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

Sandalwood: Silviculture, Conservation and Applications

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1 Sandalwood: The Green Gold

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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3 Botany of Sandalwood (*Santalum album* L.)

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

Harbaugh and Baldwin (2007) there are 16 species and approximately 14 varieties, of these one species got recently extinct. According to Rao et al. (2011) in the genus *Santalum* there are 16 species and several varieties.

The family Santalaceae is distributed between 30° N and 40° S from Indonesia (in the East) to Juan Fernandez Island (in the north) to New Zealand (in the South). Species of *Santalum* occur in Hawaii, India, Australia, Indonesia, Timor, etc. Greatest species diversity of *Santalum* is found in Hawaii islands where among the 18 species listed below, about six species can be found.

Distribution of 32 different taxa of 18 species of *Santalum* is as follows (Harbaugh and Baldwin 2007; Harbaugh et al. 2010; Butaud 2015).

1. *S. acuminatum* (R.Br.) A.DC.—Australia
2. *S. album* L.—Australia, Indonesia, India
3. *S. austrocaledonicum* Viell. var. *austrocaledonicum*—New Caledonia, Vanuatu
4. *S. austrocaledonicum* Viell. var. *minutum* N.Halle—New Caledonia
5. *S. austrocaledonicum* Viell. var. *pilosulum* N.Halle—New Caledonia
6. *S. austrocaledonicum* Viell. var. *glabrum* N.Halle—New Caledonia
7. *S. boninense* (Nakai) Tuyama—Bonin Islands
8. *S. ellipticum* Gaudich. var. *ellipticum*—Hawaiian Islands
9. *S. ellipticum* Gaudich. var. *littorale* (Rock) Skottsb—Hawaiian Islands (O‘ahu)
10. *S. fernandezianum* F.Phil.—Juan Fernandez Islands
11. *S. freycinetianum* Gaudich. var. *freycinetianum*—Hawaiian Islands (O‘ahu, Moloka‘i)
12. *S. freycinetianum* Gaudich. var. *lanaiense* Rock—Hawaiian Islands (Lana‘i, Maui)
13. *S. freycinetianum* Gaudich. var. *pyrularium* (A. Gray) Stemmerm.—Hawaiian Islands (Kaua‘i)
14. *S. haleakalae* Hillebr.—Hawaiian Islands (Maui)
15. *S. insulare* Bertero ex A.DC. var. *insulare*—Society Islands (Tahiti)
16. *S. insulare* Bertero ex A.DC. var. *alticola* Fosberg & Sachet—Society Islands (Tahiti)
17. *S. insulare* Bertero ex A. DC. var. *deckeri* Fosberg & Sachet—Marquesas Islands
18. *S. insulare* Bertero ex A. DC. var. *hendersonense* (F.Br.) Fosberg & Sachet—Pitcairn Islands
19. *S. insulare* Bertero ex A. DC. var. *marchionense* (Skottsb.) Skottsb.—Marquesas Islands
20. *S. insulare* Bertero ex A. DC. var. *margaretae* (F.Br.) Skottsb.—Austral Islands (Rapa)
21. *S. insulare* Bertero ex A. DC. var. *mitiaro* Sykes—Cook Islands (Mitiaro)
22. *S. insulare* Bertero ex A. DC. var. *raiateense* (J.Moore) Fosberg & Sachet—Society Islands (Raiatea, Mo‘orea)
23. *S. involutum* H. St. John—Hawaiian Islands (Kaua‘i)
24. *S. lanceolatum* R.Br.—Australia
25. *S. leptocladum* Gand.—Australia

26. *S. macgregorii* F.Muell.—Papua New Guinea
27. *S. murrayanum* (T.Mitch.) C.A.Gardner—Australia
28. *S. obtusifolium* R.Br.—Eastern Australia
29. *S. paniculatum* Hook. & Arn. var. *paniculatum*—Hawaiian Islands (Hawai‘i)
30. *S. paniculatum* Hook. & Arn. var. *pilgeri* (Rock) Stemmerm—Hawaiian Islands (Hawai‘i)
31. *S. spicatum* (R.Br.) A.DC.—Australia
32. *S. yasi* Seem—Fiji, Tonga

Aside from today's existing Sandalwood species, the species *S. fernandezianum*, native to the Juan Fernández Islands, became extinct around 1908 after several decades of over-harvesting (IUCN 2009, https://www.iucnredlist.org/species/30406/9544750).

The Plant List (2020) includes 61 scientific plant names of species rank for the genus *Santalum*. Of these 12 are accepted species names, while 49 remain unresolved. These are given below.

Santalum acuminatum (R.Br.) A.DC.—Accepted
Santalum austrocaledonicum Vieill.—Unresolved
Santalum boninense (Nakai) Tuyama—Unresolved
Santalum capense (Spreng.) A.DC.—Unresolved
Santalum crassifolium A.DC.—Unresolved
Santalum cuneatum Rock.—Unresolved
Santalum cunninghamii Hook.f.—Unresolved
Santalum densiflorum Gand.—Unresolved
Santalum ellipticum Gaudich.—Accepted
Santalum fernandezianum Phil.—Accepted
Santalum freycinetianum F.Phil.—Accepted
Santalum haleakalae Hillebr.—Accepted
Santalum hendersonense F.Br.—Unresolved
Santalum hornei Seem—Unresolved
Santalum insulare Bertero ex A.DC.—Unresolved
Santalum involutum H.St. John—Unresolved
Santalum lanaiense Rock—Accepted
Santalum lanceolatum R.Br.—Unresolved
Santalum latifolium Meurisse—Unresolved
Santalum leptocladum Gand.—Unresolved
Santalum littorale Rock—Unresolved
Santalum longifolium Meurisse—Unresolved
Santalum macgregorii F. Muell.—Unresolved
Santalum majus H.St. John—Unresolved
Santalum marchionense Skottb.—Unresolved
Santalum margaretae F.Br.—Unresolved
Santalum megacarpum Gand.—Unresolved
Santalum mida Hook.—Unresolved

Santalum mitchellii F. Muell.—Unresolved
Santalum multiflorum J.W.Moore—Unresolved
Santalum murrayanum C.A.Gardner—Unresolved
Santalum myrtiflorum L.—Accepted
Santalum oblongatum R.Br.—Unresolved
Santalum obtusifolium R.Br.—Unresolved
Santalum ovatum R.Br.—Unresolved
Santalum paniculatum Hook. & Arn.—Accepted
Santalum papuanum Summerh.—Accepted
Santalum persicarium F. Muell.—Unresolved
Santalum pilgeri Rock—Unresolved
Santalum preissii F.Muell.—Unresolved
Santalum pyrularium A. Gray—Accepted
Santalum raiateense J.W.Moore—Unresolved
Santalum salicifolium Meurisse—Accepted
Santalum spicatum A.DC—Unresolved
Santalum venosum R.Br.—Unresolved
Santalum yasi Seem.—Unresolved

Recently Plants of the World Online (POWO) updated the taxonomy of *Santalum* L. and listed out 17 accepted species distributed its native range of Socotra, Tropical and Subtropical Asia to Pacific, Juan Fernández Islands. Those accepted species are *Santalum acuminatum* (R.Br.) A.DC., *Santalum album* L., *Santalum austrocaledonicum* Vieill., *Santalum boninense* (Nakai) Tuyama, *Santalum ellipticum* Gaudich., *Santalum fernandezianum* Phil., *Santalum freycinetianum* Gaudich., *Santalum haleakalae* Hillebr., *Santalum insulare* Bertero ex A.DC., *Santalum lanceolatum* R.Br., *Santalum macgregorii* F.Muell., *Santalum murrayanum* (T.L.Mitch.) C.A.Gardner, *Santalum obtusifolium* R.Br., *Santalum paniculatum* Hook. & Arn., *Santalum papuanum* Summerh., *Santalum spicatum* (R.Br.) A.DC., and *Santalum yasi* Seem.

3.3 Botany

3.3.1 Santalum L.

Santalum album L., Sp. Pl. 349. 1753; Hook.f., Fl. Brit. India 5: 231. 1886; Gamble, Fl. Madras 2: 1261. 1925; Sanjai & N.P.Balakr. in N.P.Balakr. et al., Fl. India 23: 64. 2012.

Small, evergreen, semiparasitic, glabrous tree with slender drooping branches, up to 12 m high, bark grey, cracked. The sap wood white and odourless, the heart wood yellowish brown, strongly scented. Leaves chartaceous, 4–6.5 × 2–3 cm, elliptic ovate to lanceolate, opposite, base acute, margin entire, apex sub-acute, sub-coriaceous. Flowers maroon or brownish-purple within, green without in 6 cm long axillary pedunculate cymes, shorter than leaves, trichotomous, terminal and axillary;

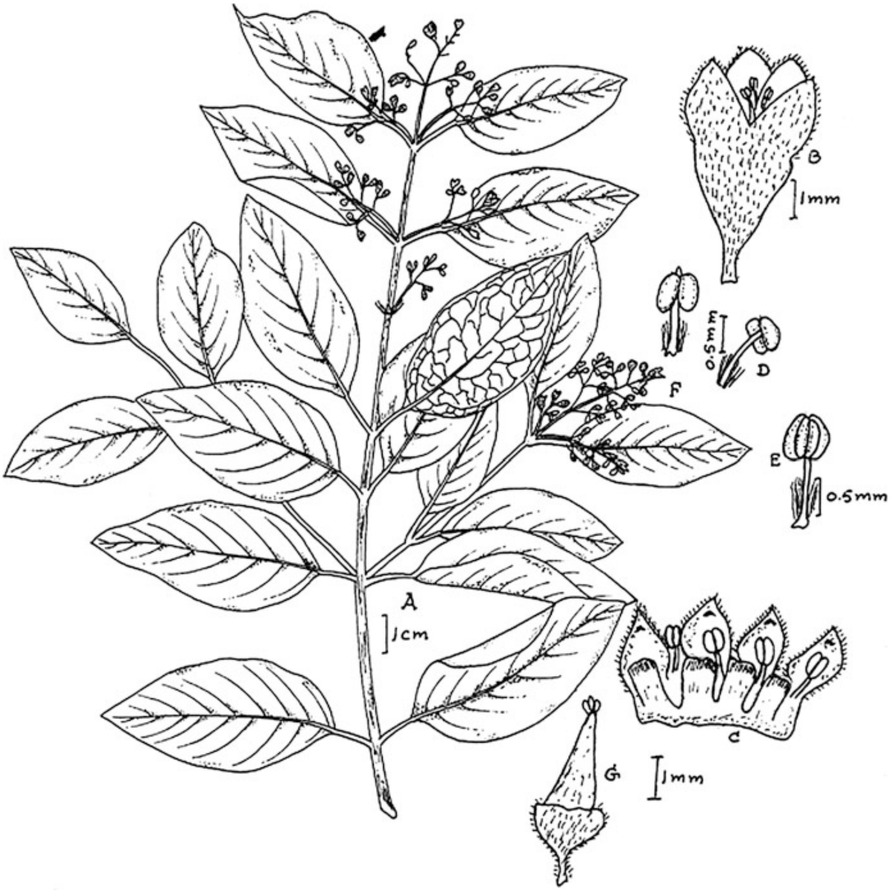

Fig. 3.1 *Santalum album* L. (**a**) Twig, (**b**) Flower, (**c**) Corolla split open, (**d**–**f**) Stamens, (**g**) Pistil (drawn by authors)

perianth lobes vary from 4 (common) to 6, broadly triangular; stamens 4–6, filaments short, inserted at the mouth of perianth tube; ovary at first free, later semi-inferior, 1-loculed, stigma 3-lobed. Drupe subglobose, 1 cm across, glabrous, purple black when ripe, endocarp hard (Figs. 3.1 and 3.2).

Occasional in open dry deciduous and scrub forests, frequently planted in gardens.

Fl. & Fr.: January–October.

Lectotype (Scott in Bosser et al., Fl. Mascareignes 159:1. 1982): Herb. Linn. No. 138. 1 (LINN).

Distribution in India Predominantly in tropical deciduous forests and moist semi-deciduous forests of Peninsular India, south of Vindhya Mountains ascending to

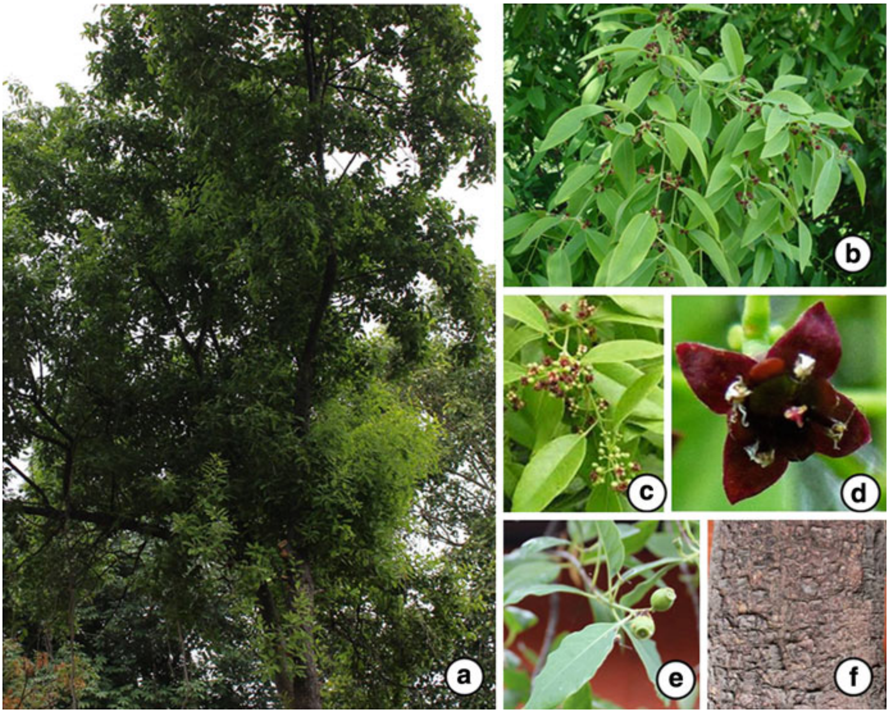

Fig. 3.2 *Santalum album*: (**a**) tree, (**b**) flowering branch, (**c**) inflorescence, (**d**) flower, (**e**) fruiting branch, (**f**) mature bark surface view (Photos by S. Karuppusamy)

1500 m altitude, parts of Rajasthan, Uttar Pradesh, Madhya Pradesh, Orissa, Maharashtra, Karnataka, Tamil Nadu, Kerala, and Andhra Pradesh.

In India *Santalum album* is found all over the country, but mainly in the states of Karnataka and Tamil Nadu where it extends over 8300 km^2. In Karnataka, it grows naturally in the southern as well as western parts over an area of 5000 km^2. In Tamil Nadu, it is distributed over an area of 3000 km^2 and dense population exists in Javadis and Yelagri hills and Chitteri hills. The tree flourishes well from sea level up to 1800 m altitude in different types of soil like sandy, clayey red soils, lateritic, loamy and even in black cotton soils. Trees growing on stony or gravelly soils are known to have more highly scented wood. It grows best where there is moderate rainfall of 600–1600 mm. In early stages it grows well under partial shade but at the middle and later stages does not grow well under heavy overhead shade.

World Distribution *Santalum album* is native to India, Sri Lanka, and Indonesia. In Indonesia the species is native to the east of the archipelago in Timor, Flores, and Sumba (Ratnaningrum et al. 2015; Seran et al. 2018). It has also been recently recorded as native in Aceh, north-western Sumatra (Septiani and Setyawati 2012). In India, the natural distribution of the species is Karnataka, Tamil Nadu, Andhra Pradesh, and Kerala states (Srinivasan et al. 1992), and the species is introduced to other parts of India. In Sri Lanka, the species is known from the Badulla Welimada region in Uva province, but can be found in outlier sites from here (Subasinghe 2014). The species is present in Northern Territory, Australia, but its origin here is uncertain (Thomson et al. 2018).

The species has been introduced to China (Li 2003; Ma et al. 2006), Fiji (Huish et al. 2015), Toga, the Cook Islands, French Polynesia and Mascarene Islands, Thailand and also parts of Indochina for commercial purposes.

3.4 Anatomical Features

3.4.1 Microscopic Characters of Leaf

Batabyal (2015) has given micromorphological characters of *S. album.* Micromorphological features of leaves with respect to stomatal structure, distribution, frequency of stomata, and overall epidermal details are as follows. Leaves are uniformly hypostomatic, in general epidermal cells of the surface of lamina are typically isodiametric, polygonal, sometimes little elongated, while those along the veins are highly elongated and lie in longitudinal files. Anticlinal wall of epidermal cells are straight, at places little undulated; periclinal wall is flat with a thick cutin deposition. The leaf surface is densely covered by wax granules. Stomata are typically paracytic and oriented parallel with the guard cells. Stomata are irregularly oriented. Venal regions are devoid of stomata. Mean stomatal frequency per square centimetre of lamina was found as 12.50 ± 02 and stomatal index as 12.05 ± 1.02.

3.4.2 Macroscopic Characters

The macroscopic and microscopic properties of the heartwood of *Santalum album* have been studied by Sundharamoorthy et al. (2018). Transverse section of wood shows alternating lighter and darker zones. The xylem consists of vessels and fibres. Vessels are large and usually occur single extending from one medullary ray to the next. Fibres are densely packed with interspersed air space termed as lacunae and constitute bulk of wood. Medullary rays are very fine, usually two cells wide and closed together. Volatile oil is deposited in the heartwood and is found in all the elements of the wood; it is not secreted by or contained in any particular cells or glands.

The sap wood of sandal which is inferior in quality can be differentiated by the colour and odour morphologically and microscopically by less distinct medullary rays, vessels, and oil globules. Texture is hard and heavy, fracture splintery and breaks with a snapping sound.

Microscopically tyloses, fibre, tailed vessels, uni- and biseriate medullary rays, brownish content, and oil globules are the unique diagnostic characters reported in heartwood of *S. album.*

3.4.3 Microscopic Characters of Heartwood

The transverse section of *S. album* heartwood shows narrow medullary rays, the vessels are partly loaded with yellow resin. The sap wood is brighter yellow in colour, both vessels and medullary rays are less distinct. The sap wood is scentless compared to heartwood due to less number of oil globules.

Transverse section of heartwood consists of tracheids, vessels, fibres, xylem parenchyma and traversed by medullary rays; vessels numerous, scattered singly throughout the region, rarely two together, barrel-shaped, pitted and with transverse to oblique perforation with tail-like projections, at one or both ends; a few tracheids elongated with tapering ends and possess bordered pits on their walls; fibres many, lignified with pointed tips; xylem parenchyma mostly rectangular, few of them contain prismatic crystals of calcium oxalate; xylem rays numerous, run straight, uni- to triseriate mostly biseriate, thick walled, radially elongated having golden yellow to brownish contents and contain a few prismatic crystals of calcium oxalate.

Sundharamoorthy et al. (2018) gave the microscopic characters of heartwood of *S. album.* Transverse section of heartwood shows isolated vessels embedded with tyloses, thick walled wide lumen fibres embedded with brownish content, occupying the major portion of the wood; vessels are arranged in diffused pore, parenchyma mostly vascicentric, medullary rays uni- and biseriate running almost straight and parallel, except when are adjacent to vessels get slightly bent (Sundharamoorthy et al. 2018) (Figs. 3.3 and 3.4).

3.4.4 Microscopy of Heartwood Powder

Microscopically tylosis, fibres, tailed pitted vessels, uni- and biseriate medullary rays, brownish content, and oil globules are the unique diagnostic characters reported.

3.5 Cytogenetics

Chromosome number: $n = 10, 20, 40$ (Kumar and Subramanyam 1986). Chromosome number of *S. album* was reported as $2n = 20$ and with basic chromosome number $x = 10$ (Fig. 3.5) (Rao 1942; Goldblatt and Johnson 2000; Harbaugh 2008). In a recent study on karyotype analysis conducted by Zhang et al. (2010), for the first time a mixoploid was found ($2n = 2x = 20$ and $2n = 4x = 40$). They also found predominance of metacentric chromosomes and a few submetacentric chromosomes. The authors also mention that considering the karyotypic analysis, *S. album* is a more primitive taxon.

