Thammineni Pullaiah · Sudhir Chandra Das
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Kondragunta Sri Rama Murthy *Editors*

Sandalwood: Silviculture, Conservation and Applications

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Sandalwood: The Green Gold

1

Thammineni Pullaiah and Mallappa Kumara Swamy

Abstract

Santalum album L., popularly known as Sandalwood, belongs to the family Santalaceae and Sandalwood is the most valued South Indian tree, which is the source of the world famous, fragrant Indian sandal wood oil, a major ingredient in cosmetics, medicines, and perfumes produced worldwide. The central portion of the tree, known as the heartwood is very hard and yellow-brown in colour. The heartwood is fragrant in nature with an oily texture, and it is one of the perfect wood materials for making highly attractive artefacts of Sandalwood, due to its durability. In Hindu and Vedic societies, it is one of the best utilized sacred components. This tree has attracted the attention of both foresters and layman, because of its high valued wood, which is being illegally harvested, creating law and order problems. Thus, native species of Sandalwood trees have become vulnerable to extinction. As a result, it is included in the list of the International Union for the Conservation of Nature (IUCN) red listed threatened species. This chapter introduces about the Sandalwood tree, its habitat, restricted distribution, conservation, and economic importance to the readers.

Keywords

East Indian sandalwood · Endangered tree · Heartwood · Essential oil · Artefacts · Perfumes

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1.1 Introduction

Sandalwood is one of the best classes of woods, commonly procured from trees belonging to the genus, *Santalum* (Santalaceae). Members of this genus are widely spread, rising in India, Indonesia, Sri Lanka, Australia, Hawaii, New Guinea, and several other South Pacific islands. The prominent species in this group include *Santalum album* L., which is commonly recognized as Sandalwood or Indian Sandalwood and *Santalum spicatum*, known as Australian Sandalwood. Some of the other members in the genus, such as *S. freycinetianum, S. ellipticum*, *S. paniculatum,* and *S. spicatum* also have odorous wood. Amongst all members, Sandalwood (*S. album*) is the most valued South Indian tree, which is the source of the world famous "Indian Sandalwood oil", a major ingredient in cosmetics, medicines, and perfumes produced worldwide. Its wood is second only to ivory for use in intricate carvings. In addition to oil, the heartwood and its powder are utilized for religious, cultural, and therapeutic needs, especially in the Asian and Arab regions. It is highly valued in certain ethnic cultures, and considered divine in some faiths/religions. It is widely utilized in various religious traditional practices, including Hinduism, Jainism, Buddhism, Sufism, and others. Sandalwood tree is a small to medium-sized tropical tree species, and is one of the most usual sources of Sandalwood. It is indigenous to the Southeast Asia and south regions of India, exclusively grows well in the Western Ghats and other foothill ranges like the Shevaroy and Kalrayan hills. The tree is long lived, and also cultivated in recent years owing to its high prices, however, its harvest is feasible only after several years. The increased global demand for its products has triggered its earlier over-exploitation, and affected the wild population to extinction. At present, Sandalwood trees are managed by the government bodies, and their cut down is monitored. Even then, lots of Sandalwood trees are being illegally harvested and traded. Sandalwood oil costs have increased in recent times to about US$ 2000 per kg. At present, due to dearth of sizable trees, Sandalwood trees are rarely utilized for fine wood-crafting as before. This chapter briefly introduces about the Sandalwood tree, its habitat, restricted distribution, conservation, challenges, ethnomedicinal uses, and economic importance to readers.

1.2 Botanical Description

1.2.1 Taxonomic Position

Sandalwood is a member of the Santalaceae family, and is also generally recognized as East or White Indian Sandalwood. *Santalum ovatum* mentioned in Prodromus Florae Novae Hollandiae (1810) by Robert Brown is also considered as the synonym of Sandalwood. The name *album* indicates the "white" of the heartwood (https://en.wikipedia.org/wiki/Santalum_album#cite_note-4). The other species, such as *S. spicatum*, *S. freycinetianum, S. ellipticum*, *S. paniculatum,* and *S. spicatum* too have aromatic timber. In particular, *S. album* and *S. spicatum* are commonly

recognized as true Sandalwoods in order to extricate them from other alike-scented wood or oil-bearing trees.

The taxonomic position of Sandalwood is as follows:

Kingdom—Plantae
Division—Magnoliophyta
Class—Magnoliopsida
Order—Santalales
Family—Santalaceae
Genus—*Santalum*
Species—*album*

Sandalwood is called by different names, such as Indian Sandalwood, White Sandalwood (English); *Chandana, Hari-chandana* (Sanskrit); *Chandan* (Hindi); *Chandan* (Bengali, Punjabi); *Srigandha, Chandana* (Kannada); *Chandanam* (Malayalam); *Santhanam, Srigandhara* (Tamil); *Chandanamu, Hari-chandanam* (Telugu); *Boga chandon* (Assamese); *Cha-chandan* (Manipuri); *Chandono, Gondassaro* (Oriya); *Sukhad, Suket* (Gujarati); *Sukhad* (Sindhi); *Bois de santal* (French); *Sandelholz* (German); *Sandalo* (Spanish); *Sandalo* (Italy); *Sandalo branco* (Portugese); *Behman surkh, Sandal-abiyaz, Sandale-abiaz* (Arabic); *Sandal suped, Sandale-suped* (Persian); *Sandal safaid* (Urdu); *vitt sandelträd* (Swedish); *Cendana* (Indonesia), *Ai nitu* (Sumba), *Hau meni* (Timor), *Chendana* (Malaysia); and Nanttha hpyu, Nathahpyu, Sandakoo, Saantagu, Mawsanku (Myanmar).

