth and significantly differ than other seed sources except Marayoor-S8. Seed source S8 shows the second-highest root length of 6.23 cm at this early stage and on par with S3. Seed source S3 maintains the highest root length at 60 DAT, reaching 7.15 cm, showing continued strong root growth. Seed source S8 also continued to demonstrate robust growth, with a root length of 7.05 cm. Seed sources S6 (Narasapura) and S7 (Tavarekere) show similar root lengths, both around 4.84 to 4.93 cm. Seed sources S1, S2, and S4 have root lengths 5.06, 5.00 and 4.73 cm respectively.

Seed source S8 (Marayoor) shows the highest root length of 9.31 cm at 90 DAT, indicating significant growth compared to earlier time points. Seed source S3 (Gottipura) follows closely with a root length of 8.40 cm, maintaining strong growth. Seed sources S6 (Narasapura) and S7 (Tavarekere) continue to exhibit similar root length, of 5.54 cm. Seed sources S1 (Bevinahally), S2 Doranalu), and S4 (Gungaraghatti) show root lengths ranging from 5.06 to 5.47 cm, indicating moderate growth. Seed source S5 (Muddenahally) displays a root length of 5.38 cm, which is relatively lower than the other seed sources.

Seed source S8 (Marayoor) maintains the highest root length at 120 DAT, reaching 11.17 cm, indicating continued significant growth. Seed source S3 (Gottipura) closely follows with a root length of 10.25 cm, demonstrating sustained strong growth. Seed sources S6 and S7 continue to show similar root lengths, around 7.02 to 7.04 cm. Seed sources S1, S2, and S4 exhibit root lengths ranging from 6.89 to 7.56 cm, representing moderate growth. Seed source S5 shows a root length of 6.96 cm at this stage. Seed source S8 recorded highest root length at 150 DAT, reaching 12.33 cm, displaying sustained significant growth. Seed source S3 continues to closely follow with a root length of 11.08 cm, maintaining strong growth.

Seed source S8 maintains the highest root length at 180 DAT, reaching 13.07 cm, indicating continued significant growth throughout the study period. Seed source S3 closely follows with a root length of 12.26 cm, demonstrating sustained strong growth. Seed sources S6 and S7 continue to show similar root lengths, around 8.64 to 8.76 cm. The differences recorded in the root length across the seed sources could be attributed to, the difference in site factors of different seed sources presence of pests, or symbiotic organisms can impact seed quality and germination and seedling attributes. Seed sources experiencing different levels of interactions with these factors may exhibit variations in germination patterns. Pests and diseases can affect seed vigor and cause delays in germination and subsequent growth (Divakara *et al.*, 2010).

Table 13. Influence of different seed source on seedling height of *Santalum album* (L.)

Seed Sources	Seedling height (cm)					
	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
S1	10.54	12.85	14.54	16.68	19.27	21.62
S2	10.20	12.10	13.95	16.27	17.74	19.92
S3	14.29	16.64	19.11	22.71	25.34	28.82
S4	11.20	13.06	14.91	18.20	20.63	22.92
S5	11.56	13.28	15.21	18.32	21.56	24.78
S6	10.22	12.09	13.90	17.06	18.62	21.41
S7	11.68	13.24	14.98	17.71	19.29	22.29
S8	15.09	17.04	20.35	24.76	27.44	29.92
SEm±	**0.11**	**0.14**	**0.22**	**0.31**	**0.44**	**0.33**
CD (p=0.05)	**0.34**	**0.42**	**0.65**	**0.95**	**1.32**	**0.99**
CV (%)	**1.62**	**1.76**	**2.35**	**2.87**	**3.51**	**2.37**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.9 Influence of seed sources on seedling height

Seedling height is a primary indicator of growth and overall health. Monitoring the height allows growers to assess the progress of the sandalwood plants and identify any potential issues early on, such as diseases, nutrient deficiencies, or water stress (Divakara *et al.*, 2010). Table 13 presents the results on the influence of different seed source on the seedling height of *S. album* seedlings over a period of 180 days. Seed sources S3 (Gottipura) and S8 (Marayoor) recorded significantly higher seedling heights compared to the other sources at 30 DAT. Seed source S8 exhibits the highest seedling height of 15.09 cm, while S3 follows closely with a height of 14.29 cm. Seed sources S4 (Gungaraghatti), S5 (Mudddenahally), and S7 (Tavarekere) showed moderate seedling heights ranging from 11.20 to 11.68 cm. Seed sources S1(Bevinahally), S2 (Doranalu), and S6 (Narasapura) have relatively lower seedling heights, ranging from 10.20 to 10.54 cm. Seed source S8 maintains the highest seedling height of 17.04 cm, while S3 closely follows with a height of 16.64 cm. Seed sources S4, S5, and S7 exhibit moderate seedling heights ranging from 13.06 to 13.28 cm. Seed sources S1, S2, and S6 have relatively lower seedling heights, ranging from 12.09 to 12.10 cm.

Seed sources S3 and S8 showed significantly higher seedling heights compared to the other sources at 90 DAT. Seed source S8 displays the highest seedling height of 20.35 cm, while S3 closely follows with a height of 19.11 cm. Seed sources S3 and S8 recorded significantly higher seedling heights compared to the other sources at 120 DAT. Seed source S8 maintains the highest seedling height of 24.76 cm, while S3 closely follows with a height of 22.71 cm. Seed sources S4, S5, and S7 exhibit moderate seedling heights ranging from 18.20 to 18.32 cm.

Seed sources S3 and S8 recorded significantly higher seedling heights compared to the other sources at 150 DAT. Seed source S8 still has the highest seedling height of 27.44 cm, while S3 closely follows with a height of 25.34 cm. Seed sources S4, S5, and S7 show moderate seedling heights ranging from 20.63 to 21.56 cm. Seed sources S1, S2, and S6 have relatively lower seedling heights, ranging from 17.74 to 18.62 cm. Seed sources S3 and S8 showed significantly higher seedling heights compared to the other sources at 180 DAT. Seed source S8 maintains the highest seedling height of 29.92 cm, while S3 closely follows with a height of 28.82 cm. Seed sources S4, S5, and S7 show moderate seedling heights ranging from 21.41 to 22.29 cm. Seed sources S1, S2, and S6 have relatively lower seedling heights, ranging from 19.92 to 21.62 cm.

Throughout the 180-day period, seed sources S3 and S8 consistently exhibit significantly higher seedling heights compared to the other sources. These two seed sources demonstrate more vigorous growth, making them suitable choices for sandalwood plantation establishments where fast-growing and tall seedlings are desired. This might be due to the genetic makeup of each seed source plays a crucial role in shaping growth parameters. Genetic diversity among seed sources can lead to variations in seedling height, leaf area, thickness, and density. Among Karnataka seed source S3 consistently displaying higher height, leaf area suggests that it might possess genetic traits that favor larger leaf expansion. Conversely, seed source S2 with smaller leaf area might have genetic limitations in growth potential (Ramya, 2010).

Table 14. Influence of different seed source on collar diameter of *Santalum album* (L.)

Seed Sources	**Collar diameter (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
S1	0.870	0.913	1.033	1.063	1.101	1.337
S2	0.933	0.957	1.063	1.073	1.103	1.153
S3	1.327	1.443	1.830	1.960	2.212	2.623
S4	1.007	1.057	1.223	1.267	1.352	1.520
S5	1.027	1.113	1.230	1.270	1.391	1.630
S6	0.950	1.023	1.160	1.193	1.221	1.260
S7	1.037	1.070	1.143	1.163	1.201	1.427
S8	1.640	1.750	1.820	1.887	2.341	2.820
SEm±	**0.016**	**0.013**	**0.014**	**0.012**	**0.013**	**0.020**
CD (p=0.05)	**0.050**	**0.039**	**0.043**	**0.038**	**0.039**	**0.062**
CV (%)	**2.588**	**1.918**	**1.891**	**1.582**	**1.581**	**2.426**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.10 Influence of seed source on collar diameter

A thicker collar diameter provides better stem stability, making the plant more resistant to winds and other environmental stresses. This is crucial, especially in open field plantations, to prevent stem damage and ensure the plant overall stability. The influence of different seed source on collar diameter of sandal seedlings is shown in Table 14. At 30 DAT, the collar diameter of *S. album* seedlings varied among the different seed sources.

Seed source S8 (Marayoor) displayed the highest collar diameter of 1.640 cm. while seed source S1 (Bevinahally) had the lowest with 0.870 cm. Significant differences in collar diameter were observed among all seed sources at this early stage of the experiment. During the 60 DAT, seed source S8 maintained the highest collar diameter of 1.750 cm, while seed sources S1 (Bevinahally) and S6 (Narasapura) exhibited the lowest collar diameter; both measuring around 0.913 cm and 1.023 cm respectively. Significant differences persisted between the seed sources, indicating variations in growth rates.

At 90 DAT, there was substantial growth in collar diameter for all seed sources. Seed sources S3 and S8 showed the highest collar diameters, reaching 1.830 cm and 1.820 cm, respectively. Meanwhile, seed source S1 had the smallest collar diameter of 1.033 cm. Significant differences in collar diameter were apparent among the seed sources at this stage of the experiment. By 120 DAT, the seedlings continued to exhibit significant growth in collar diameter. Seed source S8 maintained the highest collar diameter of 1.887 cm, while seed source S1 had the lowest collar diameter of 1.063 cm. Seed sources S3 and S8 showed consistently larger collar diameters compared to the other sources, indicating robust growth.

At the 150 DAT, seed sources S3 and S8 remained at the top in terms of collar diameter, with diameters of 2.212 cm and 2.341 cm, respectively. Seed sources S1, S2, and S6 showed the smallest collar diameters, ranging from 1.101 to 1.221 cm. At 180 DAT, seed source S8 exhibited the highest collar diameter of 2.820 cm, while seed source S1 displayed the lowest with 1.337 cm. Seed sources S3 and S8 consistently demonstrated larger collar diameters throughout the experiment. This could be attributed to differences in environmental conditions where the parent plants were grown and where the seeds were collected can impact seedling vigour and quality. Variations in climate, soil type, and other local factors can affect seedling performance. Seed sources adapted to specific environmental conditions may exhibit superior seedling characteristics under similar conditions (Annapurna *et al.,* 2005; Rakesh, 2012).

Table 15. Influence of different seed source on root to shoot ratio of *Santalum album* (L.)

Seed Sources	Root: Shoot					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
S1	0.69	0.65	0.69	0.71	0.71	0.71
S2	0.69	0.70	0.68	0.72	0.70	0.71
S3	0.77	0.75	0.78	0.82	0.78	0.74
S4	0.55	0.57	0.58	0.71	0.68	0.72
S5	0.53	0.55	0.55	0.62	0.56	0.58
S6	0.65	0.67	0.66	0.71	0.61	0.68
S7	0.60	0.59	0.59	0.66	0.64	0.65
S8	0.70	0.71	0.84	0.82	0.82	0.77
SEm±	**0.02**	**0.02**	**0.02**	**0.01**	**0.02**	**0.02**
CD (p=0.05)	**0.05**	**0.06**	**0.06**	**0.04**	**0.05**	**0.05**
CV (%)	**2.33**	**3.14**	**2.26**	**3.04**	**3.84**	**3.16**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.11 Influence of seed source on root to shoot ratio

The root-to-shoot ratios for each seed source at various time points during the growth period of the sandal seedlings are presented in Table 15. At 30 DAT, the root-to-shoot ratio of *S. album* seedlings varied among the different seed sources. Seed source S3 (Gottipura) had the highest root-to-shoot ratio of 0.77, indicating a relatively higher root mass compared to the shoot. On the other hand, seed sources S4 (Gungaraghatti) and S5 (Muddenahally) displayed lower root-to-shoot ratios of 0.55 and 0.53, respectively, indicating a higher shoot mass relative to the root. Significant differences in root-to-shoot ratios were observed among the seed sources at this early stage of the experiment. During the 60 DAT, root-to-shoot ratios exhibited minor fluctuations. Seed source S3 maintained the highest root-to-shoot ratio of 0.75, while seed source S5 displayed the lowest ratio of

0.55. Significant differences in root-to-shoot ratios persisted between the seed sources, indicating variations in their growth patterns.

At 90 DAT, there were further changes in the root-to-shoot ratios of the seedlings. Seed sources S3 and S8 exhibited the highest ratios of 0.78 and 0.84, respectively, indicating a dominance of root biomass. Conversely, seed source S5 displayed the lowest root-to-shoot ratio of 0.55, signifying a relatively higher shoot mass. Significant differences in root-to-shoot ratios were apparent among the seed sources at this stage of the experiment. By 120 DAT, the seedlings continued to show variations in their root-to-shoot ratios. Seed sources S3 and S8 still maintained the highest ratios, both around 0.82, indicating a strong root growth relative to the shoot. Seed sources S4 and S5 showed lower root-to-shoot ratios of 0.71 and 0.62, respectively, indicating a relatively higher shoot mass.

During 150 DAT, seed sources S3 and S8 remained at the top in terms of root-to-shoot ratios, with ratio of 0.78 and 0.82 respectively. Seed sources S4 and S5 showed the lowest ratios, both around 0.56, indicating a higher shoot mass compared to the root. At 180 DAT, the root-to-shoot ratios of the seedlings continued to exhibit slight variations. Seed sources S3 and S8 maintained the highest ratios, both around 0.74, signifying a continued dominance of root biomass. Seed sources S4 and S5 displayed the lowest ratios of 0.72 and 0.58, respectively, indicating a relatively higher shoot mass.

The root-to-shoot ratios of *Santalum album* (L.) seedlings varied significantly among different seed sources throughout the 180-day period. Seed sources S3 and S8 consistently displayed higher root-to-shoot ratios, indicating a preference for root growth. Ginwal *et al.* (2005) reported the process of selecting parent plants for seed production can greatly influence seedling quality. Seed sources that are chosen based on desired traits, such as vigour and quality, are likely to yield seedlings with corresponding attributes. Seed source S8 producing seedlings with high vigour and quality values might be the result of careful selection and breeding for these traits. These findings are also in line with (Annapurna *et al.*, 2005; Rakesh, 2012).

Table 16. Influence of different seed source on dry weight of *Santalum album* (L.)

Seed Sources	Dry weight (g)							
	Shoot dry weight		Root dry weight		Leaf dry weight		Total dry weight	
	30 DAT	180 DAT	30 DAT	180 DAT	30 DAT	180 DAT	30 DAT	180 DAT
S1	0.075	0.154	0.051	0.079	0.054	0.091	0.180	0.325
S2	0.062	0.116	0.042	0.078	0.042	0.082	0.146	0.276
S3	0.136	0.212	0.081	0.122	0.098	0.435	0.492	0.769
S4	0.075	0.146	0.052	0.091	0.062	0.100	0.189	0.337
S5	0.078	0.156	0.061	0.086	0.072	0.111	0.211	0.354
S6	0.074	0.186	0.052	0.082	0.062	0.093	0.188	0.361
S7	0.082	0.166	0.059	0.088	0.070	0.098	0.211	0.353
S8	0.142	0.225	0.080	0.125	0.097	0.476	0.486	0.826
SEm±	**0.013**	**0.005**	**0.001**	**0.002**	**0.003**	**0.007**	**0.014**	**0.006**
CD (p=0.05)	**0.041**	**0.015**	**0.003**	**0.007**	**0.008**	**0.021**	**0.042**	**0.019**
CV (%)	**3.031**	**2.101**	**2.504**	**2.253**	**3.141**	**4.378**	**4.077**	**2.408**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.12 Influence of seed sources on dry weight.

The influence of different seed source on the dry weight of *S. album* seedlings at two different time points was shown in Table 16. Shoot dry weight refers to the weight of the above-ground parts of the seedlings. At 30 DAT, the shoot dry weight varies across different seed sources, ranging from 0.062 g (S2-Doranalu) to 0.142 g (S8-Marayoor). Among the seed sources, S8 exhibits the highest shoot dry weight at this stage. Seed source S3-Gottipura shows the highest shoot dry weight at 180 DAT, measuring 0.212 g, while S2 has the lowest shoot dry weight of 0.116 g at the same stage. The variations in dry weight might reflect differences in physiological responses to stress, light availability, and water availability among seed sources. Some sources might have physiological mechanisms that confer better stress tolerance and growth under specific conditions Ginwal *et al*. (2005).

Root dry weight represents the weight of the below-ground parts of the seedlings. At 30 DAT, the root dry weight varies from 0.042 g (S2-Doranalu) to 0.080 g (S8-Marayoor). Seed source S8 exhibits the highest root dry weight at this early stage of growth. As the seedlings continue to grow and reach 180 DAT, the root dry weight increases for all sources. S8 still maintains the highest root dry weight of 0.125 g, while S2 has the lowest root dry weight of 0.078 g at this later stage.

At 30 DAT, the leaf dry weight ranges from 0.042 g (S2-Doranalu) to 0.098 g (S3-Gottipura). Seed source S3 shows the highest leaf dry weight at this initial stage. As the seedlings progress and reach 180 DAT, the leaf dry weight increases for all sources. Seed source S8 exhibits the highest leaf dry weight of 0.476 g at 180 DAT, while S2 has the lowest leaf dry weight of 0.082 g at the same stage.

Total dry weight is the sum of the shoot, root, and leaf dry weights of the seedlings. At 30 DAT, the total dry weight ranges from 0.146 g (S2-Doranalu) to 0.492 g (S3-Gottipura). Seed source S3 shows the highest total dry weight at this early stage of growth. As the seedlings continue to grow and reach 180 DAT, the total dry weight increases for all sources. Seed source S8 exhibits the highest total dry weight of 0.826 g at 180 DAT, while S2 has the lowest total dry weight of 0.276 g at this later stage. The observed variations in seedling characters of *S. album* among different seed sources over a period can be attributed to a combination of genetic, physiological, and environmental factors. These factors interact in complex ways to influence the development and characteristics of leaves and other growth parameters (Surendar, 2014).

4.1.13 Influence of seed source on leaf number

Table 17 presents the influence of different seed sources on leaf number of Sandal seedlings up to 180 DAT. At the early stage of 30 DAT, the number of leaves varied among the different seed sources, ranging from 6.00 to 8.15. Seed source S3 (Gottipura) had the highest number of leaves, with an average of 8.15, indicating relatively higher leaf initiation compared to other seed sources. In contrast, seed source S2 (Doranalu) exhibited the lowest number of leaves, with an average of 6.00.

By 60 DAT, the number of leaves continued to show variations among the seed sources. Seed source S3 maintained the highest number of leaves with an average of 8.63, suggesting a sustained trend of leaf development. Seed source S2, which previously had the lowest leaf count, showed some growth, reaching an average of 6.38 leaves. At 90 DAT, the leaf numbers increased further for all seed sources. Seed source S3 still displayed the highest number of leaves with an average of 11.05, showing consistent leaf initiation. Seed sources S2 and S6 exhibited similar leaf counts, with averages of 8.14 and 9.01, respectively. Seed source S1 showed significant leaf development, reaching an average of 9.14 leaves.

Table 17. Influence of different seed source on leaf number of *Santalum album* (L.)

Seed Sources	**Number of leaves**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
S1	6.14	6.95	9.14	13.30	18.65	20.04
S2	6.00	6.38	8.14	11.04	15.84	18.08
S3	8.15	8.63	11.05	17.05	21.57	25.05
S4	7.00	7.54	9.12	14.11	17.93	19.41
S5	7.05	7.42	9.70	15.00	19.41	21.72
S6	6.17	7.16	9.01	13.71	17.70	19.98
S7	7.12	7.56	8.94	14.17	17.96	19.04
S8	8.11	8.15	11.08	17.05	20.72	24.33
SEm±	**0.18**	**0.13**	**0.10**	**0.21**	**0.33**	**0.22**
CD (p=0.05)	**0.55**	**0.40**	**0.31**	**0.65**	**0.99**	**0.65**
CV (%)	**3.52**	**3.10**	**1.88**	**2.57**	**3.04**	**1.77**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

At 120 DAT, the number of leaves continued to increase significantly for most seed sources. Seed source S3 remained dominant, having the highest leaf count of 17.05 on average. Seed sources S4 and S7 also showed considerable leaf growth, reaching averages of 14.11 and 14.17 leaves, respectively. By 150 DAT, the leaf numbers displayed further growth. Seed sources S3 and S8 maintained their positions as the highest leaf count, with averages of 21.57 and 20.72 leaves, respectively. Seed sources S5 and S7 also demonstrated significant leaf development, with averages of 19.41 and 17.96 leaves, respectively. At the final stage of 180 DAT, the number of leaves continued to increase slightly for some seed sources. Seed sources S3 and S8 remained at the top with the highest leaf counts, averaging 25.05 and 24.33 leaves, respectively. Seed source S1 also showed notable leaf development, reaching an average of 20.04 leaves.

The dynamic changes in leaf number indicate significant variations in leaf initiation and development, with some seed sources consistently showing higher leaf counts throughout the experiment could be attributed to the availability of essential nutrients in the soil and their uptake by parent plants can influence seedling vigour and quality which in turn influences the leaf parameters (Annapurna *et al.*, 2005; Rakesh, 2012). Seed sources originating from environments with optimal nutrient levels and balanced nutrition might produce seedlings with better vigour and quality due to favorable nutrient status (Mathew and Vasudeva, 2003).

4.1.14 Influence of seed source on leaf parameters

Table 18 presents the influence of different seed source on leaf parameters of *S. album* seedlings over a period of 180 days. The leaf parameters assessed include leaf area, leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), and specific leaf weight (SLW). Leaf area represents the total surface area of individual leaves and is measured in square centimeters (cm^2). The significant difference was observed among all the treatments. Seed source S3 (Gottipura) exhibited the highest leaf area at both time points, with values of 10.08 cm^2 at 30 DAT and 12.93 cm^2 at 180 DAT. Seed source S2 (Doranalu) had the smallest leaf area at 30 DAT (6.35 cm^2).

Leaf Area Ratio (LAR) is the ratio of leaf area to total plant dry weight and provides insights into the efficiency of resource utilization by the leaves. Seed source S2 had the highest LAR at 30 DAT (43.54 cm^2g^{-1}) and 180 DAT (27.92 cm^2g^{-1}), indicating lowest leaf development and highest resource utilization. Seed source S3 had the lowest LAR at both time points suggesting that lowest resource utilization and effective leaf development. These findings are in line with (Annapurna *et al.,* 2005; Rakesh, 2012).

Leaf Weight Ratio (LWR) represents the proportion of leaf biomass to total plant dry weight and indicates the allocation of resources towards leaf growth. Seed source S8 had the highest LWR at both 30 DAT (0.58 g kg^{-1}) and 180 DAT (0.55 g kg^{-1}), indicating a relatively higher investment in leaf biomass. Leaf parameters like Leaf Area Ratio (LAR) and Leaf Weight Ratio (LWR) indicate how efficiently resources are allocated and utilized for leaf development. Higher LAR and lower LWR suggest a strategy of resource efficiency, directing resources toward higher leaf area relative to plant dry weight. In contrast, seed source S3 with lower LAR and higher LWR might prioritize biomass allocation to leaves (Divakara *et al.,* 2015).

Specific Leaf Area (SLA) is calculated as the leaf area per unit leaf dry weight and reflects the leaf thickness and density. Significant difference was observed among the treatments. Seed source S3 displayed the highest SLA at both 30 DAT (36.80 cm^2 mg^{-1}) and 180 DAT (29.79 cm^2 mg^{-1}), indicating relatively thicker and dense leaves. Seed source S8 had the lowest SLA at both time points.

