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Advances in Production Technology and Medicinal Properties of Red Sandalwood (*Pterocarpus santalinus*) and White Sandalwood (*Santalum album*): A Review

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Sandalwood, comprising *Santalum album* (white sandalwood) and *Pterocarpus santalinus* (red sandalwood), holds an esteemed position among high-value tree species due to its cultural, religious, medicinal, and industrial significance. White sandalwood is prized for its aromatic oil rich in α- and β-santalol, whereas red sandalwood is valued for its timber, dye compounds, and pharmacological properties. Overexploitation and illicit trade have endangered both species, necessitating scientific interventions in production technology, conservation, and sustainable utilization. This review presents a comprehensive account of sandalwood biology, climate and soil requirements, propagation techniques, nursery and plantation management, nutrient and water needs, pest and disease management, harvesting, and yield. Special emphasis is placed on medicinal properties, where modern pharmacological studies validate many traditional uses recorded in Ayurveda, Unani, Siddha, and Chinese systems of medicine. The review also covers industrial significance, socio-economic impacts, and recent advances in biotechnology and agroforestry models. Finally, research gaps and future prospects are identified to guide sustainable cultivation, conservation, and utilization strategies.

Keywords: Sandalwood, *Santalum album*, *Pterocarpus santalinus*, medicinal properties, production technology, sustainable cultivation

Introduction

Sandalwood has long been considered one of the most prestigious and culturally significant forest resources, valued for its fragrance, medicinal properties, and spiritual symbolism. Among the many sandalwood species, red sandalwood (*Pterocarpus santalinus* Linn. f.) and white sandalwood (*Santalum album* Linn.) hold a unique position due to their high economic, ecological, and therapeutic importance. Although belonging to different botanical families—*Fabaceae* in the case of red sandalwood and *Santalaceae* for white sandalwood—both species are globally recognized for their distinctive heartwood, essential oils, and bioactive compounds that contribute to diverse industrial and medicinal applications.

Red sandalwood

Commonly referred to as "Rakta Chandan," is native to the southern parts of the Eastern Ghats in India, particularly concentrated in Andhra Pradesh, Tamil Nadu, and parts of

Karnataka. Its deep reddish-purple heartwood is primarily used as a source of natural dye (santalin) and as a raw material in furniture, handicrafts, and musical instruments. From a medicinal perspective, red sandalwood has been widely used in Ayurveda, Siddha, and Unani systems of medicine for centuries. Traditionally, it has been prescribed for treating skin ailments, blood purification, diabetes, ulcers, and inflammatory disorders. Modern pharmacological studies further confirm its antioxidant, hepatoprotective, antidiabetic, antimicrobial, and anticancer properties, thus establishing its significance in both traditional and modern therapeutic applications.

White sandalwood

Popularly known as "Chandan," is an evergreen, hemi-parasitic tree native to peninsular India but also cultivated in Sri Lanka, Indonesia, and Northern Australia. It is best known for its fragrant heartwood and essential oil rich in α- and β-Santalales, which find wide application in perfumery, cosmetics, incense, aromatherapy, and pharmaceuticals. Beyond its industrial value, white sandalwood occupies a sacred place in Indian culture and religious rituals, symbolizing purity and spirituality. Medicinally, its essential oil is recognized for antiseptic, anti-inflammatory, sedative, and anticancer activities, while its powders and pastes are used for treating skin infections, digestive ailments, and psychological disorders. The dual role of white sandalwood in spirituality and medicine has contributed to its global demand and economic significance.

Distribution and Ecology

- White sandalwood: Southern India (Karnataka, Tamil Nadu, Kerala), also Australia and Indonesia (plantations).
- Red sandalwood: restricted to Eastern Ghats of Andhra Pradesh; small pockets in Tamil Nadu and Karnataka.
- Global trade: both species listed in CITES Appendix II, restricting international trade.

Climate and Soil Requirements

- White sandalwood: rainfall 600–1600 mm, well-drained red loam soils, pH 6–7.5, host-dependent.
- Red sandalwood: rainfall 700–1200 mm, shallow gravelly soils, drought tolerant, independent growth.

Propagation Techniques

Seed Propagation

- Short viability in white sandalwood (3–6 months).
- Pre-treatments: GA_3, scarification, soaking.
- Germination %: 30–60 (white), 50–70 (red).