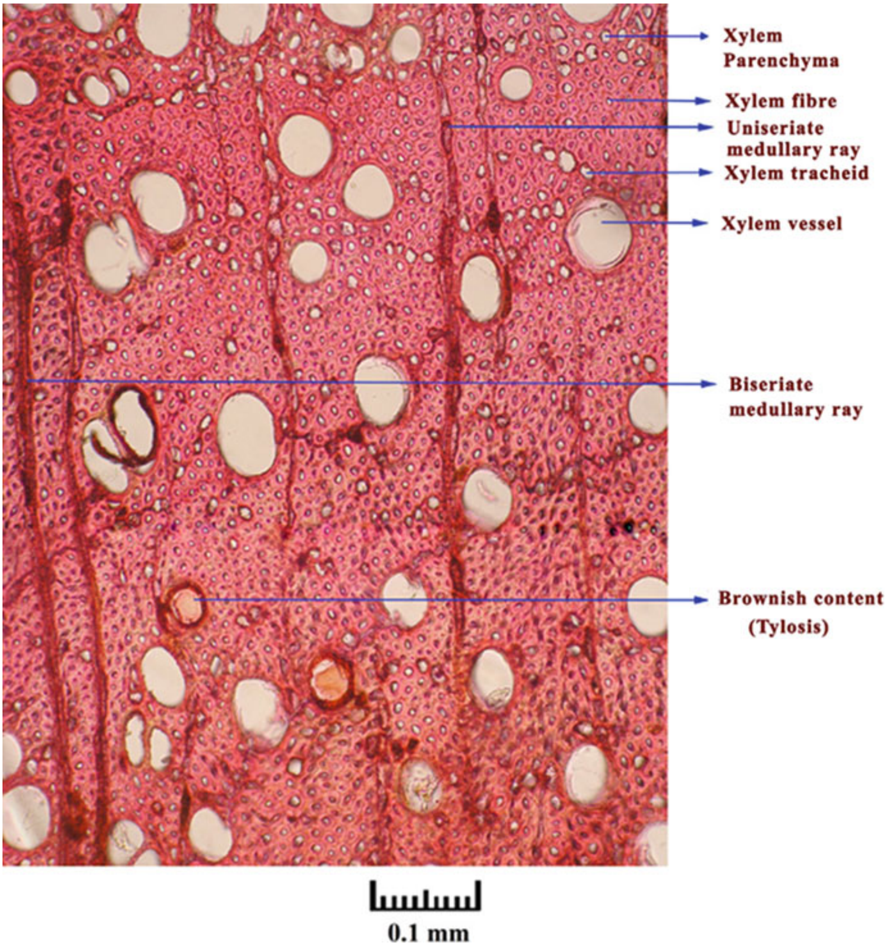

Fig. 3.3 Transverse section of Heartwood of *Santalum album* (Source: Sundharamoorthy et al. 2018)

3.6 Phenology, Reproductive Biology, and Breeding System

3.6.1 Phenology

Sandalwood tree is a true evergreen tree, the foliage gets thinner during October and November. Leaf flushing occurs during November and December. Flowering time of this species depends on the locality; for example, a population in India flowered twice throughout the year in a single population (Srimathi 1983). Flowering and fruiting of *S. album* in a natural population in Java, Indonesia revealed that flowering time of its species occurs from June to October (Haryanto et al. 2005;

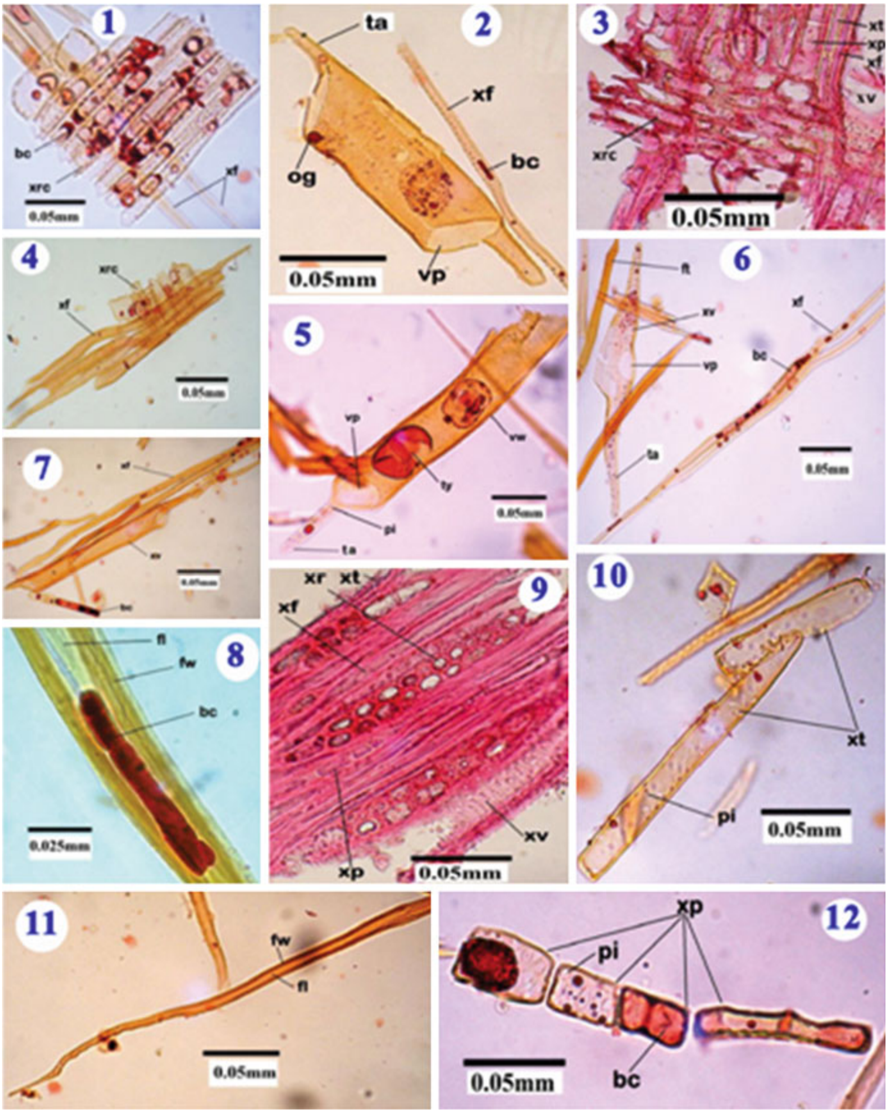

Fig. 3.4 (1) Radially cut medullary ray crossing with fibre with brownish content; (2) Oil globule, tailed pitted vessel and fibre with brownish content; (3) Radially cut xylem ray crossing with xylem vessel, fibre and tracheids; (4) Radially cut xylem ray crossing with fibre; (5) Tailed pitted vessel embedded with tylosis; (6) Tailed vessel, fibre and fibre tracheid; (7) Fibre and tailed vessel; (8) Fibre with brownish content; (9) Tangential longitudinally cut xylem ray with xylem vessel, fibre, parenchyma and tracheids; (10) Tracheids; (11) Fibre; (12) Xylem parenchyma with brownish content (Source: Sundharamoorthy et al. 2018)

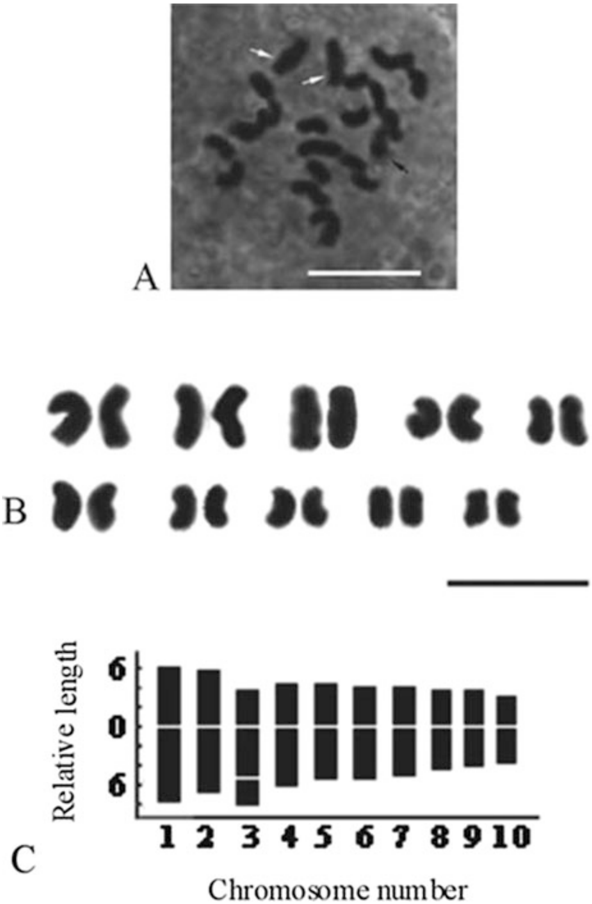

Fig. 3.5 Somatic metaphase chromosomes (**a**), karyogram (**b**), and idiogram (**c**) of the diploid *S. album.* White arrows and black arrows indicate secondary constrictions and supernumerary chromosome, respectively. Bar: 5 μm (Source: Zhang et al. (2010) copyright © 2010 Dipartimento di Biologia, Università di Firenze, reprinted by permission of Taylor & Francis Ltd., http://www.tandfonline.com on behalf of Dipartimento di Biologia, Università di Firenze)

Prasetyaningtyas 2005). As said above, in India, there are two distinct flowering seasons, the first one during March–April, and the second during August and September. Fruiting commences in May and maturation continues till June–July in the first spell and during December and January in the second spell. Since there are two flowering seasons in the year fruits are shed in January and July and germination of seedlings was noticed during March (Veerendra and Sujatha 1989). Generally the tree starts flowering at an early age of 4–6 years and flowering and fruiting season varies. Flowering time differs according to the altitude. Trees growing in lower altitudes initiate flowering about a month earlier than those growing in higher altitude (Susila and Effendi 1995). According to Brandis (1906) the flowering season is from February to July. Based on the flowering calendar, Padmanabha et al. (1991) classified Sandalwood trees into three distinct groups (1) Trees flowering twice a year (Once during March–May and second time during September–December), (2) Trees flowering once a year (September–December), and (3) Trees which do not flower even after 15 years of age. Bhaskar (1992) reported that flowering season generally lasts from June to October but some trees continue to bear flowers almost throughout the year. *Santalum album* generally produces the first set of flower buds during early part of June. The buds take 18–20 days to attain maturity. The mature flower buds open in the early hours of the day, i.e. between 3 and 6 a.m., however, a few flowers continued to open till 12 noon. Anthesis could easily be watched as the perianth lobes split open one by one.

Initially, the flowers are straw yellow coloured and gradually turn to deep purplish brown on maturation. The flowers occur in axillary or terminal cymose panicles that are shorter than leaves and the floral organs develop in acropetal succession. It takes 30–35 days from initiation of bud stage to the anthesis and 85–95 days from initial stage to ripening of the fruit (Srinivasan et al. 1992). Generally the tree starts flowering at an early age of 4–5 years and flowering and fruiting season varies. Flowering time differs according to altitude. Trees growing in lower altitudes initiate flowering about a month earlier than those growing in higher altitude (Susila and Effendi 1995). According to Brandis (1906) the flowering season is from February to July.

Fathin and Ratnaningrum et al. (2018) reported that in Gunung Sewu in Indonesia three floral variants, i.e. yellow big flower (YBF), red big flower (RBF), and red small flower (RSF)—that are distinguished based on their floral traits, with regard to the floral colour, sexual organs structures, arrangements, and the longevity. Red and maroon colours dominate RSF and RBF while YBF is yellowish to orange. The RBF and YBF have longer size of stamens and carpels with similar/lower position of stylus to the stamens, and possess shorter longevity and larger perigonium. RSF flowers are smaller, style is similar/higher than the anthers, and have greater longevity (Figs. 3.6, 3.7, and 3.8) (Fathin and Ratnaningrum 2018; Ratnaningrum and Kurniawan 2019).

3.6.2 Floral Morphology

The hermaphrodite unscented flowers are borne in terminal or axillary, cymose panicles; each inflorescence bears 67 $\pm$ 14 ($n = 30$) flowers. The duration from bud initiation to the anthesis is 30–35 days. The flowers are tetra- to pentamerous, rarely hexamerous. In the bud, the perianth lobes are joined at the tip, but they become reflexed when the flower opens. The perianth is campanulate and the lobes are valvate; each lobe is triangular in shape and has a diameter of 6 mm $\pm$ 2 mm. The perianth lobes are greenish yellow during flower opening but turn purplish red after pollination. The perianth persists in a changed colour for up to 15 days after anthesis. The stamens are epiphyllous, and their number and position vary depending on the number of perianth lobes. In tetramerous flowers the four stamens are opposite to the perianth lobes. In the pentamerous flowers, there may be 4 or 5 stamens. If there are only four stamens, three are situated opposite to each of any three of the five perianth lobes, while the fourth is located between the two remaining lobes. The filaments are thick, and with a tuft of hairs on their base. The anther is dorsifixed and with four lobes, of which the outer two are bigger than the inner. The mature pollen is

Fig. 3.6 Sandalwood variants in Gunung Sewu, Java, Indonesia: *RBF* red big flower (Source: Ratnaningrum and Kurniawan 2019)

ellipsoidal or ovate, 3-zonoporate and on an average measures 29 × 23 μm ($n = 100$). The nectaries are situated at the base of the perianth lobes. The ovary is semi-inferior, unilocular and with 2–3 or rarely four pendulous ovules lodged in the depressions at the base of the ovarian chamber. There is no demarcation between the nucellus and the integument in the ovules. The style is very short and is traversed by a narrow canal (open type). The style terminates in 3 or rarely 4 lobed stigma. The stigma is of the wet papillate type; the papillae are unicellular.

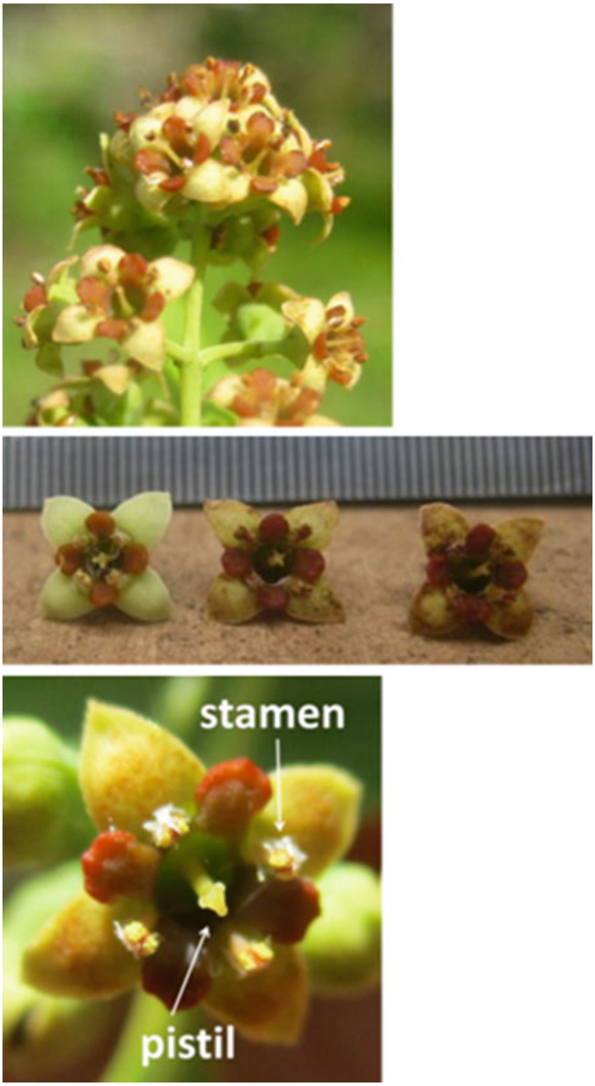

Fig. 3.7 Sandalwood variants in Gunung Sewu, Java, Indonesia: *YBF* yellow big flower (Source: Ratnaningrum and Kurniawan 2019)

3.6.3 Fruit Morphology

The fruit is a drupe, and is beaked due to the persistence of the basal part of the style. The fruit is green when young and purplish black when fully mature. The fruit is round to oblong. The duration required from fertilization stage to full ripening of the fruit is 85–95 days. The fruit wall consists of a parenchymatous and fleshy epicarp and a stony endocarp. The seed is naked, lacking a testa. The dicotyledonous embryo occupies nearly the entire length of the albuminous seeds.

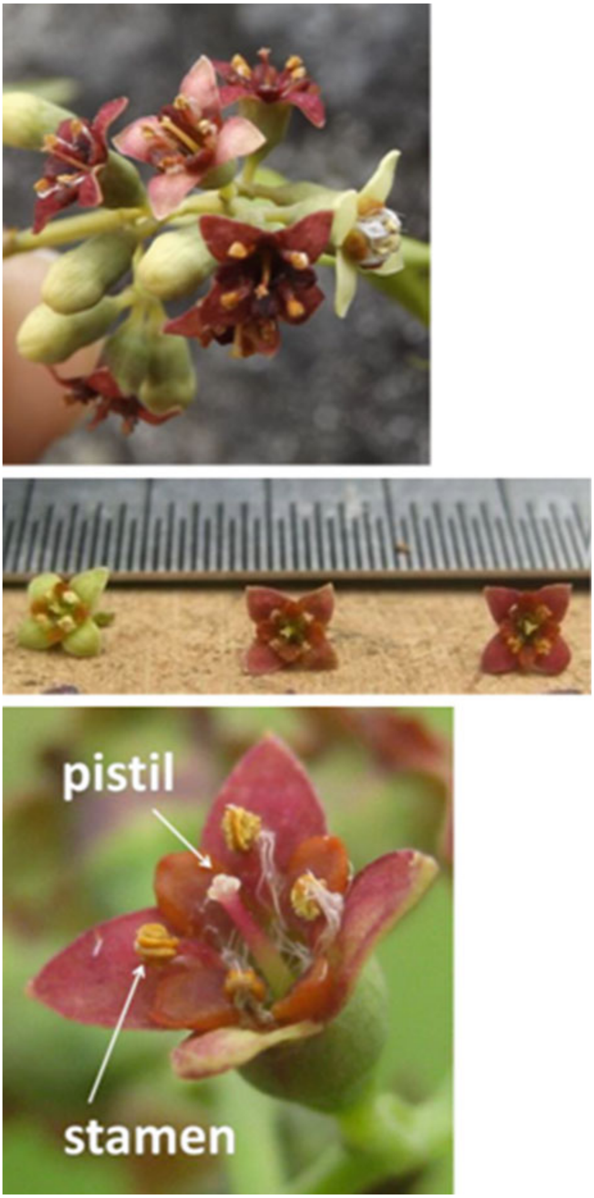

Fig. 3.8 Sandalwood variants in Gunung Sewu, Java, Indonesia: *RSF* red small flower (Source: Ratnaningrum and Kurniawan 2019)

3.6.4 Reproductive Biology and Breeding System

Studies on *Santalum* spp. indicated highly out-crossing rate and self-incompatibility (Rao et al. 2007; Dani et al. 2011; Indrioko and Ratnaningrum 2015). However, partially self-compatibility has been reported for *S. accuminatum* (Warburton et al. 2000) and *S. album* (Suma and Balasundaran 2003; Ratnaningrum and Indrioko

2014), particularly under isolated condition. Ratnaningrum and Indrioko (2014) showed evidence of dichogamy in which pollen mature 2 days before stigma receptivity.

According to Jyothi et al. (1991) and Bhaskar (1992) *S. album* is predominantly outbreeding and self-incompatible species, although its flower structure was designed for self-pollination; suggesting that pollination system of *S. album* depends on the agent of pollination. The flowers are bisexual and occur in axillary or terminal cymose panicles that are shorter than leaves and the floral organs develop in acropetal succession. It takes 30–35 days from initiation of bud stage to the anthesis and 85–95 days from initial stage to ripening of the fruit (Srinivasan et al. 1992). Initially, the flowers are straw yellow coloured and gradually turn to deep purplish brown on maturation. The flowers in Sandalwood are almost odourless or may emit very little fragrance. The number of perianth lobes vary from 4 (most common) to 6, and bear a tuft of hairs on the mouth. The floral disc has four brightly coloured scales alternating with the perianth lobes giving a false appearance of petals. Stamens vary from 4 to 6, accordingly to the number of perianth lobes, and they are adnate to the base of the perianth lobes and opposite to them. Ovary appears free at first and later the perianth tube adnates with the ovary resulting in the perigynous condition. Pollen mass is yellow and sticky. Pollen grains are triangular in polar view, subprolate in equitorial view, and 3-zonoporate with granulate exine sculpturing. Stigma is 3- or often 4-lobed, papillate and placed slightly which increase as the flower gets older. The stigma gradually turns reddish brown accordingly with the corolla. The cup-like disc secretes nectar around the base of the ovary which glistens when seen from top. Maximum nectar was found in the pale green and pale pink flowers, and it is completely absent in red and dark brown flowers.

The compatibility tests indicated that the flowers in Sandalwood are self-infertile and all the selfed flowers dropped down. On the contrary, the cross pollinated flowers which received pollen from another tree developed into fruits. The stigma was found to develop receptivity even earlier to the opening of the flower. It was found that receptivity of the stigma remains at its peak when the flowers are just open and are pale or pale pink in colour (Bhaskar 1992). *S. album* is self-incompatible and is pollinated by insects which visit the flowers for the nectar available in a cup-like disc. It has been described that the breeding system of *Santalum* species in general is facultatively allogamous with variation found between individuals at the level of self-incompatibility and having no ability for apomixis or parthenocarpy (Ma et al. 2006; Muir et al. 2007; Tamla et al. 2011).

The chief pollinators which frequently visited sandal flowers are flies, bees, and ants.

Among them, the flies were the commonest visitors which included the syrphids, *Phytomia argyrocepha*, *Dolichomerus crassa*, and *Eristalinus arvorum*, of both sexes. The domestic Indian bee (*Apis cerana*), the rock bee (*Apis dorsata*), and small bee (*Apis florea* Fabr.) also visited the flowers but not so frequently and in abundance as flies. The bees, however, did dominate in the early period of the flowering season. The flies were slower in movement than the honey bees. The black fly (*Dolichomerus crassa*) hovers for a while in air flying still and then alights on the flowers. As soon as the fly alights on the flower it pierces its thick and stout proboscis through the gap in between anthers and stigma and sucks nectar. No fly was found to dribble on the flower. While inserting and taking out the proboscis plenty of pollen were found sticking on to the mouth parts of the insect and when the same fly visited the flowers on another tree it resulted in cross pollination (Bhaskar 1992).

