

## Sandalwood: from field to industry

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Received 4 Dec 2023; Accepted 15 Jan 2024; Published 24 Jan 2024

### Abstract

Sandalwood, stands as India's oldest, most esteemed, and economically significant herbal plant. Revered for its distinctive aroma, this sacred plant finds mention in Vedas, Puranas, Buddhism, and various scriptures, playing a role in Hinduism, Buddhism, and Jainism cultures. Not only utilized for its fragrant essential oil in perfumes, food, cosmetics, and aromatherapy, but the heartwood of this plant also holds immense commercial value in both national and international markets. Ayurvedic practices have embraced its use as an expectorant, diazepam, and astringent. Beyond its traditional applications, Santalwood has been associated with diverse therapeutic and medicinal attributes, including Antioxidant, Antimicrobial, Anti-cancer, Anti-inflammatory, Antiviral, Antibacterial, Antifungal, Hepatoprotective, and Cardiac-protective properties. However, due to excessive exploitation, the plant faces inclusion in the IUCN Red List. This review provides a glimpse into the traditional medicinal uses of Santalwood, delving into its pharmacological properties, habitat, and cultivation practices.

**Keywords:** cultivation, distribution, habitat and sandalwood

### Introduction

Sandalwood, a plant species of significance in both commerce and culture, belongs to the family Santalaceae and the genus *Santalum*. Extracted from the heartwood, sandalwood oil has been utilized for centuries in perfumery, medicine, and various religious and cultural practices. The wood and its powder find applications in religious, cultural, and medicinal contexts, particularly in Asian and Arab regions. The genus *Santalum* encompasses approximately 18 sandalwood species, including *S. freycinetianum*, *S. haleakalae*, *S. ellipticum*, *S. peniculatum*, *S. pyrularium*, *S. involutum*, *S. boninense*, *S. insulare*, *S. austrocaledonicum*, *S. yasi*, *S. macgregorii*, *S. accuminatum*, *S. murrayanum*, *S. obtusifolium*, *S. lanceolatum*, *S. fernandezianum*, *S. salicifolium*, and *S. spicatum*. All these sandalwood species are classified as obligate wood hemiparasites, meaning they absorb specific nutrients like phosphates and nitrates from host trees through root connections called haustoria <sup>[1]</sup>.

Sandalwood, specifically *Santalum album* L., holds a revered status in India's culture and heritage, representing one of the world's most valuable trees <sup>[2]</sup>. The yield of sandalwood essential oil varies based on factors such as tree age, heartwood color, individual tree characteristics, location within the tree, and the tree's growth environment. Traditionally, the steam distillation of the heartwood has been a longstanding practice, resulting in marketable sandalwood essential oil. This review provides a glimpse into the traditional medicinal uses of Santalwood, delving into its pharmacological properties, habitat, and cultivation practices. Taking into consideration of all the above-mentioned facts, this review provides a glimpse into the traditional medicinal uses of Santalwood, delving into its pharmacological properties, habitat, and cultivation practices <sup>[3]</sup>.

### Distribution

Sandalwood, a precious resource in India, is predominantly distributed across the expansive landscape of the Deccan Plateau. The total extent of its distribution covers approximately 9000 km<sup>2</sup>, with a significant portion—8200 km<sup>2</sup>—encompassing the states of Karnataka and Tamil Nadu. While historically native to peninsular India, its presence has been intentionally extended to various other regions.

The natural habitat of sandalwood is primarily situated in the dry deciduous forests of the Deccan Plateau, particularly along the periphery of the Western Ghats Range. A pivotal region for its indigenous growth can be defined within a circular radius of 200 km, centered around Bangalore city. This area stands out as the primary zone of sandalwood's native distribution.

Sandalwood exhibits optimal growth conditions under precipitation levels ranging from 500 to 2000 mm and elevations spanning 650 to 1200 m. Although it can thrive beyond these parameters, instances of abundant rainfall may result in lush vegetation, yet the formation of heartwood—the prized aromatic core of the sandalwood tree—may be either absent or inconsequential. This underscores the specific environmental requirements for the successful development of sandalwood. The historical and ecological context of sandalwood in India reflects its adaptation to the unique conditions of the Deccan Plateau, with Bangalore city serving as a central reference point. The deliberate introduction of sandalwood to diverse regions has contributed to its broader distribution, emphasizing its economic and cultural significance. As a result, the sustainable management and conservation of sandalwood ecosystems become crucial for preserving this invaluable resource in India <sup>[4]</sup>.