1.2.2 Distribution and Morphological Description

According to the historical exploration, The Outer Arc of Banda Islands, situated in the South-Eastern regions of Indonesia is assumed to be the centre of origin of Sandalwood (Indrioko and Ratnaningrum 2015). It is assumed that Sandalwood, occurring in Indian regions at present is because of a gene introduced at several hundreds of year ago from Timor, an island at the Southeast Asia (Rao et al. 2001; Angadi et al. 2003). In contrast, others have claimed that Sandalwood originates from the southern regions of India (Riswan 2000). Another view has assumed that the prevailing genetic dissimilarity is because of the genetic difference affected by the bottleneck influence during the courses of natural selection (Angadi et al. 2003). Sandalwood is aboriginal to the tropical regions of the peninsular India and few parts of Australia and Indonesia (Bhaskar et al. 2010).

Sandalwood is an evergreen tree, and it grows up to 9 m in height. The age of the tree could be about 100 years. The tree is adaptable in natural habitat, customarily straight to spreading, and may possibly interlock with other species. It parasitises neighbouring plant species roots via a haustorium adaptation, i.e., a non-obligate association, however, causes no major damage to its hosts. This adaptation with other plants helps the tree to obtain macronutrients, nitrogen, phosphorus, and potassium, particularly during its initial stages of growth. During the early growth

phases, it establishes small stands and may propagate itself via wood suckering. In younger trees, the bark is observed to be black in colour, but cracked with redness. The heartwood is very hard and yellow-brown in colour. The heartwood is fragrant in nature with an oily texture. The leaves appear to be thin and opposite with ovate to lanceolate shape. Leaves are bright green with a shiny glabrous surface. Fruits are formed after 36 months, however, viable seeds are produced only after 60 months. Seeds dispersal happens through birds (https://en.wikipedia.org/wiki/Santalum_album#cite_note-4).

1.2.3 Habitat and Growth

Sandalwood is observed in the arid forests occurring at an elevation up to 700 m. In general, it grows well in weary stony red soils, nevertheless wide ranging soil types are being populated. This habitat has a yearly rainfall from 500 to 3000 mm, and temperature ranges between 0 and 38 °C. It requires good sunlight and small quantity of water for growing. It can grow up to 9 m vertically, and may start to flower after 7 years. Initially, the flowers appear to be whitish, and later they turn into orange or red. The fragrance of the tree trunk can be noticed only after 10 years of development.

1.3 Uses

The main reason for the economic and cultural value of Sandalwood is the oil contained in the Sandalwood timber, mainly in the heartwood. Noteworthy to mention that heartwood oil content differs widely within the species and between species of *Santalum*. Sandalwood is renowned for its oil, which is extremely appraised for its sweet-smelling, persistent aroma, and the fixative property, which is highly demanded by the perfume industry.

Sandalwood is sanctified in the Hindu religion, especially it is widely used in Ayurvedic preparations, and is as “chandana” in Sanskrit. There is a belief that the goddess Lakshmi exists in the heartwood of Sandalwood tree, and hence is used to worship the god Shiva. The paste and powder prepared from the heartwood are central to rituals, to produce sacred tools, to beautify the portrayals of the idols, and for soothing the mind, while meditating and offering prayer. In temples, it is distributed to devotees, who apply it on to their forehead or open neck and chest. In Jainism, Sandalwood paste assorted with Saffron is used for worshipping. Sandalwood garlands are utilized during the rituals of Jainism followers. Buddhist use it as one the most common fragrances to offer incense to the Buddha. In Sufi custom, Sandalwood paste is smeared on the Sufi’s grave by the devotees as a mark of devoutness. In East Asia, the people of Korea, China, and Japan use Sandalwood and Agarwood as a common incense materials for worshiping and many ceremonies.

Sandalwood oil has a wide range of ethnomedicinal uses, especially for treating common colds, skin diseases, bronchitis, heart illnesses, common faintness, fever,

the urinary tract infections, inflammations, liver diseases, and other illnesses (Misra and Dey 2013c). The antioxidant and antihyperglycemic potentials of Sandalwood oil and its major phytoconstituents, α-santalol have been proven in animal models (Misra and Dey 2013a). Further, different parts of the tree have been shown to have antimicrobial, anti-proliferative, and antioxidant properties, probably credited to phytoconstituents, such as α-santalol, sesquiterpenoids, shikimic acid, etc. (Misra and Dey 2012a, b, 2013b; Moy and Levenson 2017).

Jain et al. (2003) reported that heartwood of Sandalwood was priced at INR 12 lakhs per tonne and oil was priced at INR 22,000 per kg. However, the rates are highly determined by the quality of oil. Due to the high value of oil and timber, Sandalwood has been central among all Sandalwood species in the aspect of research (Subasinghe 2013).

1.4 Conservation Status, Threats, and Challenges

In 1994, Sandalwood was firstly registered as vulnerable in the IUCN Red List, due to habitat degradation as the results of population size reduction. Since 2004, Sandalwood was even measured non-existent in the wild native places in the south-eastern islands of Indonesia (Ratnaningrum et al. 2018). Considering this, the vulnerable position may be stepped up to endangered, critically endangered or even extinct in the wild, and therefore the conservation status supposed to be re-evaluated (IUCN 2009).