Frequently, some black ants were seen in Sandal flowers sucking the nectar by wholly entering into the floral tube. Plenty of pollen were seen on their abdomen and although they also took part in effecting pollination, fruits did not develop since they effected only self-pollination. A few more insects like beetles and wasps were noticed occasionally visiting Sandalwood flowers. The beetles were found foraging on the anther parts of the flower and they are also often found to effect cross pollination (Bhaskar 1992).

Sandalwood originated in the south-eastern islands of Indonesia, but recently new landraces have been reported in Gunung Sewu Geopark, Java, Indonesia. Ratnaningrum et al. (2018) compared flowering and pollination, and their effect on reproductive outputs, among Sandalwood populations in Gunung Sewu, during the dry and rainy season of 2016 flowering period. Flowering and pollination rate differed significantly between seasons but were similar among sites. Oppositely, reproductive outputs differed significantly among sites, but were similar between seasons. The rainy season produced more flowers and pollination. Pollination was less correlated to flowers abundance, but more affected by population size. The higher and cooler population visited more by Dipterans (31.8–32.6%) and Hymenopterans (28.2–30%), while the warmer, lower sites dominated by Lepidopterans (37.2–43%) and Dipterans (32.9–38.2%). Higher population received fewer visits, but more visitors diversity (28 families). In contrast, lower sites received more visits, but with less diversity (20 families). Most insect families were considered “Rare” and “Occasional”. However, pooled altogether, the whole families of Lepidopterans and Dipterans considered “Frequent” and “Effective”. The Hymenopterans considered “Frequent” and “Effective” at Nglanggeran and Wanagama. The Cicadellidae of Coleopterans, along with arachnids and grasshoppers, was considered robbers. All of the agents were diurnal. However, the time of activity was varied. Rainy season gained more flowers and visits, but in contrast, resulted in fewer fruits at all sites. Both flowers abundance and pollination were negatively correlated to the reproductive parameters. Populations might gain more flowers and visits, but the reproductive outputs were significantly lower. Particularly in the clonalized and lower heterozygosity populations, more flowers increased geitonogamy which may lead to inbreeding depression (Ratnaningrum et al. 2018).

The pollen grains did not germinate in distilled water and different concentrations of sucrose medium. However, they responded to germinate in diluted nectar of sandal flowers.

Pollen germination is monosiphonous and the generative nucleus divides in the pollen grain itself to produce 2 min dot-like male gametes which later move into the pollen tube. The callose wall of the pollen tube appears prominently hyaline and thick when stained with orcein (Bhaskar 1992).

Gynoecium in *Santalum album* has a single ovarian cavity enclosing a long and straight "placental column", partly projecting upwards into the style. There is no ovule as such in sandal as the female gametophyte does not show any distinction into integuments and nucellus. The gynoecium has 2–4 "S"-shaped embryo sacs which grow out freely into the ovarian cavity from the base of the placental column towards the protruded tip of the placental column (Bhaskar 1992). Bagchi and Veerendra (1987) reported high pollen fertility in sandal (88.4%).

Prehatan and Ratnaningrun (2005) studied pollination mechanisms and breeding systems of *Santalum album* (Santalaceae), the new landrace of Gunung Kidul, Central Java. The former were specifically determining the role of floral attractants on pollination effectiveness, while the latter were determining self-compatibility and out-crossing rate. The hermaphrodite, self-compatible, protandrous single flowers bearing papillate stigma and four anthers with less-sticky pollen were visited by visitors representing three orders, i.e. Diptera, Hymenoptera, and Lepidoptera. Visitors were active at different times and at different stages of flowering, which probably received different rewards. Both inner and outer petals were not the main attractants for pollinators. The visitation is not only determined by the colour of the petals. The mature pollen (available at anthesis), and the nectar secreted in the basal portion of petals (available at the time of stigma receptivity), was assumed as the rewards. The difference of flowering stage, in turn, has brought to the consequence of different floral visitors. Hand-pollination indicated a mixed mating system. Both the value of Out-crossing Index and Index of Self Incompatibility implied the self-compatible mechanisms. The self-compatible mating system and a limited quantity of pollen gave the impact on the highly selfing rate although there was temporal separation of sexes. Effective conservation and improvement programmes for this species need to focus on promotion of out-crossing.

The sandal trees produce quite a massive fruit crops every year. The fruits take nearly 3 months to completely mature into dark berries which are eaten by birds, especially Koel (*Eudynamys scolopacea* L.) and thereby get dispersed. After eating the fleshy pulp the seeds are dropped by the birds. It is common to see profuse sandal regeneration underneath trees such as *Ficus religiosa, Syzygium jambolana* and such other trees whose fruits are also relished by birds. The seeds usually take 3 months to germinate and by September–October a large number of recruits will form on the ground. Only one seedling is noticed to develop from one seed indicating that the rest of the embryo sacs degenerate allowing only one to successfully develop into embryo.

Due to strict cross pollination, there exist large variations in Sandalwood populations with regard to the size and colour of heartwood (which is the scented oil containing part in the tree), growth rate, and number of years required for complete heartwood formation ready to be extracted (Bhaskar 1992). Certain trees have been found to develop scented heartwood even at their very early age of 10–12 years, which otherwise takes 25 to 40 years in the usual course.

Even though there is definite geographical isolation and considerable morphological variation between *Santalum* species, reports indicate that hybrids have been obtained from crosses between *S. album* and *S. austrocaledonicum* (Tamla et al.

2011), *S. album* and *S. lanceolatum* (Tamla et al. 2011), and between *S. album* and *S. yasi* (Bulai and Nataniela 2005; Doran et al. 2005).

3.6.4.1 Floral Visitors

Flowering plants have evolved, developed, and specialized in response to the wide variety of pollen vectors which could serve for pollen transfer. The pollination biology of *Santalum album* was carried out in five different flowering seasons during the period between 2014 and 2016 by Krishnakumar et al. (2018). The study identified and confirmed that *Santalum album* is predominantly a cross pollinating species and the pollination was facilitated by *Monomorium destructor*, *Camponotus* sp., and *Apis cerana indica*. This study clearly conclude that the identification of pollinators and pollination biology is very important for obtaining good quality seed productions. Pollination of *Santalum album* flowers through insect and the insects identified as pollinators are furnished in Table 3.1. The identified pollinators are *Monomorium destructor*, *Camponotus* sp., *Apis cerana indica*, *Calliphora vomitoria*, and *Vanessa cardui* (Table 3.1). Sandalwood is usually cross pollinating species. Considering the pollinator's studies, viz., insect visits, insect visiting time, insect time spend on flower, insect stigma touch and frequency of insect visit, it is observed that *Monomorium destructor, Camponotus* sp., and *Apis cerana indica* were the good pollinators for *Santalum album* to obtain good quality seed production (Veerendra and Sujatha 1989; Krishnakumar et al. 2018).

Flowers are visited by many insect taxa of Hemiptera, Lepidoptera, Diptera, and Hymenoptera. Many of these were active in the morning (0090 h). Butterflies like *Euplorea* sp., wasps, bees, and thrips were the most common insects found. These insects foraged nectar and pollen throughout the day. The wasps, butterflies, and thrips collected pollen by foraging on several opened flowers in an inflorescence and travelled among inflorescences. Honey bees (*Apis mellifera, A. cerana indica*) were occasionally observed. They have a pollen moistening behaviour. Pollen once collected becomes hydrated and expanded. The sticky surface may cause pollen to accumulate on the hind legs of honey bees, but would not allow effective pollen transfer. It was also observed that individuals of *Paratrechina chinensis* (ants) carrying pollen on their thorax. Floral visitors of *Santalum album* are listed in Table 3.1 and figures are shown in Fig. 3.9.

Studies on artificial selfing, natural out-crossing, and obligatory selfing showed that *Santalum album* is a predominantly outbreeding species though its flower structure was designed for self-pollination. However *S. album* does produce seeds by selfing. Self-incompatibility was observed to some extent. Heterostyly was noticed in some genotypes (Veerendra and Padmanabha 1996).

Studies on *Santalum* species mating systems have indicated highly out-crossing rate and self-incompatibility (Ratnaningrum and Indrioko 2014; Rughkla et al. 2006; Rao et al. 2007; Dani et al. 2011; Tamla et al. 2011; Indrioko and Ratnaningrum 2015; Teixeira da Silva et al. 2016). However, partially self-compatibility has also been reported for *S. acuminatum* (Warburton et al. 2000) and *S. album* (Veerendra and Padmanabha 1996; Ratnaningrum and Indrioko 2014), particularly under isolated condition. Despite its abundant flowers, the fruit production is very low,

Table 3.1 Details of floral visitors of *Santalum album*

S. No.	Common name	Scientific name	Order	Reference(s)
1.	House ant/red ant	*Monomorium destructor*	Hymenoptera	Krishnakumar et al. (2018)
2.	Black tree ant	*Camponotus* sp.	Hymenoptera	Veerendra and Sujatha (1989), Krishnakumar et al. 2018
3.	Indian honey bee	*Apis cerana indica*	Hymenoptera	Veerendra and Padmanabha (1996), Bhaskar (1992), Krishnakumar et al. (2018)
4.	Giant honey bee	*Apis dorsata*	Hymenoptera	Bhaskar (1992), Prehaten and Ratnaningrum (2014)
5.	Dwarf honey bee	*Apis florea*	Hymenoptera	Bhaskar (1992)
6.	European honey bee	*Apis mellifera*	Hymenoptera	Veerendra and Padmanabha (1996), Baskorowati (2011), Krishnakumar et al. (2018)
7.	Fig wasp	*Ceratosolen* sp.	Hymenoptera	Veerendra and Sujatha (1989), Veerendra and Padmanabha (1996)
8.	Weevil wasp	*Cerceris sulphurea*	Hymenoptera	Veerendra and Padmanabha (1996)
9.	Wasp	*Allodope marginata*	Hymenoptera	Veerendra and Sujatha (1989), Prehaten and Ratnaningrum (2014)
10.	Mason wasp	*Odynerus ovalis*	Hymenoptera	Veerendra and Padmanabha (1996)
11.	Plasterer bee	*Colletes* sp.	Hymenoptera	Veerendra and Padmanabha (1996)
12.	Blue bottle fly	*Calliphora vomitoria*	Diptera	Krishnakumar et al. (2018)
13.	Hoverfly	*Syritta orientalis*	Diptera	Veerendra and Padmanabha (1996)
14.	Painted lady butterfly	*Vanessa cardui*	Lepidoptera	Krishnakumar et al. (2018)
15.	Sand fly	*Euplorea* sp.	Lepidoptera	Veerendra and Sujatha (1989), Veerendra and Padmanabha (1996)
16.	Swift	*Parnara mathias*	Lepidoptera	Prehaten and Ratnaningrum (2014)
17.	Army green moth	*Daphnis nerii*	Lepidoptera	Veerendra and Padmanabha (1996)
18.	Flies	*Phytomia argyrocephala*	Diptera	Veerendra and Sujatha (1989), Bhaskar (1992)
19.	Hoverfly	*Eristalinus arvorum*	Diptera	Bhaskar (1992)
20.	Flies	*Dolichomerus crassa*	Diptera	Bhaskar (1992)

(continued)

Table 3.1 (continued)

S. No.	Common name	Scientific name	Order	Reference(s)
21	House fly	*Musca domestica*	Diptera	Baskorowati (2011)
22	Green fly	*Lucilia sericata*	Diptera	Baskorowati (2011)

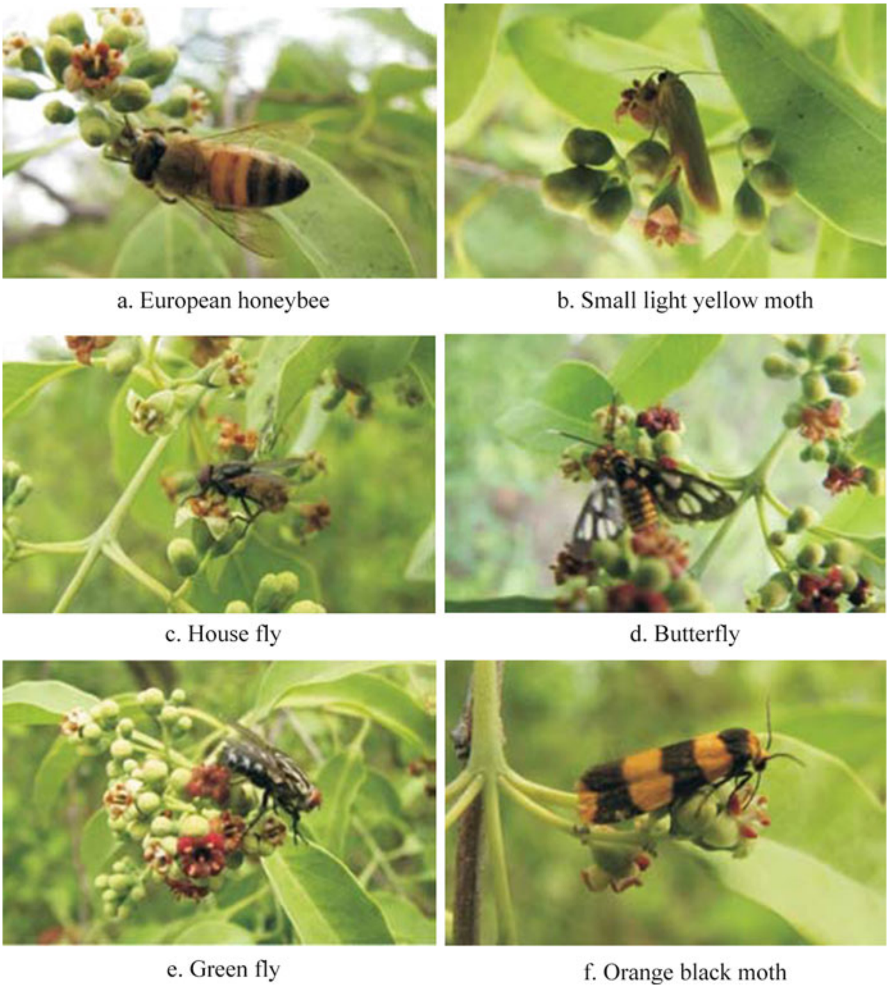

Fig. 3.9 Insects visiting flowers of collected by trapping net in Watusipat, Gunung Kidul ex-situ conservation plot during January 2010 flowering season (Source Baskarowati 2011)

ranging from less than 5% in small populations (Veerendra and Padmanabha 1996; Warburton et al. 2000; Byrne et al. 2003) to about 20% in the bigger and wider genetic bases' populations (Ratnaningrum and Indrioko 2015; Teixeira da Silva et al. 2016).

Ratnaningrum and Indrioko (2015), during ex situ conservation studies, investigated the effect of climatic change on flowering and fruiting between 2005 and 2010 in Yogyakarta, Indonesia. In seven provenances ten individuals each were marked and flowering phenology was studied. Pollination Effectiveness (PEs) and Reproductive Success (RSs) in all the individuals in all the seven provenances were marked. Fertilized flowers and seeds were summed. PEs was quantified by dividing *fertilized flower* to *flower*. RSs was calculated by using the following formula, i.e. RSs = Fruit/Flower × Seed/Ovule. Temperature and rainfall variability during this period was documented. The hotness increase up until 31.06° C at the early 2007 is the most dangerous one. There was no thirsty month in summer season during the years between 2008 and 2010, and there was prolonged rainy season. Similar flowering characters were observed with alike genotypes in the provenances. Flowering plasticity and asynchrony was witnessed among different provenances. The value of PEs and RSs and seed abortion was noticed to be provenances specific. Genetic and climatic factors strongly control both flowering and seed production. Provenances with alike genotypes showed similar responses to variation of temperature and rainfall, because of climatic alterations. Due to the dangerous temperature increase at the early 2007, diminutive flowering period, increased flowering frequency, decrease of flowers and fruits with great quantity, and developed seed abortion were observed. In contrast to this, the lengthy rain in 2010 affected to late floral initiation, lengthier flowering period, dumpier stigma receptivity and pollen endurance, paler colour of perigonium, and bigger size of reproductive organs. The maximum production of pollinated flowers and matured fruits was witnessed in arid season in comparison to those of wet season (Ratnaningrum and Indrioko 2015).

3.6.5 Variations in Fruit Morphology and Seed Setting

The duration of flowering biology in the *Santalum album* is varied from place to place depending on the climate and weather. Krishnakumar and Parthiban (2017) opined that flowering duration within population ranged from a single day to the entire year for different species. The variation in the flowering duration could possibly be due to physiological condition, health, and vigour of the trees concerned and changes in local climatic condition. According to Rathcke and Lacey (1985) flowering may prolong in a species if favourable environmental conditions persist and may cease if adverse environmental conditions set in. This lends support to the variation in the duration of flowering and fruiting in *S. album*.

The number of fruits is recorded highest in December to March (14.08) flowering season and low in July to October (8.56) in flowering season in India (Krishnakumar and Parthiban 2017). The range between length and width of fruit is 11.10–12.44 mm and 7.82–9.34 mm, respectively. The fresh and dry fruit weight of first and second season (1.36 g, 0.17 g and 1.39 g, 0.15 g), respectively. Based on the flowering parameter and fruiting parameters, the seed setting percentage is calculated. The seed setting percentage is high in second season (35.01%) and low in first season (20.52%). After the fruit is developed the mature fruit is dropped in the ground. The dropped fruits are collected and the seeds are tested for germination studies. The seed germination percentage is higher in December to March (60.40%) season and low in July to October (51.84%) season of flowering in sandal tree in natural condition. Based on seed setting and seed germination percentage indicates that the production of good quality seedling through the second season (December–March) is evident. The seed setting percentage is also based on the length of inflorescence, number of rachis per inflorescence. The high length of inflorescence gives more number of flower production; the inflorescence length also a reason for high seed production (Bonnet 1938).

3.6.6 Reproductive Rate in Climate Change

Syahbudin (2016) observed flowering and seed production of Sandalwood population along environmental gradients in Gunung Sewu Geopark, Indonesia, during the flowering periods from 2013 to 2014. He observed flowering phenology with regard to floral initiation, phases and periods, and measured Pollination Effectiveness and Reproductive Success. Flowering and seed production varied with altitude and climatic conditions, and altered by changes in rainfall, temperature, and soil moisture. Sites with lower altitude, lower rainfall, highest temperature, lowest relative humidity, and lowest soil moisture flowered earlier and shorter. Flowering delayed and prolonged by increasing altitude, temperature, and humidity. At all sites, flowering delayed and prolonged in rainy season compared to dry season. Lower populations produced more flowers in rainy season; however, higher abortion resulted in a very low seed production. Dry season produced less flowers but higher reproductive success was achieved, resulting in more fruits. The lowest altitude performed highest reproductive outputs. More marked differences among sites were observed in the dry season. Flowering and seed production was also observed to be temperature sensitive. Both drop and increase on temperature resulted in the alteration of flowering frequency and reproductive outputs. Sandalwood in Gunung Sewu grows naturally in association with tropical monsoon vegetation along with *Acacia*, cajuputi, teak, and mahogany. The conservation of this endangered species, particularly under wider range of landscapes, should be maintained with a different strategy according to the degree of plant sensitivity to environmental features.

3.7 Conclusions and Future Prospects

It should be pointed out here that there is not much work on the pharmacognosy of *S. album*. This aspect has to be looked into for the future studies. Similarly there is not much work on cytology of this genus. Out of the 18 species of *Santalum* there is only one report on the cytology and Karyotype and there is every necessity for more studies on karotype analysis of different species of *Santalum*. Similarly reproductive biology of species of *Santalum* other than *S. album* has not been studied. There is every necessity for such a study. Molecular phylogeny of different species of *Santalum* is very much required for understanding the relationships of *Santalum* species.

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Sandalwood Wood Carving

4

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Abstract

Sandalwood (*Santalum album* L.) is a prized gift of the plant kingdom woven into the culture and heritage of India. It is a valuable tree associated with Indian culture and it is the second most expensive wood in the world. The heartwood of the tree is treasured for its aroma and is one of the finest natural materials for carving. The heartwood of sandal is one of the best woods for carving because of its softness, unvarying fibers, instant close grains and knots. Since long time, several artisans and carvers are working on intricate carving of Sandalwood and it still continues. In this chapter, details of wood carving and religious importance are given.

Keywords

Sandalwood · *Santalum album* · Wood carving

4.1 Introduction

The making of sculpture in wood is widely practiced, since from the middle ages in Africa, Asia, and Europe. Wood carving is one of the oldest types of arts, and it is practiced to express an art prevailed in every single anthropological civilization,

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which dates back to the centuries. This art is meticulously devoted to diverse facets of human life, because of the availability of woods, plasticity, and low cost. As a sculpture medium, wood offers some advantages, for example, its fibrous strength allows to carve sculptures more thinly and accurately compared to stones or metals. However, the factual disadvantages as a medium for carving includes perishability, water absorbent ability, and susceptible to insects and aerial fungi, leading to wood degradation quickly. Moreover, there are several benefits of wood carving, for instance, the art lowers down stresses, blood pressure, and heart rate, supports concentration of mind or mindfulness in addition to reconnecting ourselves with nature.

