Phytology

Whispers of the sacred wood: a comprehensive review of *Santalum album*

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Abstract

Santalum album, commonly known as Indian sandalwood, is a highly valued species utilized for generations in traditional medicine, perfumery, and religious ceremonies. Renowned for its fragrant heartwood and essential oil, this review comprehensively analyzes *S. album*, covering its chemical composition, distribution, cultivation techniques, and botanical characteristics. The study delves into contemporary and ethnobotanical uses of sandalwood oil, highlighting its significance across various industries and medicinal properties. Additionally, it addresses the sustainable management strategies crucial for ensuring the species' long-term survival, considering the conservation challenges posed by overexploitation and habitat loss. Emphasizing the need for ongoing research and community involvement, the assessment underscores the importance of preserving and sustainably utilizing this invaluable resource.

Keywords: Indian sandalwood, aromatic heartwood, essential oil, sesquiterpenoids and traditional medicine

1. Introduction

Santalum album, sometimes called Indian sandalwood, has enormous cultural, economic, and ecological significance. As a member of the Santalaceae family, this tree is prized for its fragrant heartwood and essential oil, which have been used for millennia in traditional medicine, perfumery, and religious ceremonies. Although *S. album* is native to southern India and Southeast Asia, it has spread to other tropical and subtropical areas, such as northern Australia and a few Pacific islands [1].

Due to its high market value, *S. album* heartwood—also known as "liquid gold" is highly prized for both its medicinal qualities and rich, woodsy scent. A significant amount of sesquiterpenoids, mainly α- and β-santalol, are present in the heartwood essential oil, which gives it its unique scent and range of health advantages [2]. Because of these chemicals' demonstrated calming, anti-inflammatory, and antibacterial properties, sandalwood oil is a valued component of both aromatherapy and pharmaceuticals [3].

The customs of India and other Asian nations are fundamental to the cultural significance of *S. album*. Sandalwood paste is utilized in religious rituals and as a symbol of holiness and purity in Hinduism. Similar to this, sandalwood is used in Buddhist and Jain ceremonies as well as for the creation of incense and prayer beads [4]. To further increase the wood's cultural and financial worth, it is also highly sought after for use in the carving of complex sculptures and religious objects.

S. album has several advantages, but overexploitation and habitat loss pose serious challenges. Wild populations are declining as a result of irresponsible harvesting methods brought on by the strong demand for its heartwood and oil. Consequently, the International Union for Conservation of Nature has designated *S. album* as a vulnerable species [5].

Efforts must be made to preserve and responsibly manage this priceless resource, incorporating strategies like plantation farming, governmental regulation, and neighborhood-based conservation initiatives [6].

The goal of this review paper is to present a thorough analysis of the *Santalum album*, covering its chemical makeup, traditional and contemporary uses, and conservation issues.

2. History

Indian sandalwood, or *Santalum album*, has a long and complex history that dates back thousands of years. This type of tree is highly valued in many different regions for its medical, cultural, and economic purposes in addition to its fragrant heartwood and essential oil. Using ancient writings, historical accounts, and contemporary literature as a source, this section investigates the historical relevance of *S. album*.

A) Ancient use and cultural significance

Historical texts and early references

Sandalwood was highly valued for its smell and therapeutic qualities in ancient Indian texts such as the Vedas and numerous Ayurvedic teachings, where the first recorded usage of *S. album* occurs. Sandalwood paste is mentioned in ceremonies and medicinal applications in the Atharva Veda, one of the four Vedas [10].

Religious and cultural customs

Sandalwood has long been a crucial component of Hindu religious ceremonies, giving to the gods, and idol dedication. Sandalwood is used to make incense, religious objects, and ritualistic equipment in Buddhism and Jainism, two other religions where its use is documented [4].

Trading and economic value

In prehistoric trading networks, sandalwood was a highly prized item. Sandalwood was widely sold throughout the Silk Road, reaching markets in China, the Middle East, and Europe, according to historical documents. Due to this commerce, *S. album* became recognized as an economically important species and was widely cultivated and used [1].