### Habit and habitat

Sandalwood, characterized as an evergreen tree, has the potential to reach heights of 20 meters and attain a circumference exceeding 1.5 meters. It undergoes two blooming cycles annually, flourishing in Spring during April and later in September-October. The flowering process typically initiates at three years of age, with prolific seed production occurring in one of the seasons. Some trees bloom only once a year, while others exhibit irregular flowering patterns. Approximately 6000 seeds constitute 1 kilogram, and these seeds can be directly collected from the tree.

To prepare the seeds for storage, they must undergo a depulping process, thorough washing in water, drying under shade, and subsequent storage in airtight containers. Operating as a hemi-root parasite, sandalwood displays the ability to parasitize over 300 plant species, ranging from grasses to other woody plants. In communal growing conditions, self-parasitism is common. Failures in pure plantations have been attributed to a lack of understanding about parasitism dynamics. Sandalwood establishes haustorial connections with host plants, relying on them for essential nutrients such as nitrogen, phosphorus, and potassium. While it can acquire some nutrients independently, under gregarious growth conditions, the plant benefits from its host. Seedlings can survive for extended periods without a host. In a natural population, about 2% of seedlings do not develop haustoria, and they struggle to survive beyond three years without external support [5].

### Status and cultivation of sandalwood in India

Sandalwood (*Santalum* collection) is a piece of Indian culture and legacy. It is the embodiment of human greatness, conferring aroma even to the hatchet that fells it. Sandalwood tracks down portrayal in the most seasoned of Indian writings. It tracks down a notice in the old legendary Ramayana (around 2000 B.C.). It has been utilized as an article in ceremonial contributions and furthermore as a treatment for excellence help. It has almost 15 distinct names in the Indian dialects, "chandan(a)" being the Hindi name. In Indonesia too it is designated "cendana" [6].

### Basic biology

#### Sexual reproduction

Reproductive maturity for several sandalwood species, including *S. album*, *S. austrocaledonicum*, *S. macgregorii*, *S. spicatum*, and *S. yasi*, typically commences between the ages of two and five [7]. Fruit production peaks occur during both wet and dry seasons. In regions such as India, *S. album* demonstrates notable peaks during the wet months [8], while *S. yasi* in Fiji follows a similar pattern [9]. Conversely, for *S. austrocaledonicum* in Vanuatu, fruit production peaks during the dry months. Rainfall events play a crucial role in the reproductive cycle of *S. spicatum* [10] and *S. lanceolatum* [11] with considerable variation observed in the timing and location of seed crops. In tropical sandalwood species, fruit development typically spans two to three months [12]; however, in the case of *S. spicatum*, this process can extend up to six

months [13].

### Self-incompatibility

Research indicates that self-incompatibility mechanisms exist in both pre- and post-fertilization stages for sandalwood species, specifically *S. album* and *S. spicatum*. Tamla *et al.* (2012) identified potential self-incompatibility in *S. lanceolatum*, while Warburton uncovered evidence of pistil dysfunction or self-incompatibility [11]. Notably, considering the distinct phylogenetic clades of *S. lanceolatum*, *S. spicatum*, and *S. album*, self-incompatibility appears to be a shared characteristic within the *Santalum* genus [14].

### Interspecific incompatibility/hybridization

Despite complete geographic isolation and significant morphological differences, successful hybrid progeny has been observed in crosses between *S. album* and each of *S. austrocaledonicum*, *S. lanceolatum*, and *S. yasi* [15-16]. A phylogenetic analysis, utilizing nuclear ribosomal and chloroplast DNA sequences, revealed the earliest genetic divergence during the split of *S. acuminatum* and *S. spicatum* from other lineages [17]. This early divergence of *S. spicatum*, owing to incongruent mating systems and a relatively distant genetic relationship with *S. album*, can be viewed as an incompatibility mechanism within the developing zygote and between the pollen and style [18].