Some of the approaches and styles of carving wood comprise relief carving, chip carving, and Scandinavian flat-plane. Woods of different species are being used for wood carving in different countries. The nature of wood being carved limits the scope of the carver in that wood is not equally strong in all directions, it is an anisotropic material. The direction in which wood is strongest is called grain and the grain may be straight, interlocked, wavy or fiddle back, etc. Both hardwoods and softwoods can be used, and largely Sandalwood, oak, walnut, mahogany, elm, chestnut, limewood, ebony, cedar, boxwood, olive, cypress, teak, and pines are used. For large masterpieces, two or more parts of wood could be carved, and then combined. Though, hardwoods are more challenging to carve, they offer greater luster and endurance. While, softwoods are easier for shaping, they are less durable. Not all woods are weatherproof, immune to insects as compared to stones, and hence are used majorly for indoor workings. To sum up, whatsoever wood is utilized; it remains as an anisotropic material, and is strongest in the direction of the grain. Therefore, sculptors sculpt their most delicate lines with the grain rather than against it.

Sandalwood carving is being practiced in India, since almost 500 years. Hundreds of artisans are involved in this wood carving. There is a necessity to look into this wood carving, and this chapter is dedicated to provide information on the different types of Sandalwood carvings with few success stories of Sandalwood crafts commerce.

4.2 Wood Carving

Sandal wood is one of the most valuable woods in the world (Fox 2000). The heart wood is described as moderately hard, heavy, durable, yellow or brown in appearance, with an oily texture and is an exquisite material for carving intricate designs (Srinivasan et al. 1992). The heartwood of sandal is one of the best woods for carving because of its softness, unvarying fibers, instant close grains and knots. Various instruments are used for wood carving (Fig. 4.1). The carved images of gods, idols, manufacture of richly carved boxes, work tables, cabinets (Figs. 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12) and mythological figures have a high demand in the present market (Chada 1972; Kumar et al. 2012) and other carved objects have a great cultural significance in different parts of the world (Baldovini

Fig. 4.1 Instruments for wood carving

Fig. 4.2 Sandalwood carving (Source: https://medium.com/direct-create/sandalwood-carving-from-mysore-6a790ddd5a17)

Fig. 4.3 Sandalwood carving (Source: https://medium.com/direct-create/sandalwood-carving-from-mysore-6a790ddd5a17)

et al. 2011). A wide variety of articles such as pen stands, photo frames, jewel cases, hand fans, card cases, book markers, and garlands are made from the wood of *Santalum album*. The Vidhana Soudha in Karnataka in Bengaluru has an intricately carved, imposing sandal wood door leading to the Cabinet Room (Raman 1994; Kumar et al. 2012). Some of the other popular articles that are made from the wood include boxes, cabinet panels, jewel cases, combs, picture frames, hand fans, pen holders, card cases, letter openers, and bookmarks (Srinivasan et al. 1992; Kumar et al. 2012).

Sandalwood is of great religious importance and is an extremely expensive material for carving artifacts. Karnataka has a huge forest-belt and Sandalwood carvers are found in Bangalore, Mysore, Shimoga, Sorab in the foothills to Sirsi, and Honavar and Kumta on the coast. Sandal wood is of two types: Sigandha which is close grained and yellowish-brown in color and used for carving and Nagagandha which is darkish-brown in color and from which oil is extracted.

Indian Sandalwood is one of the most sacred herbs of Ayurveda. Sandalwood powder and essential oil are renowned for their many medicinal and spiritual uses. But the wood itself can be used in creating wonders in much different ways. Sandalwood is native to Karnataka and its abundance there has led to extensive usage and beautiful products coming out of it. Earlier used to create only deities, boxes have become a specialty of this region. The distinctive aroma of Sandalwood and large boxes covered with carvings of mythological scenes is what sets this apart from all other woodwork.

Fig. 4.4 Sandalwood carving (Source: https://medium.com/direct-create/sandalwood-carving-from-mysore-6a790ddd5a17)

The art of Sandalwood carving has been practiced in Karnataka for at least a thousand years, and Karnataka is world famous for its exquisitely carved figurines with intricate details. Sandalwood artisans are concentrated in Shimoga, Mysore, Uttara Kannada, and Bangalore districts of Karnataka. The spell-binding figurines in this golden colored wood are embellished with designs inspired by nature. The soft aromatic wood can be delicately carved with ease to create elegant masterpieces (https://medium.com/direct-create/sandalwood-carving-from-mysore-6a790ddd5a17).

The objects made of sandalwood are the most famous among the other wooden artifacts for its intricate carving and its sweet fragrance. Such things are considered to be the most expensive. Availability of sandalwood in abundance in the forests of Mysore and around has made this region the most flourishing for this trade. Besides

Fig. 4.5 Wood carving by Jangid (Source: www.maljiarts.com with permission)

Fig. 4.6 Wood carving by Jangid (Source: www.maljiarts.com with permission)

Fig. 4.7 Wood carving by Jangid (Source: www.maljiarts.com with permission)

Fig. 4.8 Wood carving by Jangid (Source: www.maljiarts.com with permission)

Fig. 4.9 KKSS's Vishwanath V. Ganeshpur with the $157,000 carving of Radha and Krishna (Source: Raj 2018, https://www.hinduismtoday.com/modules/smartsection/item.php?itemid=5851)

Mysore; Tirupathi in Andhra Pradesh, Madurai and Coimbatore in Tamil Nadu, Jaipur, Delhi and Varanasi are the other centers for this attractive workmanship.

The instruments employed by the sandalwood carvers are extremely simple, viz., a saw, plane, mallet hone or fine-grained hard stone, an assortment of various shapes and sizes of chisels and a few engraving tools some extremely minute and delicate. The operation is started by drawing the pattern intended to be produced on the smooth and white washed sandal wood or on a piece of paper pasted over its surface. Then it is engraved or outlined in every detail; the interspaces between the lines are next cut away, thus leaving the pattern in low relief; lastly the design itself is carved out in the minutest detail keeping the intricacies and subtle light and shade effects, every desired curve, expression and texture is fully portrayed.

Sandalwood carving is an ancient tradition and has been a part of Indian culture and heritage and finds mention in the Ramayana. The fragrant wood is used by Hindus and Buddhists in certain rituals as incense. It is one of the scents besides rose oil that is used during rituals in Islam. It is practiced by a community of craftsmen

Fig. 4.10 Wood carving (Source: Raj 2018, https://www.hinduismtoday.com/modules/smartsection/item.php?itemid=5851)

Fig. 4.11 Ganesh idol wood carving in Cauvery emporium (Source: Raj 2018, https://www.hinduismtoday.com/modules/smartsection/item.php?itemid=5851)

called the Gudigars who specialize in the art of carving sandalwood, ivory, and stone. Having migrated from Goa during the Portuguese invasion, the Gudigars settled in Uttara Kannada (north) and Mysore regions.

The hard yellow wood is used for carving into combs, beads, and religious artifacts. The most valuable part of the tree is the scented heartwood. Sandalwood

Fig. 4.12 Revered products include incense, beads and oil-scented candles, chandanam paste and carvings (Source: Raj 2018, https://www.hinduismtoday.com/modules/smartsection/item.php?itemid=5851)

carving is distinct in comparison to other woods as it is a softer aromatic wood that allows intricate carving required for making idols. The types of carving done on sandalwood are relief, chipping, incising, and piercing. The chisels used are different from those generally used for other woods. The products carved consist of idols of gods and goddesses and boxes with interlacing foliage and scroll-like patterns interspersed with animal or bird figurines that are characteristic of Karnataka. The idols are carved in the round on a pedestal or against a background. They are used in shrines at home and worshiped (https://medium.com/direct-create/sandalwood-carving-from-mysore-6a790ddd5a17).

4.3 Success Story: Masterful Carvers of Rajasthan, Rajasthan, India

India is home to a plethora of handicrafts, partly due to its long cultural past and rural majority but also to its still compelling urge for ancestral occupations, passing skills down to sons and daughters. Handicraft guilds, emporiums, and online markets bring India's unique crafts to a world fatigued by stamped-out, extruded and now 3-D printed commodities. The rare charms of a handmade product place it in high demand, whether in the world of fabrics, jewelry, toys, accessories or ceramics.

Exemplifying this point is the Jangid family of Jaipur, in Rajasthan, India, an area that for centuries has been known worldwide for quality, elegance, design, ethnic flavor, and unmatched workmanship in both utilitarian and artistic wooden masterpieces. The five-member family trace their craft back four generations to

Fig. 4.13 Wood carvings by Jangid with permission

Shri Malchand Ji Jangid, grandfather of Mahesh Jangid and guru to the family. Mahesh, 47, has inspired his two sons, Mohit, 24, and Rohit, 22, to follow the family profession, even as their peers are leaving the field for more modern careers.

The three artists begin each carving day at 9 am and work until 8 pm, breaking only for lunch. Learning to sculpt with precision and exactness on a miniature scale that challenges even the most seasoned carvers, the family looks upon their craft as a lifelong journey—not as work so much as a calling, a mission in life and a pathway to personal and family fulfillment. As a result, they are at their tasks almost 365 days a year. Rohit notes, "This is our traditional work, and we are addicted and dedicated to it. This is a kind of worship for us. Also, it is the family's only way to gain money. No other money-making job is allowed to distract us."

One of the unique aspects of the works that Mahesh and his sons produce are the pockets that pull out to reveal tiny figurines and vignettes inside. Mohit enjoys making the miniature scenes the best: "I think the addition of these miniature carvings is most important to our work, because it makes all of our items more interesting and attractive."

The Jangid family are also highly skilled in the art of *tarkashi*, inlay work on wood. In each cubic centimeter of inlaid work, up to 250 pieces of metal and wood are laid side by side. The art of inlay was highly developed in the Safavid era, during which artists created precious works including doors, windows, mirror frames, *Quran* boxes, inlaid boxes, pens and penholders, lanterns, and inlaid ornamented shrines (Figs. 4.13, 4.14, 4.15, 4.16, 4.17, and 4.18).

The family gets precious little assistance from outside; the private associations, councils, and government departments are mostly ineffective. So they do everything themselves, including marketing to art collectors. To promote his work, Mahesh participates in national art and crafts exhibitions and fairs, such as Delhi Haat, Suraj

Fig. 4.14 Wood carvings by Jangid with permission

Kund Mela, and Master Creations Delhi. He also participates in international art exhibitions and fairs in France, Germany, Egypt, Malaysia, Poland, Switzerland, and more.

4.3.1 The Carvings

One of the family's most detailed works is a village scene called "The Ashram," based on the story of Dushyanta's marriage, separation and reunion with his queen Shakuntala. This completely hand-carved sandalwood miniature stands a little over 12 by 18 in.

Another extremely impressive piece is the intricately carved Rajasthani hand fan, also made of sandalwood, with a peacock on the top that gives a pure Indian look. Concealed within the fan are several of the family's trademark hidden scenes in small fold-out sections, depicting events in Lord Krishna's life story: Shri Vashudeva crossing the river to save baby Krishna's life, Shri Krishna eating butter with his brother Balarama, and Shri Krishna dancing on Kaliya Nag. This miniature stands at 12 by 20 in.

Fig. 4.15 Wood carvings by Jangid with permission

Fig. 4.16 Wood carvings by Jangid with permission

Fig. 4.17 Wood carvings by Jangid with permission

The Jangids' "Jharokha" piece is an ornate Ganesha wall shrine measuring 26 by 28 inches. A Jharokha is a type of overhanging enclosed balcony used in Indian architecture. This type of balcony is typically used in Rajputana, Mughal, and Rajasthani architecture. Jharokhas jutting forward from the wall plane could be used both for adding to the design beauty of the building itself or for a specific purpose. One such function was to allow women in purdah to see the happenings outside the home without being seen themselves.

4.3.2 Precious Sandalwood

The woods typically used in India for ornamental and inlay work are walnut (*Juglans regia*), rosewood (*Dalbergia latifolia*), ebony (*Diospyros* spp.), teak (*Tectona grandis*), *Sal.* (*Shorea robusta*), and sandalwood (*Santalum album*). The Jangid

Fig. 4.18 Wood carvings by Jangid with permission

family works almost exclusively in Sandalwood, due to its malleable characteristics and natural fragrance. Mahesh explains: “Sandalwood is the most conducive medium for our particular craft, because it is softer than most types of wood and easier for us to work with.”

Rohit adds, “I use only the richest quality of Sandalwood, which is so expensive these days. Sandalwood is easily available here in Jaipur. I only buy auctioned sandalwood sold by the government of India. We don’t keep a stock, buying as required by each project.” Rohit’s purchasing is limited by the strict laws of the land. In India every precious Sandalwood tree is owned by the government. Even a tree on your own land does not belong to you. In many areas every tree is boldly marked with a number, so agents can be sure no trees go missing in the night.

4.3.3 Mahesh

Mahesh Jangid was born and raised in Rajasthan’s Churu District. He began woodcarving at the age of seven under the tutelage of his grandfather, Shri Malchand Ji, a nationally recognized woodcarver and National Award winner. After a basic education, Mahesh gave up studies to devote his life to carving sandalwood, and by the time he was 24 Mahesh had earned his own national carving award for extraordinary miniature work. In 1993 he won the National Award for his village scene carving, “The Ashram.” He has passed on his passion and techniques to his sons, and they, too, have won multiple awards and recognition.

Mahesh broke a record when he carved the world’s smallest jointless chain from a single piece of sandalwood—one of his specialties. The chain is just under 12.5 in. long and weighs barely over 5.5 oz. More recently he bested himself by carving a larger jointless chain, this one measuring 10 ft long with 496 links and weighing, incredibly, less than half an ounce. Mahesh has many records for making these jointless chains—two in the Limca Book of Records, one in the Indian Book of Records, and one in the Global World Record.

"The greatest challenge of my occupation," Mahesh says, "is that people take my designs from the Internet and copy them in other ordinary wood, producing cheap-quality work. This affects the popularity of my items. And there is no support from the government for us—quite the opposite. The Indian government has applied a 5% value-added tax on handicrafts this year, and they announced the age limit for the national award is 32. No older artist can apply for the national award this year."

4.3.4 Mohit

Mohit was born in Jaipur and was initiated into the craft at a young age. After graduating from school, he chose to dedicate his life to woodcarving, having already practiced the art for 15 years. He feels strongly that the Jangid family possess a rare woodcarving talent, and he would rather spend his life learning and developing that skill than taking a job he "wouldn't have respect for." Mohit feels he and his brother can do much better in life with woodcarving than in a job with limits—"a limited salary, limited time and limited work. Woodcarving, on the other hand, is limitless," he explains.

"I do prefer miniature work, because I've seen this type of carving from my childhood. Miniature work is the most important aspect of our work, because it makes our items unique in all the world. We can make all kinds of carved products, but miniature carving is my favorite. I give my best to the tiniest projects, and I always enjoy it."

Like his father, Mohit is no stranger to awards and records. In 2008–2009 he received the State Award from Rajasthan's Chief Minister Shri Ashok Gahlot for Excellence in Sandalwood Carving. He also holds a world record for the smallest playable violin, a remarkable four-stringed instrument measuring just over 5 in. tall and not quite 3/4 in. wide that is exactly to scale.

Mohit's knowledge of the epics and other religious texts helps him bring a rare blend of tradition, beauty and craftsmanship to his creations. "I enjoy all the carving we do," he says, "but carving the 'Rajasthani Doll' was my favorite project. This piece shows the beauty of the Rajasthani lady with our traditional jewelry and it tells the story of Rajasthani freedom fighters."

4.3.5 Rohit

Rohit also learned the family craft from his father from a young age. Still in school (though near graduation), he cannot dedicate to carving full-time just yet—but he already holds a record in the Indian Book of Records for his wooden house-fly, and some national and local records for the same piece. Rohit tells us: "I like miniature work in my art. Miniature carving involves engraving the wood on the contours of the design with the utmost care. We, the Jangids, are the only people who make these kind of carving products with scenes in flipped lids. All scenes have their own story." Rohit loves to show people his work and see their surprise when he opens the lids to reveal intricate details they did not expect. The surprise is a big part of the discovery and the charm of the design.

We asked Rohit how he finishes his work: "After I complete my artwork, I don't oil it. I keep it original. I give a final touch with a dry brush." How long does it take to complete a major work by hand and what price might he expect to receive upon sale? Rohit responds, "The large Rajasthani doll took a full three months with all three of us working on it. This is one of our finest pieces. The price depends on size. Small pieces go for $200 to $9,000. For the larger works, around twenty-four inches and above, it is higher; and for a museum-quality piece we receive about 500,000 rupees ($7,500)." Rohit brings his work to national and local art and craft exhibitions. Readers wishing to see more or acquire these masterpieces can visit www.maljiarts.com

4.3.6 The Future

Mahesh can rest assured that his sons will continue the family carving tradition. Both sons say they would not want to do anything else. Mohit, who recently completed his formal education, says, "I will continue to do this work for the rest of my life, because carving has no limits. How much we do and how far we go is all up to us. I like that we always get to do new things, new designs, more miniature work, etc. I would not have this kind of freedom with any other job. I am absolutely addicted to my work and am so happy that I have the talent to do this." Rohit says, "We work at home, so I will definitely teach this work to my future children. But if they then want to go into some other profession, I will support them." Rohit tells us he also had the option to choose another profession, but he picked carving for his life's work. He feels nobody should be confined to a profession that does not call forth his highest abilities—that it is best to teach him a skill, and then he can continue the work if he wants.

Mahesh exults, "I feel so proud of both of my sons for following our traditional craft. They are so dedicated to this work and are very creative. They are always thinking about how to make their carvings more attractive and beautiful. So I think they both will do much better in their lives."

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4.4 Conclusions

Sandalwood is being traded all over the world for it essential oil and for medicinal uses. In addition, Sandalwood is of great sacred significance, and is an extremely luxurious material for carving artifacts. Wood carving is being practiced by thousands of wood carvers in India, since almost for 500 years. A lot of work has been done on this aspect, and Sandalwood carving has been practiced in different parts of Karnataka, India for at least a thousand years. Karnataka state is famous for Sandalwood's beautifully carved artifacts, worldwide. Sandalwood crafting offers large income to the nation. However, the scientific aspect of wood and its characteristics have not been worked out much. Thus, there is every necessity for research on improvement of wood suitable for different of types of wood carving.

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Phytochemistry and Pharmacological Properties of *Santalum album* L.

5

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Abstract

Santalum album L. (Sandalwood) is one of the pharmacologically valued tree species. The essential oil derived from its heartwood has much more commercial importance, and is an active ingredient in various traditional medicine systems for the management and prevention of various illnesses all over the world. The versatile therapeutic and healthcare importance of Sandalwood is attributed to the rich source of phytochemicals, particularly sesquiterpenes. A variety of biological properties and impending health benefits of Sandalwood have been testified, including anti-microbial, anti-oxidant, anti-inflammatory, anti-cancer, anti-diabetic activities, and protecting properties on the gastric mucosa, liver and nervous system. No significant toxicity has been indicated by Sandalwood oil or its individual constituents. The present chapter discusses traditional uses, phytochemistry and pharmacological activities of Sandalwood. Also, it provides an

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understanding of Sandalwood oil extraction methods, chemistry of the compounds and their medicinal importance.

Keywords

Ethnomedicine · Heartwood · Aromatherapy · Ayurveda · Unani medicine · Sandalwood oil · Pharmacology · Phytochemistry · Biological activities

5.1 Introduction

The usage of plants as medication is older than documented history. Since from the past years, medicinal plants are being appreciated for their therapeutic properties, and utilized in different sectors, including the pharmaceuticals, perfumery, and cosmetic productions (Swamy and Sinniah 2015, 2016). Plants containing various bioactive chemicals create a central collection of industrial produces. Noteworthy to mention that several of the present days' drugs are obtained from herbs or they are the derivatives of phytocompounds. Despite a considerable advancement made in the synthetic medicine investigation, plant-based compounds are still recognized as the best resources for treatments, and have wide-ranging uses in the drug business (Swamy and Sinniah 2015; Swamy and Rudramurthy 2016; Mohanty et al. 2017; Lodh and Swamy 2019; Kirubakari et al. 2019; Karthikeyan et al. 2020). Several health issues are being treated based on the understandings from the traditional plant-based medications, especially the Ayurveda, Unani, Siddha, Tibetan, Chinese and other systems of health practices. The ethnic understanding of many plants has been acknowledged and accepted in the ancient Indian literature. The traditional information on medicine, ever since the period of great sage Charaka, the Indian father of medicine, has helped in discovering numerous indispensable drugs of contemporary age. The great Indian sages Charaka and Sushruta and other early intellectuals have documented various medicinal plant species, their description and therapeutic uses in their writings Charakasamhitha and Sushruta Samhita, respectively (Bhandary and Chandrashekar 2011). Thus, it can be said that the applications of herbs for human well-being are highly deep-rooted ever since from the existence of human life. Nevertheless, the latest vivid upsurge in sales of plant products in world marketplaces emphasizes the increasing acceptance of herbal treatments. India, China and several other South-East Asian countries use traditional systems of medications, involving different plant species for treating flue, stomach ulcers, malaria and many other health issues. In these regions, there is a continued public support for protecting and promoting the traditional and spiritual principles of folk medications. It has been estimated that herbal products worth in the world marketplace is around US$ 62 billion, and it may raise up to US$ 5 trillion by the end of 2050 (Kumara Swamy et al. 2011; Swamy et al. 2016, 2017; Arumugam et al. 2016; Swamy and Sinniah 2016; Ahmed et al. 2018; Swamy 2020a, b).