Specific Leaf Weight (SLW) represents the leaf dry weight per unit leaf area and provides insights into leaf thickness and density. Seed source S8 exhibited the highest SLW at both 30 DAT (0.038 g cm^{-2}) and 180 DAT (0.026 g cm^{-2}), indicating thicker and denser leaves. Seed source S6 had the lowest SLW at 30 DAT; while S3 had the lowest SLW at 180 DAT. Specific Leaf Area (SLA) and Specific Leaf Weight (SLW) reflect leaf thickness and density, which are influenced by physiological adaptations. Thinner and less dense leaves, as indicated by higher SLA values in seed source S3, might be adapted for efficient light interception and photosynthesis. Thicker and denser leaves, represented by higher SLW in seed source S8, could indicate adaptations for conserving water or reducing transpiration (Loha *et al.,* 2006).

Table 18. Influence of different seed source on leaf parameters of *Santalum album* (L.)

Seed Sources	Leaf Parameters									
	Leaf area		LAR		LWR		SLA		SLW	
	30 DAT	180 DAT	30 DAT	180 DAT	30 DAT	180 DAT	30 DAT	180 DAT	30 DAT	180 DAT
S1	7.09	8.49	39.47	26.13	0.30	0.28	132.28	92.98	0.008	0.011
S2	6.35	7.69	43.54	27.92	0.29	0.30	152.22	93.81	0.007	0.011
S3	10.08	12.93	20.62	16.83	0.56	0.57	36.80	29.79	0.027	0.034
S4	7.09	8.04	37.57	23.85	0.33	0.30	114.92	80.71	0.009	0.012
S5	7.58	9.06	35.95	25.65	0.34	0.32	105.83	81.77	0.009	0.012
S6	8.03	8.84	42.81	24.50	0.33	0.26	130.29	95.35	0.008	0.010
S7	8.08	9.72	38.25	27.55	0.33	0.28	115.44	99.04	0.009	0.010
S8	10.11	12.40	20.90	15.02	0.55	0.58	38.19	26.08	0.026	0.038
SEm±	**0.10**	**0.16**	**0.76**	**0.44**	**0.02**	**0.01**	**1.89**	**1.97**	**0.000**	**0.001**
CD (p=0.05)	**0.29**	**0.48**	**2.31**	**1.32**	**0.04**	**0.02**	**5.70**	**5.95**	**0.001**	**0.002**
CV (%)	**2.09**	**2.88**	**3.79**	**3.24**	**3.73**	**3.89**	**3.16**	**4.55**	**3.804**	**4.083**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.15 Influence of seed source on vigour index and quality parameters

Table 19 shows the influence of different seed source on the vigour index and quality parameters of *S. album* seedlings. The Vigour Index (VI) is a measure of the seedlings vigour and health based on the germination percentage and height of the seedlings. Seed source S3 (Gottipura) has the highest VI (I) 1488.0, indicating that it produced seedlings with the highest initial vigour among the Karnataka seed sources. On the other hand, seed source S2 (Doranalu) has the lowest VI value of 372.0, suggesting that it produced seedlings with the lowest initial vigour. Overall, there are significant differences in the VI (I) values among the seed sources, with S3 and S8 showing significantly higher vigour compared to the other seed sources. The VI (II) represents the vigour of the seedlings with reference to the dry biomass production. Seed source S8 (Marayoor) has the highest VI (II) value of 24.00, indicating that it produced seedlings with the highest vigour. In contrast, seed source S2 (Doranalu) has the lowest VI (II) value of 3.00, suggesting that it produced seedlings with the lowest vigour. A positive trend was observed between germination percentage and VI (Fig. 5). Similar to VI (I), there are significant differences in VI (II) values among the seed sources, with S3 and S8 showing significantly higher vigour compared to the others. Genetic diversity among different seed sources plays a significant role in shaping the vigour and quality of seedlings. Each seed source may possess distinct genetic traits related to growth, resilience, and development, leading to variations in seedling vigour. Seed source S3 exhibiting consistently higher vigour and quality values might be due to favorable genetic characteristics that promote rapid establishment and growth (Loha *et al.*, 2006).

The Dickson Quality Index (DQI) is a measure of the overall quality of the seedlings. Seed source S8 has the highest DQI value of 0.258, indicating that it produced seedlings with the best overall quality. On the other hand, seed source S1 has the lowest DQI value of 0.084, suggesting that it produced seedlings with the lowest overall quality. There are significant differences in DQI values among the seed sources, with S3 and S8 showing significantly higher quality compared to the other seed sources.

Table 19. Influence of different seed source on vigour index and quality parameters of *Santalum album* (L.)

Seed Sources	VI (I) (Vigour Index)	VI (II) (Vigour Index)	DQI (Dickson Quality Index)	SQ (Sturdiness quotient)	BVI (Volume Index)
S1	483.0	5.00	0.084	19.03	0.279
S2	372.0	3.00	0.086	17.28	0.266
S3	1488	17.00	0.249	13.58	1.300
S4	580.0	6.00	0.101	17.36	0.400
S5	908.0	8.00	0.096	18.63	0.439
S6	635.0	7.00	0.091	16.99	0.340
S7	690.0	7.00	0.095	18.17	0.336
S8	2054	24.00	0.258	14.05	1.358
SEm±	**25.85**	**0.59**	**0.002**	**0.21**	**0.023**
CD (p=0.05)	**78.17**	**1.80**	**0.007**	**0.63**	**0.068**
CV (%)	**4.97**	**4.17**	**2.990**	**2.13**	**3.644**

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

The Sturdiness Quotient (SQ) measures the strength and stability of the seedlings. Seed source S1 has the highest SQ value of 19.03, indicating that it produced the seedlings with the least stability. Seed source S3 has the lowest SQ value of 13.58, suggesting that it produced seedlings with sturdiest and stable seedlings. There are significant differences in SQ values among the seed sources, with S3 and S8 showing significantly lower sturdiness compared to S1. In the seed sources where SQ was found highest in such seed sources VI was found lowest. Suggesting a negative trend between SQ and VI (Fig. 6).

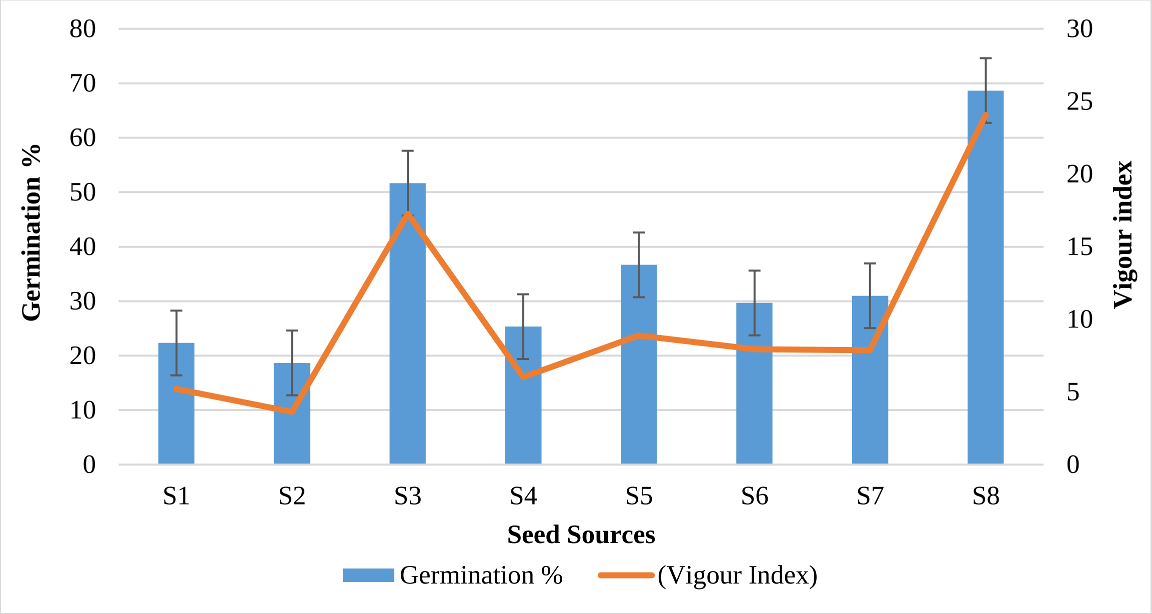


Fig. 5: Relationship between germination percentage and vigour index in *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

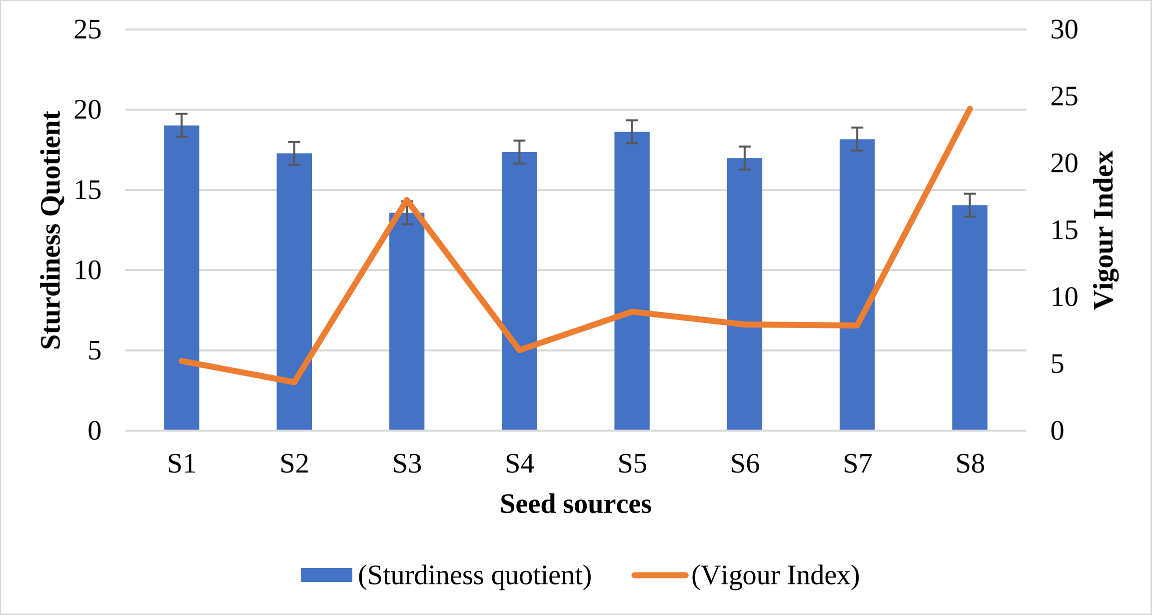


Fig. 6: Relationship between sturdiness quotient and vigour index in *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

The Bio Volume Index (BVI) represents the volume and growth of the seedlings. Seed source S8 has the highest BVI value of 1.358, indicating that it produced seedlings with the largest volume and most significant growth. Quality and volume index always follow a positive trend, indicating good quality seedlings where volume is recorded higher (Fig. 7). Seed source S2 has the lowest BVI value of 0.266, suggesting that it produced seedlings with the smallest volume and growth. Seed sources S3 and S8 consistently stand out, producing seedlings with higher vigour, better overall quality, larger volume, and more substantial growth compared to the other seed sources. These findings have important implications for the selection of seed sources for sandalwood cultivation, as choosing the right seed source can greatly influence the success and productivity of the plantation. The process of selecting parent plants for seed production can greatly influence seedling quality. Seed sources that are chosen based on desired traits, such as vigour and quality, are likely to yield seedlings with corresponding attributes. Seed source S8 producing seedlings with high vigour and quality values might be the result of careful selection and breeding for these traits (Annapurna *et al.*, 2005; Rakesh, 2012).

Fig. 7: Relationship between dickson quality index and volume index in *Santalum album* (L.)

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

Table 20. Benefit-Cost ratio of sandal seedlings raised from different seed sources

Inputs and Outputs	**Seed Sources**							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Total sum of production costs per seedling (₹)	19.10	21.21	19.98	23.11	19.81	23.76	19.99	33.45
Total sum of receipts per seedling (₹)	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
B-C ratio	1.83	1.66	1.75	1.51	1.77	1.47	1.75	1.05

S1- Bevinahally, S2-Doranalu, S3- Gottipura, S4- Gungaraghatti, S5- Muddenahally, S6- Narsapura, S7- Tavarekere, S8- Marayoor

4.1.16 Influence of seed source on benefit-cost ratio

The analysis of the benefit-cost ratio for sandalwood seedlings raised from different seed sources, encompassing a growth period of 180 days in the nursery (Table 20), reveals distinct levels of economic viability. The benefit-cost ratio (B-C ratio), a critical metric for evaluating financial efficiency, indicates the return on investment by comparing the total production costs with the receipts generated per seedling. Among the analyzed seed sources, S1-Bevinahally with a B-C ratio of 1.83, suggesting a promising financial return of 1.83 rupees for every rupee invested in seedling production. Similarly, S3-Gottipura and S5-Muddenahally also exhibit strong economic viability with B-C ratios of 1.75 and 1.77 respectively, emphasizing the potential for profitable returns. But S8 presents a BC ratio of 1.05, indicating a marginal return on investment, urging a closer examination to optimize the economic feasibility of seedling production. By comparing B-C ratio with germination performance, seedling characters and quality indices (S2-Gottipura) seed source proved to be potential enough to use as seed source for future plantation activities.

4.2 Effect of different priming treatments on seed germinability in Sandal.

Seed priming helps in achieving a higher and more uniform germination rate by initiating the early stages of germination. This can lead to a more synchronized and consistent emergence of seedlings, ultimately improving crop establishment.

4.2.1 Effect of *Pseudomonas fluorescens* biopriming on germination

Biopriming, also known as biological priming or seed biofortification, is a seed treatment technique that involves the application of beneficial microorganisms (e.g., bacteria, fungi) or their products to seeds before planting. This method aims to enhance seed germination, seedling growth, stress tolerance, and overall plant health. Table 21 presents the results of the effects of biopriming utilizing varying concentrations of *Pseudomonas fluorescens* over different durations on the germination attributes of sandal seeds. The crucial parameters evaluated included Germination Percentage (GP), Time Taken to Initiate Germination (TTIG), Time Taken to Complete Germination (TTCG), Mean Daily Germination (MDG), Peak Value of Germination (PV), and Germination Value (GV). The concentrations of *Pseudomonas fluorescens* ranged from 25(%) to 100(%), and the biopriming durations varied from 1 to 4 days.

Germination percentage showed increment with higher concentrations of *Pseudomonas fluorescens.* The most notable augmentation was observed at the 3-day duration with a 25(%) concentration (C1P4), presenting the highest germination percentage (37.67), followed by 25.67 per cent of germination in four day duration and 25(%) concentration. The lowest germination percentage was observed in 100(%) concentration for two days of duration.

Both TTIG and TTCG exhibited a consistent decline with increasing concentrations of *Pseudomonas fluorescens.* This suggests that seeds treated with higher concentrations displayed accelerated germination. Longer durations further accentuated this effect, contributing to a reduction in the time taken for both to initiate and complete germination. Same trend was observed in MDG with higher concentrations of *Pseudomonas fluorescens*. The most significant effect was observed at the 3-day duration with a 25(%) concentration (C1P4), showcasing an enhanced daily germination rate. Both PV and GV decreased with higher concentrations, implying the positive impact of biopriming with *Pseudomonas fluorescens* in lower concentration for seedling growth of sandal.

Table 21: Effect of *Pseudomonas fluorescens* biopriming on the germination and its attributes in *Santalum album* (L.)

Pseudomonas fluorescens		**GP (%)**	**TTIG**	**TTCG**	**MDG**	**PV**	**GV**
Concentration (%)	**Duration (days)**						
25	**1**	14.33	28.33	67.33	0.21	0.25	0.053
	2	21.33	24.00	65.00	0.33	0.38	0.124
	3	37.67	19.00	51.33	0.73	1.01	0.743
	4	25.67	22.67	63.00	0.41	0.42	0.172
50	**1**	12.33	27.00	74.67	0.16	0.18	0.030
	2	10.33	25.67	71.00	0.14	0.18	0.026
	3	14.67	23.67	68.33	0.22	0.25	0.054
	4	10.00	25.33	70.67	0.14	0.16	0.022
75	**1**	6.00	27.67	79.33	0.08	0.10	0.008
	2	4.33	25.33	80.67	0.05	0.08	0.005
	3	10.67	22.67	75.67	0.14	0.18	0.025
	4	8.67	25.67	78.00	0.11	0.14	0.015
100	**1**	5.00	30.00	75.00	0.07	0.09	0.006
	2	3.00	28.00	78.33	0.04	0.07	0.003
	3	7.33	25.67	75.00	0.10	0.13	0.013
	4	6.00	25.00	84.33	0.07	0.09	0.006
Interaction (CxD)	**SEm±**	**0.37**	**0.33**	**0.36**	**0.07**	**0.04**	**0.030**
	CD (P=0.05)	**1.08**	**0.96**	**1.05**	**0.01**	**0.01**	**0.013**
	CV (%)	**3.16**	**2.23**	**0.85**	**4.89**	**2.38**	**3.521**

The most effective treatment condition emerged as 3-day duration with a 25(%) concentration of *Pseudomonas fluorescens*. This combination facilitated the highest germination percentage, rapid germination, and robust seedling growth, presenting an optimal strategy for sandalwood propagation. Seed priming initiates the essential metabolic processes favouring the enhanced seed germination. Rapid, efficient and uniform seed germination is important in crop propagation. Biopriming is the treatment of seeds with beneficial microorganisms under controlled hydration which enhances the preparatory processes prior to germination without radicle emergence. The unique achievements of the primed seeds includes, increased germination rate, greater uniform germination, and greater total germination percentage (Barsa *et al.,* 2005).

The results of biopriming with *P. fluorescens* demonstrated that it can increase the germination percent of sandal seeds, and the results are in conformity with similar results on biopriming of *Abies hickelii* seeds with *P. fluorescens* which increased the germination percent by 91(%) compare to the control. *Pseudomonas fluorescens* can solubilize minerals, such as phosphorus, making them more available to plants. Phosphorus is an essential nutrient for seed germination and plant growth. (Rodriguez *et al.,* 2015). The strains of *Pseudomonas fluorescens* can produce several plant growth regulating phytohormones, including IAA (indole – 3 acetic acid) (Jeon *et al*., 2003).

4.2.2 Effect of *Trichoderma viride* biopriming on germination

The results demonstrate that varying concentrations of *Trichoderma viride* and different durations of biopriming significantly influence the germination attributes of sandal seeds (Table 22). Higher concentrations of *Trichoderma viride* and longer durations generally led to improved germination. Notably, the 100(%) concentration for 4 days consistently exhibited the highest and significant values for multiple germination attributes, indicating its potential as an effective treatment to enhance sandal seed germination.

Significant differences were observed for GP across concentrations and durations. The highest germination percentage was significantly noted at 100(%) concentration for 4 days (C4P4), with a value of 60.67(%). Treatment with 25(%) concentration for 1 day exhibited the lowest germination percentage of 8.67. The lowest time for germination initiation was observed at 100(%) concentration for 4 day duration, i.e., 18 days followed by 18.67 days in 100(%) concentration for two and three days of duration. The highest time taken to initiate germination was observed in 25(%) concentration and 1 day of priming duration (C1P1). The lowest time for complete germination was observed at 100(%) concentration for 4 days, with a value of 50.33 days. The highest time taken to complete germination was observed at 25(%) concentration for 1 day duration which is as high as 85.33 days.

Table 22. Effect of *Trichoderma viride* biopriming on the germination and its attributes in *Santalum album* (L.)

Trichoderma viride		**GP (%)**	**TTIG**	**TTCG**	**MDG**	**PV**	**GV**
Concentration (%)	**Duration (days)**						
25	**1**	8.67	30.33	85.33	0.103	0.123	0.013
	2	9.67	29.00	84.00	0.117	0.130	0.015
	3	11.33	31.00	82.33	0.137	0.153	0.021
	4	10.00	27.67	80.33	0.127	0.143	0.018
50	**1**	20.67	26.00	78.67	0.263	0.277	0.073
	2	23.33	24.67	77.00	0.303	0.323	0.098
	3	25.33	24.00	76.33	0.330	0.353	0.117
	4	28.00	24.67	76.00	0.370	0.383	0.141
75	**1**	35.67	23.33	68.67	0.520	0.540	0.281
	2	38.33	22.33	65.00	0.587	0.617	0.364
	3	40.67	21.33	62.67	0.650	0.670	0.435
	4	45.33	20.33	61.00	0.743	0.760	0.565
100	**1**	49.00	19.33	58.67	0.833	0.863	0.721
	2	54.67	18.67	56.00	0.973	1.153	1.127
	3	57.67	18.67	54.00	1.067	1.093	1.168
	4	60.67	18.00	50.33	1.207	1.233	1.487
Interaction (CxD)	**SEm±**	**0.33**	**0.34**	**0.25**	**0.006**	**0.014**	**0.017**
	CD (P=0.05)	**0.97**	**0.95**	**0.72**	**0.017**	**0.039**	**0.049**
	CV (%)	**1.79**	**2.41**	**1.61**	**1.968**	**3.345**	**3.115**

Significant differences were identified for MDG. The highest mean daily germination was observed at 100(%) concentration for 4 days (C4P4), with a value of 1.207. The highest peak value of germination was significant at 100(%) concentration for 4 days, with a value of 1.233. The highest germination value was observed at 100(%) concentration for 4 days, with a value of 1.487. The lowest germination value was recorded in the treatment of 1 day duration of biopriming with 25(%) of concentration. *Trichoderma* spp. was recently suggested as a Plant Growth Promoting Fungi (PGPF) due to their ability to produce siderophore, phosphate-solubilizing enzymes, and phytohormones (Doni *et al.*, 2014). *Trichoderma* induces the plant IAA production and improve seedling quality (Gravel *et al.,* 2006). *Trichoderma spp*. have been proven to induce positive plant growth promotion potential in enhancing the rice seed germination and vigour (Doni *et al.,*2014) and in Capsicum also the *T.viride* enhanced the germination percentage (Ananthi *et al*., 2014). Chitra (2019) also reported the superiority of biopriming treatments in sandal (88% germination with 100% concentration bioinoculant for 8 days).

4.2.3 Effect of Manganese sulfate ($MnSO_4$) nutripriming on germination

The influence of various molar concentrations of $MnSO_4$ and different durations of nutripriming on the germination attributes of sandal seeds were shown in Table 23. Germination Percentage (GP) increased with higher concentrations up to 0.4M. Later it started decreasing with increasing concentration $MnSO_4$ and duration of priming. The highest germination percentage was observed at 0.4M for 3 days (C2P3-84.00%), while the lowest was at 0.8M for 4 days (C4P4-18.33%).

Time taken to initiate germination generally increased with higher molar concentrations. The lowest TTIG was observed at a molar concentration of 0.4M for 3 days (C2P3-16.00 days), indicating quicker germination initiation followed by 0.4M concentration for 2 days nutripriming duration (C2P2-17.67 days). Time taken to complete germination also increased with higher molar concentrations and shorter durations. The shortest TTCG was observed at a molar concentration of 0.4M for 3 days (C2P3-48.00 days), indicating faster germination completion.

Table 23. Effect of Manganese sulfate nutripriming on the germination and its attributes in *Santalum album* (L.)