There was a significant degradation of Sandalwood population in the South-Eastern islands of Indonesia. In spite of this, degradation of new landraces of Sandalwood emerged along geographical gradients in Gunung Sewu Geopark, a 1300 km^2 mountainous limestone zones in the central part of Java Island (Haryono and Suratman 2010). The oldest herbarium specimen of Sandalwood in Java islands (dated by year 1853) was collected from Imogiri District, and another specimen (dated by year 1960) was found in Nglipar District; both were part of Gunung Sewu area. Gunung Sewu consisted of more than ten Sandalwood populations in the form of both planted and naturally regenerated stands. Most of these landraces are naturally isolated due to the restriction of the uplift and down lift formation of various landscape types. Some of them are also fragmented due to the various scenarios, which are involved in geographical, evolutionary, and disturbance histories.

Sandalwood tree is native to Karnataka (South India) flourishing well from sea level up to 1800 m altitude. It is a small evergreen or often deciduous tree. As a partial root parasite, Sandalwood draws nutrients through haustorial roots formed with the roots of almost any species of the host plant. Sandalwood is an achlamydosporous flowering plant, i.e., in which the seeds are devoid of integuments like many species of the family (Kuijit 1969).

Currently, most of the world demand of Sandalwood is supplied from Australia using *S. spicatum* known as Australian Sandalwood. Due to the high value and the demand, there is a growing attention at present in establishing Sandalwood,

especially Sandalwood plantations in the tropical regions over the most demanding other forest plantation species, i.e., teak, mahogany, etc. by the private sector plantation companies, due to the large domestic demand and the existing high demand. In accordance with that, there is a trend in Sandalwood plantation establishment in Australia, India, Sri Lanka, China, and Fiji since recently. However, the plantation sector lacks the information on establishing Sandalwood plantations, which is identified as a great risk when considering their profit maximizing goal. Without the knowledge of nursery techniques, host suitability, plantation establishment, growth rates, and oil characteristics, managers of Sandalwood plantations might therefore face difficulties in achieving the expected revenue outcomes (Subasinghe 2013).

Over the years, there has been a decline in Sandalwood production, resulting in the declined production of the essential oil. With stocks of South India's most valuable forest commodity getting depleted, it is necessary to intensify research towards evolving improved varieties. The species is experiencing population decline from illegal harvesting and over-exploitation. There is a diminishing availability of wood, suggesting the species has a high rate of decline. In parts of India economically viable trees (above 30 cm dbh) are commercially extinct. Commercially utilizable trees are few in number in the species range. There is also decline due to the poor recruitment caused by fire and overgrazing in the habitat and also due to infection by spike diseases in India. As the species is widespread and pressure is variable across this range, over three generations it is considered that population decline has been at least 30% (Arunkumar et al. 2019) and IUCN in 2017 listed it as a vulnerable plant species.

In an effort to boost its production, farmers are encouraged by governmental agencies to cultivate Sandalwood trees. However, its commercial cultivation is a great challenge to the agroforestry sector, because trees do not get established properly. Other challenges include the supply of elite samplings to farmers, and understanding the agronomy of the tree, diseases and pests, etc. Though, chemical synthesis of Sandalwood oil has been attempted, it is un-economical at the industrial scale. Various biotechnological applications have been attempted with little success, especially identifying key biosynthetic pathways and genes responsible for the biosynthesis of Sandalwood oil components, mainly sesquiterpenes. The information available on this plant is quite scattered and fragmentary. Thus, a comprehensive information on this species will be very helpful.

1.5 Conclusion

Sandalwood tree has attracted the attention of both foresters and layman, because of its highly valued wood, which is being illegally harvested creating law and order problem. This has created native species of Sandalwood trees to become vulnerable to extinction. Further, the genetic resources of Sandalwood in the country are hampered due to various reasons, including its high commercial value at the global level. Hence, conserving this native species is of great importance. Considering

these aspects, we propose a comprehensive monograph on Sandalwood, and as a source book. The book will provide information on taxonomy, morphology, distribution, wood anatomy, wood properties and uses, essential oil, phytochemistry, pharmacognosy, pharmacology, silvicultural aspects, propagation, cultivation practices, agroforestry, pests and diseases, biotechnology, molecular studies, biosynthesis of oil, conservation, trade and commerce, of Sandal wood, and grey areas of research. The book is profusely illustrated with colour photographs. Relevant references are provided under each chapter. This monograph on Sandalwood with systematic representation of information will be a desk reference and field guide to foresters, botanists, researchers, farmers, traders, and environmentalists.

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History of Sandalwood

2

Thammineni Pullaiah and Sudhir Chandra Das

Abstract

Vedas and Puranas are the oldest codified literature in Indian Philosophy, and such treatises quote the uses of Sandalwood for medicinal and cosmetic purposes. The essential teachings of Jainism and Buddhism too advocate oral and external uses of Sandalwood. Kautilya's text on the ancient Indian economics considers Sandalwood as a precious forest product. Pre-Christ era of Indian medicinal texts like Charaka Samhita and Sushruta Samhita along with a major post-Christ era text Ashtanga Hridaya Samhita describes detailed mentioning on Sandalwood uses. Even after 2000 years, Sandalwood is still used as a household remedy across the Indian societies. The commonly used incenses, including Sandalwood materials are being used for the religious purposes, and also for healing, particularly in the management of mental disorders. Such uses are also known to prolong the longevity as well as calm down the agitated mind.