Santalum album L. (Sandalwood) (Family, Santalaceae) is one such treasurable tree species in the globe, possessed with multiple therapeutic properties. It is commonly recognized as Srigandha in Sanskrit, Safed Chandan in Hindi, White sandalwood in English, and it is measured to be a well-regarded donation of the flora entangled into the Indian customs and heritage (Fox 2000; Kumar et al. 2015). Sandalwood producers are used throughout the world, and it is one amongst the costly woods in the globe. With more than 2000 years of antiquity, Sandalwood is much-admired for its perfumery ingredient. Along with the cultural significance, it is admired for fragrant and therapeutic qualities. Sandalwood tree grows under diverse edaphic conditions, eco-climatic environments; however, it is indigenous to South regions of India, particularly grows well in the Western Ghats, and foothills of Shevaroy and Kalrayan. The commercial significance of Sandalwood is for its fragrant heartwood and its essential oil, which is vastly utilized in the cosmetic and perfumery companies. The heartwood is ascetically hard, dense, and has high durability with an oily consistency, and hence is highly preferred as an attractive material for making wood crafts with intricate designs. The harvest and superiority of oil differ and depend on the locality, development phases of the trees and distillation methods (Kumar et al. 2015).

Medicinally, Sandalwood possesses tranquilising and recreation effects. It reduces depression, stress, anxiety, uneasiness and restlessness. It is useful in enhancing meditation, hence used in spiritual practices. Various traditional curative practices, such as Unani, Ayurveda and Siddha medicines employ Sandalwood for treating a wide range of health issues. Sandalwood products possess several pharmacological effects such as anti-microbial, anti-cancer, anti-oxidant, anti-inflammatory, hepatoprotective, anti-pyretic and palliative properties (Desai and Hiremath 1991; Biradar et al. 2009; Zhang and Dwivedi 2011; Bommareddy et al. 2007, 2019; Matsuo and Mimaki 2012; Misra and Dey 2013a; Rao et al. 2014; Khan et al. 2014; Kamalarajan et al. 2019). These biological activities are predicted for the occurrence of various chemical compounds, such as α- and β-santalol, (Z)-α-santalol, betulinic acid, vitexin, vicenin-2, isovitexin, isoorientin, orientin, chrysin-6-C-β-D-glucopyranoside, chrysin-8-C-β-D-glucopyranoside, etc. (Nikiforov et al. 1988; Zhu et al. 1993; Shukla et al. 1999; Chen and Lin 2001; Burdock 2002; Kim et al. 2005; Burdock and Carabin 2008; Kusuma and Mahfud 2018). So, in this chapter, a collation of works is prepared with the intention of producing an inclusive report linked to traditional uses, phytochemistry and pharmacological properties unveiled by Sandalwood crude extracts as well as its isolated pure phytocompounds.

5.2 Traditional Uses of Sandalwood

Since the early ages, plants have served for human adornment, and people have been using various kinds of herbs to maintain their beauty. Sandal, turmeric and other plants are used in the form of a paste to improve the complexion of a bride. The paste of Sandalwood and shikakai (*Acacia concinna*) is used for marking on the forehead. Brides use Sandalwood, rose (*Rosa damascena* Mill.) to perfume their body. Sandalwood is one of the few fragrances that are equally popular among men and women. The plant is known to pacify vitiated pitta, burning sensation, head ache, hyper-perspiration, psychotic ailments, memory loss, cardio-myopathy, jaundice, ulcer, cough and inflammation. The wood is bitter with cooling and sedative effects. The essential oil extracted from its heartwood was popular in medicines up to 1930s.

In the Indian system of medicine usage of Sandalwood oil is an age-old practice. The major Indian traditional systems of medicine, like Ayurveda and Siddha largely employ Sandalwood oil as a demulcent, diuretic and mild stimulant. The daily recommended dosage of Sandalwood oil as per the German Commission E review is 1–1.5 g and advised for maximum 6 weeks. (Anonymous 1998). The oil is astringent, disinfectant and has a pronounced effect on the pulmonary (bronchial tracts) and genitourinary tracts. It is also a carminative, anti-septic, anti-spasmodic, diuretic, anti-phlogistic, emollient, stimulant, expectorant, sedative and tonic agent (Alagesaboopathi 2009; Bhowmik and Sampath Kumar 2011). The oil is useful for chronic chest problems, sore throat, bronchitis, asthma, cystitis and bladder infections, gonorrhoea infection, excessive sweating, cooling the body during fever, sun-stroke and heat-stroke, acute dermatitis, urethritis, vaginitis, eye diseases and sexual dysfunction. The oil gives relief to dehydrated skin (anti-ageing skin care). The oil, being astringent is useful on oily skin to prevent ugly scars and help in fighting dry eczema and scabies too. Because of its wonderful qualities, the oil is used for overcoming urinary tract and pulmonary infections. It helps in producing calming and harmonious influence on the mind, and to reduce stress and anxiety. It can be used against cough, bronchitis, asthma, irritability, insomnia, stress and for refreshment (Valnet 2015). The diluted oil can also be used in bathing as a blended massage oil as it amalgams well with lavender, black pepper, bergamot, geranium, rose, myrrh and vetiver oils) for relaxation. As a gargling agent, it may be useful in overcoming sore throat. It is also useful in the preparations of lotions and creams (Bhowmik and Sampath Kumar 2011; Pullaiah 2019). Sandalwood oil is a popular remedy for diseases like gonorrhoea, gleet, urethral haemorrhage, pyelitis and chronic cystitis. This oil, when given in a little carum seeds water or infusion of ginger is a valuable remedy for bronchial catarrh. The oil is an excellent application in scabies of every stages and forms if given externally. When mixed with a double quantity of mustard oil, Sandalwood oil is said to be a good application for pimples on the nose. It is also a digestive aid, especially when blended with ginger and pepper mint, it alleviates heartburn, nausea, diarrhoea and vomiting. Importantly, the oil should be administered in diluted form. However, pregnant women and breast-feeding women should avoid its uses in aromatherapy. The oil should be used externally, and is not meant for the internal use and cuts, open wounds and exposed skin. Every care should be taken to avoid contacts with eyes. The oil may cause dermatitis and photo-allergy, and hence individuals with a known allergy should avoid its use (Bakhru 1996; de Groot and Schmidt 2017; Pullaiah 2019). Sandalwood oil is used for inflammatory conditions of the efferent urinary tract. Sandalwood oil is a stimulant and disinfectant of the whole genitourinary tract. Sandalwood oil is also used in treatment of dysuria (to promote and facilitate urination), gonorrhoea and cough (Pullaiah 2019).

The Sandalwood paste is an admired household remedy for prickly heat. It prevents excessive sweating and heals inflamed skin. The wood is medicinally useful in bilious fever. The dry Sandalwood powder can be mixed in rose water and applied as a paste over the body parts, where there is profuse sweating and inflammation. The powder is given internally as infusion or decoction as alterative, anti-septic, astringent, carminative, disinfectant, diuretic, expectorant, haemostatic, refrigerant, stimulant and a sedative. An emulsion or a paste of the heartwood is a cooling dressing in inflammatory and eruptive skin diseases, such as erysipelas and prurigo. In summer, regular application of Sandalwood paste on the body, especially for children has a refreshing effect, which heals any tiny infected spots. The Sandalwood paste applied on the forehead relieves headache and brings down the temperature in fevers. The powder of the wood is taken with coconut water in cases of morbid thirst. When the wood powder (20 g) is taken as a watery emulsion mixed with sugar, honey and rice water, it checks gastric irritability and dysentery, and also relieves thirst and body heat. The wood powder in the form of pills or added to cow's milk is administered for gonorrhoea, and if locally applied the powder allays prickly heat, and checks excessive perspiration (Alagesaboopathi 2009; Pullaiah 2019).

The Sandalwood paste and essential oil are utilized for curing skin diseases, burning sensation, cardiac debility jaundice, intermittent fever and gastric irritability. The heartwood paste is generally smeared on the forehead to get rid of headache. The stem bark ground into paste and taken orally for malarial fever. The oil obtained from the seeds is useful in curing skin diseases. The crude drug of the plant is the best medicine to control gallbladder and tuberculosis malfunctions. The Sandalwood is bitter in taste and used as a cooling agent, cardiac tonic and sedative. The wood paste when taken orally cures urinary problems, such as secretions, bleeding and promotes urination. It is also having soothing effect on the skin and mucous membranes (Pullaiah 2019).

The decoction of bark is used as good diuretic and sedative (Alagesaboopathi 2009). The extract of Sandalwood leaves mixed with cow milk when taken orally can control gonorrhoea. Stems and roots of Sandalwood are used as anti-pyretic, aphrodisiac, antibilious agents and also for treating asthma (Ravikumar and Theerthavathy 2012). One teaspoon of Sandalwood powder and turmeric powder is mixed with milk to make the paste, and is applied on the face to control pimples (Jamal et al. 2005; Bhowmik and Sampath Kumar 2011).

The powder from the heartwood mixed with gum arabic and saltpetre and often with other aromatic materials is employed for making incense sticks. Also, it is burnt as an incense in homes and holy places. The pieces of heartwood is kept in sachets and placed in linen cupboards for scenting clothes and repel insects. Finely ground Sandalwood paste is applied on the body for cooling effect (http://tropical.theferns.info/viewtropical.php?id=Santalum+album). It can be used externally and internally or in aromatherapy. It has a sedative effect on the mental and emotional levels, and can be used to reduce stress, depression and anxiety (Valnet 2015). Sandalwood paste is taken orally for several ailments such as abdominal pain, headache, abnormal thirst and vomiting. It also stimulates digestive enzymes, respiratory system and excretory system.

Several researchers documented the usage of Sandalwood for curing skin diseases and skin care. One teaspoon of Sandalwood powder and a pinch of powdered camphor is prepared into a paste by adding small quantity of water, and smeared on the affected areas of rashes and allergies, psoriasis, eczema and burns. After 1 h wash with cold water. Sandalwood powder and turmeric powder are mixed and prepared into a paste with lime juice, and smeared on the affected areas to get relief from itching. Sandalwood paste is applied on the skin to heal rashes. Powders of Sandalwood bark, wood and turmeric powder are mixed and prepared into a paste, and smeared on the area of snake bite (Pooja and Vidyasagar 2015). Bark and leaf paste is applied once in day for 4–6 days to cure skin allergy (Shivakumar Singh and Vidyasagar 2013). The stem bark of Sandalwood is pulverized into a paste and applied externally to cure herpes (Bhandary and Chandrasekhar 2011). Sandalwood paste is smeared superficially to cure herpes and skin eruptions (Rajagopal Reddy et al. 2015).

5.2.1 Ayurvedic Perspective

In Ayurveda, Sandalwood has the highest priority for medicinal uses. The aroma of wood and essential oils brings pleasantness and holistic environment. Interestingly, Ayurveda believes that there is a central node of nerves on the forehead (Sthapani marma) between the eyebrows. The application of Sandalwood paste in between the eyebrows (Sthapani marma) stimulates the nervous system, and serves to tranquilize the individual. According to Ayurveda, the Sandalwood is claimed to be medhavardhaka, smrutivardhaka, buddhivardhaka, surabhi, santapasantipradam, saumanasyajanana, hrudya, ahladakaraka, pittashamaka, trsnahar, pipasahara, dahasamaka, etc. It relieves sunmada, angamarda, arochak, shira-shoola, shwas, shirovibhram and pittaja shirahshoola. The Kalpa (formulations) containing Sandalwood are claimed to improve brain functions and intelligence (medhya, medhavardhaka, smrutivardhaka, buddhivardhaka), and useful in different psychiatric disorders (manasroga, mastishkaroga, siroroga).

The Bhavprakash nighantu, i.e., the classical texts of Ayurveda states that Sandalwood is known with the names of Srikhanda, Chandan, Madhrashri, Tilaparnaka, Gandhasara, Malayaja and Chandradyuti. It is white in colour, bitter in taste, and after being rubbed gives yellow colour. If it is broken in pieces, it gives red colour, and appears white from the outside. It is considered as the best if it is rough in texture. This has properties like cold potency, pacifies pitta in the body, it manages fatigue, weakness, thirst, heat and blood impurities (Pandey 1998).

5.2.2 Unani Perspective

According to Unani physicians, there are three varieties of Sandal, viz., yellow, red (Sandal Surkh) and whitish yellow (Sandal Safed). The last variety is more fragrant than the other two varieties. In view of Galen and Ibne Maswaih Sandal Surkh is more potent, but according to some other physicians, the Sandal Safed is relatively stronger (Ibne Sina and Al-Qanoon 2007). In Unani classical texts, Sandal

Safed (*S. album*) and Sandal Surkh (*Pterocarpus santalinus*) have been mentioned along with their medicinal properties and therapeutic uses. It is used both internally and externally, since antiquity. Therapeutically, this drug is widely used in many cardiac, brain, liver, stomach and intestinal ailments as well as in various skin disorders for its Mufarrreh wa Muqawwie qalb (exhilarant and cardio tonic), Muqawwie dimag (brain tonic), Muqawwie hararategareezi, Qabiz (astringent), Muhallile warm (anti-inflammatory), Musaffie dam (blood purifier) and Mujaffif (desiccant) properties (Ibne Sina and Al-Qanoon 2007).

There are claims in Unani medicine that the Sandalwood is musakkin (soothing, sedating), mubarrid (cooling), mufarreh (exhilarant, pleasure promoting, mood uplifting); useful in the du'fidimagh (weak function of the brain) and relieves du'fiquwwatihafizah (amnesia); useful in sivdaV-har (hot-type headache) or suc/a'sa/iraiv/(bilious headache) and khafqan-i-har (palpitation due to heat); is muqawwiqalb (cardiotonic) and relieves du'fiqalb (heart's weakness). Sandalwood plays a potential role of Unani medicinal plant in management of Kalaf (chloasma), and can be used as a mufrad (single) or with other compounds (Ahmad 2006). It has been found that α–santalol present in Sandalwood inhibits tyrosinase, an essential enzyme for the synthesis of pigment melanin. This property helps in limiting the abnormal pigmentation associated with ageing and exposure. It contains raade-mawaad (divergent) and blood purifier activities (Kauser et al. 2014). The raade-mawaad (divergent) property of Sandalwood helps in diverting the fasidmawaad of chloasma from the site of lesion and hence helps in reducing the condition. In Unani system of medicine, UBTAN is a semisolid preparation of powdered drugs in the form of lubdi (mass) used to remove the dead cells from the skin enhancing lecture of the body. For that Basen (Bengal Gram, *Cicer aietinum*), Haldi Sandal Safed (*Santalum album*), Khas (*Vetiveria zizanioides*) 5 g each and Roghan Chameli oil (*Jasminum officinale*) are prepared into a paste. The whole paste is smeared on the body regularly get charismatic look. In West and South Asia, a popular drink, Sherbat is made from fruits and flower petals of Sandalwood. The common Ashriba is made by using one or more of Sandalwood powder, bael (an Ayurvedic ingredient), rose water, gurhal, mango, pineapple, lemon, orange and falsa. It is utilized in the Unani system of medication for the treatment of gastric ulcers and various cardiac, brain, liver, stomach and skin disorders. There is a good medicine for excessive pigmentation in Unani system of medicine. The application of Sandalwood paste or Sandalwood oil reduces the excessive pigmentation (Ahmad et al. 2013; Kausar et al. 2014).

5.3 Phytochemistry

The impending benefits of Sandalwood and its products have been well discovered in current times by several researchers. Different investigations on its phytochemistry and therapeutic properties are well defined, and many present studies have focused to isolate pure bioactive compounds and their mechanisms of action. The title tree species constitute several phytoconstituents, including many oxygenated terpenes, sesquiterpene hydrocarbons, sesquiterpenic alcohols, organic acids, lignans, glycosides and aldehydes.

Sandalwood oil, one amongst the oldest perfume materials has been mentioned in Sanskrit manuscripts, and its uses are described by the people, ever since the early eighteenth century (Arctander 1960). The volatile oil is attained by steam distillation approach using the dehydrated Sandalwood tree trunk and roots. The Sandalwood oil appears to be pale-yellow liquid, having the distinctive woody odour, and a faintly bitter flavour (Burdock 2002; FCC 2003). The main constituents of the oil (>90%) are alcohols, namely α-santalol and β-santalol, giving specific odour and aroma (Burdock and Carabin 2008). The oil also constitutes supplementary constituents, mainly sesquiterpene hydrocarbons (6%), such as epi-β-santalene, α- and β-santalenes, in addition to trace amounts of santene, tricycloekasantalal, dendrolasin and β-farnesene, dihydro-b-agarofuran, borneol, teresantalic acid, teresantol, santanol and santalone (Taufel et al. 1996; Burdock 2002; Burdock and Carabin 2008). Kim et al. (2005) identified a new aromatic ester and three novel neolignans from the heartwood, in addition to other recognized 14 volatiles. Burdock (2002) identified stearolic acid and santalbic acid from the seed oil. Generally, the amount of α-santalol was found to be higher (46%), when compared to β-santalol with only 20% (Bauer and Garbe 1985; Taufel et al. 1996; Anonis 1998). Majorly, α- and β-santalol are credited for the pleasurable smell of Sandalwood, though 2-furfuryl pyrrole may possibly also contribute. Trace amounts of phenols, lactones and terpenes are also being reported. Nearly 2–4% of santalol occurs as ester, and in one of the Sandalwood oil sample, hentriacontan-16-one compound has been reported (Anonymous 1999).

The oil yield of the heartwood fluctuates conferring to the tree age, geographical distribution, and location of the tree (Lawrence 1991; Nautiyal 2019). Between 85 and 240 kg of heartwood can be obtained from trees having a girth size of 100 cm. Chemical constituents and oil yield fluctuates from one tree to another, and is greater in the older or matured tree. The roots have the highest oil content of almost 10%, while lowermost is observed in wood chips (1.5–2%). Also, it has been stated that about 3–6% oil yield is possible from the sap wood, while about 2.5% oil is obtainable from heart wood (Burdock 2002). It has been revealed that girth size of different trees can influence on the oil yield and chemical constituents (Bisht et al. 2019). Chemical profiling of the oil samples was carried out by gas chromatography-mass spectrometry (GC-MS-QP-2010 Ultra Auto Sampler). A chemically diversified alkanes, sesquiterpenoids, sesquiterpene, fatty acids and alcohols were detected. The major constituents were α-santalol (41.7–53.67%), β-santalol (18.2–27.9%), epi-β-santalol (2.7–7.18%), β-santalene (1.39–5.30%), α-santalene (0.4–4.87%) and α-bergamotol (3.1–9.3%). In this study, it was concluded that the oil yield and its composition vary among the trees with different girth. But no particular trends were observed between the girth size and oil yield.

Sandalwood heartwood and the root samples were pulverized and separated through 60μm sieves to obtain uniformity in the powder. Later, the oil was extracted from this powder using any one of the 8 approaches, i.e., solvent extraction (benzene, toluene, ethyl alcohol and diethyl ether), subcritical carbon dioxide ($SC\text{-}CO_2$) extraction, steam distillation and hydrodistillation. Steam distillation for 10 h in a pilot plant yielded the highest level of α-santalol (54.7%) and β-santalol (29.2%), followed by $SC\text{-}CO_2$ extraction for 4 h, yielding 54.5% of α-santalol and 28% β-santalol (Nautiyal 2019). The heartwood and roots coarse powder affect the process of distillation. The tree parts, such as sapwood, heartwood and bark, the age of the tree, and agronomic and climatic conditions of cultivation can influence on the yield of oil. Up to 10.3% oil can be obtained from roots, while heartwood can yield up to 4%. For completing the oil extraction, it requires 48–72 h of distillation process (Zhang et al. 2012).

In Kupang (Indonesia), refiners are using the steam distillation to extract sandalwood oil, since from a long period (Ferhat et al. 2006). In general, steam distillation is run for about 40–70 h. High pressure can be applied to obtain higher yield of oil in a shorter time during the distillation. However, increasing the temperature could decompose the essential oil constituents and make it less odoriferous. A new technique, involving less energy and solvents was developed by Kusuma and Mehfud (2018) to extract oil by employing microwaves. Microwave hydrodistillation technique comprised of three apparatuses, a compressor, microwave and condenser. Compressor helps in maintaining required pressure, microwave produces required temperature and condenser regulates temperature. Pressure mediates the diffusion of essential oils from wood slices into the distillation chamber. Application of pressure is essential to extract the essential oil because of its high density. The content of oil attained from Sandalwood powder using various extraction approaches varied from 43 to 84% (Hettiarachchi et al. 2010).

GC-sniffing technique (GC-Olfactometry) was useful in identifying the most powerful odorous volatile chemicals of Sandalwood oil, including α-santalol, β-santalol, α-santalene, α-bergamotol, epi-β-santalol and spirosantalol (Nikiforov et al. 1988). All these chemo-constituents have very high importance in aromatic industries. Numerous silica gel column chromatography based separations also have witnessed the presence of oxygenated compounds (96.6%) and hydrocarbons (3.4%) in the oil.

Sandalwood oil distilled from the heartwood of trees grown in the South China Botanical Garden, Guangzhou, China (Zhu et al. 1993) possesses with α-santalol (22.0%), α-santalol isomers (7.7%), β-santalol (1.9%), β-santalol isomers (5.5%), epi-β-santalene (2.3%), α-santalene (1.5%), β-santalene (1.8%), and *cis*-α-santalol (11.7%). Brunke et al. (1995, 1997) identified few more chemical constituents from the East Indian Sandalwood oil, such as cyclosantalol (1.6%), epi-cyclosantalol (1.2%), minor amounts of (<0.01%) of dihydroalbene, acetyldihydroalbene and epi-cyclosantalic acid.