$MnSO_4$		GP (%)	TTIG	TTCG	MDG	PV	GV
Concentration (M)	**Duration (days)**						
0.2	**1**	50.67	20.67	61.33	0.830	0.847	0.700
	2	57.33	20.00	63.67	0.900	0.920	0.829
	3	60.67	19.00	58.67	1.030	1.053	1.089
	4	50.67	20.67	60.00	0.843	0.863	0.729
0.4	**1**	70.67	18.00	50.67	1.393	1.417	1.977
	2	78.67	17.67	48.67	1.617	1.633	2.641
	3	84.00	16.00	48.00	1.750	1.770	3.098
	4	79.00	18.00	52.00	1.520	1.537	2.335
0.6	**1**	58.67	24.33	61.67	0.953	0.973	0.926
	2	40.33	28.67	70.00	0.573	0.597	0.344
	3	38.33	33.00	73.67	0.520	0.543	0.283
	4	30.00	34.67	75.00	0.400	0.420	0.168
0.8	**1**	28.67	35.00	76.33	0.377	0.397	0.149
	2	25.00	38.00	77.67	0.320	0.333	0.107
	3	20.67	38.33	78.67	0.263	0.290	0.076
	4	18.33	39.67	81.33	0.227	0.237	0.053
Interaction (CxD)	**SEm±**	**0.35**	**0.31**	**0.40**	**0.010**	**0.010**	**0.022**
	CD (P=0.05)	**1.02**	**0.90**	**1.15**	**0.028**	**0.029**	**0.065**
	CV (%)	**1.20**	**2.03**	**1.06**	**1.959**	**2.008**	**4.081**

Significant difference was observed in Mean daily germination. The highest MDG was observed at a concentration of 0.4M for 3 days (C2P3-1.750), followed by same molar concentration of 2 days priming duration (C2P2-1.617) indicating a higher rate of germination per day. Lowest MDG was recorded in 0.8M concentration of $MnSO_4$ for 4 days of primng duration (C4P4-0.227). The highest PV was observed at a concentration of

0.4M for 3 days (1.770), indicating the maximum rate of germination. Germination value decreased with higher molar concentrations. The highest GV was observed at a molar concentration of 0.4M for 3 days (3.098), indicating an overall higher value of germination.

The results demonstrate that increasing the molar concentration of $MnSO_4$ up to certain extent led to better germination attributes, including higher germination percentage, faster initiation and completion of germination, higher mean daily germination, and increased peak value of germination. Shorter durations also contributed to improved germination attributes. Seed priming initiates the essential metabolic processes favouring the enhanced seed germination. Rapid, efficient and uniform seed germination is important in crop propagation. Nutripriming initiates the essential metabolic processes favouring the enhanced seed germination. Rapid, efficient and uniform seed germination is important in crop propagation. Increased germination rate and uniformity is attributed to metabolic repair during imbibition (Bray *et al.,* 1989), enhancement of germination promoting metabolites (Barsa *et al.,*2005), osmotic adjustments (Bradford,1986) and for seeds that are not re-dried after treatment, a simple reduction in lag time of inhibitions (Bradford,1986).

For instance, nutripriming with $MnSO_4$ could increase germination by 91% compared to the control which was in conformity with the substantial increase in the germination of many crops due to nutripriming with $MnSO_4$ (Munawar *et al.,* 2013; Muhammad *et al.,* 2015; Mirlotf *et al.,* 2015; Sreepriya and Girija 2019). The increase in the duration of the nutripriming signifcantly reduced germination at all concentrations. This might be due to Mn toxicity occurring in seeds due to increased soaking period, which prevents germination as well as further seedling growth, as reported in wheat (Burke *et al.,* 1990).

4.2.4 Effect of Potassium nitrate (KNO_3) nutripriming on germination

The impact of nutripriming using varying concentrations of potassium nitrate (KNO_3) and different durations of priming on the germination attributes of sandal seeds are presented in Table 24. The Germination Percentage (GP) exhibited significant variation among different concentrations and durations of KNO_3 nutripriming. The treatment with

2.0% KNO_3 for a 4-day duration (C4P4) resulted in the significantly highest germination percentage (79.67%) followed by 73.00 (%) GP in same concentration of KNO_3 and 3-day duration of nutripriming (C4P3). Conversely, the lowest germination percentage (24.00%) was observed at 0.5(%) KNO_3 for 1-day duration of nutripriming (C1P1).

Table 24. Effect of Potassium nitrate nutripriming on the germination and its attributes in *Santalum album* (L.)

KNO_3		**GP (%)**	**TTIG**	**TTCG**	**MDG**	**PV**	**GV**
Concentration (%)	**Duration (days)**						
0.5	**1**	24.00	28.67	64.33	0.373	0.397	0.148
	2	25.33	28.00	63.00	0.403	0.423	0.170
	3	30.67	26.67	61.67	0.497	0.513	0.255
	4	32.67	27.00	60.67	0.537	0.557	0.300
1.0	**1**	44.67	25.00	59.67	0.747	0.763	0.572
	2	47.33	23.33	58.00	0.817	0.843	0.689
	3	51.00	23.00	55.00	0.927	0.943	0.876
	4	54.33	22.67	55.00	0.987	0.417	0.415
1.5	**1**	56.00	21.00	52.67	1.067	1.087	1.156
	2	58.67	20.00	50.00	1.173	1.187	1.392
	3	61.33	19.67	48.67	1.260	1.280	1.614
	4	63.00	19.00	48.00	1.310	1.330	1.746
2.0	**1**	68.33	18.33	45.00	1.517	1.540	2.339
	2	70.67	17.33	44.33	1.593	1.613	2.573
	3	73.00	16.67	43.67	1.673	1.693	2.831
	4	79.67	16.00	40.67	1.960	1.980	3.880
Interaction (CxD)	**SEm±**	**0.37**	**0.27**	**0.28**	**0.012**	**0.078**	**0.242**
	CD (P=0.05)	**0.94**	**0.80**	**0.83**	**0.034**	**0.224**	**0.084**
	CV (%)	**1.07**	**2.20**	**0.90**	**1.601**	**1.318**	**1.132**

The Time taken to initiate germination (TTIG) was significantly affected by the concentration and duration of KNO_3 priming. The treatment with 2.0(%) KNO_3 for 4 days demonstrated the significantly shortest TTIG (16.00 days), indicating faster initiation of germination. In contrast, 0.5(%) KNO_3 for 1 day showed the significantly longest TTIG (28.67 days). TTCG varied significantly with different molar concentrations and durations. The treatment with 2.0% KNO_3 for 4 days resulted in the significantly shortest TTCG (40.67 days), indicating quicker germination completion. Conversely, 0.5(%) KNO_3 for 1 day exhibited the significantly longest TTCG (64.33 days).

Mean Daily Germination (MDG) showed significant variation across treatments. The treatment with 2.0(%) KNO_3 for 4 days demonstrated the significantly highest MDG (1.960), suggesting a higher rate of germination per day. On the other hand, the significantly lowest MDG (0.373) was recorded for 0.5(%) KNO_3 for 1 day duration of nutripriming. The Peak Value of Germination (PV) significantly varied with different treatments. The highest PV (1.980) was observed in the treatment with 2.0(%) KNO_3 for 4 days, indicating the maximum rate of germination. Conversely, the significantly lowest PV (0.397) was recorded 0.5(%) KNO_3 for 1-day duration of nutripriming. Germination Value (GV) exhibited significant differences among treatments. The treatment with 2.0(%) KNO_3 for 4 days showed the significantly highest GV (3.880), indicating an overall higher value of germination. In contrast, the significantly lowest GV (0.148) was observed at 0.5(%) KNO_3 for 1 day. These results underline the influence of different concentrations and durations of KNO_3 nutripriming on the germination attributes of sandal seeds, providing crucial insights for optimizing germination protocols in sandalwood cultivation. The increase in germination of the nutriprimed seeds can be attributed to synthesis of plant or tree growth hormones and enhancement of nutrient availability (Deepa *et al.*, 2010). With the adoption of nutripriming, the total germination period of sandal seeds was reduced by half from 8 to 26 days. Nutripriming treatments could also reduce the days to initiate germination from 14 days to 9 days (Sudheesh *et al.*, 2016).

Hydropriming, a seed treatment technique, involves soaking seeds in water for a specific duration before sowing to initiate the germination process. Though hydropriming offers several advantages, it’s important to consider potential drawbacks or demerits associated with this method. Table 25 shows the effect of hydropriming at various durations on the germination attributes of sandal seeds. The Germination Percentage (GP) exhibited variability based on the hydropriming duration. Hydropriming for 4 days resulted in the highest germination percentage (16.67%), followed by 10.33(%) of germination in 3 days duration of hydropriming. The lowest germination percentage (2.67%) was recorded at hydropriming duration of 1 day.

Table 25. Effect of hydropriming on the germination and its attributes in *Santalum album* (L.)

Hydropriming (days)	**GP (%)**	**TTIG**	**TTCG**	**MDG**	**PV**	**GV**
1	2.67	45.33	83.00	0.032	0.057	0.002
2	3.00	42.33	80.00	0.038	0.057	0.002
3	10.33	39.00	75.67	0.137	0.160	0.022
4	16.67	37.67	72.33	0.230	0.257	0.059
SEm±	**0.41**	**0.58**	**00.37**	**0.005**	**0.004**	**0.001**
CD (P=0.05)	**1.35**	**1.91**	**01.23**	**0.018**	**0.014**	**0.005**
CV (%)	**8.66**	**2.43**	**00.83**	**3.437**	**2.337**	**1.212**

Time Taken to Initiate Germination (TTIG) was affected by the hydropriming duration. The shortest TTIG was observed at 4 days of hydropriming (37.67 days), indicating quicker germination initiation. Conversely, the longest TTIG (45.33 days) was recorded at hydropriming duration of 1 day. Time Taken to Complete Germination (TTCG) increased with shorter hydropriming durations. The shortest TTCG was observed at 4 days of hydropriming (72.33 days), indicating faster germination completion. Conversely, the longest TTCG (83.00 days) was recorded at hydropriming duration of 1 day.

Mean Daily Germination (MDG) showed a similar trend to TTCG. The highest MDG was observed at 4 days of hydropriming (0.230), suggesting a higher rate of germination per day. In contrast, the lowest MDG (0.032) was recorded at hydropriming duration of 1 day. The Peak Value of Germination (PV) demonstrated variability based on hydropriming duration. Hydropriming for 4 days resulted in the highest PV (0.257), indicating the maximum rate of germination. Conversely, the lowest PV (0.057) was recorded at a hydropriming duration of 1 day.

Germination Value (GV) exhibited variation with hydropriming duration. The highest GV was observed at 4 days of hydropriming (0.059), indicating an overall higher value of germination. In contrast, the lowest GV (0.002) was recorded at hydropriming duration of 1 day. Compared to all other methods of priming lowest performance was observed in hydropriming. These results highlight the effect of hydropriming at various durations on the germination attributes of sandal seeds. The findings are crucial for optimizing hydropriming protocols in sandalwood cultivation. Hydropriming increases activities of antioxidant enzymes like superoxide dismutase, peroxidase, and catalase and ascorbate peroxidase. (Huang *et al.*, 2006). In fact, increased level of antioxidant enzymes protects the cell against oxidative damage by removal of free radicals or reactive oxygen species (Ahmed *et al.*, 2012). The germination trial indicated that all the biopriming treatments can enhance the germination of sandal seeds compared to hydropriming.

4.2.6 Benefit-Cost ratio of sandal seedlings

Table 26 presents the benefit-cost ratios (B-C ratios) associated with employing different priming methods of *S. album* seeds over a 180-day period in nursery. The B-C ratio serves as a pivotal economic indicator, demonstrating the cost-effectiveness and financial feasibility of employing distinct priming methods in the seedling production process. The total production costs per seedling varied among the priming methods, with $MnSO_4$ representing the most cost-effective option at ₹21.04 per seedling, followed closely by KNO_3 at ₹ 22.11 per seedling. Though hydropriming recorded highest B-C ratio considering its poor performance that priming method was not recommendable. These findings are important in selection of priming techniques, as the economic viability significantly impacts the overall success and sustainability of *S. album* seedling production.

Table 26. Benefit-Cost ratio of sandal seedlings raised by using different priming methods

Inputs and Outputs	Priming methods				
	PF	TV	$MnSO_4$	KNO_3	HP
Total sum of production costs per seedling (₹)	26.89	26.01	21.04	22.11	18.18
Total sum of receipts per seedling (₹)	35.00	35.00	35.00	35.00	35.00
B-C ratio	1.30	1.35	1.66	1.59	1.94

PF- *Pseudomonas fluorescens,* TV- *Trichoderma viridae,* $MnSO_4$- Manganese Sulphate, KNO_3- Potassium Nitrate, HP- Hydropriming

4.3 Selection of suitable planting container and optimization of potting media for quality stock production

The selection of an appropriate planting container and optimization of potting media are crucial aspects for quality stock production in plant nurseries. The choice of container affects root development, aeration, and drainage, directly impacting the growth and health of seedlings. Optimal potting media composition ensures proper water retention, nutrient availability, and root anchorage, facilitating robust seedling growth. Together, these elements contribute to consistent and healthy seedling production, setting the foundation for successful transplantation and enhanced overall crop yield and better nursery management regime.

4.3.1 Influence of different containers and potting media on shoot length

To produce large scale sandal plantations in non-forest areas or private plantation, quality seedlings is the pre-requisite. In this context, best suited growing media is necessary for the production of high-quality seedlings. The growing media and planting container in which seedlings are raised has an important bearing on the quality of nursery stock. Table 27 presents the shoot length of *S. album* seedlings under different container (C) and potting media (P) combinations up to 180 days. At 30 DAT, seedlings planted in container C4 (9.09 cm) when filled with potting media P2. Combination C4P2 (Poly bag of 30 cm x20cm; Soil+ Rice husk + FYM in 2:1:1) recorded highest growth. This was closely followed by combination C4P1 (Poly bag of 30 cm x20cm; Soil+ Coir pith compost + FYM in 2:1:1). In contrast, container C1 (Root trainer of 150 cc) with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) displayed the lowest shoot length (5.09 cm) at this early stage.

At 60 DAT, container C4 (Poly bag of 30 cm x20cm) with potting media P2 (Soil+ Rice husk + FYM in 2:1:1) consistently showed superior growth, reaching a shoot length of 10.34 cm. Conversely, container C1 (Root trainer of 150 cc) filled with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) continued to demonstrate the least growth (5.38 cm) among all treatments. Same trend was followed at 90 DAT, container C4 combined with potting media P2 continued its dominance with a shoot length of 12.63 cm, emphasizing its positive effect on growth. The least growth was observed in container C1 with potting media P4, with a shoot length of 6.11 cm.

Progressing to 120 DAT, container C4 and potting media P2 remained the most effective and significantly different treatment combination, resulting in a shoot length of 14.11 cm. Container C1 with potting media P4 maintained its position as the least effective treatment, with a shoot length of 7.12 cm. At 150 DAT, container C4 and potting media P2 continued to excel, producing a shoot length of 12.63 cm. Conversely, container C1 with potting media P4 recorded the lowest shoot length at 8.99 cm.

The final assessment at 180 DAT reinforced the superior growth observed in container C4 with potting media P2, showcasing a shoot length of 14.81 cm. On the contrary, container C1 with potting media P4 displayed the lowest growth at 11.35 cm. Producing large-sized seedling stock prior to planting may also improve seedling growth and survival rates during the critical early period of seedling establishment and although this may increase initial costs, the increased likelihood of canopy closure may reduce the need for future expenditure on follow-up plantings and prolonged grass and weed control and also using large stock was advantageous when planting areas had excessive herbaceous competition (Egnell and Leijon, 1999).

Table 27. 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 (CxP)	**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**

C1-Root trainer of 150 cc	P1- Soil+ Coir pith compost + FYM in 2:1:1
C2-Root trainer of 300 cc	P2- Soil+ Rice husk + FYM in 2:1:1
C3-Poly bag of 25cm x15cm	P3- Soil+ Perlite + FYM in 2:1:1
C4-Poly bag of 30 cm x20cm	P4- Soil+ M-Sand +FYM in 2:1:1
	P5- Soil+ River sand+ FYM in 2:1:1

Two different sizes of root trainers are used in this study and growth progression was recorded (Plate 10). This progression in growth can be attributed to the long-term effects of potting media on nutrient availability and root development. Potting media P2 (Soil + Rice husk+ FYM in 2:1:1) seems to sustain optimal nutrient levels, promoting steady and significant growth. This may be due to rice husk created lighter and friable growth medium which resulted in an almost loose root plug formation. A firm and cohesive root plug is very important for container seedlings because it facilities water and nutrient uptake by the roots as well as the seedling extraction. Composted rice husk is reported to serve as a practical soil substitute for plants grown in containers (Laiche and Nash, 1990).

4.3.2 Influence of different containers and potting media on root length

Root length is a critical parameter as it directly correlates with the overall health and nutrient uptake capacity of seedlings. Table 28 shows the root length in *S. album* seedlings over duration of 180 days focusing on the effects of various containers (C) and potting media (P). At 30 DAT, container C4 (Poly bag of 30 cm x 20 cm) filled with potting media P2 (Soil+ Rice husk + FYM in 2:1:1) exhibited the highest root length (8.50 cm). The treatment combination C4P2 is followed by container C3 (Poly bag of 25cm x15cm) and the potting media P2 (Soil+ Rice husk + FYM in 2:1:1) with the root length of 8.05 cm. In contrast, container C1 (Root trainer of 150 cc) paired with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) displayed the lowest root length (3.50 cm) at this early stage. At 60 DAT, container C4 with potting media P2 maintained its significant difference, resulting in the longest roots (9.40 cm). In contrast, container C1 with potting media P4 continued to display the least growth (4.46 cm) among all treatments.

At 90 DAT, container C4 with potting media P2 once again demonstrated the highest root length (10.99 cm), emphasizing its positive effect on root growth. Container C1 with potting media P4 recorded the least root length at this stage (6.37 cm). Progressing to 120 DAT, container C4 with potting media P2 maintained its position as the most effective treatment, resulting in the longest roots (11.36 cm). Container C1 with potting media P4 displayed the lowest root length at 6.99 cm.

Table 28. Influence of different containers and potting media on root length 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 (CXP)	**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**

C1-Root trainer of 150 cc	P1- Soil+ Coir pith compost + FYM in 2:1:1
C2-Root trainer of 300 cc	P2- Soil+ Rice husk + FYM in 2:1:1
C3-Poly bag of 25cm x15cm	P3- Soil+ Perlite + FYM in 2:1:1
C4-Poly bag of 30 cm x20cm	P4- Soil+ M-Sand +FYM in 2:1:1
	P5- Soil+ River sand+ FYM in 2:1:1

At 150 DAT, container C4 with potting media P2 continued to excel, producing the longest roots (11.36 cm). Container C1 with potting media P4 continued to exhibit the least growth at 8.02 cm. The final assessment at 180 DAT reinforced the superior growth observed in container C4 with potting media P2, showcasing the longest roots at 12.18 cm. This might be attributed to poly bag raised seedlings produces fibrous root system which absorb water and nutrients from the soil more efficiently, ultimately leading to better growth and survival (Benson and Shephered, 1977).

The maximum root length at early stage recorded in P2, the results are supported by Hartmann *et al.* (2007). They observed that higher amount of rice husk, vermiculite, perlite and peat moss in the media and combinations of these materials aids anchorage of young roots and promotes faster root growth in early stage.

4.3.3 Influence of different containers and potting media on total height

Total height of *S. album* seedlings over a 180-day period, emphasizing the influence of containers (C) and potting media (P) on the growth and development of the seedlings were recorded in Table 29. At 30 DAT, the total height of *S. album* seedlings varied significantly across different treatments. Container C2, particularly when combined with potting media P2, exhibited the tallest seedlings with a mean height of 12.70 cm. Treatment C1 (Root trainer of 150 cc) paired with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) demonstrated the shortest seedlings with an average height of 8.59 cm.

Variation in height can be attributed to the varying effects of potting media on the initial growth of the seedlings. Potting media P2 (Soil+ Rice husk + FYM in 2:1:1), being rich in essential nutrients and providing adequate aeration, seems to have a positive influence on the early growth stages. Conversely, potting media P4, which might lack essential nutrients, could be hindering the initial growth.

At 60 DAT, the trends in total height growth persist. Treatment C4 with potting media P2 yielded the tallest seedlings with a mean height of 18.99 cm, showcasing a substantial growth rate. In contrast container C1 paired with potting media P4 continued to produce the shortest seedlings, with an average of 9.85 cm. It is important to note the significance of the containers in facilitating growth. Container C4, presumably providing ample space and conducive conditions for root development, appear to enhance overall growth compared to container C1, which might have space limitations.

At 90 DAT, the impact of the potting media on total height is quite evident. Treatment C4 with potting media P2 once again led to the tallest seedlings, with an average height of 20.28 cm. But treatment C1 paired with potting media P4 demonstrated the least growth, yielding seedlings with an average height of 11.27 cm. Upon reaching 120 DAT, treatment C4 with potting media P2 recorded significantly higher growth in terms of total height, with seedlings reaching an average height of 22.70 cm. This suggests that treatment C4 and the nutrient-rich potting media P2 have a long-term positive influence on the growth of *S. album* seedlings. Whereas, treatment C1 with potting media P4 resulted in the least growth, with an average height of 13.49 cm.

At 150 DAT, container C4 with potting media P2 continued to demonstrate the highest growth rate, yielding seedlings with an average height of 24.34 cm. On the other hand, treatment C1 with potting media P4 still had the least growth, with an average height of 15.98 cm. The growth trend observed at 120 DAT persisted, emphasizing the role of potting media in sustaining growth during the later stages of the growth cycle. Potting media P2 seems to provide the necessary nutrients and conditions for sustained growth, while potting media P4 appears to be less effective in promoting growth.

Finally, at 180 DAT, treatment C4 with potting media P2 remained the most effective in promoting total height, resulting in an average height of 26.98 cm. Container C1 with potting media P4 continued to have the least growth, with an average height of 18.86 cm. This substantial growth in the later stages is crucial for the eventual successful transplantation of the seedlings. The seedlings reaching a considerable height by 180 DAT suggest a healthy growth trajectory and a strong potential for further development.

Table 29. Influence of different containers and potting media on seedling height of *Santalum album* (L.)

Treatments		**Seedling 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 (CxP)	**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**

C1-Root trainer of 150 cc
C2-Root trainer of 300 cc
C3-Poly bag of 25cm x15cm
C4-Poly bag of 30 cm x20cm

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

Plate 8: **Standard potting media (Soil:Sand:FYM) used in the study to raise sandal seedlings**

Plate 9: **Alternate media for River sand (Rice husk, Coirpith compost and Perlite) used in the study to raise sandal seedlings**

This progression in growth can be attributed to the long-term effects of potting media on nutrient availability and root development. Potting media P2 seems to sustain optimal nutrient levels, promoting steady and significant growth throughout the period. The differences observed in growth became more pronounced as the seedlings aged. Potting media P2 may have sustained its nutrient availability over the long term, ensuring consistent growth. Meanwhile, potting media P4, which seemed less effective, may have exhausted its nutrient supply sooner. Adequate aeration and drainage in the potting media are vital for root health. Potting media P2 may have provided better aeration, ensuring that oxygen reached the root system efficiently. This improved oxygen supply can enhance nutrient uptake and stimulate growth (Prajapathi and Tandel, 2021; Annapurna *et al.,* 2005; Rathore *et al.,* 2004).