B) Medieval and colonial periods

Middle ages

Sandalwood was in high demand throughout this time, especially in the Islamic world where it was utilized for religious, medicinal, and perfumery purposes. The fact that sandalwood is included in Islamic pharmacopeia attests to its significance as a remedy in medieval times [7].

Colonial era

The trade and cultivation of *S. album* underwent substantial modifications throughout this time. Due to their recognition of the significance of sandalwood, European colonists—especially the British and Dutch—established massive plantations throughout their territories, which included India and Indonesia. Regulatory measures were also introduced during this time to prevent overexploitation and regulate the sandalwood trade [6].

C) Modern developments and conservation efforts

20th century

Due to the significant demand for *S. album* essential oil in the fragrance and cosmetics sectors, the 20th century saw a boom in the economic exploitation of the plant. Sandalwood's market worth increased throughout this period due to advances in scientific understanding of its chemical composition and therapeutic qualities [2].

Sustainable management practices

Various projects have been launched to support the sustainable management and cultivation of *S. album* in response to conservation problems. The goal of these initiatives is to protect this important species for future generations by establishing community-based conservation programs, establishing legislative frameworks to control harvesting and trade, and establishing plantations of sandalwood [9].

Conservation challenges

The widespread feeling of natural *S. album* trees has resulted in notable population reductions, raising questions regarding the species' future. Due to habitat loss and overexploitation, *S. album* was listed by the International Union for Conservation of Nature (IUCN) as a vulnerable species by the late 20th century [5].

3. Botanical characteristics of *Santalum album*

A tree in the Santalaceae family, *Santalum album* is also referred to as Indian sandalwood. Comprehending the botanical traits of *S. album* is essential for its propagation, protection, and sustainable management. This section explores the species' intricate morphology, growing environment, and hemi-parasitic behavior, all of which are backed by extant research.

a) Morphology

Leaves

S. album has opposite, simple leaves, ovate to lanceolate. Shiny green leaves with smooth margins Leaves are typically 3 to 8 cm long and 1 to 3 cm wide, with an easily discernible venation pattern [1].

Flowers

The flowers of *S. album* are small, hermaphroditic, and arranged in terminal or axillary cymes. The flowers are chromatically tetramerous greenish-white to brownish-red, being about 4-6 mm in diameter. These flowers have a sweet fragrance, attracting pollinators such as bees [6].

Fruit

S. album produces drupes that are globose to ovoid in shape and have a diameter of one to two centimeters. When the fruit ripens, it turns black and has one hard seed inside. These seeds don't germinate well and need particular circumstances to sprout successfully [2].

Bark and wood

Young *S. album* trees have smooth, reddish-brown bark that turns rough and dark brown with age. Dense, aromatic, and yellowish-brown, the heartwood is highly appreciated. When the tree is at least fifteen years old, the heartwood begins to mature and release its aroma [4].

a) Leaves and flowers b) Fruits c) Wood

Fig 1

b) Growth conditions

Climate

S. album thrives in tropical and subtropical climates, particularly in regions with moderate rainfall ranging from 600 to 1600 mm annually. The species prefers temperatures between 12°C and 30°C and can endure short periods of drought [1].

Soil

The tree grows well in a variety of soil types, including sandy, loamy, and lateritic soils, but it prefers well-drained soils with a pH range of 6.0 to 7.5. Rich organic content in the soil is beneficial for its growth [6].

Light

S. album requires full sunlight for optimal growth. However, young seedlings benefit from partial shade during the early stages of development [2].

c) Hemi parasitic nature

As a hemi-parasitic plant, *Santalum album* attaches itself haustatorily to the roots of its hosts to take up nutrients and water. As the tree ages, the importance of this parasitic relationship decreases. However, it is still crucial during the seedling stage. Species belonging to the genera Albizia, Cassia, and Acacia are common hosts. One important adaptation that helps *S. album* survive and flourish is its capacity to make these parasitic linkages, especially in nutrient-poor soils [3].

d) Reproductive biology

Pollination

The majority of insects that pollinate *S. album* flowers are bees, who are drawn to the blooms' aroma and nectar [4].