Wei et al. (2000) stated that heartwood size increases when the branches are damaged due to wind currents. The chemical constituents of the Sandalwood oil obtained from the 25 years old tree were shown to have epi-β-santalene (0.12%), α-santalol (43.09%), α-santalene (0.08%), β-santalol (22.5%), β-santalene (0.25%), (Z)-*trans*-α-bergamotol (9.44%), curcumene (0.05%), nuciferol (9.65%), epi-β-santalol (3.66%) and (Z)-lanceol (0.51%). Gowda et al. (2006) revealed that the heartwoods of 30 years-old trees hold about 5% oil, although the 12–15 years-old trees heartwoods possess oil content in the range of 3.5–4.0%. Further, the profitable viability was explored for introducing Sandalwood farms, and anticipated that the monetary profit would be very rewarding after 15 years.

Chen and Lin (2001) examined the variation in the volume of various chemical constituents in the Sandalwood oil obtained by various methods of extraction. Their results revealed the occurrence of α-santalol (30.7–41.5%), β - santalol (22.62–26.8%), α-santalene (0.08–0.65%), β-santalene (0.04–1.42%), epi β-santalol (3.94–6.75%), epi β -santalene (0.16–0.89%), curcumenol (0.09–0.33%), nuciferol (2.08–2.47%) and lenceol (0.46–0.88%).

Braun et al. (2003) estimated the chemical constituents present in the Sandalwood oil available in the Germany market. The chemical substances present in the oil included α-santalol (1.9%), β- santalol (0.6), α-santalene (0.7%), β- santalene (1.2%), epi β- sanatalol (3.5%), epi β-santalene (0.8%), epi-cyclosantalol (0.3%), dihydrosantalol (0.6%), trans α-santalol (0.4%), cis β-santalol (19.8%), trans β-santalol (1.5%), santene (0.2%), α- cedrene (0.1%), α-santene (0.7%), trans α-bergamotene (0.2%), trans β-bergamotene (0.17%), γ-curcumene (0.1%), cyclosantalol (0.4%), α-bergamotol (0.2%), epi-cyclosantalol (0.3%), α-bisabolol (0.2%), trans α- begamotol (6.4%), cis α- bergamotol (0.2%), fokienol (0.5%), Z-nuciferol (3.4%), Z-lanceol (1.4%), E-nuciferol (0.1%) and spirosantalol (0.9%). Some more chemicals, such as epi sesquithujene, E- α-bisabolene, E- β-farnesene, cis α-bergamotene, β-alaskene, α-alaskene, E- γ-bisabolene and (Z) γ -bisabolene were also present in very trace amounts (0.1%). Chiral compound exploration of the β-bisabolols exposed that the main stereo isomer was (6R, 7R) - β- bisbolol and the remaining forms are enantiomers.

Kusuma and Mahfud (2018) analysed the Sandalwood oil extracted through microwave air-hydrodistillation and microwave-assisted hydrodistillation approaches. Their study showed that the oil quality fulfils with the standard oil quality, which was confirmed based on the occurrence of the major volatiles, such as α- and β-santalol, α-bergamotol, α-santalene, cis-lanceol, α-curcumene and α-bergamotene. As the standards set by the International Organization for Standardization for the total content of santalol (50–70%) can be achieved, microwave-assisted hydrodistillation and microwave air-hydrodistillation approaches are suitable for obtaining Sandalwood oil in large scale to meet the international standards. The microwave air-hydrodistillation technique proved to be more efficient than the microwave hydrodistillation in terms of both quantity and quality of the essential oil. Microwave hydrodistillation yielded 37 compounds, whereas 43 chemical substances were extracted through microwave air-hydrodistillation method. Further, Kusuma and Mahfud (2018) suggested that the usage of airflow in the microwave-assisted air-hydrodistillation augments the diffusion of heavyweight fractions of essential oils from the wood slices. Their data supports that microwave air-hydrodistillation method is superior over to microwave hydrodistillation as the heavier fraction of essential oils is completely recovered from the wood slices. Sandalwood oil obtained using microwave hydrodistillation had only two heavyweight fractions (MW $\geq$ 222.37). While, the oil derived using

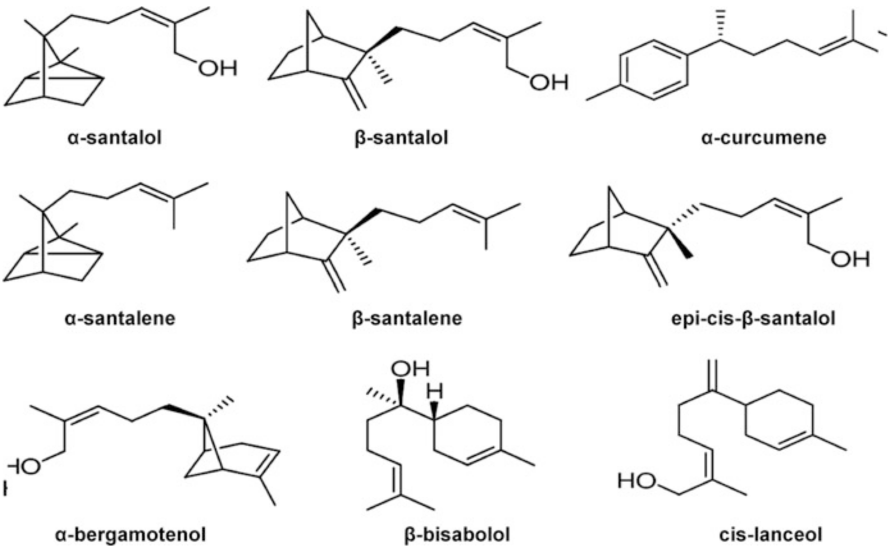

Fig. 5.1 The major volatile compounds stated from Sandalwood oil (drawn by author)

microwave air-hydrodistillation possessed seven heavyweight fractions (MW $\geq$ 222.37). Most of these heavy weight fractions belong to the oxygenated terpenes. These heavy fractions of essential oils give the characteristic aroma and fragrance to the Sandalwood oil. Overall, it has been established that oxygenated terpenes occurring in Sandalwood oil attained by microwave air-hydrodistillation present superior quality of the oil.

Gas Chromatographic examination (GC) showed the presence of peak areas for chief components, such as α-santalol, β-santalol, β-santalene and α-santalene in the first hour (Nautiyal 2014). Later in the second hour, peak areas for α- and β-santalene, α- and β-santalol were noticed. The peak areas for α- and β-santalene, α- and β-santalol were found in the third hour of extraction. Finally, in the fourth hour, peak areas for α- and β-santalene, α- and β-santalol were recorded. Noteworthy to mention that high quantities of α-and β-santalol were recorded in the second hour. A total of 35 volatile compounds were identified and quantified using GC-MS (Gas Chromatography-Mass Spectrometry) method. The data showed a chemically varied sesquiterpenoids, sesquiterpene, alcohols, alkanes, and fatty acids were witnessed. The foremost components were α-santalol (33–35%), β-santalol (17–18%), β-santalene (1.1–2.3%), α-santalene (0.56–1.6%), epi-β-santalene (0.8–1.6%), epi-β-santalol (2.2–3.5%) and α-bergamotol (4.0–7.7%) (Bisht and Hemanthraj 2014). Some of the volatile constituents are depicted in Fig. 5.1.

Immersion of Sandalwood pieces in ice-cold water for 3 days, prior to hydrodistillation enhances the production of Sandalwood oil (Nautiyal 2014). The oil was pale-yellow in colour having a pleasant aroma, and the oil yield was about 1.71%. Even after the softening of Sandalwood chips for a lengthy period, it was problematic for the vapour to penetrate through vessels, medullar ray cell, wood parenchyma and fibres comprising essential oil. Conversely, un-pulverized wood slices give little quantity of oil. GC examination indicated the occurrence of higher quantities of α-santalol (48.38%) and β-santalol (28.73%), in addition to lower levels of α- and β-santalene. Alkaline water was used to charge the Sandalwood coarse powder, and used for hydrodistillation to recover 2.68% of oil. The result showed the yield of α-santalene (4.25%), β-santalene (3.01%), α-santalol (41.90%) and β-santalol (19.89%). The use of alkaline/neutral media reduces the development of artefacts all through distillation. However, the acidic media may promote the transformation of heat-sensitive monoterpenes (Nautiyal 2014, 2019).

Due to the scarcity and unavailability of good quality of Sandalwood trees the cost of the Sandalwood oil is increasing year by year. To meet the market demands scientists are searching for alternative production through synthetic methods (Shvets and Dimoglo 1998; Bajgrowicz and Frater 2000). Buchbauer et al. (1992, 1997, 2001) attempted to synthesize santalol derivatives with comparable olfactory activity.

5.4 Pharmacology of Sandalwood

5.4.1 Anti-Microbial Activities

5.4.1.1 Antiviral Activity

The antiviral properties of Sandalwood have been established through various biological studies. Sandalwood oil has been revealed to be used in preventing and treating skin blemishes, warts and other viral-prompted tumours on the skin (Haque and Haque 2000, 2002). The traditional Indian medical system, Ayurveda and Chinese Traditional Medicine have mentioned about the antiviral potency of Sandalwood oil (Chattopadhyay et al. 2009). Sandalwood oil exhibits the potential antiviral property against Herpes simplex virus 1 and 2 under in vitro studies in a concentration dependent way by inhibiting replication process. Furthermore, it was presumed that Sandalwood oil protects the cells via modulation sulphydryl groups and liver's glutathione S-transferase (GST) (Benencia and Courreges 1999). Schnitzler et al. (2007) reported that the Sandalwood oil suppresses the replication of HSV virus Type 19, and β-santalol showed anti-influenza activity against H3N2 virus. Sandalwood oil exhibited in vitro inhibitory effects against HSV-2 in infected Cellosaurus (RC-37) cell lines. The Sandalwood oil prevents viral particle's adsorption onto the host cell by inhibiting the interactions of virus and host cell, non-specifically (Koch et al. 2008). The chief constituents of Sandalwood oil, i.e., α- and β-santalols and their synthetic derivatives are employed in treating warts and Molluscum contagiosum, a skin infection. They have also considered to cure HIV and other RNA viral diseases. Constituents of Sandalwood oil also showed curative properties against psoriasis, eczematic rashes, skin dryness, skin allergies, seborrhoea and basic acne lesion on the face (de Groot and Schmidt 2017). In addition to these, Sandalwood oil and chemical derivatives of santalols are reported to be very effective against cold sores, affected by HSV (Singh and Nulu 2010).

Haque and Coury (2017) evaluated the efficiency of Sandalwood oil in unproblematic management of cutaneous viral warts affected by Human Papilloma Virus (HPV), and presented a case study. They subjected the Sandalwood oil externally twice a day for 12 weeks. Among ten patients tested eight patients (80%) were completely recovered from HPV. They considered wart size, severity, healing time, side effects for evaluation. All the ten patients failed to show any side effects, such as erythema, skin irritation, itching, scarring or peeling of skin, and discomfort. Thus, Sandalwood oil can be suggested for a person with HPV as it is an effective and unproblematic curative method.

5.4.1.2 Antibacterial Activity

In an early study, tannins present in the stem bark of Sandalwood tree were reported to exhibit inhibitory property against *Staphylococcus aureus* (Shankaranaryana 1986). Likewise, many investigations were carried out to investigate the antibacterial activities of Sandalwood oil, and most of these studies have indicated the effective inhibitory activities of Sandalwood oil against several bacterial pathogens (Beylier and Givandan 1979; Jirovetz et al. 2006; Kumar et al. 2015). Chaurasia (1978) reported a higher anti-microbial activity of Sandalwood oil against *Escherichia coli* and *Bacillus mycoides*. Viollon and Chaumont (1994) evaluated 26 essential oils for their anti-microbial activity against axillary microflora, and found that Sandalwood oil and its synthetic analogues showed the best results. A study by Warneke et al. (2009) reported that Methicillin resistant *S. aureus* can be inhibited effectively by using Sandalwood oil. Purified α- and β-santalol compounds and crude extracts of Sandalwood oil exhibit anti-microbial property against a gram-negative bacterium, *Helicobacter pylori,* which is responsible for peptic ulcers (Ochi et al. 2005). Methanol extract of Sandalwood was reported to be active against *B. subtilis*, *Salmonella typhi, S. aureus* and *Pseudomonas aeruginosa,* and highly active against fungus *Candida albicans* (Bakkiyaraj and Pandiaraj 2011). Simanjuntak (2003) carried out experiments on the anti-microbial activity of different constituents of Sandalwood oil, such as α-santalol, β-santalol and epi-β-santalene, and found that α-santalol and β-santalol as the effective constituents against *S. aureus* and *S. typhimurium,* however epi-β-santalene also showed good results against *S. typhimurium*. Jirovitz et al. (2006) reported that santalols exhibited anti-microbial activity against yeast, gram positive bacteria at higher concentrations, whereas at lower concentrations, they were effective against gram-negative bacteria. Misra and Dey (2012a) showed that the crude phytoextracts of immature tree shoots and in vitro shoots exhibited antibacterial activities against 13 bacterial strains, including *Klebsiella aerogenes*, *P. aeruginosa*, *P. fluorescens*, *Acinetobacter calcoaceticus*, *E. coli*, *Citrobacter freundii*, *B. subtilis*, *Alcaligenes faecalis*, *S. typhimurium*, *Arthrobacter nicotianae*, *Enterobacter cloacae*, *Micrococcus flavus* and *S. aureus*.

5.4.1.3 Antifungal Activity

Chourasia and Tirumala (1987) reported the antifungal properties of Sandalwood oil against pathogenic fungi, such as *Trichophyton rubrum, T. mentagrophytes* and *Microsporum canis*, however inefficient against *Aspergillus niger*, *A. fumigatus* and *Candida albicans*. Chaumont and Bardey (1989) reported that Sandalwood oil is having antifungal property against *M. canis, T. mentagrophytes* and *T. rubrum*. Sandalwood oil exhibited anti-dermatophytic activity against *M. canis, T. rubrum* and *T. mentagrophytes* (Simanjuntak 2003). Warneke et al. (2009) reported that Sandalwood oil is an effective antifungal agent against *Candida* species that are resistant to antifungals. Many fungal dermatophytes and yeasts, including *Microsporum, Trichophyton* and *Candida* species were effectively inhibited by the Sandalwood oil (Inouye et al. 2010; Nardoni et al. 2015; Moy and Levenson 2017). Lately, antifungal activity of Sandalwood oil against *C. albicans, Aspergillus niger* and *Cryptococcus neoformans* was reported by Powers et al. (2018).

5.4.2 Anti-Oxidant Efficacy

Anti-oxidant property of Sandalwood has been reported by several researchers. It has been tested in vitro for its promising controlling influence on nitric oxide (NO) levels by the use of NO donor, sodium nitroprusside. Sandalwood extract showed significant NO scavenging activity in a dose-dependent way (Jagetia and Baliga 2004). Other studies also have evidenced the NO scavenging activity and 2,2-diphenyl-1-picrylhydrazyl (DPPH) anti-oxidant activity (Patrick and Timothy 2002; Jagetia and Baliga 2004). Khan et al. (2014) reported that Sandalwood can protect cardiac tissue from oxidative stress induced cell injury and lipid peroxidation, and also interferes with doxorubicin (DOX)-induced inflammatory in cardiac tissue.

Pedpati et al. (2012) reported that cyanidin-3-glucoside, an anthocyanin pigment occurring in Sandalwood was reported to be anti-oxidant in nature, and hence nutritionally vital. In a comparative study done by Mishra and Dey (2012b), it has been revealed that even in vitro grown callus cells show significant anti-oxidant property. Banerjee et al. (1993) reported that Sandalwood oil administration to the adult male Swiss albino mice increases the acid-soluble sulphydryl (SH) levels and GST activity in the liver, suggesting the possible chemo-preventive action of Sandalwood oil. The methanol extracts of Sandalwood showed DPPH and hydroxyl radicals scavenging activities, in addition to acetyl cholinesterase inhibitory activity in albino mice. Hence, it is a potent curative agent against neurological disorder, such as dementia, age-related memory loss and Alzheimer's-related depression. Misra and Dey (2013b) reported that Sandalwood oil and its chief compound, α-santalol exhibit anti-oxidant and anti-hyperglycaemic activities in d-galactose and alloxan-mediated oxidative stresses prompted diabetic Swiss albino mice.

5.4.3 Anti-Inflammatory Activity

Santalols, the major constituents in Sandalwood oil have been testified for their significant anti-inflammatory property (Sindhu et al. 2010; Rajsmita and Keshavamurthy 2019). Sandalwood disclosed significant anti-inflammatory and anti-ulcer properties in the carrageenan-induced paw edema, cotton pellet-stimulated granuloma, as well as pylorus ligation-encouraged ulcer. These research findings suggest the need to include in the list plants, which cures inflammatory disorders like ulcers in the Indian traditional medicines. Saneja et al. (2009) employed methanolic extract of heartwood to test the anti-inflammatory, anti-oxidant, and analgesic activity in mice. Sharma et al. (2018) reported that East Indian Sandalwood oil is capable of suppressing lipopolysaccharides (LPS)-stimulated Nuclear Factor (NF)-kB activation, and subsequent chemokine and cytokine expressions by reducing transcription and activation of PDEs (Cyclic adenosine monophosphate phosphodiesterase). Hence, it can be suggestible that East Indian Sandalwood oil can cause pro-inflammatory inducements by hindering the capability of PDEs to hydrolyse cyclic adenosine monophosphate (cAMP), and consequently allowing for protein kinase A (PKA)-mediated attenuation of NF-kB activation. Moreover, α-santalol has also been found to have anti-inflammatory effects by altering the expression of various cytokines and chemokines. In addition to that both α and β-santalol have been reported to suppress arachidonic acid pathway mediated by lipopolysaccharides, thereby decreasing prostaglandin E2 and thromboxane B2. Sandalwood oil is reported to cure wide range of skin diseases, such as acne, psoriasis, eczema, common warts and Molluscum contagiosum (Moy and Levenson 2017). Having good anti-inflammatory properties East Indian Sandalwood oil has been advised to treat a number of inflammatory skin disorders like psoriasis and atopic dermatitis, possibly as a result of inhibition of phosphodiesterases (de Groot and Schmidt 2017; Bommareddy et al. 2019).

5.4.4 Hepatoprotective Activity

Hegde et al. (2014) reported that the hydro-alcoholic extract of the leaves of Sandalwood shows a noteworthy hepatoprotection against carbon tetrachloride (CCl_4) and paracetamol-induced hepatotoxicity in mice. The mechanisms involve decreasing of serum marker enzymes activities, lipid peroxidation, bilirubin oxidation, and significantly increasing the glutathione levels, catalase and superoxide dismutase in a dose-dependent manner. Observations on the loss of weight in the liver tissue and histopathological examinations further confirmed the hepatoprotective activity. The traditional drug, Khamira Gaozaban Ambari Jadwar Ood Saleeb Wala includes Sandalwood as a main ingredient, and is shown to have free radicals scavenging and hepatoprotective activities against CCl_4-induced toxicity in albino rats (Akhtar et al. 2013). Hepatoprotective activity was showed by lowering the serum glutamic oxaloacetic transaminase, serum alkaline phosphatase, glutamic pyruvic transaminase, bilirubin, total cholesterol and total proteins contents, and hepatoprotective nature was also ascribed to its anti-oxidant properties. Rao et al. (2014) reported that the hydro-alcoholic extract of the stems also exhibited a significant effect of hepatoprotective properties against paracetamol-prompted hepatotoxicity via diminishing the activities of serum marker enzymes and lipids oxidation. Kamalarajan et al. (2019) testified that chloroform extract of Sandalwood possesses hepatoprotective and anti-oxidant activities by lowering the serum hepatic marker enzyme activities. The effective hepatoprotective and anti-oxidant response was noticed at 400 mg/kg/BW (Body Weight), which is equal to the response of the standard drug, silymarin.