4.3.4 Influence of different containers and potting media on collar diameter

The effect of containers and Potting media on collar diameter of *S. album* seedling up to 180 days is recorded in Table 30. At 30 DAT, treatment C4 (Poly bag of 30 cm x20cm) with potting media P2 (Soil+ Rice husk + FYM in 2:1:1) exhibited the significantly largest collar diameter, measuring 1.823 cm. Treatment C1 (Root trainer of 150 cc) with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) had the smallest collar diameter at 0.647 cm. These differences suggest that both the choice of container and potting media significantly impact the initial collar diameter of *S. album* seedlings.

Upon reaching 60 DAT, the collar diameter of seedlings increased across all treatments. Container C4 with potting media P2 continued to lead in collar diameter, measuring 1.907 cm, while treatment C1 with potting media P4 still had the smallest collar diameter at 0.767 cm. The differences in collar diameter between treatments highlight the ongoing influence of both containers and potting media on the growth of the seedlings. At 90 DAT, the collar diameter of all seedlings increased further. Container C4 with potting media P2 maintained the largest collar diameter at 2.083 cm, while treatment C1 with potting media P4 had the smallest collar diameter at 0.850 cm.

Table 30. 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 (CxP)	**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**

C1-Root trainer of 150 cc
C2-Root trainer of 300 cc
C3-Poly bag of 25cm x15cm
C4-Poly bag of 30 cm x20cm

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

After 120 days of transplantation container C4 with potting media P2 still exhibited the largest collar diameter, with an average of 2.120 cm. Container C1 with potting media P4 had the smallest collar diameter at 0.950 cm. The difference in collar diameter between treatments underscores the enduring effect of the chosen containers and potting media throughout the growth period. At 150 DAT, the collar diameter of seedlings continued to increase. Container C4 with potting media P2 remained at the forefront, with collar diameter of 1.927 cm. On the other hand, container C1 with potting media P4 recorded the smallest collar diameter at 1.060 cm. This suggests that container C4, especially when paired with potting media P2, provides optimal conditions for the collar diameter development of *S. album* seedlings.

Finally, at 180 DAT, container C4 with potting media P2 maintained its significant difference in collar diameter, measuring 2.517 cm. Conversely, container C1 with potting media P4 still had the smallest collar diameter at 1.113 cm. Root trainer raised seedlings performance was recorded against polybag raised seedlings (Plate 11). This reiterates the long-term impact of the initial choice of containers and potting media on the collar diameter of seedlings. Aklibasinda *et al.* (2011) reported the effect of different growing media on scotch pine (*Pinus sylvestris*) seedling growth parameters such as collar diameter, seedling length, root length and number of leaves, and dry biomass and the results revealed that the best growth attributes were shown by the media of 10(%) rice hulls to 90(%) peat material (Einert and Guidry, 1975). 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).

4.3.5 Influence of different containers and potting media on shoot dry weight

The impact of varying containers and potting media on the shoot dry weight of *S. album* seedlings was recorded in Table 31. At 30 days after transplanting (DAT), notable variations in shoot dry weight were observed among different container and potting media combinations. C4 (Poly bag of 30 cm x20cm) with potting media P2 (Soil+ Rice husk + FYM in 2:1:1) displayed the highest shoot dry weight at 0.106 g, indicating the positive influence of this combination on early-stage growth. But C1 (Root trainer of 150 cc) with potting media P4 (Soil+ M-Sand +FYM in 2:1:1) exhibited the lowest shoot dry weight at 0.041 g.

The influence of potting media on shoot dry weight continued at 60 DAT, with C4 and P2 combination yielding the highest value at 0.131 g. On the other hand, C1 with potting media P4 resulted in the lowest shoot dry weight at 0.048 g. Similarly at 90 DAT, reiterating the impact of containers and potting media, C4 with P2 displayed the highest shoot dry weight at 0.137 g, while C1 with P4 exhibited the lowest at 0.058 g. At 120 DAT, C4 with P2 still presented the highest shoot dry weight at 0.148 g. Conversely, C1 with P4 had the lowest at 0.068 g. The trend suggested that container and potting media combinations sustained their impact on seedling growth throughout the early stages. A significant increase in shoot dry weight was observed at 150 DAT for C1 with potting media P5, reaching 0.093 g.

At 180 DAT, C1 with P2 displayed the highest shoot dry weight at 0.159 g, suggesting a continued positive effect of this combination on seedling growth. Whereas, C1 filled with potting media P4 exhibited the lowest shoot dry weight at 0.093 g. The interaction effect (CXP) showed variations in shoot dry weight due to the combined influence of containers and potting media. The results emphasize the importance of carefully selecting containers and potting media for the cultivation of *S. album* seedlings. Optimal combinations, such as C4 with P2, exhibited consistent positive effects across various time points. Understanding these effects is crucial for enhancing the growth and ultimately the yield of sandalwood seedlings, which is essential for sustainable cultivation practices. This might be attributed to the root trainer raised seedlings produces fibrous root system which absorbs water and nutrients from the soil more efficiently, ultimately leading to better growth and survival (Benson and Shephered, 1977).

Potting media that promote efficient nutrient absorption and photosynthesis contribute to higher shoot dry weight. P2 may have encouraged these processes, resulting in increased shoot dry weight. Adequate root development is crucial for plant stability and nutrient uptake. The combination of C4 and P2 likely facilitated better root growth and anchorage, indirectly enhancing shoot dry weight (Thompson and Troeh, 1978).

Table 31. Influence of different containers and potting media on shoot dry weight of *Santalum album* (L.)

Treatments		**Shoot dry weight (g)**					
Containers (C)	**Potting media (P)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
C1	**P1**	0.074	0.078	0.081	0.086	0.069	0.125
	P2	0.095	0.107	0.113	0.132	0.145	0.159
	P3	0.064	0.069	0.075	0.084	0.094	0.114
	P4	0.041	0.048	0.058	0.068	0.083	0.093
	P5	0.061	0.066	0.071	0.076	0.093	0.111
C2	**P1**	0.076	0.085	0.091	0.097	0.123	0.126
	P2	0.096	0.104	0.114	0.118	0.130	0.148
	P3	0.066	0.073	0.078	0.083	0.097	0.115
	P4	0.043	0.051	0.060	0.066	0.079	0.093
	P5	0.061	0.067	0.076	0.088	0.073	0.285
C3	**P1**	0.096	0.100	0.122	0.118	0.127	0.146
	P2	0.116	0.122	0.129	0.134	0.148	0.173
	P3	0.086	0.094	0.099	0.107	0.119	0.136
	P4	0.063	0.073	0.080	0.088	0.099	0.113
	P5	0.074	0.084	0.231	0.272	0.292	0.305
C4	**P1**	0.106	0.111	0.119	0.128	0.137	0.156
	P2	0.125	0.131	0.137	0.148	0.154	0.175
	P3	0.092	0.099	0.111	0.115	0.127	0.135
	P4	0.073	0.080	0.089	0.095	0.115	0.123
	P5	0.097	0.101	0.105	0.108	0.130	0.144
Interaction (CxP)	**SEm±**	**0.002**	**0.002**	**0.031**	**0.039**	**0.020**	**0.055**
	CD (P=0.05)	**0.005**	**0.006**	**0.090**	**0.112**	**0.113**	**0.153**
	CV (%)	**3.598**	**4.270**	**3.523**	**1.070**	**4.120**	**1.966**

C1-Root trainer of 150 cc
C2-Root trainer of 300 cc
C3-Poly bag of 25cm x15cm
C4-Poly bag of 30 cm x20cm

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

4.3.6 Influence of different containers and potting media on root dry weight

Effect of various containers (C) and Potting media (P) on the root dry weight of *Santalum album* seedlings were recorded (Table 32). The root dry weight ranged from 0.039g (C1P4-Root trainer of 150 cc; Soil+ M-Sand +FYM in 2:1:1) to 0.111g (C1P2-Root trainer of 150 cc; Soil+ Rice husk + FYM in 2:1:1). Among the containers, C4 showed the highest root dry weight in combinations with P2 (Soil+ Rice husk + FYM in 2:1:1) 0.098 and P5 (Soil+ River sand+ FYM in 2:1:1) 0.090.

By 60 DAT, root dry weight varied from 0.047 g (C1P4- Root trainer of 150 cc; Soil+ M-Sand +FYM in 2:1:1) to 0.104 g (C4P2- Poly bag of 30 cm x20cm; Soil+ Rice husk + FYM in 2:1:1). Combinations involving C4 displayed higher root dry weights, particularly in combinations C4P2 and C4P5. Conversely, C2 consistently demonstrated lower root dry weights. Advancing to 90 DAT, the range of root dry weight expanded from 0.052g (C1P4) to 0.093g (C4P3). Combination C4P2 consistently displayed the highest root dry weight, showcasing the positive influence of this specific combination. At 120 DAT, the range of root dry weight was 0.058 g (C2P4) to 0.131 g (C4P2).

At 150 DAT, root dry weight ranged from 0.090 g (C4P1) to 0.109 g (C4P3). Combinations C4P2 and C4P5 continued to exhibit the highest root dry weights. At 180 DAT, the range of root dry weight expanded from 0.083 g (C4P4) to 0.122 g (C4P3). Combinations involving container C4, particularly with potting media P2 and P5, consistently demonstrated superior root dry weight, highlighting the importance of these combinations in promoting robust root development in *Santalum album* seedlings. On the other hand, the fibrous root system produced might be due to the presence of ridges meant for guiding the roots to the drainage hole and ultimately lead to the development of lateral/adventitious root system thereby morphologically desirable, vigorous balanced root system is developed. Therefore, the higher container volume and presence of ridges and drainage hole in container C4 recorded higher seedling growth and survival in the nursery. The results are supported by Carlson and Endean (1996) in *Picea glauca*, Sofi (2005) in *Cedrus deodara*, Hodgson (1977) in *Pinus patula*.

Table 32. Influence of different containers and potting media on root dry weight of *Santalum album* (L.)

Treatments		**Root dry weight (g)**					
Containers (C)	**Potting media (P)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
C1	**P1**	0.049	0.056	0.063	0.071	0.076	0.115
	P2	0.085	0.092	0.097	0.102	0.107	0.111
	P3	0.076	0.081	0.087	0.091	0.096	0.109
	P4	0.039	0.047	0.052	0.058	0.064	0.071
	P5	0.077	0.058	0.090	0.098	0.104	0.110
C2	**P1**	0.052	0.059	0.065	0.072	0.077	0.083
	P2	0.086	0.091	0.096	0.102	0.107	0.111
	P3	0.077	0.083	0.088	0.093	0.388	0.111
	P4	0.040	0.048	0.054	0.059	0.065	0.071
	P5	0.078	0.084	0.091	0.098	0.103	0.109
C3	**P1**	0.054	0.061	0.068	0.074	0.081	0.086
	P2	0.088	0.095	0.103	0.107	0.112	0.116
	P3	0.079	0.083	0.088	0.093	0.097	0.104
	P4	0.042	0.046	0.056	0.062	0.068	0.073
	P5	0.080	0.085	0.092	0.102	0.108	0.112
C4	**P1**	0.064	0.071	0.080	0.085	0.090	0.095
	P2	0.098	0.104	0.111	0.121	0.127	0.131
	P3	0.089	0.093	0.098	0.104	0.109	0.122
	P4	0.052	0.058	0.066	0.071	0.077	0.083
	P5	0.090	0.095	0.104	0.111	0.117	0.122
Interaction (CxP)	**SEm±**	**0.002**	**0.010**	**0.065**	**0.005**	**0.006**	**0.006**
	CD (P=0.05)	**0.005**	**0.017**	**0.004**	**0.002**	**0.186**	**0.021**
	CV (%)	**4.618**	**3.417**	**2.737**	**1.123**	**3.852**	**2.623**

C1-Root trainer of 150 cc
C2-Root trainer of 300 cc
C3-Poly bag of 25cm x15cm
C4-Poly bag of 30 cm x20cm

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

4.3.7 Influence of different containers and potting media on total dry weight

The impact of different containers (C) and potting media (P) on the total dry weight of *Santalum album* seedlings over a 180-day period is shown in Table 33. At 30 DAT, combinations C4P2 (Poly bag of 30 cm x20cm; Soil+ Rice husk + FYM in 2:1:1) and C4P5 (Poly bag of 30 cm x 20 cm; Soil+ River sand+ FYM in 2:1:1) displayed the highest total dry weight, 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, notably in combination C1P4. Moving to 90 DAT, the influence of container C4 remained significant. Combinations C4P2 and C4P5 demonstrated total dry weight 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, reinforcing their positive influence. At 180 DAT, the pattern remained consistent, with combinations C4P2 and C4P5 showcasing total dry weight 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. 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*.

Table 33. Influence of different containers and potting media on total dry weight of *Santalum album* (L.)

Treatments		Total 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 (CxP)	**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**

C1-Root trainer of 150 cc	P1- Soil+ Coir pith compost + FYM in 2:1:1
C2-Root trainer of 300 cc	P2- Soil+ Rice husk + FYM in 2:1:1
C3-Poly bag of 25cm x15cm	P3- Soil+ Perlite + FYM in 2:1:1
C4-Poly bag of 30 cm x20cm	P4- Soil+ M-Sand +FYM in 2:1:1
	P5- Soil+ River sand+ FYM in 2:1:1

4.3.8 Influence of different containers and potting media on number of leaves

The effect of containers and potting media on number of leaves of *Santalum album* seedling up to 180 days is provided in Table 34**.** In the early stages at 30 DAT, the highest number of leaves was observed in treatment combination C4P2, (10.12) indicating that this combination of container and potting media was conducive to leaf growth. And, container C1 filled with potting media P4 (5.62) exhibited the lowest leaf count during this phase, suggesting that the choice of potting media significantly influenced the early leaf development of seedlings.

At 60 DAT, treatment C4P2 (11.89) continued to demonstrate the significantly highest leaf count, highlighting its sustained positive impact on leaf growth. Conversely, treatment combination C1P4 (6.92) maintained the lowest leaf count, indicating the persistent influence of potting media P4 on restricting leaf development. As growth progressed to 90 DAT, combination C4P2 (13.11) again emerged as the highest in leaf count, underscoring its consistent positive effect on *Santalum album* seedling growth. Treatment C1P4 (8.58) recorded least leaf count, reinforcing the impact of potting media P4 on impeding leaf growth.

The trend continued at 120 DAT, with treatment C4P2 (14.28) maintaining the highest leaf count, indicative of its sustained positive influence on leaf growth throughout the growth period. Treatment C1P4 (9.60) consistently exhibited a lower leaf count, further highlighting the persistent impact of potting media P4 in limiting leaf development. The findings stress the importance of ongoing monitoring and appropriate interventions to ensure optimal leaf growth.

At 150 DAT, C4P2 (18.77) exhibited the highest leaf count once again, reinforcing its beneficial effect on leaf production even in the later stages of growth. Whereas, treatment C1P4 (12.66) showed the lowest leaf count, indicating the enduring impact of potting media P4. In the final observed stage at 180 DAT, Treatment C4P2 (20.49) maintained its lead in leaf count, emphasizing its long-term positive influence on leaf growth. Treatment C1P4, characterized by potting media P4, consistently presented the lowest leaf count, reiterating the need to carefully choose potting media to encourage robust leaf development as the seedlings near the end of the growth period.

Table 34. 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 (CxP)	**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**

C1-Root trainer of 150 cc
C2-Root trainer of 300 cc
C3-Poly bag of 25cm x15cm
C4-Poly bag of 30 cm x20cm

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

Higher leaf counts may correlate with a larger leaf area, contributing to increased photosynthetic activity, which is essential for overall plant growth and development. The influence of early growth patterns, particularly during the initial 30 to 60 DAT, might have set the trajectory for subsequent growth, influencing leaf count in later stages. The persistent influence of potting media P4 in limiting leaf development, as seen in combination with C1 across various stages, suggests a consistent effect of this specific medium on leaf growth Dominguez-Lerena *et al.* (2006).

4.3.9 Influence of different containers and potting media on leaf area

The impact of different containers (C) and potting media (P) on the leaf area of *Santalum album* seedlings is shown in Table 35, starting from 30 days after transplantation (DAT), was evaluated. At 30 DAT, combination C4P2 (Poly bag of 30 cm x20cm; Soil+ Rice husk + FYM in 2:1:1) exhibited the highest leaf area of 15.25 cm^2, followed by C3P2 (Poly bag of 25cm x15cm; Soil+ Rice husk + FYM in 2:1:1) with 14.52 cm^2. Conversely, combinations with container C1, especially (C1P4- Root trainer of 150 cc; Soil+ M-Sand +FYM in 2:1:1) 7.73cm^2, displayed relatively smaller leaf areas.

At 60 DAT, the trend continued, with combination C4P2 maintaining the highest leaf area of 15.47 cm^2. At 90 DAT also, combination C4P2 displayed the highest leaf area of 15.66 cm^2, reinforcing its positive influence. Combinations involving container C1, particularly C1P4, exhibited smaller leaf areas. By 120 DAT, C4P2 remained dominant, showcasing a leaf area of 15.92 cm^2. At 150 DAT and 180 DAT, combination C4P2 consistently displayed the highest leaf areas, underlining its sustained impact. Container C1, particularly in combinations like C1P4, continued to yield smaller leaf areas. Overall, container C4, especially when paired with potting media P2, consistently resulted in larger leaf areas, while container C1 demonstrated a trend of smaller leaf areas. These findings emphasize the importance of container and potting media selection in influencing the leaf area development of *Santalum album* seedlings.

Plate 10: Root trainers of different size used in the study to raise sandal seedlings

Plate 11: Root trainer raised 30 days old sandal seedlings in the nursery.

Plate 12: Overall view of the nursery after transplanting sandal seedlings into containers

Table 35. 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 (CxP)	**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**

C1-Root trainer of 150 cc	P1- Soil+ Coir pith compost + FYM in 2:1:1
C2-Root trainer of 300 cc	P2- Soil+ Rice husk + FYM in 2:1:1
C3-Poly bag of 25cm x15cm	P3- Soil+ Perlite + FYM in 2:1:1
C4-Poly bag of 30 cm x20cm	P4- Soil+ M-Sand +FYM in 2:1:1
	P5- Soil+ River sand+ FYM in 2:1:1

Larger leaf area correlates with increased photosynthetic activity, contributing to better plant growth and development. The persistent influence of potting media P2 in promoting larger leaf areas, especially in combination with C4, indicates a consistent effect of this specific medium on leaf development. In summary, the choice of container and potting media significantly influenced the leaf area of *Santalum album* seedlings. Combinations involving container C4, especially with potting media P2, consistently resulted in larger leaf areas. A good overall growth was observed in that combination (Plate 12). Factors such as nutrient availability, moisture retention, root development, growth-promoting properties of the medium, and their interaction played vital roles in influencing the observed leaf areas. Understanding and selecting the appropriate combinations are crucial for enhancing seedling growth and ensuring sustainable cultivation practices for sandalwood (Khedkar and Subramanian, 1997).

4.3.10 Benefit-Cost ratio of different containers

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 36). 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 36. 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

C1-Root trainer of 150 cc, C2- Root trainer of 300 cc, C3- Poly bag of 25 cm x 15 cm, C4- Poly bag of 30 cm x 20 cm

4.3.11 Benefit-Cost ratio of different potting media

Table 37 presents the benefit-cost ratio (B-C ratio) associated with using different potting media (P1, P2, P3, P4, and P5) for raising *Santalum album* seedlings in a nursery over a 180-day growth period. The benefit-cost ratios highlight the cost-effectiveness and potential returns associated with each potting media. Potting media P2 stands out with the highest B-C ratio of 1.59, indicating highest returns for the investment made. On the other hand, potting media P1 and P3 have the lowest BC ratio, suggesting a less efficient use of resources relative to the other media. P4 also had highest B-C ratio but performed poor in terms of growth parameters.

These results provide valuable insights for decision-makers in choosing the appropriate potting media for *Santalum album* seedling production. The present study pointed out that the potting media of soil, rice husk and FYM in 2:1:1 ratio can be considered as a cheap alternative for production of quality planting stock of commercially important sandal seedlings in humid tropics of Karnataka and other areas of India, where the rice husk is readily available and less expensive than traditional substrates, thereby reducing dependence on costlier river sand. Further, converting these locally available organic waste materials into good quality manure can reduce the problems of environmental pollution and waste disposal and can also alleviate the problem of raw material scarcity in nurseries apart from mitigating the ecological hazards of sand mining.

Rice husk is an abundantly available waste material in all the rice producing countries, and it contains about 30–50 (%) of organic carbon. The production of rice husk is about 100 million tons per year (Oosterkamp, 2014). Rice husk is a cellulose-based fiber and contains approximately 20(%) silica in amorphous form. In addition, it consists of 60–65 (%) volatile matter, 10–15 (%) fixed carbon, and 17–23 (%) ash (Hu *et al.*, 2008). Rice husk can absorb water ranging from 5 to 16 (%) of unit weights, and the unit weight of rice husk is 83–125 kg/m^3 which makes it better potting media compare to others (Phonphuak and Chindaprasirt, 2015).

Table 37. 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

P1- Soil+ Coir pith + 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

4.4 Influence of host plant on the seedling characteristics of Sandal

The influence of the host plant on Sandal seedling characteristics is pivotal in its growth and quality. Different host plants can impact growth rates, root development, and overall health of Sandalwood seedlings. Understanding these interactions is vital for nurseries and cultivators to select suitable host plants that optimize seedling growth and ensure the production of high-quality Sandalwood trees. The choice of host plant can significantly influence the success and efficiency of Sandalwood cultivation, ultimately impacting the yield and quality of this economically valuable plant.

4.4.1 Influence of different host species on shoot length

The growth and development of sandalwood plants, including shoot length, can be influenced by various factors, and the host plant plays a significant role in this regard. Sandalwood is a parasitic plant that relies on host trees for nutrients and water. The interaction between the sandalwood plant and its host tree can affect the growth and shoot length of the sandalwood plant. Table 38 shows the effect of various host species on the shoot length of *Santalum album* seedlings. Over 180 days, distinct patterns emerged in shoot growth. At 30 days after transplantation H5 (*Crotalaria retusa*) displayed the longest shoot length (7.00 cm), followed closely by (H2- *Mimosa pudica*) (6.99 cm). H1 (*Crotalaria juncia*) had the next highest shoot length at 6.09 cm, while H3, H0, H4, and H6 ranged between 6.18 cm to 6.40 cm. At 60 DAT, H5 maintained its significance difference with the longest shoots (9.76 cm), followed by H1 (9.39 cm). H3 and H4 also showed substantial growth with shoot lengths reaching 9.32 cm and 8.44 cm, respectively. H0 exhibited the lowest shoot length at 7.79 cm.

At 90 DAT, H5 continued to exhibit the longest shoot length (11.78 cm), while H1 and H3 also displayed significant growth with shoot lengths of 11.35 cm and 11.12 cm, respectively. Conversely, H0 had the lowest shoot length at 8.91 cm. This pattern persisted at 120 DAT, 150 DAT, and 180 DAT, with H5 consistently displaying the longest shoot length. Which may be due to the reason *Crotalaria* and *Cajanus* being leguminous plant, roots helped to nourish and establish the sandal seedlings. Therefore, all stress and defense parameters were found to be lower in presence of parasite. This indicates a substantial lowering of guard and reduced defense in these species more so than *Alternanthera*, allowing a robust interaction with the parasite benefiting the parasite. Radomiljac *et al.* (1998) proposed that legume plants can act as better host for sandalwood. *Cajanus* is a legume plant and seems to show significant flexibility and modulation of its defense system when it interacts with sandalwood. This may contribute to *Cajanus* and *Crotalaria* being a superior primary host than other species. Host species H5 consistently displayed a greater shoot length, suggesting its potential as a favorable host for optimal growth. But, H0 consistently showed poor performance, highlighting the significance of appropriate host selection for effective sandalwood cultivation and maximizing leaf area, a vital aspect of plant growth and photosynthesis. Moreover, selection of suitable pot host species is dependent on a multitude of parameters, not just initial *S. album* growth under nursery conditions. A high level of pot host field persistence whilst parasite is important. *C. retusa* grew prolifically in the nursery and promoted good early *S. album* field growth Surata (1995).