Seed distribution

The primary agents of *S. album* seed distribution are birds and animals. They aid in the species' proliferation by eating the fruit and excreting the seeds in various places [2].

4. Chemical composition

Santalum album, also referred to as Indian sandalwood, is highly prized for its essential oil and heartwood, both of which have an intricate and unique chemical makeup. This section examines *S. album* essential oil's primary and secondary ingredients, their corresponding qualities, and the consequences of these chemical components for a range of uses. The data offered is backed up by pertinent academic research.

a) Primary constituents

Sesquiterpenoids make up the majority of the essential oil of *S. album* and are mainly in charge of giving it its distinctive scent and medicinal qualities.

α-Santalol

Usually accounting for 40-55% of the oil, this sesquiterpenoid alcohol is the most prevalent element in sandalwood oil. The scent of α-Santalol is woodsy, sweet, and balsamic. Its calming, antibacterial, and anti-inflammatory qualities have all been thoroughly investigated [12].

β-Santalol

Making up 15–25% of the oil, β-santalol is the second most abundant component. It has a somewhat distinct scent characteristic from α-santalol, yet it smells comparable nonetheless. According to Jirovetz *et al*. (2006), β-Santalol also plays a role in the oil's antibacterial and anti-inflammatory properties.

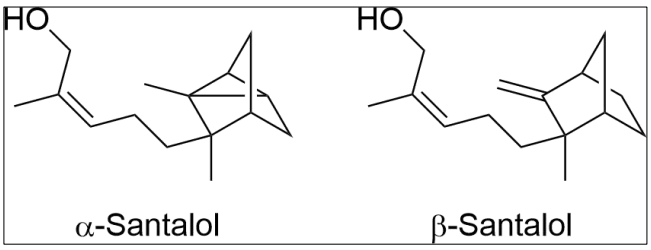

Fig 2

b) Secondary constituents

S. album essential oil comprises several additional chemicals that complement the core sesquiterpenoids and improve its overall characteristics.

Isomers of santalene

α- and β-santalene are among them, and they add to the smell character of the oil. Despite their lesser presence, they contribute to the fragrance's depth and complexity [26].

Compounds of santalenes and nortricyclo

According to Adams *et al*. (2011), some compounds including trans-α-bergamotol and epi-β-santalene contribute delicate notes to the oil's aroma and might potentially strengthen its medicinal qualities.

Additional tiny constituents

The oil also includes alcohols and other sesquiterpenoids, such as lanceol and santalic acid, which together give sandalwood oil its overall scent and practical qualities [2].

c) Extraction and quality factors

Extraction techniques

The content and quality of sandalwood oil are greatly influenced by the extraction technique used. The most popular technique for extracting the oil is traditional steam distillation, which efficiently extracts both main and secondary compounds. Higher-purity oils with greater preservation of the delicate sesquiterpenoids can be produced using modern procedures such as supercritical CO_2 extraction [15].

Aging and storage

Age and storage circumstances can have an impact on the chemical makeup of sandalwood oil. The oil's quality may be maintained and the deterioration of its aromatic components can be avoided by properly storing it in dark, cold

environments in securely closed containers [14].

d) Therapeutic properties

The many therapeutic benefits of *S. album* essential oil are supported by its distinct chemical makeup.

Anti-inflammatory

The oil can be used to treat skin disorders and reduce inflammation because both α- and β-santalol have strong anti-inflammatory properties [12].

Antibacterial

It has been demonstrated that the essential oil possesses antibacterial action against a range of pathogens, which is why traditional medicine uses it to treat illnesses [13].

Calming and sedative

The high α-santalol concentration produces sedative effects that help to promote relaxation and lessen anxiety [15].

Antioxidant

According to Adams *et al.* (2011), the oil's sesquiterpenoids also have antioxidant qualities, which aid in defending cells against harm from free radicals.

5. Common uses of *Santalum album*

a) Traditional medicine

Ayurveda, Traditional Chinese Medicine (TCM), and Unani medicine are among the many traditional medical systems that have traditionally used *Santalum album*.