Vegetative Propagation

- Stem cuttings with IBA.
- Root suckers (in white sandalwood).
- Grafting techniques.

Tissue Culture

- Nodal explants and somatic embryogenesis successful.
- White sandalwood: micropropagation protocols standardized.
- Red sandalwood: limited commercial application.

Nursery and Plantation Management

Seedlings attain transplanting stage within 3–4 months when they reach 30–40 cm in height. For field plantation, pits of 45 × 45 × 45 cm are dug and filled with a mixture of topsoil and farmyard manure. Spacing of 3 × 3 m is recommended for block plantations, whereas wider spacing (5 × 5 m) is adopted in agroforestry systems. Planting is ideally done at the onset of the monsoon, followed by immediate watering and mulching. Regular weeding, pruning, and protection from grazing are necessary during the initial years.

Nutrient and Water Management in Red and White Sandalwood Cultivation

The successful establishment and sustainable productivity of red sandalwood (*Pterocarpus santalinus*) and white sandalwood (*Santalum album*) plantations largely depend on proper nutrient and water management. Although both species are naturally hardy and drought-tolerant, scientific management of soil fertility and irrigation at critical stages is essential for improving seedling survival, enhancing biomass production, and ensuring high-quality heartwood and oil yield. Given the increasing commercial and medicinal value of these species, nutrient and water management practices play a decisive role in sustainable cultivation under varied agro-climatic conditions.

1. Soil Fertility and Nutrient Requirements

Red Sandalwood (*Pterocarpus santalinus*): Red sandalwood is a leguminous species belonging to the Fabaceae family, capable of symbiotic nitrogen fixation through root nodules. This biological advantage reduces its dependence on external nitrogen inputs compared to non-leguminous tree species. However, the tree still requires balanced nutrition, particularly phosphorus (P) and potassium (K), to support root development, nodulation, and wood formation. Studies from the Eastern Ghats have shown that red sandalwood responds well to farmyard manure (FYM), compost, and small doses of NPK fertilizers during the establishment phase. The application of 20–30 g N, 15–20 g P_2O_5, and 15–20 g K_2O per plant per year in the first three years significantly improves seedling growth and canopy development. Micronutrients such as zinc and boron are also crucial for heartwood development and overall plant health.

White Sandalwood (*Santalum album*): White sandalwood is a hemi-parasitic tree that depends on host plants for nutrients and water uptake through haustorial connections. Therefore, nutrient management is more complex compared to red sandalwood. In addition to direct fertilization, the health and vigor of host plants (such as *Cajanus cajan*, *Casuarina equisetifolia*, *Dalbergia sissoo*, or *Acacia* spp.) need to be maintained. Research indicates that sandalwood seedlings exhibit improved growth when supplied with 30–40 g N, 20–25 g P_2O_5, and 20–25 g K_2O annually in split doses during the juvenile stage. Application of organic manures, vermicompost, and biofertilizers (Azotobacter, Azospirillum, and phosphate-solubilizing bacteria) significantly enhances nutrient availability and root colonization. Neem cake and mycorrhizal inoculation are particularly beneficial in white sandalwood plantations, as they enhance nutrient uptake, reduce soil-borne diseases, and improve heartwood formation.

2. Role of Organic Amendments

Organic amendments play a vital role in nutrient cycling, soil moisture retention, and microbial activity in both red and white sandalwood plantations.

- Farmyard Manure (FYM): Incorporation of 5–10 kg FYM per pit at planting provides a slow-release nutrient source and improves soil structure.
- Compost and Vermicompost: These enhance organic carbon content, improve microbial activity, and increase the availability of N, P, and micronutrients.
- Neem Cake: Apart from providing NPK, neem cake acts as a natural nematicide, protecting sandalwood roots from soil-borne pathogens and root-knot nematodes.
- Biofertilizers: Application of Rhizobium in red sandalwood and mycorrhizal inoculants in white sandalwood improves nutrient uptake and supports long-term sustainability.

Integration of organic and inorganic nutrient sources ensures balanced nutrition, minimizes soil degradation, and enhances tree productivity.