Table 38. Influence of different host species on shoot length of *Santalum album* (L.)

Host	**Shoot length (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	6.40	7.79	8.91	9.99	12.63	14.65
H1	6.09	9.39	11.35	14.25	19.49	21.46
H2	6.99	8.10	9.73	12.68	18.03	19.92
H3	6.18	9.32	11.12	13.54	19.02	21.59
H4	6.99	8.44	10.67	13.14	18.63	21.67
H5	7.00	9.76	11.78	14.47	19.68	22.18
H6	6.24	8.00	9.68	13.05	18.55	20.03
SEm±	**0.11**	**0.15**	**0.18**	**0.18**	**0.19**	**0.32**
CD (P=0.05)	**0.34**	**0.46**	**0.54**	**0.56**	**0.59**	**0.99**
CV (%)	**2.91**	**2.98**	**2.94**	**2.42**	**1.86**	**2.77**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

4.4.2 Influence of different host species on root length

Host trees provide essential nutrients to the sandalwood plant through their root system. The sandalwood plant roots can tap into the host trees nutrient-rich root zone, promoting root growth and development. Table 39 presents the influence of different host species on the root length of *S. album* seedlings at various time intervals. At 30 DAT, no significant difference was observed in the root length of the seedlings suggesting that the less to no influence of host at early stage. H1(*Crotalaria juncia*) displayed the longest root length at 4.63 cm, followed by H4- *Cajanus cajan* (4.67 cm) and H5- *Crotalaria retusa* (4.55 cm), while H2- *Mimosa pudica* exhibited the shortest root length at 4.28 cm. Moving to 60 DAT, H5- *Crotalaria retusa* exhibited a significant increase in root length, measuring 6.74 cm, the longest among all host species. H1 and H4 continued to show notable growth, with root lengths of 6.43 cm and 5.74 cm, respectively.

Table 39. Influence of different host species on root length of *Santalum album* (L.)

Host	**Root length (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	4.33	4.93	6.76	7.73	9.32	10.14
H1	4.63	6.43	8.27	9.25	11.22	13.21
H2	4.28	5.71	7.78	8.05	10.04	11.12
H3	4.58	6.00	7.92	8.91	11.11	12.78
H4	4.67	5.74	7.69	8.62	10.66	12.05
H5	4.55	6.74	8.56	9.88	11.47	13.79
H6	4.59	5.41	7.41	8.44	10.49	11.73
SEm±	**0.22**	**0.17**	**0.13**	**0.14**	**0.10**	**0.14**
CD (p=0.05)	**NS**	**0.52**	**0.40**	**0.42**	**0.32**	**0.42**
CV (%)	**2.82**	**3.05**	**2.89**	**2.71**	**1.69**	**1.94**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

At 90 DAT, H5 maintained its significant difference with the longest root length at 8.56 cm, followed by H1 and H4 at 8.27 cm and 7.69 cm, respectively. The trend continued at 120 DAT and 150 DAT, with H5 consistently displaying the longest root length. Finally, at 180 DAT, H5 recorded the longest root length at 13.79 cm, underlining its positive effect on root development. During the initial growth phase, seedlings may be primarily reliant on their internal reserves and early interactions with the substrate. Host species may not exert a significant influence on root length at this stage due to the dominance of endogenous factors and limited response to external environmental cues. Padmanabha *et al.* (1988) also reported best host species *Casuarina equisetifolia, Melia dubia*, *Acacia nilotica, Wrightia tinctoria, Pongamia pinnata*, *Terminalia arjuna*, *T. alata*, *Dalbergia sissoo, Cassia siamea* and *Bauhinia biloba* for the sandal.

4.4.3 Influence of different host species on seedling total height

Influence of different host species on the seedling height of *Santalum album* over a span of 180 days is shown in Table 40. At the early stage of 30 DAT, all host species demonstrated relatively similar seedling heights, ranging from 10.72 cm to 11.66 cm. No significant difference was observed among the treatments. This uniformity may be attributed to the initial growth phase, where the impact of the host species is less pronounced. However, as the seedlings progressed to 60 DAT, variations became noticeable. Host species H1- *Crotalaria juncia* displayed the highest height at 15.82 cm, while H0 (No host) exhibited the lowest at 12.72 cm. These disparities continued to amplify at 90 DAT, with H1- *Crotalaria juncia* maintaining the lead at 19.62 cm and H0 at 15.67 cm.

The differences in seedling height among the host species persisted at 120 DAT and 150 DAT, indicating a sustained influence on growth rates. Host species H5 consistently demonstrated the highest seedling height across these periods. By 180 DAT significant distinctions were evident in seedling height among the host species. Host species H5 exhibited the tallest seedlings at 35.97 cm, followed by H4 at 33.72 cm. Conversely, H0 had the shortest seedlings at 24.79 cm. These findings show the importance of different host species on *Santalum album* seedling growth over time, highlighting the importance of host selection for optimal growth outcomes. Our results are also in line with Das and Tah (2013) where they conducted experiments in different soil environments of South West Bengal, both in nursery and field condition after transplantation of sandalwood saplings with different hosts singly or in combination of hosts. They found that Arhar

(*Cajanus cajan*) is the best host followed by Arhar & Tulsi (*Ocimum sanctum*) combination followed by Tulsi singly. Though sandalwood plants survive without host, the girth, height and growth are much better with the hosts.

Table 40. Influence of different host species on seedling total height of *Santalum album* (L.)

Host	**Seedling total height (cm)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	10.73	12.72	15.67	17.72	21.95	24.79
H1	10.72	15.82	19.62	23.50	30.71	34.67
H2	11.27	13.81	17.51	20.73	28.07	31.04
H3	10.76	15.32	19.04	22.45	30.13	34.37
H4	11.66	14.18	18.37	21.77	29.28	33.72
H5	11.54	16.50	20.34	24.35	31.15	35.97
H6	10.83	13.42	17.09	21.48	29.04	31.76
SEm±	**0.28**	**0.22**	**0.22**	**0.26**	**0.22**	**0.36**
CD (p=0.05)	**NS**	**0.67**	**0.68**	**0.61**	**0.66**	**1.11**
CV (%)	**4.37**	**2.60**	**2.11**	**1.77**	**1.35**	**1.95**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

4.4.4 Influence of different host species on collar diameter

The effect of different host species on the collar diameter of *Santalum album* seedlings at various time intervals is recorded in Table 41. At the outset, there were noticeable variations in collar diameter among the host species. Specifically, at 30 DAT, H5- *Crotalaria retusa* showcased the largest collar diameter (1.66 cm), while H2- *Mimosa pudica* displayed the smallest collar diameter (0.79 cm). These differences persisted and became more pronounced as the seedlings progressed through subsequent time points.

Table 41. Influence of different host species on collar diameter of *Santalum album* (L.)

Host	Collar diameter (cm)					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	0.77	0.97	1.05	1.16	1.25	1.32
H1	1.27	1.56	1.69	1.81	2.14	2.28
H2	0.79	0.67	1.16	1.26	1.47	1.61
H3	0.97	1.29	1.36	1.46	1.90	1.99
H4	0.95	1.20	1.28	1.48	1.55	1.73
H5	1.66	1.76	1.84	1.88	2.44	2.65
H6	0.90	1.05	1.30	1.44	1.49	1.66
SEm±	**0.07**	**0.14**	**0.08**	**0.08**	**0.11**	**0.09**
CD (p=0.05)	**0.22**	**0.41**	**0.24**	**0.23**	**0.33**	**0.27**
CV (%)	**3.31**	**4.80**	**3.85**	**3.81**	**4.35**	**3.12**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

At 180 DAT, host species H5 recorded the largest collar diameter of 2.65 cm, followed by H1 recorded 2.28 cm. And, H0 exhibited the smallest collar diameter at 1.32 cm. The results emphasize that the choice of host species plays a crucial role in determining the collar diameter of *Santalum album* (L.) seedlings. Host species H5, fostered larger collar diameters, indicating a more conducive environment for stem growth. On the other hand, host species like H2 resulted in smaller collar diameters, suggesting less optimal conditions for stem development. The maximum collar diameter after 180 days was found with *Crotalaria spp.* and *Cajanus cajan* may be due to its fibrous roots which does not compete for root development and subsequently given good foliage (leaf area) to the sandal seedlings. Surendran *et al*. (1998) observed that despite the large host range of the majority of parasitic plants, many of them also show high level of host preference. Similarly

Tennakoon and Cameron (2006) also advocated successful haustorial formation is the key to the survival of the individuals of the ecologically important sandal plant.

4.4.5 Influence of different host species on root to shoot ratio

The root-to-shoot ratio in *Santalum album* seedlings under the influence of different host species at various time intervals is shown in Table 42. Initially, at 30 DAT, H1-*Crotalaria juncia* displayed the highest root-to-shoot ratio of 0.76, while H2- *Mimosa pudica* exhibited the lowest (0.61), indicating diverse resource allocation strategies. As the study progressed to 60 DAT, H2 displayed an increased ratio, possibly indicating a shift towards root growth. In contrast, ratio of H1 decreased, suggesting a potential emphasis on shoot growth. This suggests dynamic allocation patterns influenced by the host species.

Table 42. Influence of different host species on root to shoot ratio of *Santalum album* (L.)

Host	**Root: Shoot**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	0.68	0.63	0.61	0.50	0.51	0.50
H1	0.76	0.69	0.73	0.65	0.58	0.62
H2	0.61	0.70	0.80	0.63	0.56	0.56
H3	0.74	0.64	0.71	0.66	0.58	0.59
H4	0.67	0.68	0.72	0.66	0.57	0.56
H5	0.65	0.69	0.73	0.68	0.59	0.62
H6	0.74	0.68	0.77	0.65	0.57	0.59
SEm±	**0.03**	**0.02**	**0.02**	**0.02**	**0.01**	**0.01**
CD (p=0.05)	**0.09**	**0.03**	**0.06**	**0.05**	**0.03**	**0.04**
CV (%)	**3.38**	**4.20**	**4.31**	**4.33**	**3.03**	**3.42**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

At 90 DAT, H0 demonstrated a significant rise in the root-to-shoot ratio, possibly implying a strategic allocation of resources to the root system for enhanced growth and establishment. However, at 120 DAT, H1 showcased a considerable decline in the ratio (0.65), suggesting a shift in resource allocation towards the shoot system. By 150 DAT, a similar pattern was observed with H0 displaying the highest ratio, possibly indicating a greater emphasis on root development.

By the final assessment at 180 DAT, the root-to-shoot ratio varied across host species. H5 and H1 exhibited the highest ratio at 0.62, suggesting a resource allocation strategy favoring root growth. Conversely, H2 and H4 displayed the lowest ratio at 0.56, potentially indicating a focus on shoot growth. These findings emphasize the influence of host species on resource allocation dynamics and underscore the importance of host selection in optimizing growth and development in *Santalum album* seedlings. Though earlier Barrett and Fox (1997) reported that sandal seedlings without a host did not show significant difference in growth up to 3-4 months as compared to seedlings with hosts but Annapurna *et al.* (2006) has reported that requirement of host and its growth stage play a significant role in the growth of *S. album* seedlings in terms of height, collar diameter, total dry weight and quality indices. The present studies also support the significant role of host plants on growth performance of sandal seedlings.

4.4.6 Influence of different host species on shoot dry weight

Shoot dry weight is a crucial measure of plant growth and biomass. Table 43 reveals how different host species influenced the shoot dry weight of *Santalum album* seedlings at monthly intervals up to six months. At 30 DAT, H5 (*Crotalaria retusa)* showed the highest shoot dry weight (0.187g), while H0 (No Host) had the lowest shoot dry weight (0.079g). These early results indicated that host species had a notable impact on shoot dry weight. As time progressed to 60 DAT, H5 consistently maintained the lead with a shoot dry weight of 0.201g, whereas H0 showed a modest increase to 0.094g.

By 90 DAT, all host species displayed an increase in shoot dry weight. H5 consistently had the highest shoot dry weight at 0.208g, while H0 exhibited an increase to 0.099g. This pattern was sustained at 120 DAT and 150 DAT, indicating continuous growth and biomass accumulation. H5 consistently exhibited the highest shoot dry weight during these periods. At 180 DAT, H5 demonstrated the highest shoot dry weight at 0.231g, emphasizing its consistent favorable effect on biomass accumulation. Conversely, H0 had a shoot dry weight of 0.115g, indicating a relatively lower biomass compared to other host species.

Table 43. Influence of different host species on shoot dry weight of *Santalum album* (L.)

Host	**Shoot dry weight (g)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	0.079	0.094	0.099	0.106	0.112	0.115
H1	0.165	0.174	0.181	0.191	0.201	0.207
H2	0.116	0.121	0.128	0.133	0.141	0.146
H3	0.148	0.156	0.160	0.171	0.178	0.188
H4	0.137	0.148	0.156	0.149	0.171	0.178
H5	0.187	0.201	0.208	0.217	0.223	0.231
H6	0.130	0.138	0.145	0.151	0.157	0.164
SEm±	**0.006**	**0.007**	**0.006**	**0.008**	**0.006**	**0.006**
CD (p=0.05)	**0.018**	**0.020**	**0.019**	**0.025**	**0.017**	**0.017**
CV (%)	**3.411**	**4.679**	**4.004**	**3.980**	**2.736**	**2.546**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

Host species, particularly H5, consistently promoted higher shoot dry weights, suggesting its potential as a favorable host for biomass accumulation. Conversely, H0 consistently exhibited lower shoot dry weight, implying it may not be as conducive to biomass production compared to other host species. Understanding these variations is crucial for effective sandalwood cultivation, as shoot dry weight directly reflects the plant's overall biomass and productivity. The observed differences in shoot dry weight among host species provide practical insights for optimal host selection, ultimately contributing to enhanced biomass accumulation and productivity in sandalwood cultivation. As the seedlings progress, sustained nutrient availability and favorable soil conditions become critical for consistent root growth. Hosts providing a nutrient-rich substrate with good aeration and water retention properties create an environment conducive to root system expansion, resulting in longer roots (Taide *et al.* 1994).

4.4.7 Influence of different host species on root dry weight

Influence of different host species on the root dry weight of *Santalum album* seedlings is recorded in Table 44. At 30 DAT, H5 (*Crotalaria retusa*) demonstrated the highest root dry weight of 0.077g, while H0 (No host) had the lowest (0.042g) root dry weight. This early disparity underscored the substantial impact of the host species on root dry weight. As the study progressed to 60 DAT, H5 consistently maintained the root dry weight (0.081g), while H0 showed a modest increase to 0.048g.

Table 44. Influence of different host species on root dry weight of *Santalum album* (L.)

Host	**Root dry weight (g)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	0.042	0.048	0.053	0.055	0.057	0.062
H1	0.071	0.078	0.080	0.085	0.099	0.120
H2	0.051	0.063	0.067	0.074	0.079	0.090
H3	0.065	0.074	0.076	0.081	0.091	0.119
H4	0.061	0.069	0.072	0.079	0.086	0.115
H5	0.077	0.081	0.084	0.089	0.102	0.121
H6	0.054	0.065	0.069	0.075	0.083	0.105
SEm±	**0.002**	**0.003**	**0.004**	**0.003**	**0.004**	**0.005**
CD (p=0.05)	**0.005**	**0.010**	**0.012**	**0.010**	**0.013**	**0.105**
CV (%)	**3.954**	**4.491**	**3.598**	**4.398**	**4.451**	**4.196**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

By 90 DAT, all host species exhibited an increase in root dry weight. H5 consistently displayed the highest root dry weight of 0.084g, while H0 exhibited an increase to 0.053g. This pattern continued at 120 DAT and 150 DAT, suggesting sustained root growth and development. H5 consistently held the highest root dry weight during these periods. At 180 DAT, H5 showcased the highest root dry weight of 0.121g, emphasizing its consistent favorable effect on root biomass. Conversely, H0 had a root dry weight of 0.062g, indicating relatively lower root biomass compared to other host species.

Host species, particularly H5, consistently promoted higher root dry weights, suggesting its potential as a favorable host for root biomass development. Conversely, H0 consistently exhibited lower root dry weight, implying it may not be as conducive to root biomass production compared to other host species. Understanding these variations is crucial for effective sandalwood cultivation, as root biomass is integral to the plant's overall growth and nutrient absorption. These observed differences in root dry weight among host species provide practical insights for optimal host selection, ultimately contributing to enhanced root biomass accumulation and productivity in sandalwood cultivation. Radomiljac *et al.* (1999) also found lower root to shoot ratio for Sandal seedlings grown with N_2-fixing hosts compared with seedlings grown with *E. camaldulensis* or with no host.

4.4.8 Influence of different host species on total dry weight

Table 45 reveals how different host species influence the total dry weight of *Santalum album* L. seedlings. The results revealed significant variations in dry weight across the host species during the study period. Initially, at 30 DAT, the seedlings showed varying dry weights, ranging from 0.122 g (H0-No host) to 0.264 g (H5- *Crotalaria retusa*). H5 exhibited the highest weight, suggesting strong early growth potential. As the seedlings progressed to 60 DAT, all host species displayed an increase in dry weight, with H5 continuing to demonstrate the highest weight (0.282g). This growth pattern persisted through 90 DAT, 120 DAT, and 150 DAT, indicating consistent growth across the host species. At the final observation point of 180 DAT, H5 maintained the highest total dry weight of 0.352g, maintaining its sustained and robust growth compared to the other host species. By the later stage, a host that sustains favorable soil conditions and adequate nutrient supply allows for continued root elongation. The root systems ability to efficiently explore the soil and absorb essential nutrients contributes to longer root lengths, highlighting the long-term positive influence of the host. In summary, the varying root length trends observed across different time intervals can be explained by the influence of the host environment on nutrient availability, soil structure, and overall growth-promoting conditions that affect the root development of *Santalum album* seedlings (Subasinghe, 2013)

Table 45. Influence of different host species on total dry weight of *Santalum album* (L.)

Host	**Total dry weight (g)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	0.122	0.142	0.151	0.161	0.169	0.178
H1	0.236	0.252	0.261	0.276	0.300	0.327
H2	0.167	0.183	0.195	0.206	0.220	0.236
H3	0.213	0.230	0.236	0.252	0.269	0.307
H4	0.197	0.218	0.228	0.229	0.257	0.293
H5	0.264	0.282	0.293	0.306	0.325	0.352
H6	0.184	0.203	0.215	0.226	0.240	0.269
SEm±	**0.007**	**0.009**	**0.009**	**0.011**	**0.008**	**0.010**
CD (p=0.05)	**0.020**	**0.028**	**0.029**	**0.033**	**0.025**	**0.029**
CV (%)	**3.723**	**4.374**	**4.275**	**4.957**	**2.457**	**3.886**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

4.4.9 Influence of different host species on leaf number

Influence of different host species on the number of leaves in *Santalum album* seedlings at distinct monthly intervals, spanning from 30 to 180 days is shown in Table 46. At 30 DAT, it was evident that the choice of host significantly impacted the number of leaves. H5 (*Crotalaria retusa*) emerged as the most favorable host, fostering a higher leaf count of 8.17, while H0 (No host) showed the least leaf count of 6.14. This early disparity pointed to host-specific effects on the initial stages of leaf growth. At 60 DAT, the trends in leaf count persisted, and the differences among host species became more pronounced. H5 maintained a substantial lead with 8.84 leaves, highlighting its positive influence on leaf development. Conversely, H0 exhibited a modest increase, emphasizing its relatively slower pace of leaf growth.

Table 46. Influence of different host species on leaf number of *Santalum album* (L.)

Host	**Leaf number**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	6.14	6.51	7.11	9.00	11.64	13.66
H1	7.85	8.58	9.88	14.72	18.58	24.19
H2	6.87	7.33	8.57	13.20	16.48	20.83
H3	7.52	8.48	9.70	14.32	18.26	23.75
H4	7.36	8.04	9.38	14.12	17.79	22.52
H5	8.17	8.84	11.56	15.37	19.57	24.46
H6	7.16	7.72	8.85	13.74	17.24	21.71
SEm±	**0.04**	**0.09**	**0.07**	**0.10**	**0.13**	**0.14**
CD (p=0.05)	**0.14**	**0.28**	**0.20**	**0.30**	**0.40**	**0.44**
CV (%)	**1.06**	**1.98**	**1.24**	**1.24**	**1.34**	**1.15**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

The influence of host species on leaf count was further magnified at 90 DAT. H5 continued to demonstrate a prominent effect on leaf production, yielding the highest count at 11.56 leaves. In contrast, H0, while progressing, maintained a lower leaf count, suggesting a less conducive environment for leaf proliferation. At 120 DAT and 150 DAT, the gap in leaf count among the host species remained consistent. H5 consistently provided an environment conducive to abundant leaf growth, while H0 consistently lagged behind, showcasing the least number of leaves. At 180 DAT H5 exhibited the highest leaf count at 24.46, showcasing its sustained positive impact on leaf development. Conversely, H0, though improving, continued to trail behind with 13.66 leaves.

Hosts like H5 consistently promoted higher leaf counts, indicating their favorable influence on leaf development. Conversely, H0 consistently exhibited a lower leaf count, underlining the importance of host selection in optimizing leaf production. These findings stress the significance of understanding host-plant interactions for effective sandalwood cultivation, with further research needed to uncover the mechanisms driving these variations and refine host species selection for enhanced growth and productivity. Similar to the findings of this study Annapurna *et al.* (2006) reported maximum number of leaves, small size haustoria and effective haustorial connections with *A. sessilis* while a larger size and the small number of haustoria could be observed with *M. pudica*.

4.4.10 Influence of different host species on leaf area

Influence of various host species on the leaf area of *Santalum album* seedlings at distinct monthly intervals is recorded in Table 47, the leaf area varied among host species, with H5- *Crotalaria retusa* exhibiting the largest area (10.34 cm²) and H0-No host displaying the smallest (7.18 cm²). This initial difference in leaf area suggests diverse growth patterns attributed to the different host species.

Progressing to 60 DAT, H5 maintained a higher leaf area of 11.18 cm², while H0 showed a modest increase to 8.16 cm². At 90 DAT, H5 continued to exhibit a prominent leaf area of 11.41 cm², reinforcing its positive effect on *Santalum album* seedling leaf development. In contrast, H0 showcased a smaller leaf area of 8.44 cm² at the same period.

By 120 DAT, H5 sustained a larger leaf area of 11.74 cm², while H0 exhibited a modest increase to 8.56 cm². At 150 DAT and 180 DAT, H5 consistently demonstrated the highest leaf area, indicating a sustained favorable impact on leaf growth. Conversely, H0 consistently exhibited the smallest leaf area, implying a less conducive environment for leaf development compared to other host species.

Host species H5 consistently displayed a larger leaf area, suggesting its potential as a favorable host for optimal leaf growth. But, H0 consistently showed a smaller leaf area, highlighting the significance of appropriate host selection for effective sandalwood cultivation and maximizing leaf area, a vital aspect of plant growth and photosynthesis.