5.4.5 Anticancer Activity

Zhang and Dwivedi (2011) reported that α-santalol possesses the chemo-preventive properties on TPA (12-O-tetradecanoylphorbol-13-acetate)-induced and DMBA (7,12-dimethylbenz(a)anthracene)-prompted skin cancer growth in mouse models, and also it prevented UVB-promoted skin cancer enlargements in SKH-1 hairless mouse model in a dose-dependent way. Investigations have revealed that α-santalol mediates its anti-carcinogenic property by inducing apoptosis by activating caspases along with the interference of cytochrome C enzyme release and mitochondrial membrane potential in A431 (epidermoid carcinoma) cell lines. Further, it can alter manifold cell cycle controlling proteins, and inhibit cell growth via inducing G2/M phase arresting in melanoma cells, i.e., UACC-62 and A431 (Dwivedi et al. 2006; Zhang and Dwivedi 2011). Dwivedi et al. (2003) reported that α-santalol, the chief constituent in Sandalwood oil hindered the papilloma growth in both strains (CD-1 and SENCAR) of mice. Further, Santha and Dwivedi (2015) reported the anticancer activity of the oil against chemically encouraged skin tumourigenesis in SENCAR and CD-1 mice, ultraviolet-B (UVB)-encouraged skin cancer formation in SKH-1 mice, and in vitro models of skin, breast and prostate cancer. The oil also arrests cell cycle and induces apoptosis in cancer cells. Kaur et al. (2005) reported that the α-santalol has been used for skin cancer chemoprevention in animal models of skin tumours. Further, they stated that α-santalol at lower concentrations, i.e., between 25 and 75μM may possibly encourage apoptosis mediated death in A431 (human epidermal carcinoma) cells via reducing the release of cytochrome C enzyme, damaging the mitochondrial potential, in addition to activation of caspases. In another investigation, topical application of α-santalol to the female nude mice strain, SKH-1 showed chemo-preventive effects, including reduced activity of ornithine decarboxylase (Dwivedi et al. 2006). Bommareddy et al. (2007) stated that α-santalol prevents UVB-induced skin tumours by inhibiting in vitro lipid peroxidation activity in liver and skin microsomes. Another study reports the anticancer property of α-santalol against breast cancer cells, namely MCF-7 and MDA-MB-231. The compound exhibited chemo-preventive activity via the cell cycle arresting at G2/M phase and induction of apoptosis (Santha et al. 2013). Arasada et al. (2008) reported that α-santalol significantly increases apoptosis related proteins (caspase 3 and 8) levels and tumour suppressor protein (p53) via an extrinsic pathways in UV-B-induced skin tumourigenesis model in SKH-1 mice. Alpha-santalol also prompts apoptotic activity in human prostate cancer cells by the activation of caspase 3 enzymes (Bommareddy et al. 2012, 2017). In another study, 2 aromatic glycosides, 6 new sesquiterpenoids and a number of neolignans were isolated from the heartwood chips of Sandalwood, and were shown to possess antitumour promoting activity in Burkitt lymphoma (Raji) cells, activated with Epstein–Barr virus Early Antigen (EBV-EA). Further, in vivo investigation demonstrated its potential tumour suppression effects in mouse model (Kim et al. 2006). In addition to α-santalol, its derivatives established tumour-selective cell toxicity in human promyelocytic leukaemia (HL-60) cells and normal human diploid fibroblast cultures (Matsuo and Mimaki 2012). Two lignans isolated from the heartwood samples suggestively indicated apoptosis mediated anti-tumour in HL-60 (human promyelocytic leukaemia) cells and A549 (human lung adenocarcinoma) cells (Matsuo and Mimak 2010). The use of α-santalol between 10 and 40μM was shown to be efficient in inhibiting angiogenesis via interfering on vascular endothelial growth factors, which further trigger to inhibit the progression of prostate malignancy (Saraswati et al. 2013). Ortiz et al. (2016) performed the cell toxicity and genotoxicity of Sandalwood oil in MCF-10A and MCF-7 human breast cancer cells. Their findings showed that Sandalwood oil (6–8μg/mL) exhibits both cytotoxic and genotoxic activity in MCF-7 cell lines. However in MCF-10A cell line, only cytotoxicity was observed. It was also revealed that Sandalwood oil effectively initiated the DNA damage in MCF-7 cells. Powers et al. (2018) reported the cytotoxic property of Sandalwood oil against MCF-7 and MDA-MB-231 cancerous cell lines. Jain and Nair (2019) have reviewed in detail on the molecular pathways involved in the chemoprevention by sandalwood oil and α-santalol. Molecular pathways include the induction of apoptosis via caspase cascades pathway activation. In precise, α-santalol activates caspases and cleavage of poly (ADP-ribose) polymerase. Further, α-santalol could also elicit the mitochondria to discharge Cytochrome C into cytosol. It may suppress the intracellular signal transduction pathway, i.e., PI3K/Akt pathway (Bommareddy et al. 2015). It induces arresting of cell cycle at G2/M phase and apoptosis by upregulating the levels of p21 and p53, correspondingly. Sandalwood oil also prevents the release of cytokines and uplifts the synthesis of interleukins (IL-1β), causing the suppression of the downstream NF-κB pathway. Moreover, Sandalwood oil suppresses activator protein 1 (AP-1), and may also enhance IL-6 levels to exhibit anti-inflammatory action.

Palatty et al. (2014) studied the comparative effects of 2 commercial products, namely Johnson's baby oil (Johnson and Johnson Ltd., India) and Vicco® turmeric cream (VTC) of Vicco Laboratories Pvt. Ltd., India on 50 patients having neck and head tumour, requiring >60 Gy of remedial chemoradiotherapy or radiotherapy. Sandalwood oil is one of the main ingredients in VTC. They divided them in to two groups, and the first group was allocated with external application of Johnson's baby oil and the second group with VTC. After 2 weeks of radiotherapy, second group observed the reduced levels of Grade 3 dermatitis. It indicated that Sandalwood oil has the curative potential against Grade 3 dermatitis. Rao et al. (2017) stated that the certain benefit of VTC is due to having sandalwood oil and turmeric in preventing radio dermatitis in women undergoing curative radiotherapy for their breast cancer.

5.4.6 Anti-Hyperglycaemic and Anti-Hyperlipidaemia Effect

Petroleum ether fraction of Sandalwood when administered orally for a long duration showed anti-hyperlipidaemic and anti-hyperglycaemic effects in streptozotocin-mediated diabetic rats. A drastic decline in the blood glucose level was observed. Metformin treated group also presented a decreased blood glucose levels as against the increased levels in the diabetic control group. In addition to blood glucose, low density lipoprotein, total cholesterol and triglyceride levels were also reduced, and cardio-protective high density lipoprotein levels were increased in the treated rats. It was concluded that Sandalwood has the potential anti-hyperglycaemic and anti-hyperlipidaemic activities (Kulkarni et al. 2012).

5.4.7 Effects on Central Nervous System

Several research findings have stated that Sandalwood is an excellent memory enhancer (Jackson et al. 2009; Biradar et al. 2009). Studies on sedative effect have shown that inhalation of East Indian Sandalwood oil decreased the motility of mice to an extent of 40–78% compared with 0% control (Khanna et al. 2004). Battaglia (2007) reported that Sandalwood oil relaxes the nervous system and reduces psychological traumas such as insomnia, headache, tensions, anxiety and emotional aerosols. Sandalwood oil and aqueous extract are generally used as sedatives (Okugawa et al. 1995; Joshi et al. 2013). Santalols, the bioactive principles are reported to have depressant activity on central nervous system (CNS) and hence administered patients suffering from insomnia (Ohmori et al. 2007). It is very exciting to recognize that synthetic Sandalwood compounds and Sandalwood oil stimulate the olfactory receptor neurons (Bieri et al. 2004). In addition to these, neuroleptic property of different solvent extracts of heartwood has been reported in mice. Both α- and β-santalols suggestively increased the levels of 5-hydroxyindoleacetic acid, 3, 4-dihydroxyphenylacetic acid and homovanillic acid in the brain of mice, when administered through intragastric and intracerebroventricular routes. α-santalol acted as a strong dopamine D2 and serotonin 5 HT2A receptor binding antagonism (Okugawa et al. 1995). As an antipsychotic agent, α-santalol effects were similar to that of chlorpromazine (Okugawa et al. 2000). α-santalol promoted substantial physiological changes, including sedative and relaxing influences, whereas Sandalwood oil instigated physiological deactivation, however activated behavioural changes after transdermal absorption (Hongratanaworakit et al. 2004). Likewise, α-santalol was shown to exhibit a superior inhibitory activity on both cholinesterase and tyrosinase enzymes, and thus Sandalwood can be used as one of the potential candidates for treating Alzheimer's disease and preventing hyperpigmentation of the skin (Misra and Dey 2013a).

Mohankumar et al. (2018) examined the protective effects of East Indian Sandalwood oil, α- and β-santalol against proteotoxic (α-synuclein) and neurotoxic (6-OHDA/6-hydroxydopamine) stress conditions in a model organism, *Caenorhabditis elegans*. Their results showed that East Indian Sandalwood oil and its bioactive compounds exerted superior anti-apoptotic and free radical scavenging activities by prolonging the life span, and prevented the reactive oxygen species production, and germ cell apoptosis in *C. elegans* intoxicated with 6-OHDA. Adding East Indian Sandalwood oil and α- and β-santalol curtailed the α-synuclein- and 6-OHDA-encouraged Parkinson's illness related pathological conditions and upgraded the physiological functions. Further, the gene expression studies have shown that East Indian Sandalwood oil, or α- and β-santalol arbitrated protecting effects involve ERK-MAPK signal pathway and mitochondrial electron transport chain, and not through DAF-2/DAF-16, the key genes that are involved in the genetic pathways, mediating endocrine signalling. In addition, East Indian Sandalwood oil, or α- and β-santalol selectively controls SKN-1 and its downstream targets that resist against neurotoxic and stresses. They have suggested geroprotective and neuroprotective mechanisms of East Indian Sandalwood oil, α- and β-santalol on *C. elegans* (Fig. 5.2).

5.4.8 Other Uses of Sandalwood

Khan et al. (2014) examined that the water extract of Sandalwood inhibits significantly the cardiac tissue damage against doxorubicin induced cardiotoxicity in rat model. Also, it showed significant protective effect against isoproterenol-stimulated myocardial infarction in Albino Wistar rats in a dose-dependent manner. The oral administration of the hydro-alcoholic extracts of Sandalwood was effectively tolerated both physical (stress) and chemical induced gastric ulceration in rats (Ahmed et al. 2013). The Sandalwood oil (at a dose of 200 mg/kg) revealed significant anti-pyretic effects against yeast-induced pyrexia in Albino rats (Desai and Hiremath 1991). Sandalwood oil was shown to exhibit superior repellent activity to the pest, *Varroa jacobsoni* (ectoparasitic mite) in honey bee colonies. Hence, it can be used as an acaricide. Also, Choi et al. (2006) described the modest property against *Lycoriella mali*, a mushroom-infesting fly. Sandalwood oil is used to cure major burns as it contains anti-septic properties (Bhowmik and Sampath Kumar 2011). It also impedes the prompt of the growth and development of leukocytes. Sandalwood oil acts as an expectorant and used in bronchial infections and cough. Sandalwood oil is effective in healing some neurotical problems, such as sciatica and lumbago. Sandalwood oil is utilized as a fragrant agent in several products, such as soaps, cosmetics and perfumes (Deite 1892). Sandalwood oil's tranquillizing effect makes it more helpful for meditation as it encourages a feeling of deep harmony. The application of Sandalwood oil raised systolic blood pressure, skin conductance level and pulse rate. In addition, it encouraged to attain higher levels of alertness and mood in humans. Sandalwood is also used as a sex tonic and aphrodisiac. It is also used as a decongestant, anti-infectious, anti-depressant agent (Coombs 1995). Sandalwood paste and oil are generally employed as cooling agents which dissipate heat from the body. And it also enhances beauty by making the skin glow. The scent of the essential oil has also been said to calm the mind and acts as a mood enhancer

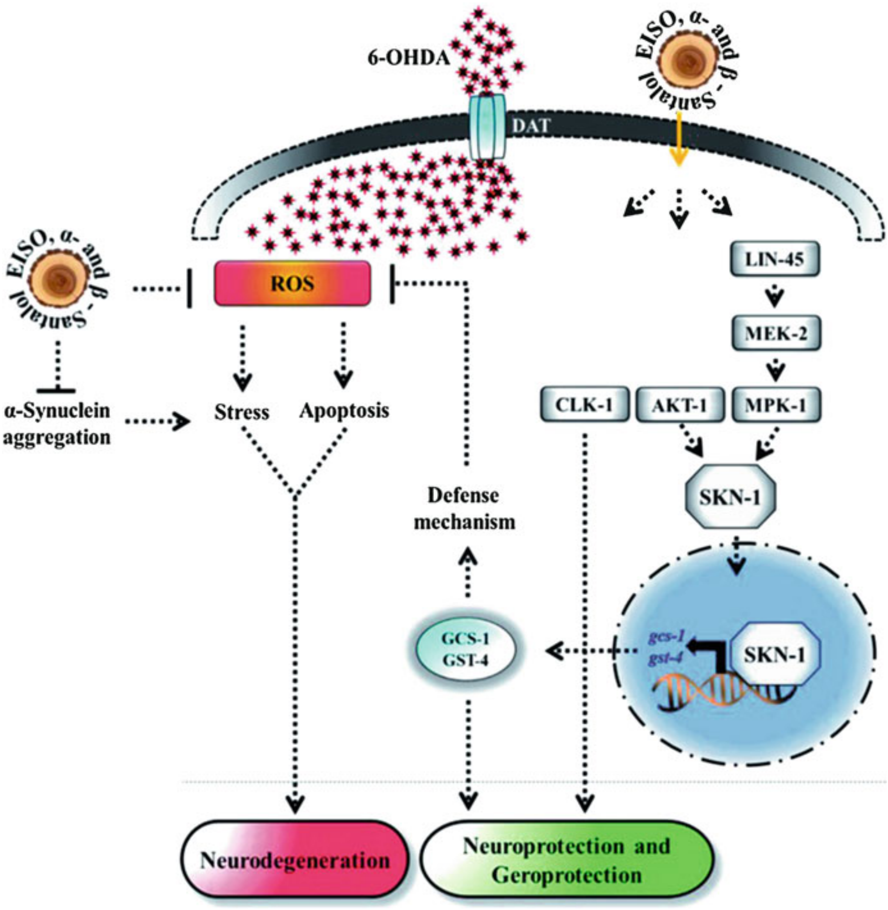

Fig. 5.2 The proposed neuroprotective and geroprotective mechanism of EISO and its active components on *C. elegans*. East Indian Sandalwood Oil (EISO) and santalol isomers likely acted through AKT-1 and ERK-MAPK mediated SKN-1 dependent pathway, which transactivates the stress-responsive genes *gcs-1* and *gst-4* that enhanced the tolerance to stress and extend the mean lifespan. The direct antioxidant activity, α-synuclein inhibitory potential, anti-apoptotic activity, and CLK-1 dependency of EISO, α- and β-santalol can also contribute for the reduction of neurodegeneration and longevity extension in *C. elegans* (Adapted from Mohankumar et al. 2018)

(Rajsmitha and Keshavamurthy 2019). Sandalwood oil is effective in treating liver and gallbladder complaints, dysentery, piles, inflammation of mouth and pharynx. It is used as a digestive and muscle relaxant. It also cures chronic colds and cough, scabies and urinary infections, expectorant, stimulant and carminative (Burdock and Carabin 2008). Application of Sandalwood oil is an effective remedy for acne and tinea. Research findings reported that Australian sandalwood oil was effective than tea tree oil to cure gonorrhoea when taken orally or external application. It acts as potent antibacterial agent against *Candida*. Also, the inhalation of Sandalwood oil can help in calming and improving the respiratory system (Nautiyal 2019). Sandalwood oil has also shown a promise in human clinical trials for treatment of acne, psoriasis, eczema, common warts and *Molluscum contagiosum* (as reviewed by Moy and Levenson (2017)).

Sandalwood oil is commonly accepted as safe for the use as a flavouring ingredient in food by the Food and Drug Administration (FDA) of United States and Council of Europe (CoE 2000). It is also recognized by the Flavor and Extract Manufacturers Association, and the FDA also recognizes sandalwood oil as a natural flavouring agent (https://www.drugs.com/npp/sandalwood-oil.html; Kuriakoje et al. 2010). Sandalwood oil is employed as a natural flavouring agent in most of the food products, mainly frozen dairy desserts, alcoholic and non-alcoholic beverages, puddings, baked goods and confectioneries. Generally, the admitted levels of Sandalwood oil are below 0.001% (10 ppm). High levels of Sandalwood oil (98.89 ppm) are administered for hard candies. The maximum permitted levels of Sandalwood oil in foodstuffs are nearly at 90 ppm (Burdock and Carabin 2008).

5.5 Adulteration and Authentication of Sandalwood

The escalating demand for Sandalwood oil and non-availability of good quality trees keep rising the cost at an alarming rate. Hence, it became the most adulterated essential oil (Kuriakoje et al. 2010). As a result, the British Pharmaceutical Codex regulatory agencies are facing a severe problem to prevent the adulteration. Adulteration of Sandalwood oil leads to so many health complications. Addition of adulterants to the Sandalwood oil changes the composition of volatile chemo-constituents, physical properties, quality of the Sandalwood oil, and exhibits potential allergic reactions. Low grade essential oils from the other species of *Santalum*, castor oil, cedar wood oil are informed as the regular adulterants (Anonis 1998).

The Sandalwood oil can be blended by adding the essential oils obtained from different species of *Santalum* genus, other than the *S. album.* The essential oils that are generally mixed with the Sandalwood oil are copaiba (*Copaifera langsdori*) oil, amyris (*Amyris balsamifera*) oil and Atlas cedar (*Cedrus atlantica*) fractions (Nautiyal 2019). Artificial Sandalwood can be prepared by adding synthetic Sandalwood oil essence to the odourless essential oils. Another method of adulteration is the stretching, where odourless essential oils are mixed with the Sandalwood oil to increase the volume. Synthetic derivatives of β-santalol are commonly used as adulterants in Sandalwood oil.

Various synthetic chemical compounds derived from β-santalol are mixed with the actual Sandalwood tree. The production of synthetic Sandalwood oil is not a simple process. Adding the similar chemical compounds is not enough to make substitute for Sandalwood oil. So many synthetic essential oil manufacturers have been trying to bring the right substitute for the Sandalwood oil for many decades. The proposed substitute for Sandalwood oil must have all the qualities taste, odour, colour, etc. The available synthetic chemical compounds which are almost similar to Sandalwood oil are the α-campholenic aldehyde derivatives, originated from α-pinene, a less expensive product expelled as a by-product in the paper manufacturing industry. The flavour of α-campholenic aldehyde derivatives is almost comparable to Sandalwood oil (Nautiyal 2019).

Nowadays getting authentic pure Sandalwood oil is becoming very difficult as the demand is ever increasing. Hence, it gives a scope to adulterate with so many chemical compounds that may cause side effects. It is the primary responsibility of the perfumery industries, pharmaceutical companies and government authorities to check the adulterations of Sandalwood oil. Sandalwood oil producing companies must assign standard marking like hallmark for gold. There are several methods to test the purity of Sandalwood oil. Sandalwood oil adulteration can be easily detected by professionals or chemists through the application of advanced technology to analyse. Without having any machinery, a skilled person can recognize the pure Sandalwood oil, simply by its aroma (Nautiyal 2019).

The recommended levels of total free alcohols, calculated as santalols in the Sandalwood oil should not be lesser than 90% w/w. The validation of santalol content in Sandalwood oil by the described acetylation method generally lacks the specificity and accuracy (FCC 2003; Nautiyal 2019). Kuriakoje et al. (2010) identified the Sandalwood oil adulteration by using Near Infrared (NIR) analysis. In addition to this, they used multivariate calibration models like the partial least square regression and principal component regression as rapid analytical techniques. By using NIR spectroscopy with chemometric methods, even 1% of adulterants (low grade oils) in the Sandalwood oil can be effectively identified. Moreover, it is very simple, non-destructive, instant and rapid process.

The development of improved novel, rapid and non-destructive approaches is in the present day demand for determining the adulterants, instead of time-consuming old analytical techniques, which are not economical. Nautiyal (2011) evaluated the quality of Sandalwood oil using different techniques. The Sandalwood oil's quality depends on the international standards, (ISO 22759:2009) and (ISO-FDIS 3518:2001) for *S. spicatum* and *S. album*, respectively. Undeniably, all Sandalwood offered in the present market is not 100% genuine, and there is a scarcity of true *S. album* species. Mainly, santalol isomer is considered as the choice for Sandalwood oil quality evaluation, and the occurrence of $<90\%$ santalol content fulfils the quality. Routinely, GC study is the preferred analytical technique for assessing the essential oil quality (Nicolas et al. 2011; Nautiyal 2019).

The common Sandalwood adulterants found in Indian marketplace are the *Osyris wightiana* (Santalaceae), known as 'Nepal sandalwood' and *Erythroxylum monogynum* (Erythroxylaceae), known as 'Indian bastard sandal' (Anupama et al. 2012). The wood colour, grain and scent of Sandalwood and *O. wightiana* differ only slightly, thus making it difficult to distinguish them. The heartwood of *O. wightiana* is indistinctly aromatic, and used to adulterate Sandalwood (Shyaula 2012). The heartwood of *E. monogynum* possesses a pleasant scent and appears to be reddish-brown, and hence commonly used for adulteration (Oyen and Dung 1999). DNA barcoding can be used to identify the market adulterants of Sandalwood timberwood (Arun Suma et al. 2014). The typical DNA barcodes, i.e., chloroplast genomic sequences, such as the rbcL, trnH, −psbA and matK suggested by the

Consortium of Barcode of Life (COBOL) were investigated to differentiate wood adulterants of Sandalwood. SNPs (Single Nucleotide Polymorphisms) recognized with trnH, −psbA and rbcL sequences of *E. monogynum* and matK sequences of *O. wightiana* might be resourcefully exploited for detecting or checking Sandalwood adulterants.

5.6 Conclusions and Future Prospects

Sandalwood, a semi-parasitic tree is one of the most economically valued tree species, only after *Dalbergia melanoxylon* (African blackwood). Sandalwood oil, extracted from the tree heartwood is accepted as standards by the International Organization for Standardization (ISO). Sandalwood oil is majorly used as a flavouring for foodstuffs and liquid refreshments, and as a perfume in cosmetics, incense, ointments and detergents. In the traditional medicinal systems of the world, it has been used for treating numerous health issues. The essential oil constitutes nearly 90% santalols, i.e., α-santalol (up to 49%), β-santalol (up to 33%), α-trans-bergamotol (up to 5%) and epi-beta-santalol (up to 7%). Mainly, the santalols are accountable for the pleasing odour of Sandalwood, even though 2-furfuryl pyrrole might also add the effect.