### Plantation establishment of sandalwood

The successful establishment of sandalwood (*Santalum spicatum*) plantations involves strategic planning and implementation. In the southwestern region of Australia, a specific approach is followed to optimize cultivation and minimize costs. Initially, sandal seeds are directly sown in the field alongside planted hosts, such as *Acacia acuminatum*, with a well-structured timeline. Sandal is planted first, followed by *Acacia acuminatum* in the second and third years, creating an efficient and cost-effective cultivation method.

The challenges of accommodating both host and parasite in sandal cultivation should be addressed through careful spacing and planting density considerations. Therefore, the propagation sandalwood can be carried by the following techniques:

#### Direct sowing of seeds

In the southwestern region of Australia, sandal seeds are directly sown in the field alongside planted hosts to optimize cultivation. Sandal is initially planted, followed by *Acacia acuminatum* in the second and third years. This method involves planting four untreated *S. spicatum* seeds at a depth of five centimeters, positioned as close to the host as practical—approximately one meter away. This approach not only reduces the time required for field establishment but also lowers cultivation costs [19].

#### Seedlings without primary host

When cultivating sandal seedlings in containers without a primary host, they are planted in the same pit or a nearby one alongside their host. Sandal heavily relies on seed reserves and

endosperm during the initial six months to a year. It is recommended to plant sandal and host in the same pit, with a separation of 20 to 30 centimeters. While the initial shade provided by the host may benefit young sandal growth, it becomes necessary to prune the host more frequently as sandal matures to ensure an increased amount of sunlight for optimal development <sup>[20]</sup>.

### Seedlings with primary host

Seedlings with a primary host begin forming haustoria within 30 days of germination with the corresponding host species. Sandal requires hosts at three life stages: the seedling stage (primary host or pot host), the intermediate stage between the nursery and the field, and as a long-term host in the field throughout the sandal tree's life (secondary host) <sup>[21]</sup>. In practice, hosts are mainly utilized in two stages: first, as primary hosts during the seedling stage for a brief period of six months to two years, and second, as long-term hosts in the field, including perennial trees. Utilizing appropriate hosts in both the field and pot significantly enhances the success rate of sandal establishment and growth <sup>[21-23]</sup>.

### Spacing and planting density

Considering the challenges of accommodating both host and parasite in sandal cultivation, the spacing and planting density are crucial. Sandalwood typically spreads its lateral roots 1.5–3 meters into the surrounding areas to form an association with the host. This extension not only physically anchors the sandal plant but also benefits its growth. Maintaining a host-to-parasite ratio of 1:1 is essential for the survival and productive output of sandal trees, ensuring they match the performance of host plants <sup>[24]</sup>.

### Sandalwood uses

Sandalwood, also known as East Indian sandalwood, holds economic significance, particularly for its heartwood, which is prized for its aromatic properties. The heartwood, forming the central part of the tree, is described as astringent, bitter, moderately hard, heavy, dense, yellow or brown in appearance, with a smooth surface-making it an ideal material for intricately carved designs. Renowned for its exquisite scent, sandalwood is the second most expensive wood globally, following African Blackwood (*Dalbergia melanoxylon*). Carved images of deities and mythical figures crafted from sandalwood have a high demand in the market.

Various items such as boxes, cabinet panels, jewellery cases, brushes, photo frames, hand fans, pen holders, card cases, letter openers, and bookmarks are crafted from sandalwood. Beyond its commercial applications, sandalwood holds sacred importance in religious ceremonies, playing a vital role in 'homa' (havana), a Sanskrit term for rituals involving offerings into a sacred fire. Buddhists use sandalwood during prayers and meditation.

Sandalwood's sapwood, devoid of scent, is white or yellow and is employed in crafting turnery items and agarbattis (incense sticks). Sandalwood oil, extracted through steam distillation of heartwood powder, is a highly valued product sold by weight.

The oil, with its light yellow to yellow thick consistency, exudes sweet, aromatic, persistent, spicy, warm, woody, animalic, smooth, and nutty notes. It finds extensive applications in perfumery, cosmetics, aromatherapy, and the pharmaceutical industry. Serving as excellent fixatives, sandalwood oil is highly sought after in perfumery and toiletry, especially for delicate and rare fragrances. Many Indian attars use sandalwood oil as a base due to its ability to enhance and sustain the ethereal notes of other herbs or flowers.