Selection of suitable pot host species is dependent on a multitude of parameters, not just initial *S. album* growth under nursery conditions. A high level of pot host field persistence whilst parasite is important. *C. retusa* grew prolifically in the nursery and promoted good early *S. album* field growth Surata (1995).

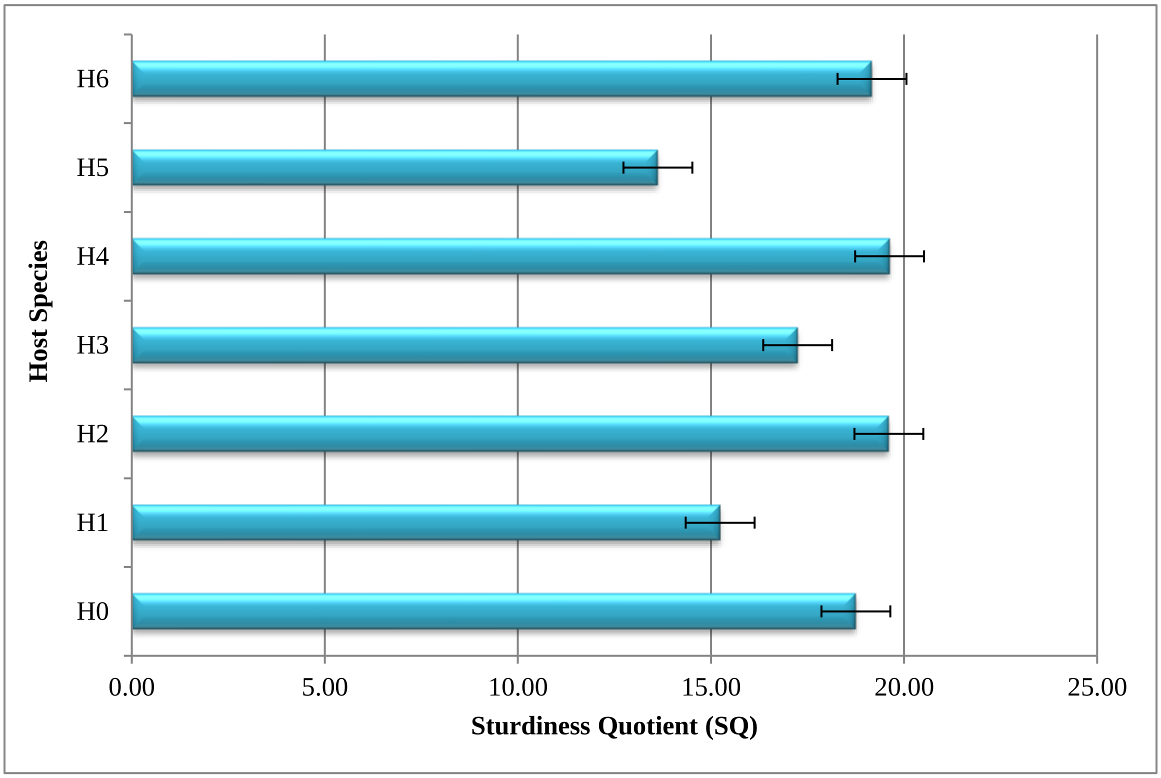
Table 47. Influence of different host species on leaf area of *Santalum album* (L.)

Host	**Leaf area (cm^2)**					
	30 DAT	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**	**180 DAT**
H0	7.18	8.16	8.44	8.56	8.68	8.75
H1	9.64	10.50	11.18	11.35	11.60	12.54
H2	8.05	8.36	8.92	9.74	10.39	11.07
H3	9.49	10.37	10.58	10.86	11.44	12.11
H4	8.63	9.74	10.15	10.78	11.08	11.75
H5	10.34	11.18	11.41	11.74	11.88	12.73
H6	8.45	9.18	9.79	10.49	10.85	11.48
SEm±	**0.17**	**0.12**	**0.09**	**0.19**	**0.13**	**0.13**
CD (p=0.05)	**0.52**	**0.38**	**0.28**	**0.58**	**0.41**	**0.39**
CV (%)	**3.34**	**2.21**	**1.59**	**3.12**	**2.13**	**1.94**

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

4.4.11 Influence of different host species on sturdiness quotient

Sturdiness quotient is a critical metric reflecting the robustness and strength of seedlings, an essential aspect of plant health and growth (Annapurna *et al.,* 2006). The sturdiness quotient of *S. album* seedlings associated with various host species are presented in Fig.8. The control or baseline sturdiness quotient without any specific host (H0-No host) is recorded at 18.75, serving as a reference point for evaluating the influence of other host species. Notably, seedlings hosted by H2 (*Mimosa pudica*) exhibited a relatively high sturdiness quotient of 19.61, suggesting a lower robustness, potentially resulting in less sturdy seedlings. Similarly, H4 (*Cajanus cajan*) also demonstrated a high sturdiness quotient of 19.62, indicating a negative impact on seedling strength compared to the control. But, H5 (*Crotalaria retusa*) showcased a sturdiness quotient of 13.62, implying a potential increase in the robustness of the seedlings associated with this host species. Seedlings under H1 (*Crotalaria juncia*) and H3 (*Casuarina equisetifolia*) exhibited sturdiness quotients of 15.24 and 17.24, respectively, suggesting a relatively moderate effect on seedling sturdiness. Finally, H6 (*Alternanthera sessilis*) displayed a sturdiness quotient of 19.17, indicating a potential negative influence on seedling strength. These results are in line with Surata (1995). A decrease in sturdiness quotient may signify a shift in resource allocation from stem mechanical support to other aspects of plant growth, such as root development or foliage expansion. This reallocation of resources could contribute to increased overall robustness with decrease in sturdiness quotient (Tennakoon and Cameron, 2006).

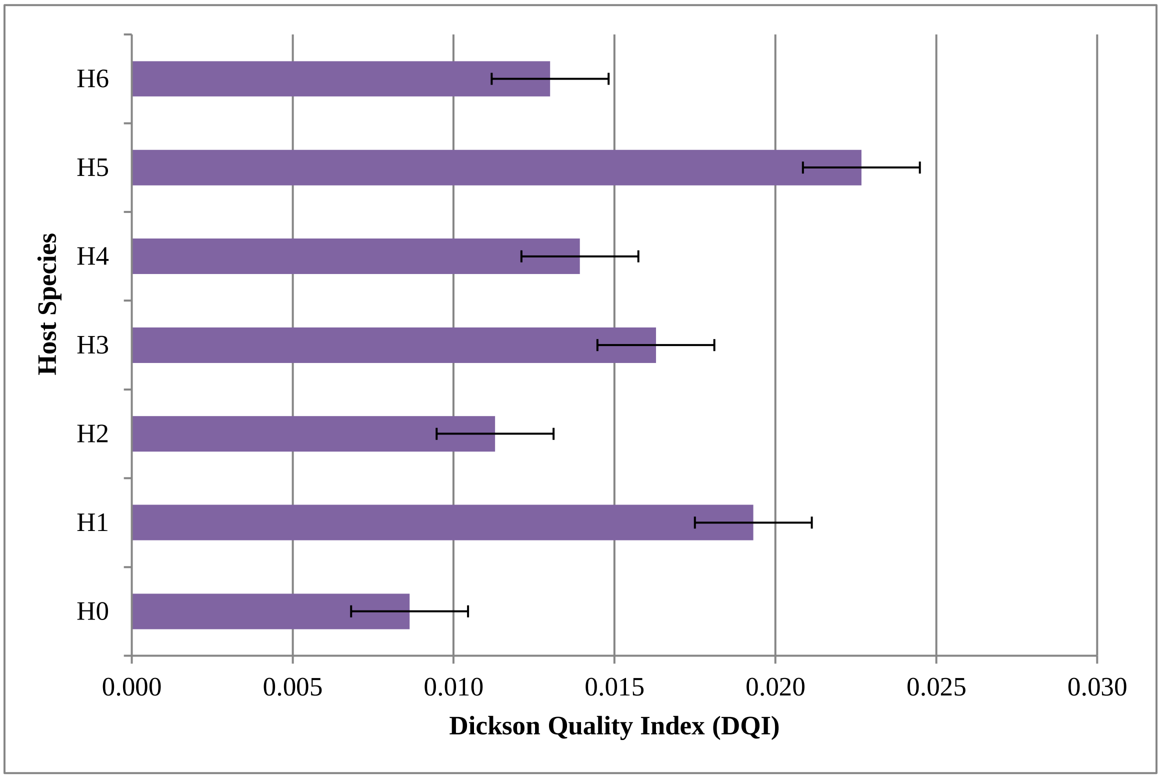


H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

Fig. 8: Influence of different host species on sturdiness quotient of *Santalum album* (L.)

4.4.12 Influence of different host species on Dickson Quality Index (DQI)

The quality index is a comprehensive measure that encompasses various aspects reflecting the overall quality and health of the seedlings. Analyzing the results, it is evident that each host species plays a distinct role in influencing the quality index of the seedlings. The presented Fig. 9 outlines the quality index of *Santalum album* associated with different host species. Examining the results, H5 (*Crotalaria retusa*) exhibited the highest quality index with a value of 0.023, indicating a significant positive influence on the overall quality and health of the seedlings. H2 (*Mimosa pudica*) and H6 (*Alternanthera sessilis*) followed closely with quality indices of 0.011 and 0.013 respectively, demonstrating their substantial positive impact on the seedling quality. The sandal seedling without host recorded DQI of 0.009. These host species appear to provide favorable growth conditions, nutrients and other factors that enhance the overall quality of seedlings.



H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

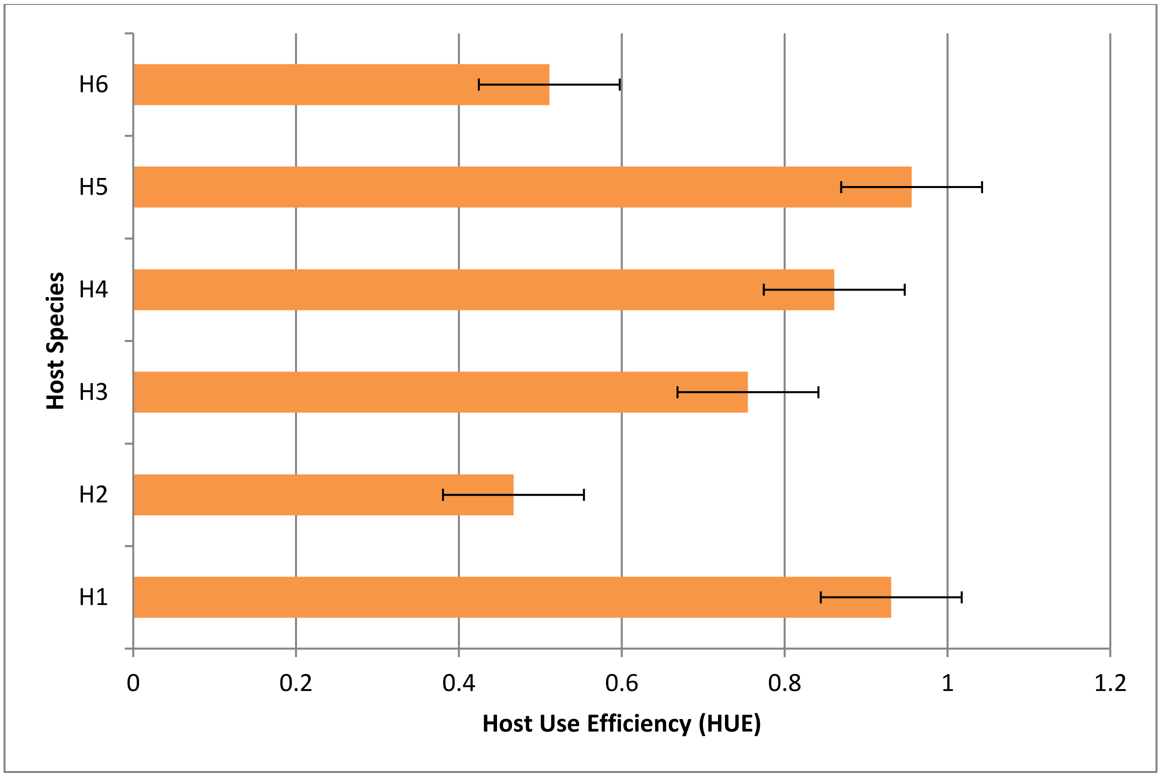
Fig. 9: Influence of different host species on dickson quality index of *Santalum album* (L.)

In contrast, H5 (*Crotalaria retusa*) displayed a lower quality index of 0.023, suggesting potential challenges in achieving a higher quality level under this host species. The seedlings associated with H1 (*Crotalaria juncia*) and H3 (*Casuarina equisetifolia*) showed moderate quality indices of 0.021 and 0.014, respectively, indicating a positive but relatively lesser influence on the seedling overall quality compared to H4, H2, and H6.

The choice of host species significantly affects the quality index of *Santalum album* seedlings, with H4, H2, and H6 showcasing the most favorable influence in enhancing the seedling overall quality. This understanding is crucial for growers and cultivators aiming to optimize the quality of *Santalum album* seedlings, an important plant known for its aromatic and commercial value. Subasinghe (2011) also reported the similar findings.

4.4.13 Influence of different host species on Host Use Efficiency (HUE)

HUE is a critical metric that assesses the efficiency with which seedlings utilize a particular host for their growth and development. Fig. 10 provides insights into the Host Use Efficiency (HUE) of *Santalum album* seedlings associated with different host species. Among the host species analyzed, H5 stands out with the highest HUE value of 0.956. This indicates an extremely efficient utilization of the resources provided by H5, suggesting optimal conditions for the growth of sandal seedlings. Following closely, H1 and H4 also demonstrate relatively high HUE values of 0.931 and 0.861, respectively, showcasing efficient utilization of their respective hosts for seedling development. On the other hand, H2 and H6 display lower HUE values of 0.467 and 0.511, suggesting a comparatively lower efficiency in utilizing the respective hosts for growth. H3 falls in the middle with a moderate HUE value of 0.755, indicating a reasonable utilization of its host resources by the seedlings. To understand the influence of host and the support system it provides to the sandal seedlings it is important to check for its efficiency. In summary, the HUE values shed light on the varying degrees of efficiency with which different host species are utilized by *Santalum album* seedlings (Radomiljac *et al.*, 1998).

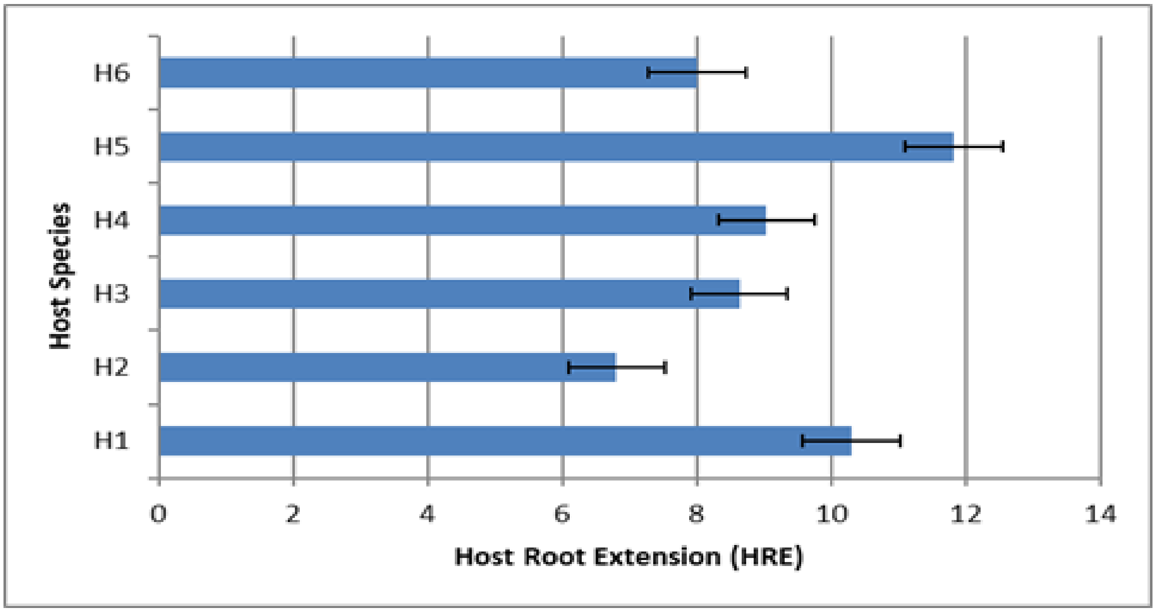


H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

Fig. 10: Influence of different host species on Host Use Efficiency (HUE) of *Santalum album* (L.)

4.4.14 Influence of different host species on Host Root Extension (HRE)

Host Root Extension **(**HRE) is a crucial measure reflecting the development and extension of the root system of sandal based on host, an essential aspect of plant growth. The Fig. 11 presents the influence of different host species on Host Root Extension (HRE) of *Santalum album* seedlings, Among the host species studied, H5 demonstrates the highest HRE value of 11.83, indicating a substantial and significant extension of the root system. This suggests that H5 provides highly favorable conditions for robust root development in sandal seedlings. Following closely, H1 and H4 also exhibit notable HRE values of 10.31 and 9.04, respectively, underlining their positive influence on root extension. On the other hand, H2, H3, and H6 display slightly lower HRE values of 6.81, 8.64, and 8.01, respectively, suggesting a moderate extension of the root system under these hosts. These variations in HRE values emphasize the differing influences of various host species on the extension of the root system in *Santalum album* seedlings. These dynamics are vital for effective cultivation and optimizing the growth and root development of sandal. (Brand *et al.*, 2012).

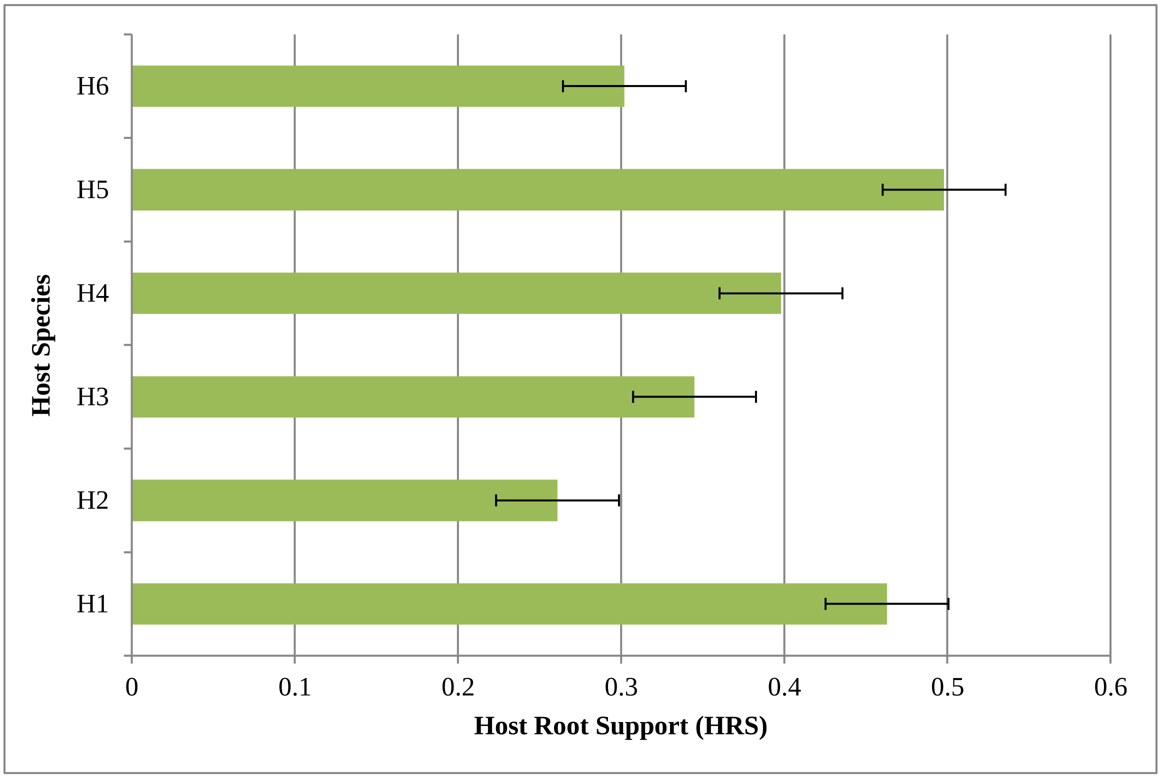


H0-No host, H1-Crotalaria juncia, H2-Mimosa pudica, H3-Casuarina equisetifolia, H4-Cajanus cajan, H5-Crotalaria retusa, H6-Alternanthera sessilis

Fig. 11: Influence of different host species on Host Root Extension (HRE) of *Santalum album* (L.)

4.4.15 Influence of different host species on Host Root Support (HRS)

Host Root Support (HRS) is a metric measuring the ability of the root system to offer stability and support to the plant. Fig. 12 presents the results for the influence of different host species on Host Root Support (HRS) of sandal seedling. Among the host species examined, H5 stands out with the highest HRS value of 0.498, indicating a relatively strong root support system. This suggests that H5 provides optimal conditions for robust root growth, enabling the seedlings to establish a stable and supportive root structure. Following H5, H1 and H4 also display notable HRS values of 0.463 and 0.398, respectively, emphasizing their positive influence on root support. On the other hand, H2, H3, and H6 exhibit lower HRS values of 0.261, 0.345, and 0.302, respectively, suggesting a comparatively lesser level of root support under these hosts. These variations in HRS values underscore the distinct influences of different host species on the root support capabilities of *Santalum album* seedlings. Though the earlier Barrett and Fox (1997) reported that sandal seedlings without a host did not show significant difference in growth up to 3-4 months as compared to seedlings with hosts but Annapurna *et al.* (2006) has reported that requirement of host and its growth stage play a significant role in the growth of S. album seedlings in terms of height, collar diameter, total dry weight and quality indices. The present studies also support the significant role of host plants on growth performance of sandal seedlings.



H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

Fig. 12: Influence of different host species on Host Root Support (HRS) of *Santalum album* (L.)

Table 48. Benefit-Cost ratio of sandal seedlings raised with different host species

Inputs and Outputs	Host Species					
	H1	**H2**	**H3**	**H4**	**H5**	**H6**
Total sum of production costs per seedling (₹)	19.89	20.01	24.32	22.85	19.89	21.89
Total sum of receipts per seedling (₹)	35.00	35.00	35.00	35.00	35.00	35.00
B-C ratio	1.75	1.74	1.43	1.53	1.75	1.59

H0-No host, H1-*Crotalaria juncia*, H2-*Mimosa pudica*, H3-*Casuarina equisetifolia* , H4-*Cajanus cajan*, H5-*Crotalaria retusa*, H6-*Alternanthera sessilis*

4.4.16 Benefit-Cost ratio of sandal seedlings

The B-C ratio is a fundamental financial metric that sheds light on the economic efficiency of the seedling production process by comparing the benefits obtained against the costs incurred. Upon examining the B-C ratios associated with each host species, it is evident that H1 (*Crotalaria juncia*) and H5 (*Crotalaria retusa*) stand out as the most financially efficient choices. Both H1 and H5 demonstrated the highest BC ratio of 1.75, indicating a significant financial gain for every rupee invested in their cultivation. This implies that utilizing H1 and H5 as host species for sandalwood seedlings resulted in a highly favorable economic outcome, generating substantial revenue compared to the production costs per seedling.