Keywords

History · Sandalwood · Fragrance · Indian culture · Incense

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2.1 Introduction

Since from the ancient times, populace have tried to determine medicines for alleviating discomfort and treatments against several kinds of health problems. The expansion of civilization and progressive societies, the curative characteristics of many plants were recognized, recorded, and carried to succeeding generations, i.e. the utilities of one civilization were carried to one more (Petrovska 2012). These understandings were further upgraded by the next societies, leading to novel discoveries, which were passed till contemporary times. This non-stop and continuous individual's curiosity in curative plants has encouraged modern researchers to further investigate on their claims regarding the herbal medications (Swamy and Sinniah 2015; Kirubakari et al. 2019). Noteworthy to mention that most of the currently available effective drugs in the market are mainly originated from the plant resources, and plant-derived drug research is a perpetual process, even today (Lodh and Swamy 2019). The traditional herb-based medications, specifically the Ayurveda, Unani, Tibetan, Siddha, Chinese, and other medicinal systems of healthcare practices are recorded to be very effective. These ethnic healing practices are well-acknowledged since from the period of Charaka, the well-known sage, who is also called as father of Indian medicine, and has aided in the discovery of a wide ranging potential therapeutic drug molecules that are used in the present days. The Indian sages and others have mentioned the medicinal uses of many plants, including Sandalwood (*Santalum album*) in their literatures, Charaka Samhita and Susruta Samhita (Bhandary and Chandrashekar 2011; Arunkumar et al. 2012).

Sandalwood (White Sandal) is the fragrant heartwood of some species of the genus *Santalum*. The widely distributed and economically important *Santalum* genus belongs to the family Santalaceae, which includes 30 genera with about 400 species, and many of which being completely or partially parasitic (John 1947). Both heartwood and oil of Sandalwood are used in incense, perfumes, medicines and are of great commercial importance (Kumar et al. 2015). Internationally Sandalwood has been one of the most valued woods for centuries, prized for its oil and burning properties as well as its medicinal characteristics. Sandalwood oil is essential in the formula of all leading perfumes, soaps, and cosmetics. Approximately, 150 tonnes of Sandalwood oil is produced per annum worldwide (Krishnakumar et al. 2017; Goswami and Jagatpati 2018). This chapter is intended to provide a detailed information on the historical aspects of Sandalwood.

2.2 Religious Ceremonies

Historically, sandalwood has a rich tradition of trade with the East, dating as far back as the fifth century BC (Edwards 1951) when its aromatic heartwood and oils were already recognized as prized commodities. Sandalwood trade in India was started as early as the thirteenth century by Indian rulers trying to monopolize. Indian sandalwood was extensively exploited in the Pacific throughout the first half of the nineteenth century although initial evidence of sandalwood trade originated much

earlier, with the beginning of Buddhism into China from India (Ritter 1836; Thomson et al. 2005). This occurred in the first century AD typified by smouldering sandalwood incense in temples. Trade then extended to the Pacific when Americans and Australians began to trade with China, leading to the discovery of sandalwood in the Pacific, including Hawaii, and Australia (Thomson et al. 2005). Commercial exploitation of sandalwood has, however, resulted in the acute degradation of natural populations of many species, including those in India (Rashkow 2014), Indonesia (Ora 2012), Papua New Guinea (Gunn et al. 2002), and Vanuatu (Gillieson et al. 2008).

2.2.1 Hinduism

Sandalwood paste is integral to rituals and ceremonies, to mark religious utensils and to decorate the icons of the deities. It is also distributed to devotees, who apply it to their foreheads or the necks and chests. Preparation of the paste is a duty fit only for the pure, so is entrusted in temples and during ceremonies only to priests. The paste is prepared by grinding wood by hand upon granite slabs shaped for the purpose. With the slow addition of water, a thick paste results (called *kalabham* in Malayalam language and *gandha* in Kannada), which is mixed with saffron or other such pigments to make *chandanam*. *Chandanam*, further mixed with herbs, perfumes, pigments, and some other compounds, results in *javadhu*. *Kalabham, chandanam* and *javadhu* are dried and used as *kalabham* powder, chandanam powder, javadhu powder, respectively. *Chandanam* powder is very popular in India and is also used in Nepal. In Tirupati after religious tonsure, sandalwood paste is applied to protect the skin. In Hinduism and Ayurveda, sandalwood is thought to bring one closer to the divine. Thus, it is one of the most used holy elements in Hindu and Vedic societies (Tah 2017; Nirupama and Tah 2018).

2.2.2 Jainism

Sandalwood use is integral part of daily practices of Jainism. Sandalwood paste mixed with saffrons used to worship Tirthankar Jain Deities. Sandalwood powder is showered as blessings by Jain Monks and Nuns (Sadhus and Sadhvis) to their disciples and followers (Tah 2017; Nirupama and Tah 2018).

2.2.3 Buddhism

Sandalwood is mentioned in various Suttas of the Pâli Canon. In some Buddhist traditions, sandalwood is considered to be of the *padma* (lotus) group and attributed to Amitabha Buddha. Sandalwood scent is believed by some to transform one's desires and maintain a person's alertness while in meditation. It is also one of the

more popular scents used when offering incense to the Buddha and the guru (Tah 2017; Nirupama and Tah 2018).

2.2.4 Islam

In *sufi* tradition, sandalwood paste is applied on the *sufi*'s grave by the disciples as a mark of devotion. It is practiced particularly among the Indian Subcontinent disciples. In the Tamil culture irrespective of religious identity, sandalwood paste or powder is applied to the graves of sufis as a mark of devotion and respect (Tah 2017; Nirupama and Tah 2018).