As one of the most precious perfumery materials throughout history, the popularity of sandalwood oil remains steadfast. Beyond perfumery, the oil is employed as a flavoring agent in various food products such as frozen desserts, candies, pan masala, baked goods, gelatin, puddings, as well as in alcoholic and non-alcoholic beverages <sup>[25]</sup>.

### Oil content in sandalwood

The valuation of a sandalwood tree hinges upon three crucial factors: (i) the volume of its heartwood, (ii) the concentration, and (iii) the quality of its heartwood oil. The distinctive and prized fragrance of sandalwood oil is primarily determined by the concentration of two significant sesquiterpene alcohols, namely *cis*- $\alpha$ -santalol and *cis*- $\beta$ -santalol. These compounds collectively form what is known as the complete santalol content, accounting for approximately 90% of the total volatile material extracted from the wood, according to numerous established records.

The heartwood of *Santalum* species is recognized for possessing the highest oil concentration and the most significant proportion of santalols. Scientific studies suggest that the *Santalum* collection heartwood, in particular, exhibits superior qualities in this regard. Importantly, the content of sandalwood oil tends to increase with the age of the tree, as additional heartwood is formed over time.

The biosynthesis of sandalwood sesquiterpenes, including *cis*- $\alpha$ -santalol and *cis*- $\beta$ -santalol, is dependent on a specific group of enzymes known as sesquiterpene synthases. These enzymes are distinctive for each type of sesquiterpene, playing a pivotal role in the production of the unique aromatic compound's characteristic of sandalwood oil. The intricate process of biosynthesis contributes to the overall quality and olfactory properties of sandalwood oil, making it a highly sought-after and valuable commodity in various industries, including perfumery, cosmetics, and traditional medicine <sup>[26]</sup>.

### Pharmacological and therapeutic properties of sandalwood Antiulcer

The antiulcer properties of the sandalwood plant were investigated using Wistar albino rats through three *in vivo* models. The hydro-alcoholic extract of the stem was administered in dosages of 250 and 500 mg/kg. The models included the water-immersion restrain stress model, the indomethacin-induced gastric ulceration model, and the ethanol model. Results indicated a significant decrease in the average number of ulcers, cumulative ulcer index, and ulcer severity. These findings suggested an improvement in gastric protection <sup>[27]</sup>.

### Antibacterial

In terms of antibacterial activity, the essential oil derived from the sandalwood plant demonstrated noteworthy efficacy against methicillin-resistant *Staphylococcus aureus*, anti-mycotic resistant *Candida* species, and Herpes simplex virus type 1 [28]. Alpha and beta-santalol, along with the crude extract of sandalwood oil, exhibited antibacterial action against *Helicobacter pylori*—a gram-negative bacterium closely associated with stomach, duodenal, and gastric ulcers [29].

### Cardioprotective

The sandalwood plant's aqueous extract exhibited cardioprotective qualities. In a rat model, it significantly inhibited damage to heart tissue induced by doxorubicin-induced cardiotoxicity, reducing lipid peroxidation. Another study demonstrated a dose-dependent cardioprotective effect of the plant's aqueous extract in albino Wistar rats subjected to ISO-induced myocardial infarction. These findings collectively highlight the diverse therapeutic potential of the sandalwood plant, ranging from antiulcer and antibacterial properties to cardioprotective effects [30].

### Conclusion

In conclusion, sandalwood, belonging to the family Santalaceae and the genus *Santalum*, stands as a significant plant species with profound cultural, economic, and medicinal importance. Extracted from its heartwood, sandalwood oil has been cherished for centuries, finding applications in perfumery, medicine, and diverse religious practices. The genus *Santalum* encompasses around 18 sandalwood species, characterized as obligate wood hemi-parasites due to their nutrient absorption from host trees through haustoria. Sandalwood, especially *Santalum album* L., holds a revered status in India's culture, representing one of the world's most valuable trees.

The review delves into the pharmacological and therapeutic properties of sandalwood, highlighting its antiulcer, antibacterial, and cardioprotective qualities. The essential oil displayed antibacterial efficacy against resistant strains, while the aqueous extract exhibited cardioprotective effects. In essence, the traditional medicinal uses of sandalwood, coupled with its habitat, distribution, cultivation practices, and pharmacological properties, emphasize its multifaceted significance. From cultural rituals to economic value and therapeutic potential, sandalwood remains a versatile and invaluable resource that demands careful conservation and sustainable management for future generations.

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