Following closely in terms of economic efficiency are H2 (*Mimosa pudica*) and H6 (*Alternanthera sessilis*), with B-C ratios of 1.74 and 1.59, respectively. These host species also proved to be financially viable options, showcasing that the returns from sandalwood seedling production exceeded the costs associated with their cultivation. H4 (*Cajanus cajan*) exhibited a B-C ratio of 1.53, indicating a positive economic return on investment and emphasizing its economic viability as a host species. On the other hand, H3 (*Casuarina equisetifolia*) displayed a B-C ratio of 1.43, indicating that the benefits slightly outweighed the costs associated with the production of sandalwood seedlings using this host species.

While H3 presented a slightly lower B-C ratio compared to others, it still remained economically sound, signifying that the benefits justified the costs involved.

In summary, the B-C ratios emphasize the economic feasibility of employing various host species for sandalwood seedling production, with H1 (*Crotalaria juncia*) and H5 (*Crotalaria retusa*) emerging as the most financially efficient choices. These findings provide valuable insights for stakeholders and growers, aiding in informed decision-making regarding the selection of host species for the profitable cultivation of sandalwood seedlings.

SUMMARY

V SUMMARY

This study focused on identifying superior seed sources for sandal in Karnataka, evaluating their growth and yield potential, as well as refining nursery techniques to enhance seedling quality. By integrating the knowledge of suitable seed sources and effective nursery techniques, sustainable and profitable sandalwood nursery management regime can be achieved.

No major variations were observed in seed quality parameters (100 fruit weight, 100 seed weight, seed length, and seed width) of eight seed sources (S1 to S8). Only 100 fruit weight found significantly different among sources. However, no significant differences were found in seed length and seed width, suggesting similarity in seed physical quality.

The study examined germination attributes (TTIG, TTCG, MDG, PV, and GV) in *Santalum album* seeds from various sources. Early germination was noted in Marayoor (S8) and Gottipura (S3). Time to initiate germination varied, with the shortest in Dornalu (S2) and longest in Gottipura (S3). Mean Daily Germination was highest in Marayoor (S8), while peak value of germination and germination value were also significant in Marayoor (S8). Genetic differences among sources may account for variations in germination attributes, affecting the timing and speed of germination.

Electrical conductivity varied, indicating differences in cell membrane integrity. Lower EC, in Marayoor-S8 (0.50), suggests better membrane integrity and reduced ion leakage, possibly due to optimal seed maturity and hydration. Genetic factors likely influence carbohydrate and protein accumulation, affecting seed composition. Total carbohydrate and protein content showed significant variation across sources. Oil content differed, with a negative correlation between protein and oil content, suggesting a trade-off in resource allocation during seed development.

The physico-chemical properties of *Santalum album* seed oil were analyzed, comparing Marayoor (S8) with the average of Karnataka sources (S1-S7). Marayoor seed source oil had slightly low er specific gravity (0.901) but a higher refractive index, suggesting variations in composition. Viscosity showed consistent flow behavior, while freeze point matched uniformly. In terms of chemical properties, Marayoor exhibited a higher acid value (4.581), indicating more free fatty acids. Saponification and iodine values differed, implying variations in ester linkages and unsaturation degree. Environmental factors like soil composition and conditions could influence these oil property variations.

Comparing fatty acid profiles of sandal seed oil from Marayoor (S8) and the average of Karnataka sources (S1-S7) revealed consistent essential fatty acids but a notable difference in oleic acid levels. Marayoor had lower oleic acid (22.83%) compared to the Karnataka average (29.12%), suggesting potential environmental or genetic influences. Notably, Ximenynic acid levels were significantly lower in Marayoor (61.38%) than the Karnataka average (68.41%), likely due to local stressors affecting fatty acid biosynthesis.

The influence of different seed sources on seedling shoot length of sandal seedlings shows that, seed source Gottipura-S3 displayed continuous growth, increasing from 8.05 cm at 30 DAT to 16.55 cm at 180 DAT. Significant shoot length differences were observed among various seed sources at different time intervals. These variations in seedling growth can be attributed to a complex interplay of genetic diversity, environmental factors, seed maturity, and treatment practices.

The study analyzed the influence of seed sources on seedling root length at various intervals. Seed source Gottipura-S3 showed strong initial and sustained root growth, with highest lengths at 30 DAT (6.24 cm) and 180 DAT (12.26 cm). Marayoor-S8 also displayed robust growth throughout the study. Other sources exhibited moderate to lower root lengths, possibly affected by site conditions, pests, or symbiotic organisms influencing seed quality and germination.Seedling height is a crucial indicator of growth and health in sandalwood plants. Seed sources S3 and S8 consistently showed significantly higher seedling heights, indicating vigorous growth.

Collar diameter, crucial for stem stability, was studied in sandal seedlings from different sources. Seed source S8 consistently displayed the highest diameters, reaching 2.820 cm at 180 DAT, ensuring better stability. S1 consistently had the lowest diameters, highlighting growth variations. S3 and S8 consistently showed larger diameters, possibly influenced by their adaptation to specific environmental conditions. Understanding seedling traits like collar diameter is essential for effective sandalwood plantation management.

The root-to-shoot ratios of *S. album* seedlings varied over a 180-day period across different seed sources. At 30 DAT, S3 (Gottipura) had the highest ratio (0.77), indicating more root mass, while S4 (Gungaraghatti) and S5 (Muddenahally) had lower ratios (0.55 and 0.53), indicating more shoot mass. This trend continued with fluctuations until 180 DAT, with S3 and S8 consistently displaying higher ratios (0.74-0.84) indicating root dominance, and S4 and S5 displaying lower ratios (0.56-0.72) indicating shoot dominance. The selection of parent plants significantly influenced seedling quality.

The leaf count of seedlings varied among seed sources. At 30 DAT, S3 (Gottipura) had the highest leaf count (8.15), while S2 (Doranalu) had the lowest (6.00). S3 (Gottipura) consistently maintained the highest leaf count, reaching 25.05 leaves on average by 180 DAT. The leaf parameters showed that (10.08 cm^{2} at 30 DAT, 12.93 cm^{2} at 180 DAT) and specific leaf area (SLA) (36.80 cm^{2} mg^{-1} at 30 DAT, 29.79 cm^{2} mg^{-1} at 180 DAT). S8 had the highest leaf weight ratio (LWR) (0.58 g kg^{-1} at 30 DAT, 0.55 g kg^{-1} at 180 DAT) and specific leaf weight (SLW) (0.038 g cm^{-2} at 30 DAT, 0.026 g cm^{-2} at 180 DAT). Conversely, S2 exhibited the highest leaf area ratio (LAR) (43.54 cm^{2}g^{-1} at 30 DAT, 27.92 cm^{2}g^{-1} at 180 DAT), suggesting efficient resource utilization.

The dry weight was analyzed at 30 DAT and 180 DAT for shoot, root, leaf, and total weights. At 30 DAT, shoot dry weight varied from 0.062 g (S2) to 0.142 g (S8). S3 had the highest shoot dry weight (0.212 g) at 180 DAT. Root dry weight ranged from 0.042 g (S2) to 0.125 g (S8) at 180 DAT. Leaf dry weight varied from 0.042 g (S2) to 0.476 g (S8) at 180 DAT. Total dry weight ranged from 0.146 g (S2) to 0.826 g (S8) at 180 DAT. These differences may stem from genetic, physiological, and environmental factors, affecting seedling characteristics.

The impact of seed sources on seedling vigor and quality. S3 (Gottipura) demonstrated the highest initial vigor (VI I: 1488) and S8 (Marayoor) exhibited the highest vigor relative to biomass (VI II: 24). S8 also had the best overall quality (DQI: 0.258), while S1 (Bevinahally) had the lowest (DQI: 0.084). S3 showcased sturdy seedlings (SQ: 13.58), and S8 displayed significant growth with (BVI: 1.358). Careful selection of seed sources, particularly S3 and S8, significantly influences sandalwood cultivation success.

The analysis of the benefit-cost ratio for sandalwood seedlings from various sources over 180-day nursery growth period demonstrates distinct economic viability. S1-Bevinahally stands out with a promising B-C ratio of 1.83, indicating a substantial financial return of 1.83 rupees for every rupee invested in seedling production. Additionally, S3-Gottipura and S5-Muddenahally display strong economic viability with BC ratios of 1.75 and 1.77, underlining potential for profitable returns. However, S8 (Marayoor) presents a marginal B-C ratio of 1.05, prompting further examination to optimize economic feasibility in seedling production. Comparatively, considering germination performance, seedling characteristics, and quality indices, S3-Gottipura proved potential as a valuable seed source for future plantation activities.

Biopriming sandal seeds with *Pseudomonas fluorescens* at varying concentrations (25-100%) and durations (1-4 days) showed significant effects on germination attributes. Higher concentrations negatively correlated with increased germination percentage, peaking at 37.67% for 25% concentration at 3-day duration (C1D3). Time to initiate and complete germination decreased with higher concentrations, indicating faster germination. Mean daily germination also followed this trend. Peak value of germination and germination value reduced with higher concentrations, emphasizing the positive impact of lower *Pseudomonas fluorescens* concentration on seedling growth. The most effective treatment was at 3-day duration with a 25% concentration, optimizing germination and seedling growth.

Varied *Trichoderma viride* concentrations and biopriming durations significantly affect sandal seed germination. The most effective treatment was 100(%) concentration for 4 days (C4D4), yielding a high germination percentage (60.67%) and rapid germination initiation (18 days) and completion (50.33 days). Mean daily germination, peak value of germination, and germination value were also highest at this treatment. *Trichoderma viride*, known for plant growth-promoting attributes, promotes seedling growth and vigor by inducing essential plant growth hormones.

The impact of $MnSO_4$ concentrations and nutripriming durations on sandal seed germination attributes showed that, optimal germination occurred at 0.4M concentration for 3 days, yielding an 84.00 (%) germination rate, while the lowest was at 0.8M for 4 days (18.33%). Higher concentrations led to quicker germination initiation (lowest TTIG at 0.4M for 3 days - 16.00 days) and completion (lowest TTCG at 0.4M for 3 days - 48.00 days). Mean daily germination and peak germination value were highest at 0.4M for 3 days, indicating favorable germination rates. Increasing $MnSO_4$ concentration generally improved germination attributes. Nutripriming with $MnSO_4$ significantly enhanced germination compared to hydropriming. However, longer durations reduced germination across concentrations, likely due to Mn toxicity.

Sandal seed germination was observed with 2.0(%) KNO_3 for 4 days, resulting in the highest germination (79.67%) and the shortest initiation (TTIG - 16.00 days) and completion time (TTCG - 40.67 days). This treatment also led to the highest daily germination rate (MDG - 1.960), peak value of germination (PV - 1.980), and overall germination value (GV - 3.880). Conversely, 0.5(%) KNO_3 for 1 day showed the lowest germination attributes.

Hydropriming of sandal seeds showed varying germination outcomes based on the duration. Optimal results were obtained with a 4-day hydropriming, yielding the highest germination (16.67%) and fastest initiation (TTIG - 37.67 days) and completion (TTCG - 72.33 days) of germination. This duration also resulted in the highest daily germination rate (MDG - 0.230), peak value of germination (PV - 0.257), and overall germination value (GV - 0.059). Conversely, a 1-day hydropriming exhibited the lowest germination attributes.

Benefit-Cost ratios (B-C ratios) for different *Santalum album* (L.) seed priming methods showed that, $MnSO_4$ and hydropriming were cost efficient, with $MnSO_4$ being the most economical at ₹21.04 per seedling. Surprisingly, despite higher costs (₹22.11 per seedling), KNO_3 displayed a strong B-C ratio of 1.59, highlighting its cost-effectiveness and potential for significant returns.

Shoot lengths across different container (C) and potting media (P) combinations varied significantly. C4P2 (Poly bag of 30cmx20cm; Soil+ Rice husk + FYM in 2:1:1) consistently displayed the highest growth, reaching 14.81 cm at 180 DAT. In contrast, C1P4 (Root trainer of 150 cc; Soil+ M-Sand + FYM in 2:1:1) exhibited the lowest growth at 11.35 cm. The progressive growth is attributed to potting media effects on nutrient availability and root development. P2 (Soil + Rice husk+ FYM) sustained optimal nutrient levels, fostering steady and significant growth, possibly due to its loose root plug formation, enhancing water and nutrient uptake.

Container C4 paired with potting media P2 consistently showed the highest root lengths, reaching 12.18 cm at 180 DAT. Conversely, C1P4 (Root trainer of 150 cc; Soil+ M-Sand + FYM in 2:1:1) exhibited the lowest growth at 7.51 cm. Notably, P2, composed of soil, rice husk, and FYM, facilitated early-stage maximum root length.

Collar diameter increased across treatments, P2 with its nutrient-rich composition, consistently promoted larger collar diameters. Notably, C4 with P2 maintained significant differences, underlining its enduring positive impact on seedling growth. The total dry weight ratio varied, combinations involving container C4, especially with potting media P2 and P5, consistently exhibited higher total dry weight ratios. Potting media P2 and P5 likely created an optimal growth environment by promoting efficient root development and nutrient absorption. Container C4, when paired with these potting media, enhanced nutrient uptake, resulting in increased total dry weight ratios.

The impact of containers and potting media on the number of leaves shows that, combination C4P2 (Poly bag of 30cmx20cm; Soil+ Rice husk + FYM in 2:1:1) consistently displayed the highest leaf count, indicating its sustained positive influence on leaf growth from early to later stages. But combination C1P4 (Root trainer of 150 cc; Soil+ M-Sand + FYM in 2:1:1) consistently had the lowest leaf count, highlighting potting media P4 enduring effect in limiting leaf development. Combination C4P2 consistently resulted in the largest leaf areas, emphasizing its sustained positive influence on leaf growth. In contrast, container C1, especially with potting media P4, tended to yield smaller leaf areas.

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.

The seedling height at 30 DAT, ranged from 10.72 cm to 11.66 cm. At 60 DAT, H1 (*Crotalaria juncia*) displayed the highest at 15.82 cm, H0 (no host) the lowest at 12.72 cm. By 180 DAT, H5 (*Crotalaria retusa*) had the tallest at 35.97 cm, followed by H4 (*Cajanus cajan*) at 33.72 cm. H0 had the shortest at 24.79 cm. Host species H5 recorded the largest collar diameter of 2.65 cm, followed by H1 recorded 2.28 cm. And, H0 exhibited the smallest collar diameter at 1.32 cm.

The impact of host species on the total dry weight shows that, initially, at 30 DAT, dry weight ranged from 0.122 g (H0) to 0.264 g (H5), indicating strong early growth potential. H5 consistently showed the highest dry weight, reaching 0.352g at 180 DAT, emphasizing its sustained and robust growth compared to other hosts. The results underscore the host's critical role in providing favorable soil conditions and adequate nutrients, influencing root elongation and, subsequently, total dry weight.

The sturdiness quotient values for *S. album* seedlings associated with various host species varied significantly. H5 (*Crotalaria retusa*) showcased a sturdiness quotient of 13.62, implying a potential increase in the robustness of the seedlings associated with this host species. HUE (Host Use Efficiency) is a critical metric that assesses the efficiency with which seedlings utilize a particular host for their growth and development. H5 stands out with the highest HUE value of 0.956. Similar trend was observed in case of HRE (Host Root Extension) and HRS (Host Root Support).

B-C ratio of H1 (*Crotalaria retusa*) and H5 (No host) demonstrated the highest BC ratio of 1.75, indicating a significant financial gain for each rupee invested. H2 (*Mimosa pudica*) and H6 (*Alternanthera sessilis)* followed closely with B-C ratios of 1.74 and 1.59, respectively, affirming their economic viability. H4 (*Cajanus cajan*) also exhibited positive returns with a B-C ratio of 1.53. Overall, this analysis guides informed decision-making on host species selection for profitable sandalwood seedling cultivation.

The comprehensive studies on nursery management regime of Indian sandalwood encompassed vital aspects such as seed source selection, nursery management, seedling growth, and host-plant interactions. By identifying superior seed sources and refining nursery techniques, optimal conditions for sandalwood seedling growth and sustainability are achieved. The assessment of germination attributes and the application of priming techniques further enhance seedling viability and growth potential. Understanding the influence of host species on seedling growth guides informed decisions for profitable cultivation. Economic viability assessments provide critical insights into resource allocation, ultimately contributing to a more efficient and economically viable approach to sandalwood cultivation. In conclusion, these studies collectively offer a holistic framework for successful and sustainable sandalwood cultivation, vital for the economic and environmental prosperity of the Indian sandalwood nursery management regime.

Future line of work

1. The findings presented in the study open several promising avenues for future research in the field of sandalwood cultivation and nursery management. Since it is a nursery study, field trials need to be conducted.

2. Further research on genetic variations among sandalwood seed sources helps to understand the genetic factors influencing traits like germination, growth, and oil properties which could lead to the development of superior sources.

3. Continuing studies on nursery techniques, including different seed priming methods, can help optimize the germination and growth of sandalwood seedlings. Further experimenting with various management techniques could lead to more efficient and cost-effective practices.

4. Economics and legal aspects of the oil extracted from sandal seeds implies a need of research. Further economic modelling and analysis can refine the understanding of the costs and returns associated with different nursery management regime. This can assist farmers and investors in making more informed decisions regarding resource allocation.

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VI REFERENCES

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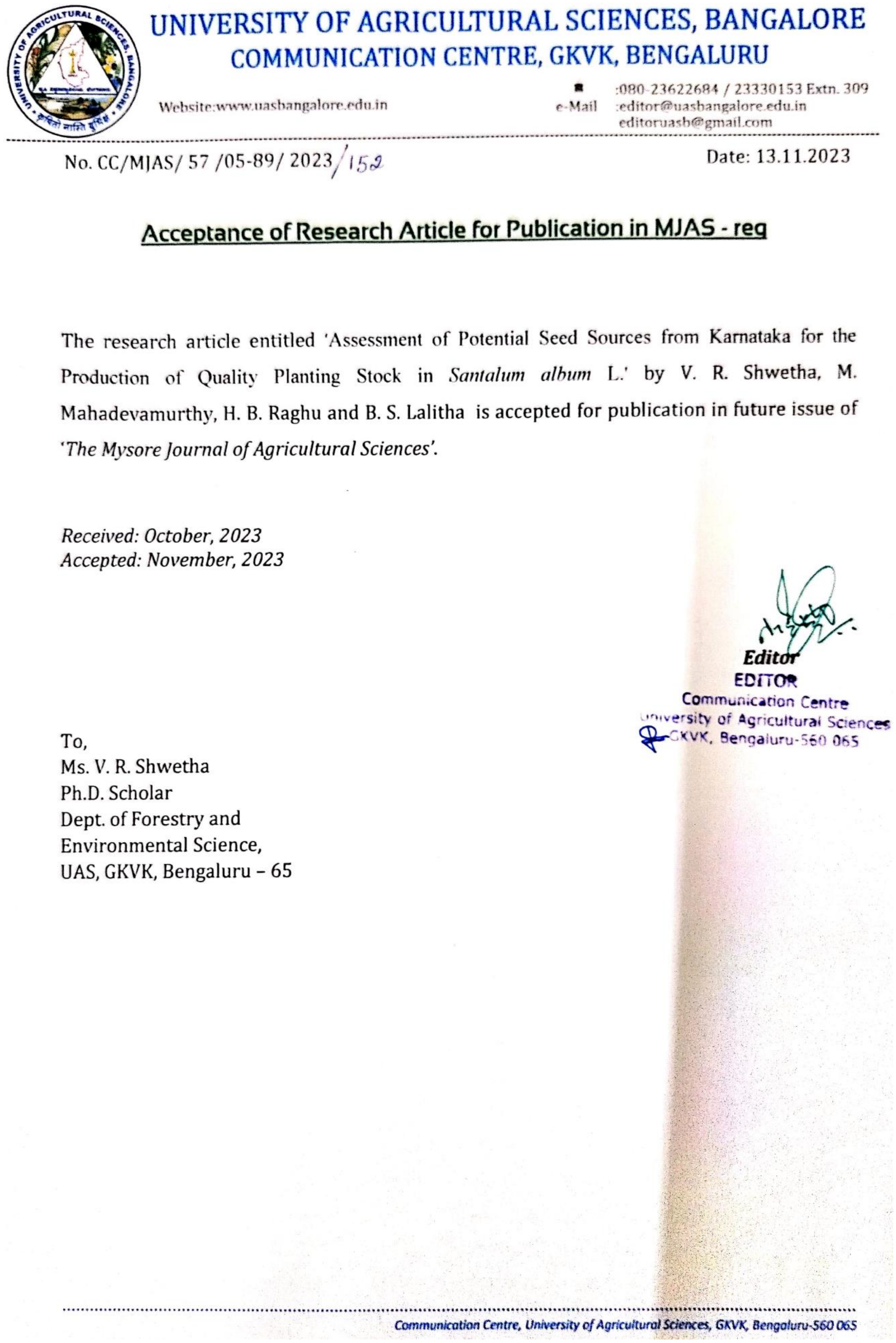

UNIVERSITY OF AGRICULTURAL SCIENCES, BANGALORE
COMMUNICATION CENTRE, GKVK, BENGALURU

Website:www.uasbangalore.edu.in
☎ :080-23622684 / 23330153 Extn. 309
e-Mail :editor@uasbangalore.edu.in
editoruasb@gmail.com

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EDITOR
Communication Centre
University of Agricultural Sciences
GKVK, Bengaluru-560 065

To,
Ms. V. R. Shwetha
Ph.D. Scholar
Dept. of Forestry and
Environmental Science,
UAS, GKVK, Bengaluru – 65

Assessment of Potential Seed Sources from Karnataka for the Production of Quality Planting Stock in *Santalum album* L.

V.R. Shwetha[1], M. Mahadevamurthy[2], H.B. Raghu[3] AND B.S. Lalitha[4]
1,2&3. Department of Forestry and Environmental Science, UAS, GKVK, Bengaluru-65
4. Department of Agronomy UAS, GKVK, Bengaluru-65
e-Mail: shwethachanduvr@gmail.com

ABSTRACT

This study was conducted to assess and compare the potential seed sources from different regions of Karnataka with the Marayoor seed source. Seeds were collected from seven different locations in Karnataka and Marayoor seeds were procured from Kerala Forest Research Institute. Significant variations were observed among the seed sources for most of the assessed parameters. Marayoor seed source S_8 (68.66%) displayed the highest germination. Among the Karnataka seed sources Gottipura seed source S_3 (51.67%) recorded the higher germination percentage indicating higher probability establishment. Seed source S_3 recorded significantly highest growth parameters compared to other Karnataka seed sources throughout the study. The Leaf area, Leaf area ratio, Leaf weight ratio, Specific leaf area, and Specific leaf weight, were assessed and seed source S_3 recorded higher results compared to all other Karnataka sources in the study. Apart from Marayoor source, seed source S_3 showed the highest Vigour Index (1488.35) as well as the Quality Index (0.249), indicating seedlings with greater initial vigour and overall quality. Seed source S_3 also showed the lowest Sturdiness Quotient (13.58), indicating stronger and more stable seedlings. These findings can contribute to the selection of suitable seed sources for sandalwood plantation and breeding programs in Karnataka, promoting the conservation and sustainable utilization of this valuable timber species.