2.2.5 Chinese and Japanese Religions

Sandalwood, along with agarwood, is the most commonly used incense material by the Chinese and Japanese in worship and various ceremonies. However, Taoists are forbidden from using sandalwood (as well as benzoin resin, frankincense, foreign produced) incense and instead either use agarwood, or better still *Acronychia pedunculata*, in worship (Dastur 1962).

2.2.6 Zoroastrianism

Zoroastrians offer sandalwood twigs to the firekeeping priests who offer the sandalwood to the fire to keep the fire burning. Sandalwood is offered to all of the three grades of fire in the fire temple, including the Atash Dadgahs. Sandalwood is not offered to the *divo*, a homemade lamp. Often, money is offered to the *mobad* (for religious expenditures) along with the sandalwood. Sandalwood is called *sukhar* in the Zoroastrian community. The sandalwood in the fire temple is often more expensive to buy than at a Zoroastrian store. It is often a source of income for the fire temple (Tah 2017; Nirupama and Tah 2018).

2.3 History of Sandalwood in India

The inseparable relationship of Sandalwood with the Indian culture is underlined by the fact that no ceremony, auspicious or otherwise, is complete without Sandalwood products (Rajan 1994). Being indigenous to India, Sandalwood has been synonymous with Indian heritage, and the country has traditionally enjoyed a niche market for its highly priced Sandalwood oil. India accounts for nearly 90% of oil production in the world. Decline in Sandalwood population in India is mostly due to the illicit and distress felling and poor artificial regeneration in establishing Sandalwood in wild. In India, even though sandal tree is found distributed all over the country, nearly 90% of its natural population is distributed in Karnataka and Tamil Nadu and

a small extent in Kerala and Andhra Pradesh. Till 2002, State Governments, especially in Karnataka and Tamil Nadu have had monopoly control over all Sandalwood resources, including those in private lands. But, this monopoly has neither deterred illegal and indiscriminate felling of Sandalwood by smugglers and poachers nor helped to conserve the species in its natural habitat or its sustainable utilization. The change in Government policy after 2002 has encouraged the private sector and individual farmers to grow Sandalwood in their land.

The fragrant heartwood of *Santalum album* is known as Sandalwood and essential oil from it as Sandalwood Oil. Indian Sandalwood consists maximum oil (6%) and α- and β- santalol (90%) which is used as world-class perfumes as a fixative (Shankaranarayana and Theagarajan 2000). Commercially Sandalwood oil is known as a scented oil in the world. The aroma of the Sandalwood oil and the heartwood is well-regarded by individuals, belonging to three main religions of the world, i.e., Hindus, Buddhists, and Islamises. According to *Vamana Purana*, the wood is commended for worshipping the God Shiva. The Goddess Lakshmi is believed to exist in the Sandalwood tree as portrayed in the *Brahma Vaivarta Purana* (Sensarma 1989). The ancient Egyptians imported the wood and used it in medicine, for embalming the dead and in ritual burning to venerate the gods (Burdock and Carabin 2008). It is customary in certain communities among the Hindus to put a piece of Sandalwood in the funeral pyre. The beige-coloured paste of Sandalwood is applied on the forehead and other body parts, especially by devotees of the god Krishna (Vaishnavites) and for ritual bathing of Hindu gods (Arunkumar et al. 2012).

There are references of Sandalwood in Indian mythology, folklore, and ancient scripts. "Chandana" the Sanskrit name ascribed to *Santalum album* L. was known and used in India from the earliest historic times and is frequently mentioned in the ancient Sanskrit writings, some of which dated before Christian era. Kautilya's Arthashastra (320 B.C.) considered Sandal as one of the important forest products to increase royal revenue. Charaka Samhita, the major text book of internal medicine in Ayurveda (300 B.C.) quotes uses of Sandal over 160 times in the entire text. In treatments of major diseases like fever, piles, haemorrhagic conditions, diabetes, dropsy, mental disorders, management of poisons, and skin disorders widespread uses of sandal are reported. Sushruta Samhita (150 B.C.), a great text on Indian wisdom on surgical procedures, equally preferred sandal for the management of wounds. Sandalwood fumigation is indicated in warding off evils and organisms, which contaminate the wounds. Such fumigations hasten the wound healing and surgical wards remain aseptic. Dusting of wounds with sandal for early healing is common. In the Amarakosha (Lexicon third or fourth century A.D.) sandal is mentioned and it is said that "Vina-malayam anyathra chandanam vivarditha" (Majumdar 1941). There are at least three kinds of sandal, namely White Sandal (*Santalum album)* called as "Sweta Chandana", Red Sandal (*Pterocarpus santalinus)* called as "Rakta Chandana", and Sandal Ku-chandana (*Adenanthera pavonina).*

The Vedic literature, belonging to 2000 B.C. lists over 700 substances including cinnamon, ginger, mustard, and Sandalwood for various utilities. Vedas describing the uses of such aromatic substances suggest that this was a developed art of healing.

Such fragrant substances are not only perfumery, but also used in the form of smoke, wind, odour, or essence. Such substances are widely used in religious ceremony to sooth the mind and to deepen the meditation. Incense is one of the oldest ways of utilizing essential oil. It creates various atmospheric and therapeutic effects. The traditional incense is used for prayer and meditation and also useful all time to bring a calm, and clear environment in the living place. Treatises of loud hymns, Rig Veda and singing hymns, Sama Veda do not make direct reference to Sandalwood. But during the period of Yajur Veda, havanas (sacrificial fires), where many aromatic and oily plant parts were sacrificed included Sandalwood. Atharva Veda consists of hymns and musical spells. The plant parts are extensively used to ward off or to invoke bad and good things (Bhat and Prajapati 2007). It is interesting to note that some Sanskrit texts of medieval period throw light even on the quality test, classification, and types of Sandalwood.