3. Irrigation and Water Management

Water availability is a critical factor influencing sandalwood growth, survival, and heartwood quality. Although both species are adapted to semi-arid and tropical conditions, irrigation during early growth stages and dry spells is essential for establishment.

Seedling Stage: During the first 6–12 months, frequent but light watering is required for both species. Red sandalwood seedlings benefit from irrigation once every 5–7 days during summer, while white sandalwood seedlings require slightly more frequent watering due to

their dependence on host plants. Over-irrigation should be avoided, as it leads to root rot and poor haustorial formation in white sandalwood.

Juvenile Stage (1–5 years): Red Sandalwood: Irrigation at 10–12-day intervals during dry periods significantly enhances growth and biomass accumulation. Mulching around the base of seedlings conserves soil moisture and suppresses weed growth.

White Sandalwood: Adequate watering is required not only for sandalwood seedlings but also for associated host plants. Irrigation every 7–10 days ensures continuous nutrient transfer through haustoria. Drip irrigation is considered the most effective system, as it delivers water directly to the root zone of both sandalwood and host species, reducing wastage and waterlogging.

4. Nutrient-Water Interactions

The interaction between nutrient supply and water availability is crucial. Adequate soil moisture enhances nutrient solubility and uptake, while water stress reduces nutrient absorption efficiency. For red sandalwood, proper water availability ensures efficient nodulation and nitrogen fixation. In white sandalwood, irrigation supports host plant vigor, which directly influences nutrient transfer to the sandalwood tree. Hence, integrated nutrient and water management is essential for optimizing growth and quality.

5. Deficiency Symptoms

Nitrogen Deficiency: Yellowing of older leaves, stunted growth; corrected with urea or ammonium sulphate application.

Phosphorus Deficiency: Poor root development, purplish discoloration; corrected with single superphosphate (SSP).

Potassium Deficiency: Marginal leaf scorching and weak stems; corrected with muriate of potash.

Micronutrient Deficiency: Zinc deficiency causes chlorosis and reduced leaf size; corrected with zinc sulphate sprays.

Harvesting and Yield

White sandalwood: harvested after 20–25 years; heartwood yield 15–20 kg/tree, oil content 1–3%. Red sandalwood: harvested after 20–25 years; heartwood 500–800 kg/tree.

Medicinal Properties

White Sandalwood (*Santalum album*)

Active compounds: α-santalol, β-santalol, santalyl acetate.

Uses:

- Antimicrobial (skin infections, acne).
- Anti-inflammatory (eczema, psoriasis).
- Anticancer (chemo preventive).
- Sedative and anxiolytic (aromatherapy).
- Skin care (Ayurveda, cosmetics).

Red Sandalwood (*Pterocarpus santalinus*)

Active compounds: santalin A & B, flavonoids, pterostilbene.

Uses:

- Antidiabetic.
- Hepatoprotective.
- Antioxidant.
- Anti-ulcer and gastroprotective.
- Cardioprotective.
- Blood purifier and cooling agent.

Industrial Importance

- White sandalwood: perfumery, incense, cosmetics, Ayurveda oils.
- Red sandalwood: timber (handicrafts, furniture), natural dye (food and textile).
- Export potential and global market challenges.

Socio-economic Significance

- Provides rural employment.
- Export revenue to India.
- Illegal trade challenges and farmer benefits.

Conservation and Policy Issues

- Both species under CITES Appendix II.
- State ownership laws (in Karnataka, Tamil Nadu).
- Need for farmer-friendly policies to encourage cultivation.
- Community-based agroforestry models for conservation.

Research Gaps and Future Prospects

- Genetic improvement programs lacking.
- Biotechnological tools (DNA fingerprinting, molecular markers).
- Clonal orchards and tissue culture commercialization.
- Standardized agroforestry systems.
- Value addition and pharmaceutical product development.

Conclusion

Red and white sandalwood are globally significant species with immense medicinal, industrial, and socio-economic value. Sustainable production technology integrating modern science with traditional knowledge is the only pathway to secure their future. Balanced nutrient and water management, host compatibility, pest resistance, and biotechnological interventions are critical. Medicinal validation of bioactive compounds opens new pharmaceutical opportunities. Policy reforms and farmer participation can transform sandalwood cultivation into a profitable, sustainable venture.

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