Keywords: Seed Sources, Growth Parameters, Quality Index, Sturdiness quotient

Sandalwood ***(Santalum album*** .L) is one of the hemi parasitic plants in the family Santalaceae and the genus *Santalum.* It is most celebrated tree species of the tropics and is often regarded as the paragon of Indian timbers. Revered for centuries for its aromatic properties, this tree species remains a symbol of economic significance, cultural heritage, and ecological importance. Nowhere this significance is more pronounced than in the state of Karnataka, where sandalwood's remarkable attributes have been harnessed to create a thriving industry, particularly in the production of high-quality sandal oil. A cornerstone of successful sandalwood propagation lies within its seeds, which serve as the initial point of growth for this species. However, the journey from seed to thriving seedling is heavily influenced by the source of those seeds (Shankar and Devakumar, 2018). The provenance of the parent tree, often referred to as the seed source, plays an instrumental role in shaping the attributes of subsequent generations. From germination rates to seedling vigor and growth patterns, the choice of seed source profoundly affects the trajectory of sandalwood cultivation and the broader goals of forest regeneration.

The characteristics of the seed source, encompassing its genetic makeup, adaptability to diverse environments, and overall seed quality, have a cascading impact on the performance of germination and seedling growth. This nexus between genetic potential and environmental adaptation constitutes a linchpin in the broader strategy of successful sandalwood cultivation and the sustainable rejuvenation of forest ecosystem (Ananthapathmanabha, 2012). While Karnataka boasts a substantial expanse under sandalwood cultivation, a seed source of note hails from the Marayoor region in Kerala. The Marayoor seed source has gained prominence due to its exceptional qualities, including rapid growth, high yields, and favorable oil content (Rao *et. al.,* 2007). This study assumes a significant mantle in the continuum of sandalwood conservation and cultivation. By subjecting various sandalwood seed sources from distinct regions within Karnataka to meticulous evaluation, it seeks to elucidate their performance vis-à-vis the benchmark Marayoor seed source. By evaluating germination rates, seedling growth patterns, and the holistic quality of the resulting plants, this study aims to uncover novel insights into seed source viability and its intricate interplay with sandalwood propagation.

Material and methods

Seeds were collected from seven different locations of Karnataka during October-November 2021 (Table 1) and Marayoor seeds were procured from Kerala Forest Seed Centre a division of Kerala Forest Research Institute. After collection fresh fruit weight was measured and fruits were soaked in water for depulping. Depulped seeds were shade dried and pretreated with 1000 ppm GA_3 for 24 hours. The evaluation was conducted in a nursery setting to provide controlled environmental conditions and eliminate potential variations due to site-specific factors. Standard nursery bed of 10×1m was prepared and 100 pretreated seeds per replication were sowed. Nursery beds were watered regularly until the germination was completed.

Table 1: Geographical information of seed source locations

Sl no.	Location	Range	Latititude Longitude	Altitude (m)	Ann. rainfall (mm)	Avg. Temp. (^{0}C)	Soil types
S_1	Bevinahally	Tondebhavi	13.505598 N 77.486271 E	755	747	28	Clay loam
S_2	Doranalu	Tarikere	13.679082 N 75.834471 E	680	914	24	Red sandy loam,
S_3	Gottipura	Hoskote	13.0997540 N 77.8449375 E	875	857	25	Red loamy and lateritic soil
S_4	Gungaraghatti	Dharwad	15.5271742 N 74.9437982 E	720	786	28	Well drained loamy sand over gravel
S_5	Muddenahally	Chikkaballapur	13.403345 N 77.690987 E	993	808	28	Red loamy
S_6	Narsapura	Kushtagi	15.625631 N 76.154781 E	639	172	31	Black clayey soil
S_7	Tavarekere	Sira	13.797152 N 76.804344 E	802	638	28	Clalyey soil
S_8	Marayoor	-	-	-	-	-	-

Daily germination counts were recorded until germination was completed. The percentage, mean daily germination (MDG), the peak value of germination (PV) was calculated. The germination value (GV), an index combining speed and completeness of germination was calculated using the formula suggested by Czabator (1962): GV = Final Mean daily germination (MDG) X Peak Value of germination. The mean daily germination is calculated as the cumulative percent of full seed germination at the end of germination test, divided by the number of days from sowing to the end of the test. Peak Value of germination denotes the speed of germination, which is the maximum mean daily germination, recorded at any time during the period of test. Along with germination parameters electrical conductivity and biochemical assay of seeds was done. To measure the electrical conductivity, the leachate after soaking was filtered. Five ml of the leachate was diluted to final volume of 25 ml with distilled water and the electrical conductivity was determined using a conductivity meter. The total carbohydrate content of seeds was estimated following the Anthrone reagent method (Yemm and Wills, 1954), protein by Lowry's method (Lowry *et al.,* 1951) and crude fat content by Soxhlet extraction (Kennedy ,1949).

After Biochemical assay seeds were sown in nursery bed, the emerged seedlings were transplanted to polythene bags filled with the medium soil: sand: Farm Yard Manure in a ratio of 2:1:1 and kept in the shade house. The growth and biomass attributes were recorded up to 180 DAT (Days after Transplanting). Seedling growth attributes viz. seedling height (shoot length+root length), collar diameter, number of leaves, root:shoot ratio, biomass production and the leaf parameters like Leaf area, LAR(Leaf Area Ratio), LWR (Leaf Weight Ratio), SLA (Specific Leaf Area), SLW (Specific Leaf Weight) was computed for the period from 30 to 180 days. At the end vigour index and quality parameters like seedling quality index, sturdiness quotient and bio volume index were recorded. Vigour index was calculated using the formula (Abdul Baki,1973).

Vigour index = Germination percentage x Total dry weight

The seedling quality index was calculated as (Dickson et al., 1960).

$$Quality\ index = \frac{Total\ dry\ weight\ of\ seedlings\ (g)}{\frac{Height\ of\ seedling(cm)}{Diameter\ of\ seedlings\ (mm)} + \frac{Shoot\ dry\ weight\ (g)}{Root\ dry\ weight\ (g)}}$$

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

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

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

B.V. I. = (Collar diameter) ^{2} x Height (cm)

All the statistical analyses were conducted in Agricolae and ICAR Goa WASP 2.0.

Results and Discussion

The present study aimed to identify potential seed sources from Karnataka for the production of high-quality planting stock of *Santalum album* L. The results revealed significant variations among the seed sources for almost all the assessed parameters. Table 2. shows the results of the influence of seed source on various initial seed quality parameters in *Santalum album* L. Significant differences were found in 100 Fruit weight, ranging from 60.54 g (S_5) to 68.51 g (S_3). However, no significant differences were observed in 100 Seed weight, Seed length, and Seed width, indicating similarity in physical quality parameters across different seed sources. The Fig.1 shows the influence of seed sources on germination percentages of *Santalum* *album* L. The germination percentage varied among the seed sources, ranging from 18.67% (S_2) to 68.66% (S_8). Seed source S_8 displayed the highest germination percentage (68.66%) followed by seed source S_3. This indicates that seeds from this source have a higher probability of successful germination and early establishment when compared to other sources. On the other hand, seed sources S_2 and S_1 showed relatively lower germination percentages of 18.67% and 22.33%, respectively. These sources may have seeds with lower viability; potentially due to factors such as poor seed quality or storage conditions. The low germination percentages from these sources warrant caution when considering them for planting or reforestation projects, as they may result in lower plant establishment success (Jagadish, 2008). The table 3 presents the results of the influence of seed source on germination attributes of *Santalum album*. The germination attributes measured include Time taken to Initiate Germination (TTIG), Time taken to Complete Germination (TTCG), Mean Daily Germination (MDG), Peak Value of Germination (PV), and Germination Value (GV). Germination attributes in sandal varied among seed sources. Marayoor (S_8) showed early germination (TTIG = 20.67 days) followed by Gottipura (S_3). Mean Daily Germination was highest in (Marayoor S_8) 1.33 and lowest in (Bevinahally S_2) 0.22. Peak Value of Germination was highest in (Marayoor S_8) 1.86 and lowest in Doranalu (0.22). Germination Value was highest in Marayoor (S_8) (GV = 2.47) and lowest in Doranalu (S_2) (GV = 0.05). Significant differences were observed among the seed sources for all germination attributes.

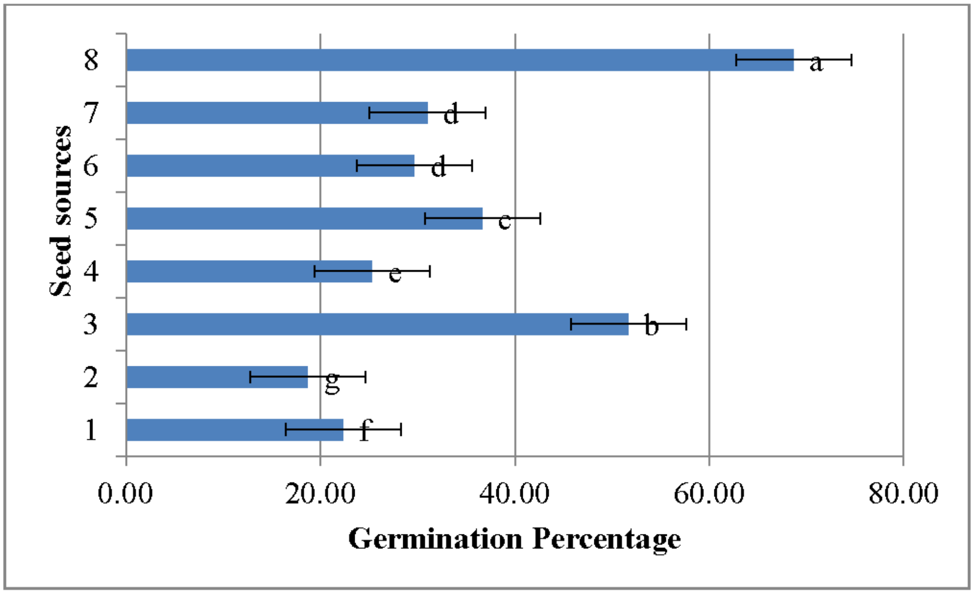

Fig. 1 Influence of Seed Sources on the Germination Percentage of *Santalum album* L.

Table2. Influence of seed source on initial seed quality parameters in *Santalum album*

Seed Sources	**100 Fruit weight (g)**	**100 Seed weight (g)**	**Seed length (mm)**	**Seed width (mm)**
S_1	68.47	17.07	7.50	6.64
S_2	65.58	16.83	7.64	6.55
S_3	68.51	17.10	7.45	6.46
S_4	67.08	17.97	7.37	6.46
S_5	60.54	16.58	7.44	6.28
S_6	61.40	17.90	7.48	6.44
S_7	61.96	16.92	7.72	6.46
S_8	-	17.89	7.65	6.57
SEm±	**0.97**	**0.34**	**0.13**	**0.09**
CD (p=0.05)	**2.94**	**NS**	**NS**	**NS**
CV (%)	**2.58**	**3.45**	**3.06**	**2.44**

Table 3. Influence of seed source on germination attributes of *Santalum album* L.

Seed Sources	**TTIG**	**TTCG**	**MDG**	**PV**	**GV**
S_1	23.00	81.33	0.28	0.39	0.11
S_2	31.00	86.33	0.22	0.25	0.05
S_3	19.33	57.67	0.90	1.05	0.94
S_4	20.67	69.33	0.37	0.40	0.14
S_5	21.33	63.67	0.58	0.58	0.33
S_6	24.00	61.00	0.49	0.40	0.20
S_7	20.00	62.67	0.49	0.53	0.26
S_8	16.67	51.67	1.33	1.86	2.47
SEm±	**0.77**	**0.99**	**0.02**	**0.03**	**0.04**
CD (p=0.05)	**2.34**	**2.98**	**0.07**	**0.09**	**0.11**
CV (%)	**6.08**	**2.56**	**6.46**	**7.82**	**11.17**

Variations in electrical conductivity and biochemical composition among different sandal seed sources are presented in table 4. Electrical conductivity ranged from 0.50 dS cm^{-1} (S_8) to 0.88 dS cm^{-1} (S_2), indicating differences in the cell membrane system degradation. Total Carbohydrate varied from 1.01 mg g^{-1} (S_2) to 1.63 mg g^{-1} (S_8), Total Protein from 0.041 mg g^{-1} (S_1) to 0.074 mg g^{-1} (S_8), and Crude Fat from 43.89% (S_2) to 53.22% (S_8). Gottipura seed source (S_3) recorded the highest crude fat (51.14%), followed by Muddenahally (S_5). Significant differences were observed among the treatments for all parameters. Seeds with lower EC values (S_8) typically exhibit better cell membrane integrity, indicating lower leakage of ions and solutes. This could result from factors like optimal seed maturity at harvest, efficient seed hydration, and reduced exposure to stressors such as high temperatures or pathogenic infections Jijeesh *et al.* (2022). The variations in total carbohydrate, total protein, and crude fat content among different seed sources are indicative of genetic diversity and metabolic differences. Genetic variability can influence the synthesis and accumulation of biochemical compounds within the seeds (Polaiah *et al.,* 2020; Mohapatra and Anil, 2022).

Table 4. Changes in the electrical conductivity and biochemical composition of sandal seeds with respect to different seed sources

Seed Sources	Electrical conductivity (dS cm^{-1})	Total carbohydrate (mg g^{-1})	Total protein (mg g^{-1})	Crude fat (%)
S_1	0.83	1.03	0.041	44.53
S_2	0.88	1.01	0.042	43.89
S_3	0.52	1.61	0.073	51.14
S_4	0.80	1.23	0.048	44.95
S_5	0.68	1.42	0.051	48.21
S_6	0.73	1.23	0.049	45.02
S_7	0.71	1.35	0.051	45.19
S_8	0.50	1.63	0.074	53.22
SEm±	**0.01**	**0.01**	**0.001**	**0.23**
CD (p=0.05)	**0.02**	**0.02**	**0.003**	**0.69**
CV (%)	**1.95**	**1.05**	**2.953**	**0.84**

Comprehensive analysis of growth parameters across various seed sources (S_1 to S_8) is shown in table 5. The study evaluates height, collar diameter, number of leaves, total dry weight, and root-to-shoot ratio as indicators of growth performance. The results reveal significant variations among the seed sources, highlighting the potential influence of genetic traits and environmental factors. Notably, S_3 and S_8 exhibit superior height, with 28.82 cm and 29.92 cm respectively, while S_2 demonstrates the shortest height at 19.92 cm. Collar diameters variation ranges from 1.153 mm (S_2) to 2.730 mm (S_8). Source S_3 boasts the highest leaf count (25.05), while S_2 displays the fewest (18.08). These findings underscore the favorable growth attributes of the Gottipura (S_3) and Marayoor sources. Moreover, S_8 demonstrates the highest total dry weight (0.826 gm) and root-to-shoot ratio (0.77), reflecting significant biomass production and root system dominance. Genetic diversity and environmental influences are proposed as contributors to shoot length disparities (Xiaojin *et al.,* 2011). S_3 consistently excels, potentially due to advantageous genetic traits, whereas S_1, S_2, and S_6 show slightly diminished shoot growth, likely due to specific genetic traits or environmental adaptations.

Table 5. Comparative analysis of seed source on the growth attributes of *Santalum album* L. seedlings up to180 days after transplanting

Seed Sources	**Height (cm)**	**Collar diameter (mm)**	**No. of leaves**	**Total dry weight (gm)**	**Root:Shoot**
S_1	21.62	1.337	20.04	0.325	0.71
S_2	19.92	1.153	18.08	0.276	0.71
S_3	28.82	2.523	25.05	0.769	0.74
S_4	22.92	1.520	19.41	0.337	0.72
S_5	24.78	1.630	21.72	0.354	0.58
S_6	21.41	1.260	19.98	0.361	0.68
S_7	22.29	1.427	19.04	0.353	0.65
S_8	29.92	2.730	24.33	0.826	0.77
SEm±	**0.33**	**0.020**	**0.22**	**0.006**	**0.02**
CD (p=0.05)	**0.99**	**0.062**	**0.65**	**0.019**	**0.05**
CV (%)	**2.37**	**2.426**	**1.77**	**2.408**	**4.16**

Table 6 examines the influence of diverse seed sources on leaf parameters of *Santalum album* L. seedlings over a 180-day period post-transplantation (DAT). Leaf area, leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), and specific leaf weight (SLW) were assessed at 30 DAT and 180 DAT to track parameter changes over time. Notable variations in leaf parameters were observed among the treatments, implying genetic, physiological, and environmental influences. Seed source S_3 demonstrated the highest leaf area at both time points (10.08 cm^2 and 12.93 cm^2 at 30 DAT and 180 DAT respectively), while S_2 displayed the smallest leaf area initially (6.35 cm^2). LAR highlighted resource utilization efficiencies, with S_2 having the highest LAR (43.54 cm^2g^{-1} and 27.92 cm^2g^{-1} at 30 DAT and 180 DAT respectively) and S_3 having the lowest at both times. LWR indicated allocation strategies, where S_8 invested most in leaf biomass (0.58 g kg^{-1} and 0.55 g kg^{-1} at 30 DAT and 180 DAT respectively), and S_3 allocated the least. SLA demonstrated leaf thickness and density variations, with S_3 having the highest values (36.80 cm^2 mg^{-1} and 29.79 cm^2 mg^{-1} at 30 DAT and 180 DAT respectively), and S_8 displaying the lowest. Source S_8 exhibited the highest SLW (0.038 g cm^{-2} and 0.026 g cm^{-2} at 30 DAT and 180 DAT respectively). The dynamic interplay of genetic traits, physiological adaptations, and environmental factors contributed to the observed leaf parameter variations among seed sources, ultimately influencing cultivation and breeding decisions(Rocha *et al.*, 2014).

Insights into the ramifications of distinct seed sources on the vigour index (VI), vigour index II (VI II), Dickson quality index (DQI), sturdiness quotient (SQ), and bio volume index (BVI) of Sandal seedlings are discussed in table 7. The highest VI value (1488.35) was recorded by seed source S_3, indicating robust initial vigour, while the lowest (372.66) pertains to S_2, signifying limited vigour. Sources S_3 and S_8 consistently exhibit elevated vigour across parameters. The highest VI II value (24.07) emerges from S_8, contrasting with the lowest (3.63) from S_2. Marayoor source S_8 showed highest DQI value (0.258), showcasing superior overall seedling quality, while S_1 scores the lowest (0.084), denoting diminished quality. S_3 and S_8 maintain significantly higher quality than other sources. In sturdiness assessment, S_1 reports the highest SQ value (19.03), suggesting fragility, while S_3 records the lowest (13.58), implying robustness. Noteworthy SQ differences prevail, with S_3 and S_8 presenting lowered sturdiness relative to S_1.

Table 6. Influence of different seed sources on leaf parameters of *Santalum album* L. seedlings upto 180 DAT

Seed Sources	**Leaf Parameters**									
	Leaf area cm^2		**LAR** cm^{2}g^1		**LWR** g kg^{-1}		**SLA** cm^2 mg^{-1}		**SLW** gcm^{-2}	
	30 DAT	**180 DAT**	**30 DAT**	**180 DAT**	**30 DAT**	**180 DAT**	**30 DAT**	**180 DAT**	**30 DAT**	**180 DAT**
S_1	7.09	8.49	39.47	26.13	0.30	0.28	132.28	92.98	0.008	0.011
S_2	6.35	7.69	43.54	27.92	0.29	0.30	152.22	93.81	0.007	0.011
S_3	10.08	12.93	20.62	16.83	0.56	0.57	36.80	29.79	0.027	0.034
S_4	7.09	8.04	37.57	23.85	0.33	0.30	114.92	80.71	0.009	0.012
S_5	7.58	9.06	35.95	25.65	0.34	0.32	105.83	81.77	0.009	0.012
S_6	8.03	8.84	42.81	24.50	0.33	0.26	130.29	95.35	0.008	0.010
S_7	8.08	9.72	38.25	27.55	0.33	0.28	115.44	99.04	0.009	0.010
S_8	10.11	12.40	20.90	15.02	0.55	0.58	38.19	26.08	0.026	0.038
SEm±	**0.10**	**0.16**	**0.76**	**0.44**	**0.02**	**0.01**	**1.89**	**1.97**	**0.000**	**0.001**
CD (p=0.05)	**0.29**	**0.48**	**2.31**	**1.32**	**0.04**	**0.02**	**5.70**	**5.95**	**0.001**	**0.002**
CV (%)	**2.09**	**2.88**	**3.79**	**3.24**	**6.73**	**3.89**	**3.16**	**4.55**	**3.804**	**6.083**

Exploring growth, S_8 commands the highest BVI value (1.358), reflecting extensive volume and growth, as S_2 exhibits the lowest (0.266), symbolizing limited expansion. BVI distinctions are pronounced, notably for S_3, S_4, S_5, and S_8. These findings collectively highlight the pivotal role of seed sources in shaping vigour, quality, sturdiness, and growth attributes of *Santalum album* seedlings. The variations in vigour and quality parameters might reflect differences in physiological responses to stress, light availability, and water availability among seed sources. Some sources might have physiological mechanisms that confer better stress tolerance and growth under specific conditions (Baiyeri and Mbah, 2006).

Table 7. Influence of different seed sources on Vigour index and quality parameters of *Santalum album* L. seedlings.

Seed Sources	**VI I (Vigour Index)**	**VI II (Vigour Index)**	**DQI (Dickson Quality Index)**	**SQ (Sturdiness quotient)**	**BVI (Bio Volume Index)**
S_1	483.03	5.22	0.084	19.03	0.279
S_2	372.66	3.63	0.086	17.28	0.266
S_3	1488.35	17.26	0.249	13.58	1.300
S_4	580.31	6.02	0.101	17.36	0.400
S_5	908.98	8.89	0.096	18.63	0.439
S_6	635.04	7.95	0.091	16.99	0.340
S_7	690.74	7.88	0.095	18.17	0.336
S_8	2054.49	24.07	0.258	14.05	1.358
SEm±	**25.85**	**0.59**	**0.002**	**0.21**	**0.023**
CD (p=0.05)	**78.17**	**1.80**	**0.007**	**0.63**	**0.068**
CV (%)	**4.97**	**10.17**	**2.990**	**2.13**	**6.644**

The process of selecting parent plants for seed production can greatly influence seedling quality. Seed sources that are chosen based on desired traits, such as vigour and quality, are likely to yield seedlings with corresponding attributes. Seed source S_8 producing seedlings with high vigour and quality values might be the result of careful selection and breeding for these traits. Differences in environmental conditions where the parent plants were grown and where the seeds were collected can impact seedling vigour and quality. Variations in climate, soil type, and other local factors can affect seedling performance. Seed sources adapted to specific environmental conditions may exhibit higher vigour under similar conditions. The selection of seed sources, exemplified by S_3 and S_8, bears substantial implications for the success and productivity of sandalwood plantations.

The findings of this study provide valuable insights into selecting suitable seed sources for enhancing the production of superior planting stock of *Santalum album* in Karnataka, thus contributing to the conservation and sustainable utilization of this valuable timber species. The implications of these results and their potential applications for sandalwood plantation management and genetic improvement programs are of paramount importance. This study emphasizes the importance of informed seed source selection for successful sandalwood plantation establishment, promoting higher yields and overall productivity.

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

Shwetha V.R.[1*], Mahadevamurthy M.[1], Raghu H.B.[1], Vijayalakshmi K.P.[2] and Maheshnaik B.L.[3]
[1]Department of Forestry and Environmental Science, UAS, GKVK, Bangalore (Karnataka), India.
[2]Department of Silviculture and Agroforestry, UAHS, Shimoga Bangalore (Karnataka), India.
[3]Department of Silviculture and Agroforestry, UAS, Dharwad Bangalore (Karnataka), India.

(Corresponding author: Shwetha V.R.)*

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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± 2°C 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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