Kautilya's Arthashastra (320 BC) considered Sandalwood as one of the important forest products to increase the royal revenue. It also says that trade of Sandalwood should be conducted under a licence issued by King. The text also narrates the healing power of Sandalwood specially to remove the poisonous effect of materials handled by the King. Charaka Samhita, the major textbook of internal medicine in Ayurveda (B.C. 300) quotes uses of Sandalwood over 160 times in the entire text. Among these, about 81 indications are external uses of Sandalwood and the rest prescriptions refer to oral use. In the treatment of major diseases like fever, haemorrhagic conditions, management of poisons, and skin disorders wide spread uses of Sandalwood are seen in Charaka Samhita. Susruta Samhita (150 B.C.), a great text on Indian wisdom on surgical procedures, equally preferred Sandalwood for management of wounds. Sandalwood fumigation is indicated in warding off evils and organisms, which will contaminate the wound. Such fumigations hasten the wound healing and surgical wards remain aseptic. Dusting of wounds with Sandalwood for early healing is recommended.

Ganeshaiah et al. (2007) have given a detailed account of bio-resources, including Sandalwood, of Vijayanagara Empire during the fifteenth and sixteenth century. About 80–90% of the geographic distribution of Sandalwood in Deccan India overlaps with the regime of Krishnadevaraya and the later kings. This overlap has in fact rendered it the cliché "Chandanada Nadu", i.e. the land of Sandalwood for Karunadu, another name for the regime of Vijayanagara (Srinivasan et al. 1992). Though the regime had officially recognized three Dravidian languages, Kannada, Telugu, and Tamil, historically Vijayanagara began as Karunadu or Karnataka, the land that traditionally became associated with Sandalwood (Ganeshaiah et al. 2007). Sandalwood as a prospective economic resource had played an important role in many of Krishnadevaraya's (the famous ruler of Vijayanagara Dynasty) expeditions to different parts of the Deccan during the early part of the sixteenth century (Ganeshaiah et al. 2007). Tippu Sultan who ruled the Kingdom of Mysore had declared Sandalwood tree as a royal tree and took over Sandalwood trade of the state on a monopoly basis around 1792 (Adkoli 1977). This practice was continued by the later Maharajas of Mysore and subsequently by the Karnataka Government until

recently. The extraction and disposal of Sandalwood came under the jurisdiction of the Forest Department in 1864.

In Karnataka (formerly Mysore), the forest working plan for Sandalwood extraction was prepared for Hunsur Taluk in 1910, Heggadadevanakote in 1920, and Narasimharajapura in 1926. In 1871, the parasitic nature of sandal was reported by John Scott. Watt (1893) described the technique of raising sandal seedlings in tile pots in the nurseries and planting in the field. McCarthy (1899) first noticed the spike disease of sandal in Coorg. Brandis (1903) suggested that though sandal is a root parasite, it may derive part of its nutrition from the soil as well. Barber (1905) noted that haustoria formation occurred only on certain roots of sandal and not on all of them. This plant forms a non-obligate relationship with a number of host plants (Nagaveni and Vijayalakshmi 2004).

Nalwadi Krishnaraja Wodeyar (1884–1940) (aka Krishnaraja Wodeyar IV), whose period of sovereignty is often described as the Golden Age of Mysore, was instrumental in conceiving the idea of starting a Sandalwood oil factory. Outbreak of the World War I had a severe impact on the forest economy of Mysore due to the discontinuation of the traditional export markets for Sandalwood. Out of 1313 tonnes of Sandalwood offered for sale in 1914–15, only 70 tonnes could be disposed off. And the huge stock of unsold wood was fortuitously noticed by the Maharaja of Mysore, during his visit to the Forest Department at Sankey Road in Bengaluru in 1916. It dawned upon him that oil should be extracted from this stock to obtain a high value-added product. After discussing this matter with the then Dewan of Mysore, Shri M. Visvesvaraya and Alfred Chatterton, the first Director of Industries and Commerce of erstwhile State of Mysore, the first sample of Sandalwood oil was extracted under the leadership of Prof. J. J. Sudbourough and Prof. H. E. Watson, scientists working at the Indian Institute of Science (IISc), Bengaluru (Subbaryappa 1992). After the successful operation, a Sandalwood oil distillery was started in 1916 in the vicinity of Sankey Tank, Malleswaram, Bengaluru. This unit was later shifted to Mysore in 1917 and eventually became the renowned Government Sandalwood Oil Factory. The Mysore Sandalwood oil gained international popularity for its fine quality.

Sandalwood was a priced commodity for both Arabs and Europeans (Rao et al. 2001). While it is generally believed that Europeans colonized Asian countries mainly for spices, that Sandalwood also played a significant role in the political wars of the time is not widely known (Chandrasekharaiah 1971; Srinivasan et al. 1992; Padhmanabha 2000; Rao et al. 2001). History records that Portuguese used to deploy military units from Goa to Timor, a small island in the Pacific Ocean for gaining access to the Sandalwood resources available there. The fort built by them in the central part of Timor was later invaded by the Dutch, who in turn began establishing their Sandalwood extraction units in the South Western part of the island. However, deploying additional military units from Goa, the Portuguese tried to regain control over the Sandalwood resources of the island and did partially succeed with the help of the Tomasse, a new breed of warriors born out of marriages between the natives and Portuguese soldiers who had earlier settled there. Finally their prolonged conflict was resolved by dividing the entire island into the Eastern

and Western halves between the Portuguese and the Dutch (Ganeshaiah et al. 2007). The Indian Sandalwood was superior in terms of its oil quality (Ganeshaiah et al. 2007) and hence the Portuguese and later the British buyers turned towards it. Obviously, the Vijayanagara kings who had the most Sandalwood resources under their territory had a greater leverage in trading it for guns and horses. Thus Vijayanagara rulers had economic reasons to occupy fresh territories of Sandalwood, and retain those under their control so that they gain complete control over this important resource. Such control over resource became much more important in the background of the renewed business prospects that opened with the arrival of the Europeans and the military superiority gained with such association. Quite reasonably, several of Krishnadevaraya's expeditions to different parts of the Deccan could have been driven by this economic potential of Sandalwood.