Ayurveda

Sandalwood oil is highly valued for its antibacterial, soothing, and cooling qualities in Ayurvedic treatment. It is used to relieve the symptoms of headaches, sleeplessness, anxiety, and skin disorders including eczema, rashes, and acne. Additionally, sandalwood paste is administered topically to lessen inflammation and encourage the healing of wounds [18].

Traditional Chinese Medicine (TCM)

S. album is used in Traditional Chinese Medicine (TCM) to treat gonorrhea, vomiting, stomach discomfort, and chest pain. According to Zhang *et al*. (2013), it is said to improve the flow of qi, or vital energy, lessen inflammation, and support digestive health.

Unani medicine

Sandalwood is used by unani practitioners in their medicine because of its relaxing and cooling properties. It is utilized to cure fevers, boils, and other inflammatory diseases, as well as to balance the body's humors [8].

b) Religious and cultural practices

The sandalwood holds a significant place in various cultural and religious traditions, especially in Hinduism, Buddhism, and Jainism.

Hinduism

Many Hindu rites and rituals involve the use of sandalwood paste. It is used to prepare idols and holy objects and is put as a sacred mark (tilak) on the forehead. It is said that the aroma of sandalwood inspires spirituality and tranquility [4].

Buddhism

Sandalwood is used to make prayer beads (malas) and incense sticks in Buddhist rituals. Sandalwood incense's soothing scent facilitates meditation and fosters inner serenity [19].

Jainism

Sandalwood is utilized in Jain rites and rituals, which are similar to those of Buddhism and Hinduism. It is utilized in the creation of holy symbols and for anointing idols [16].

c) Perfumery and cosmetics

The fragrance and cosmetics industries place a high value on *S. album* essential oil.

Perfumery

Sandalwood oil's deep, woodsy, and enduring scent makes it a crucial component of luxury fragrances. In many perfume compositions, it acts as a base note, giving additional volatile ingredients a stable basis to balance them out [2].

Cosmetics

Sandalwood oil's anti-inflammatory, antibacterial, and calming qualities are utilized in skincare products. According to Singh *et al*. (2015), it can be found in soaps, lotions, and creams intended to cure acne, lessen skin redness, and enhance general skin health.

d) Aromatherapy

Calming effects

Due to its ability to reduce tension and promote calmness, sandalwood oil is frequently used in aromatherapy. It is frequently used in diffusers, massage oils, and bath products since it is said to support mental clarity and emotional equilibrium [20].

Meditation and relaxation

Sandalwood oil's calming scent helps to create a calm and concentrated atmosphere during meditation sessions. It assists users in reaching a more profound level of attention and relaxation [17].

e) Woodworking and handicrafts

Sculpture and carving

S. album heartwood, with its fine texture, is widely prized for its ability to carve elaborate sculptures, religious icons, and ornamental objects.

Craftspeople use it as a material because of its strength and scent.

Furniture and Handicrafts: Fine furniture and handicrafts are made from sandalwood. These products have more value

because of the wood's pleasing scent and visual appeal, which makes them in high demand in marketplaces [16].

f) Industrial Uses

Pharmaceuticals

Research has been done on the possible medical uses of the bioactive components in sandalwood oil. These include qualities that might be used to create novel drugs, such as anti-inflammatory, antibacterial, and anti-cancer effects [12].

Flavors and fragrances

Sandalwood oil gives a distinctive scent to a variety of items in the flavoring sector. Additionally, it is used in the creation of scents for candles and air fresheners, among other home items [2].

The botanical applications of *Santalum album* are numerous and noteworthy, including aromatherapy, woodworking, religious rituals, perfumes, cosmetics, and industrial purposes. *S. album* has a long history and serves a variety of purposes, which emphasizes the need to protect this endangered species and encourage sustainable practices to guarantee its availability and use for future generations.