2.4 History of Sandalwood in Australia

History of Sandalwood in Australia has been given in the website https://newmountain.com.au/pages/sandalwood-history. Sandalwood has known to be used by different civilizations for over 3000 years. Up until the start of the nineteenth century no one knew there was sandalwood in the Pacific and Australia, other than the Chinese expeditions led by the famous eunuch admiral, Zheng He in the fifteenth century. Trading Houses were desperate to find a commodity to trade with China for the growing demand for tea in Europe and particularly England. There was a serious imbalance in trade. In 1811–1819 the total value of goods imported by the East India Company to England from China was over 72 million pounds. Tea accounted for over 70 million pounds. In the 1800s, traded sandalwood was sourced mainly from India and was labelled "Old Mountain" by the Chinese.

For centuries, Indian Sandalwood was called "Old Mountain" by the Chinese. When the Australian Sandalwood became globally recognized as a valuable commodity, the Chinese began calling it "New Mountain". New Mountain Merchants belongs to Wescorp Group which supplies the world market with over 50% of traded sandalwood.

There are many species of *Santalum* in Australia. The two main species that are harvested are *S. lanceolatum* which grows throughout Australia except Tasmania and southern Victoria and *S. spicatum* which grows in Western Australia and parts of western South Australia. *S. spicatum* is a desert tree and as a result is much slower growing. The oil has a different, less heady aroma and has become the preferred wood for incense manufacturing across Asia. It is a big part of the Asian culture and the wood is commonly used to make joss sticks for the incense trade. India alone consumes 500 million incense (agarbatti) sticks per day.

When the first shipment of 4 tonnes of Western Australia sandalwood was exported to Singapore on the sailing ship SS Champion by Western Australia settlers in 1844, it became globally recognized as a valuable commodity and thus became known as "New Mountain". This first shipment saw the birth of the "New Mountain" Sandalwood industry. This shipment received $20 per tonne. In the nineteenth

century sandalwood was Western Australia's second largest export. In 1882 the colony exported 9605 tonnes and earned $192,000. In 1920, a total of 13,945 tonnes were exported at a value of $467,000.

Realizing the value of this precious commodity and the need to sustain it, the Western Australian government introduced the Sandalwood Act in 1929, which strictly controls harvesting and replanting, and ensures regeneration and sustainability of the Sandalwood industry. It means that only a lower percentage of Sandalwood oil can be harvested each year. Forest Products Commission (FPC) has developed operation Woylie which has proven to be very successful in re-establishment of the natural Sandalwood in the range lands. FPC has contractors that plant 10–12 tonne of selected seed each year in the rangelands in a short opportune window of sowing. All of the State's harvested Sandalwood come from natural arid rangelands of Western Australia. The State's Sandalwood resource is governed by the Department of Protection and Wildlife (DPAW) and harvested by the FPC on behalf of the State. FPC is the largest supplier of "wild" Sandalwood in the world. Western Australia is the only region in the world that can guarantee harvest of approximately 2000 tonnes of Sandalwood each year on a sustainable basis so that there will be a planned stable market for future generations. Wescorp Sandalwood Pty Ltd is the sole processor, marketer, and exporter of *S. spicatum* for FPC. *S. spicatum* is responsible for the supply of over 50% of *Santalum* to the trading world (https://newmountain.com.au/pages/sandalwood-history).

2.5 History of Sandalwood in Hawaii

Raj (2018) has given an account on the History of *Santalum* in Hawaii Islands. Kaui Island was once, briefly a major source of Sandalwood. The Hawaiian island chain is home to six of the world's 17+ species. The Hawaiians knew the tree as *iliahi* and used it for scenting kapa cloth and as a medicine. Hawaiian species, such as *Santalum paniculatum*, are not as large or straight as their Indian cousin, and the wood is less desirable. Until the early eighteenth century, the remote islanders were unaware of its great value in the global market, especially in China (Raj 2018).

However, when King Kamehameha I learned of its high demand—caused then, as now, by low supply from India—he ordered the entire able-bodied population to harvest the trees, everyone from chiefs to common people. Workers would uproot the trees to get at the oil-rich stumps, saw up the logs, and transport them on their backs, down the mountains through challenging terrain. Pits were dug to the same dimensions as a cargo ship's hull to measure a shipload. Wood was stacked in the pit until full. Then the logs were transported to the beaches. The conditions were unpleasant for these workers, who were already plagued by diseases brought by the Europeans. Even worse, the king's greed for sandalwood resulted in reduced agricultural production of food, and famine ensued. Kamehameha finally placed a kapu (ban) on the harvest of iliahi in order to bring island life back into balance (Raj 2018).

In 1819, he died and his son Liholiho took the throne as Kamehameha II. Shortly thereafter, he abolished the kapu system, sending the iliahi harvest back into overdrive. By 1821 the kingdom of Hawaii was $300,000 in debt for foreign goods, ships, and liquor. The abuse of credit was fuelled on both sides. The Hawaiian chiefs indulged in lavish commodities, while foreign traders, eager for the Sandalwood, pushed the credit system on the islanders. As the iliahi got harder to find, workers resorted to burning forests to locate the trees by their powerful smell. The older trees survived the fires—only to be cut down—but the younger saplings were eradicated in the process (Raj 2018).

By the time Kamehameha II passed away in 1824, the next heir to the throne inherited a debt of $500,000 owed to American traders—a fortune in those days. In 1827, the new king enacted Hawaii's first written law, the sandalwood tax, to pay this debt. This tax required every man to deliver 70 pounds of sandalwood, or pay four Spanish dollars, to the district governor each year. Women of age 13 and older were required to weave a 12 foot by 6 foot mat, or to pay one Spanish dollar. By 1830, the forests were exhausted, and Hawaii's sandalwood trade ended (Raj 2018).

Today one can find a tree on the Hawaiian Islands only with great difficulty. A few commercial-scale efforts are being made, but the primary interest is in simply preserving the native varieties. In fact, planting of anything other than indigenous species—especially India's *Santalum album*—is discouraged, as unwanted hybrids would result (Raj 2018).

2.6 Conclusions

Sandalwood products are very precious commercially, and the history of Sandalwood tree's existence dates back to the Vedic period. Since form the existence of human societies, the uses of Sandalwood have been mentioned in the literature. The tree is being used for many applications, including religious, therapeutics, creation of beautiful artefacts, etc. However, an ever increasing demand has led to indiscriminate harvesting, leading to threatened status. Therefore, conservation of Sandalwood species is of prime importance in the present time. Overall, the historical aspects of Sandalwood in this chapter could be very useful for plant biologists, chemists, traders, and many others, who are having interest in this commercial tree species.

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Botany of Sandalwood (*Santalum album* L.)

3

Thammineni Pullaiah and Subbiah Karuppusamy

Abstract

The genus *Santalum* has been included in Santalaceae family, and is categorized as a hemiparasitic plant. This genus is represented by about 19 accepted tree species that are distributed in India, Indonesia, Philippines, Pacific Islands, and Australia. *S. album* is the most famous and treasured species, and is also known as Sandalwood, Indian Sandalwood, or White Sandalwood. The tree is well known for its uses worldwide, since the ancient times. Presently, this species is categorized as a "vulnerable species", because of over-exploitation of trees from their natural habitats. Consequently, Sandalwood products have become costly and rare, and various efforts have been taken by the Indian government to protect this appreciated resource. This chapter provides the botany, identification characters, distribution, phenology, anatomical features, reproductive biology, breeding system and variations of Sandalwood in their environmental gradients with photographs.

Keywords

Sandalwood · *Santalum* · Santalaceae · Taxonomy · Reproductive biology

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3.1 Introduction

The genus *Santalum* has been included in Santalaceae family. This is a genus of trees and woody shrubs, represented by about 19 accepted species that are distributed India, Indonesia, Philippines, Pacific Islands, and Australia. Sandalwood is the common name specified to a class of woods from *Santalum* tree species. Notably, *S. album*, also known as Sandalwood, Indian Sandalwood, or White Sandalwood and *S. spicatum*, known as Australian Sandalwood are the most important ones, though other species in this genus also possess scented wood (Kumar et al. 2015). Sandalwood is a moderate-sized hemiparasitic tree, and well-known for its commercial uses, worldwide, since the ancient times. Due to its high demand and profitmaking applications in the world market, the trees are being over-harvested, and thus caused severe damage to its natural habitats (IUCN 2009; Arunkumar et al. 2019). Hence, various measurements have been taken by public and private sectors in protecting this valuable natural species. However, its feasible conservation and sustainable cultivation are yet to be achieved. This is due to the fact that there is a meagre knowledge on this tree species with regard to its tree biology and agronomical aspects.

Understanding botany is the important parameter for conservation of any plant species (Bapat et al. 2012). Investigations on the identification, classification/nomenclature, cataloguing, and distribution of plants are of supreme importance for investigations, not only in botany, but also in several disciplines of forestry and protection. Understanding the appropriate taxonomic identification of a species, its adaptation, distribution, floral biology, reproductive biology, cytogenetics, etc., is of immense practical impact for the conservation of biodiversity, biotechnology, tree improvement programmes, and controlling of its invasive species (Barrett 2010). For commercial exploitation of this valuable tree, it is necessary to understand its botanical aspects, botany of the related species, its identification characters, distribution, chromosome numbers, reproductive biology, etc. Hence, this chapter provides the botany, identification characters, distribution, phenology, anatomical features, reproductive biology, breeding system, and variations in Sandalwood in their environmental gradients.

3.2 Taxonomy and Distribution

Santalum album is commonly known as White or East Indian Sandalwood. The name, *Santalum ovatum* used by Robert Brown in *Prodromus Florae Novae Hollandiae* (1810) was described as a synonym of *S. album*. The epithet *album* refers to the "white" of the heartwood. The name "Sandalwoods" and the taxonomy of the genus are derived from this species historical and widespread use.

Sandalwood trees belong to the genus *Santalum* of the family Santalaceae. Santalaceae encompasses about 42 genera and 992 species (The Plant list 2020), among them 19 species belong to the *Santalum* genus (Fox 2000; Harbaugh and Baldwin 2007; Harbaugh 2007; Harbaugh et al. 2010; Butaud 2015). According to