6. Conservation and sustainable management of *Santalum album*

Due to its significance for the economy, culture, and ecology, *Santalum album*, also known as Indian sandalwood, has to be preserved and managed sustainably. Its population has been drastically decreased by overexploitation, habitat degradation, and illicit trading; therefore, comprehensive policies are required to ensure its long-term existence. This section examines recent methods and research on *S. album* conservation and sustainable management.

a) Current conservation status

IUCN red list

The International Union for Conservation of Nature (IUCN) has designated *Santalum album* as a vulnerable species. The main concerns are habitat degradation, illegal trading, and overharvesting for its prized heartwood and essential oil [5]. The decline in natural populations emphasizes how urgently conservation action is required.

Lawful structures

Several nations have put laws in place to safeguard *S. album*. State governments in India oversee the sandalwood trade and have severe rules against unapproved harvesting and trading. These legislative frameworks seek to encourage sustainable practices and put a stop to illicit activity [27].

b) Sustainable cultivation practices

Agroforestry systems

one successful conservation tactic is to include *S. album* into agroforestry systems. Growing sandalwood alongside other crops or trees, or agroforestry, boosts biodiversity and benefits farmers financially. This method encourages sustainable land use in addition to sandalwood conservation [23].

Management of the host plant

Santalum album is a hemi-parasitic plant that needs a host to flourish as best it can. Studies reveal that choosing suitable host plants, including those that fix nitrogen, can greatly enhance the development and productivity of sandalwood. Sandalwood cultivation requires this symbiotic interaction to be effective [24].

Clonal propagation

To provide genetically homogeneous and disease-free planting material, clonal propagation techniques, including tissue culture and vegetative propagation, have been developed. By offering a substitute supply of sandalwood, these techniques can aid in the establishment of expansive plantations and lessen the strain on natural populations [28].

c) Legal and policy interventions

National and international law

To stop illicit trade and guarantee sustainable management, it is essential to bolster national laws and international accords. The worldwide trade of sandalwood is regulated by organizations like the Convention on Worldwide Trade in Endangered Species of Wild Fauna and Flora (CITES), which aims to stop illicit extraction and encourage sustainable usage [22].

Observation and implementation

Enforcing conservation measures and ensuring compliance require efficient monitoring systems. This entails tracing the origin of sandalwood goods and enforcing severe sanctions against illicit activity. Sandalwood's legality may be confirmed and its origin traced using cutting-edge technology like DNA barcoding [30].

d) Research and development

Genetic studies

To comprehend the variety and organization of *S. album* populations, genetic studies are crucial. The development of plans to protect genetic resources and improve the adaptability of farmed populations depends on this knowledge. Finding improved genotypes for agriculture can also be facilitated by genetic research [26].

Phytochemical research

Examining *S. album* phytochemical characteristics may help identify novel medicinal ingredients and raise the plant's market value. The creation of high-value goods that may propel sustainable commerce and conservation initiatives is aided by ongoing research in this field [31].

Conclusion

In conclusion, *Santalum album* stands as a unique convergence of economic value and ecological heritage. Its extensive applications across perfumery, cosmetics, and traditional medicine underscore its significance and versatility. The sesquiterpenoids, particularly α- and β-santalol, in their essential oil, provide the characteristic scent and therapeutic

properties that make Indian sandalwood highly prized.

Historically revered in Hinduism, Buddhism, and Jainism, *S. album* has played an essential role in cultural and religious practices. Its use in traditional medical systems like Ayurveda, Traditional Chinese Medicine, and Unani highlights its longstanding therapeutic importance. Economically, the significance of sandalwood is evident from its historical trade and continuing high demand in the fragrance and medicinal industries.

However, the extensive exploitation of wild populations has led to significant conservation challenges. Overharvesting, habitat loss, and illegal trade have increased the species' vulnerability, necessitating urgent conservation measures. Effective strategies must include community-based conservation programs, stringent regulations, and sustainable cultivation practices to ensure *S. album* long-term survival.

Future efforts should focus on conservation, sustainable management, and innovative applications to maintain the legacy of *S. album*. By balancing utilization and preservation, we can ensure this invaluable species continues to benefit future generations, preserving its cultural, economic, and ecological significance. Through collaborative and dedicated efforts, the rich heritage and benefits of Indian sandalwood can be safeguarded and perpetuated.

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