Today, the oil is infrequently used pharmaceutically, however its extensive usage as a prevalent essence continues. Numerous in vitro and in vivo investigations have been performed to witness the medicinal values of Sandalwood and its essential oil. Sandalwood products possess anti-microbial activities, and found to be effective in inhibiting several drug-resistant microbial species. Both oil and its major compound, α-santalol exhibit chemo-preventive activities against many cancers. The molecular mechanisms of actions of such antitumour effects are credited to modifications in major cancer signalling pathways, including AP-1, MAPK, PI3K/Akt and β-catenin pathways, in addition to the caspases/PARP activation and p21 up-regulations. Further, α-santalol impedes cell proliferation via inducing G2/M phase cell cycle arrest. Further, investigations suggest that Sandalwood oil may be useful for treating ailments related to anxiety, central nervous system, cardio-metabolic risks, liver damages, etc. However, reliable clinical data concerning the usages of Sandalwood oil for the treatment of the above said health problems are limited, and hence requires more focus in this regard. In general, Sandalwood oil has a tolerable safety profile.

In recent times, Sandalwood adulteration is one of the major challenges as the demand for its products is rising in the world market. Some of the techniques such as DNA barcoding technique and NIR analysis can trace the adulterants of Sandalwood. However, future research should also consider in developing more such improved rapid analytical methods to complement the authentication of Sandalwood samples. Investigations, involving animal models should be encouraged to identify the toxicity and safety characteristics of Sandalwood and its compounds. Additionally, beneficial prospects of several novel bioactive compounds from Sandalwood using both in vitro and in vivo models must be explored in detail.

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Wood Property Variation in Sandalwood

6

E. V. Anoop, Pavin Praize Sunny, and M. C. Anish

Abstract

Sandalwood (*Santalum album* L.) a prestigious timber species in India is considered as one of the most precious plants in the biosphere. The heartwood of the tree is a treasure trove of santalol, which gives it a distinct and unique aroma, and is best suited for carvings and handicrafts. Sandalwood oil is widely used in perfumes, cosmetics, and ayurvedic medicines. The monopoly of Sandalwood trade by the Governments of Karnataka, Tamil Nadu, and Kerala and its consequences have resulted in severe exploitation to drive Sandalwood into the vulnerable grouping of the International Union for Conservation of Nature Red List of Threatened Species. The inherent variability in different wood properties, and also the chemical components inside the wood enhances its versatile utility. The highly priced heartwood is commercially used to extract the essential oil by using the process of distillation. A considerable genotypic variability in wood properties exists across different sites. It is imperative that a deeper understanding of the relationship between wood properties and rate of growth of Sandalwood will help to prioritize the important traits, while selecting superior plus trees for tree improvement programmes. This chapter attempts to understand the variation in wood property of Sandalwood which will help in the efficient utilization of the species for varied end uses.

Keywords

Chemicals · Heartwood · Oil · Sandalwood · Variability · Liquid gold · Conservation

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6.1 Introduction

Santalum album (Sandalwood or sandal tree) is an evergreen semi-parasitic tree renowned for its fragrant heartwood, and is synonymous with ancient Indian culture and heritage (Srinivasan et al. 1992; Kumar et al. 2016). The south Indian states of Tamil Nadu and Karnataka together account for more than 90% of the natural population of Sandalwood in India (Dutt and Verma 2005; Kumar et al. 2016; Sandeep et al. 2020). Sandalwood is found naturally in the dry-deciduous forests of south India and other parts of the country, and the wood of which is of superior quality compared to wet tropical homestead grown trees in south India. Incidentally, the last remaining largest natural tract of sandal is found in the natural forests of Marayoor forest division of Idukki district, Kerala. Traditionally high-quality Sandalwood is used for extraction of the precious Sandalwood oil which is often called 'liquid gold'. Other uses include costly carvings for handicrafts, medicinal, cosmetics and even as 'fuel wood' for funerals and for making sandal paste in Hindu temples across the state. The demand for this high-quality Sandalwood far exceeds supply and hence each auction held at Marayoor Forest division fetches record prices.

The production of Sandalwood in India dropped from 4000 tonnes heartwood per year in the 1950s to a mere 500 tonnes in 2007, despite global annual demands of 5000–6000 tonnes for its wood and 100–120 tonnes for its oil, respectively (Gairola et al. 2008). Illicit felling and smuggling are very rampant, and are the major problems in the sandal tree-growing states. High economic value of Sandal wood provides sufficient incentives to farmers for growing this tree on a commercial scale. However, the area under sandal tree is decreasing fast, because of illicit felling coupled with the difficulty in field establishment of sandal trees in new areas. India had been the leader in Sandalwood oil production for perfumes and pharmaceuticals from time immemorial (Hansda 2009). The wood was imported to ancient Egypt for the purpose of preparation of medicines, for embalming the dead, in ritual burning to venerate the gods, etc. (Burdock and Carabin 2008). The studies on wood properties (such as anatomical, physical, and biochemical, etc.) in sandal are of great relevance, because of the wide genetic diversity base that it possesses. This will facilitate initiation of massive tree improvement programs of the species (Kumar et al. 2012), which are few and far between in the country. Sandalwood, in its usual zone of distribution needs a critical attention, mainly the need for conservation of its natural habitats, preventing the loss of genetic diversity loss, because of meticulous exploitation, bio resource development problems, and other pertinent challenges.

The importance and value of Sandalwood is predominantly dependent on the volume of its heartwood, the oil concentration and superiority (Doran et al. 2005; Brand and Pronk 2011). In turn, the superiority of Sandalwood oil is governed by, mainly two chief sesquiterpene alcohols, namely α-santalol and β-santalol) that are responsible for the pleasant characteristic aromatic odour. As recorded in the standard documents (ISO 2002; Howes et al. 2004), the blend of these two chemical compounds accounts up to 90% of the total volatile compounds from the wood.

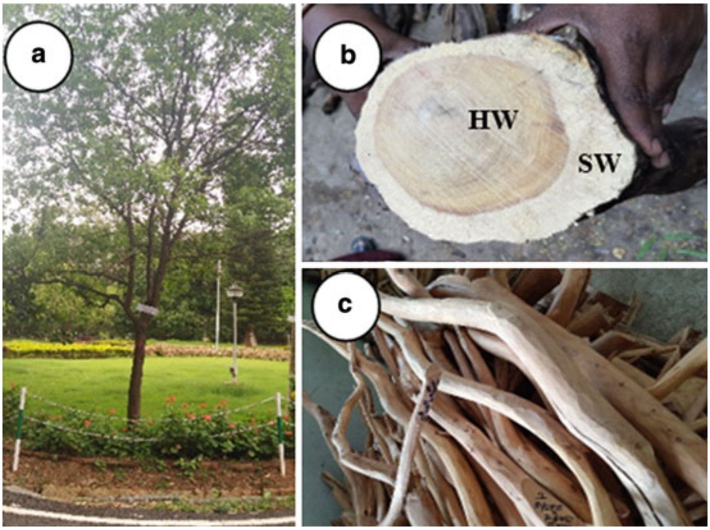


Fig. 6.1 (**a**) A Sandalwood tree grown in IWST, Bangalore, India, showing optimum growth; (**b**) Sandalwood disc showing darker heartwood (HW) and paler sapwood (SW) in periphery; (**c**) Sandalwood billets stored in a depot at Marayoor, Kerala (Photos by M.C. Anish)

Heartwood contains the maximum oil concentration and the highest quantity of santalols (Verghese et al. 1990; Baldovini et al. 2011). With ageing, Sandalwood oil content rises as more and more heartwood is developed over a period. A group of enzymes known as sesquiterpene synthase decides biosynthesis of the sandalwood sesquiterpenes. Though the enzymes are genetically controlled, sesquiterpenes biosynthesis may also be controlled by many factors, including environmental regulatory or genetic v/s environmental factors (Jones et al. 2008, 2011).

Unlike other commercial timber species, the unique characteristics of Sandalwood (Fig. 6.1), such as its ability to grow under diverse ecological conditions, relatively short duration of juvenility, prolific coppicing ability, etc., portrays the immense potential of this species for tree improvement (selection, breeding and silvicultural manipulation). Therefore, a comprehension of wood property variation in such an important species will enhance the interest for its mass multiplication which in turn will bridge the national and international level demand–supply gap.

This chapter attempts to convey an awareness into the wood property variation in Sandalwood (Fig. 6.2), with particular emphasis on the anatomical, physical, and chemical properties of this highly priced species, the natural population across its natural range of distribution dwindling and now restricted to a few patches in south India. A deeper understanding of the wood properties and the extractive content (santalol) within it will help in better utilization as well provide basic information for tree improvement programmes of this species.

Table 6.1 Classification of Sandalwood based on wood quality (source: Kumar et al. 2012)

S. No.	Class	Description	Fixed price (in rupees in lakhs) per metric tonne of wood for the year 2010–2011
1	Vilayat Budh (class I billets)	Sound billet weighing not less than 9 kg and not exceeding 112 pieces per tonne	41.00
2	China budh (class II billets)	Slightly inferior billet weighing less than 4.5 kg and not exceeding 224 pieces per tonne	41.00
3	Panjam (class III billets)	Billets having small knots, cracks and hollows weighing not less than 2.2 kg and not exceeding 448 pieces per tonne	37.00
4	Ghotla (billets of short length)	Includes short and sound pieces. There are no limits of weights and numbers per tonne	41.00
5	Ghatbadla	Billets with knots, cracks, small hollow, weighting not less than 4.5 kg and not exceeding 250 pieces per tonne	41.00
6	Bagardad	Consists of solid pieces without limit as regards dimensions, weight or number	39.50
7	Roots (class I)	Pieces weighing not less than 6.75 kg and not exceeding 150 pieces per tonne	36.25
8	Roots (class II)	Consists of pieces weighing not less than 2.25 kg and not exceeding 448 pieces per tonne	37.40
9	Roots (class III)	Consists of small and side roots below 2.25 kg in weight	33.70
10	Jajpokal or Badla (class I)	Consists of hollow pieces weighing not less than 3.10 kg and not exceeding 320 pieces per tonne	40.75
11	Jajpokal or Badla (class II)	Hollow pieces weighing not less than 1.3 kg	37.10
12	Ainbagar	Consists of solid, cracked and hollow pieces weighing not less than 450 g	40.10
13	China Sali or large Chilta	Consists of pieces and chips of heartwood weighing not less than 2.25 g	32.20
14	Ain Chilta	Consists of small pieces of heartwood	28.20
15	Hatri Chilta	Consists of heartwood and chips obtained by planning billets with Hatri or Randha (plane)	19.00
16	Milva Chilta	Consists of pieces and chips having fair proportion of heartwood and sapwood	15.50
17	Basola Bukni	Consists of small heartwood and sapwood chips	11.50
18	Saw dust	Sawn powder obtained while sawing the sandalwood	7.50

Fig. 6.2 Classification of Sandalwood based on Wood quality—for legends see Table 6.1 (source: Kumar et al. 2012)

6.2 Physical Properties of Wood

6.2.1 Specific Gravity

Specific gravity/density is one of the physical property that impacts most other wood properties, and is measured as a trustworthy indicator of wood quality. This property in turn reflects the quantity of wood matter per unit volume of wood, and hence is a factor that influences the quantity of wood biomass (Wiemann and Williamson 2013). It also determines the economic utility of wood, and it differs within species in each region and between regions. Wood density is considered as the single best identifying factor of wood, which associates with several ecological, mechanical, and physiological properties. The specific gravity of Sandalwood ranges from 0.87 to 0.91 (Rao et al. 1998). The quantification of variation in wood weight of Sandalwood is chiefly controlled by its age, higher aged trees, being denser due to the larger proportion of heartwood that it contains. The juvenile, mature and its interface are characterized by large variation in wood traits like density (Kumar et al. 2012).

6.2.2 Shrinkage and Swelling

Shrinkage and swelling, affected due to the anisotropic behaviour of wood is a key factor in utilization of any wood species. This behaviour is caused because of the complex swelling or shrinkage phenomenon associated with the adsorption or desorption of bound moisture lower than the fibre saturation point (Okuma 1998). There may be several reasons for the limited availability of data on these physical traits of Sandalwood, such as price of wood, limitations of destructive sampling, existing legal frameworks, etc.

Many variables affect the rates of shrinkage and swelling associated with these environmental changes; for example, the rate of movement differs between species, with the section size (especially thickness), whether the wood is drying down or wetting up and type of surface coatings. A timber species' propensity for movement during climatic changes in its surrounding environment determines its classification as stable or otherwise. Knowledge of the potential for timber components to 'move' is critical for successful design and performance of finished products. Timber products are often sold and used in a very different environment from where they were manufactured. Without due consideration to the potential for movement at the design stage, the product will possibly perform poorly.

6.2.3 Moisture Content

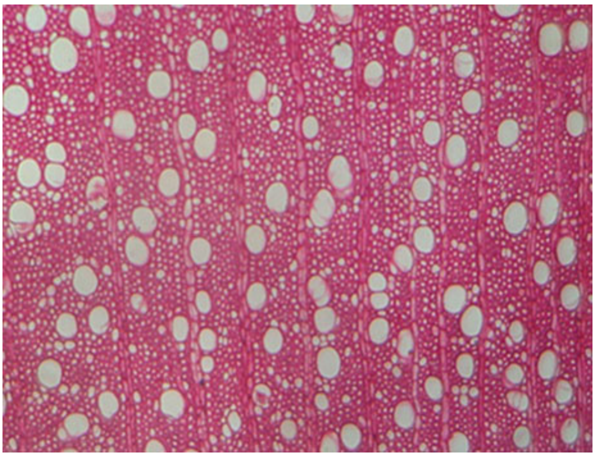
The moisture content in a given portion of wood is articulated to the percentage of weight of the water to its oven dry weight. The moisture content directly influence on physical behaviour, strength, weight, and processing characteristics that impact on its utilization. Generally, the strength related properties rise with reduction of moisture content in any wood without knots. Studies have shown that during the drying of Sandalwood, a significant amount of volatile compounds are lost along with the moisture content. The moisture rich Sandalwood yields more oil than the dried ones. The moisture content of Sandalwood, determined by oven dry method was found to be 12.37%. It was estimated that the initial moisture content of Sandalwood chips varies with atmospheric moisture content in a range up to 2.39% for heartwood and 5.37% for sapwood (Ramaswamy et al. 1953).

6.3 Anatomical Properties

The anatomical characteristics of mature stem wood of Sandalwood are as follows (Fig. 6.3, 6.4, 6.5, and 6.6). Vessels are solitary: small to very small, 50–80 µm in diameter, not visible with hand lens, numerous (30–40 per mm^2). Rays are fine to

Fig. 6.3 Sandalwood (timber gross view)

Fig. 6.4 Transverse section (TS; X4)



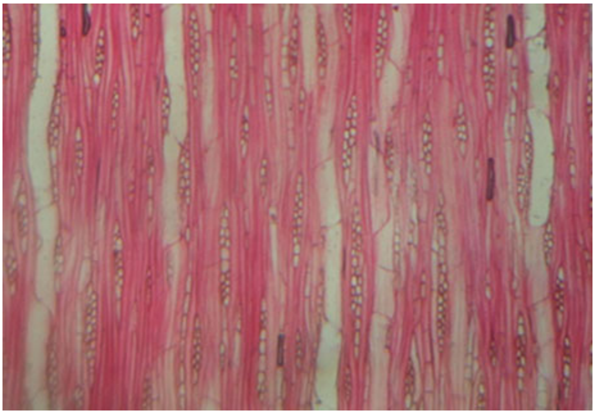


Fig. 6.5 Tangential longitudinal section (TLS; X4)

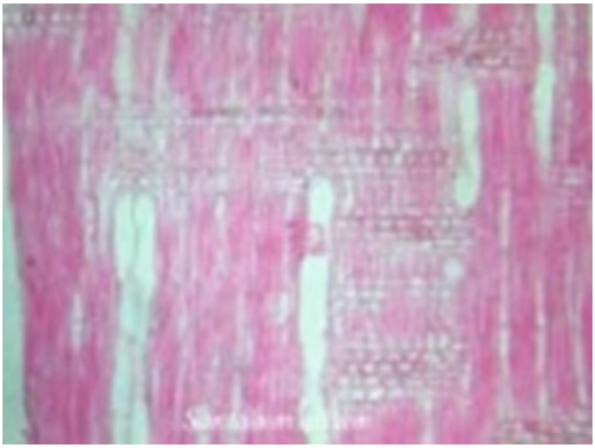


Fig. 6.6 Radial longitudinal section (RLS; X4) (images by authors)

very fine, numerous, and closely spaced. Regarding microanatomy, vessel element length ranges from 300 to 480 μm with a mean of 400 μm. Vessel perforation is simple and the outline is circular to oval. Inter-vessel pitting is alternate; pit outline is polygonal in shape. Pits are non-vestured and medium-sized (6–9 μm). Vessel-ray pitting is similar to inter-vessel pitting, sometimes with a much-reduced border. Parenchyma are diffuse, scattered in arrangement and in aggregates of 3–4 cells in a line, crystals occasional solitary or in 4–6 locules, infrequent, scanty, and paratracheal. Rays are 1–2 seriate, fine to very fine (Anoop et al. 2005). Number of rays per mm is 6–9, heterogeneous, 1–3 seriate, composed of procumbent and upright cells. Height of rays ranges from 200 to 420 μm with an average of 295 μm. Chambered crystalliferous cells are present in the axial parenchyma. Fibres are thin to libriform, non-septate with bordered pits on radial and tangential walls. Length of fibre ranges from 920 to 1380 μm with a mean of 1160 μm.

The root wood consists of vessels which are very small to extremely small, 36–72 μm in diameter, 66–71 per mm^2, mostly solitary, round to oval, without tyloses and deposits, perforation is simple, intervascular pitting small (4 μm) and vessel members 180–450 μm in length. Parenchyma are diffuse and also diffuse in aggregates, strands of 2–4 cells, crystals are present. Fibres are thin to thick walled, non-septate, 990–1512 μm in length and 13–23 μm in diameter, interfibre pits are numerous and bordered. The number of rays is 9–11 per mm, heterogeneous, 1–3 seriate mostly, composed of upright and procumbent cells, 36 μm in width and up to 21 cells or 324 μm in height (Rao et al. 1998).

The anatomical properties of a tree will be influenced significantly in varying degrees by genetic and environmental factors. Horizontal and vertical deviations of wood anatomical properties of a tree's main stem are habitually somewhat large, and have been revealed to be strongly interrelated to juvenile and mature wood formation (Larson 1962, 1964). Mature wood and juvenile wood production is due to the activity of the vascular cambium, which results in two different types of wood with drastic differences in behaviour and uses.

6.4 Different Sources of Wood Variation

Wood is a variable substance with the occurrence of differences amongst species and genera. A species varies with geographical sources, and also even between trees within a location. Sandalwood exhibits significant variability for many traits, such as heartwood proportion, oil content, bark characteristics, etc. Besides the above-mentioned attributes, the Sandalwood with its high coppicing capacity could be cultivated under diverse ecological conditions, with short duration of juvenility, features it as a preferable species for tree breeding trials. Jayappa et al. (1995) reported that there exists variation in the heartwood oil (composition) extracted from the trees of different locations. Study on the heartwood formation showed significant tree to tree variability within a locality and girth classes of Sandalwood (Srimathi and Kulkarni 1980). Thus, the variation in Sandalwood is attributed to the external factors like site conditions, environment and silviculture treatment, in addition to the genetic makeup of the tree. According to Kumar et al. (2012), the creation of a baseline data on the relationship between the heartwood and oil content, variation across age and location will be a reliable information for identification of superior genotypes. In Sandalwood, the tree girth or diameter is found to be a relevant indicator for genotypic selection in tree improvement programmes. Also, there are observations to show that in the case of Sandalwood, heartwood development is more closely allied to the tree's age rather than tree's diameter. Further, Kumar et al. (2011) recommended that superior genotypes among Sandalwood could be identified at an intermediary stage between juvenile and mature phases of the tree.

Quantifying variation in heartwood diameter and oil concentration in Sandalwood is another important aspect or the species improvement programmes in Sandalwood. Information on available range of variation in the desired traits facilitates selection of superior genotypes and paves the way for Sandalwood domestication in the long run. In a study by Kumar et al. (2011) in a Sandalwood plantation at Hoskote, Karnataka, considerable variation has been recorded for tree diameter, heartwood diameter, and oil percentage. Heartwood diameter varied from 1.34 to 9.55 cm (4.83 ± 2.46 cm), with 36% of the trees falling in the diameter class 4.98–6.81 cm. Only 13.61% of the trees had heartwood diameter more than 6.81 cm. Additionally, the data generated allow quantifying the relationship between the measured traits. Similar to these findings, a resilient positive association between heartwood diameter and tree diameter was observed in an uneven aged population of a similar species named *Santalum austrocaledonicum* found in the islands of Vanuatu. Accordingly, heartwood oil accumulation in Sandalwood is positively correlated to the tree age while it is independent of the heartwood growth. The same study also indicated that the harsh growth conditions have only limited influence on the oil accumulation in Sandalwood.

6.5 Sandalwood and Its Adulterants

Sandalwood is exceptionally prone to adulteration, and several police cases being booked in this regard, frequently. This species tree materials are generally adulterated with its related and other similar species, however, the dearth of methodological tools required for authenticating species of the source wood has led to difficulties, and even failure by the prosecution to prove the identity of the adulterant species in court cases. The most common adulterant of Sandalwood is the African sandal (*Osyris lanceolata*), and the other being bastard sandal (*Erythroxylum monogynum*).

Bhat et al. (2006) had studied the reliability of using various techniques to differentiate the woods of *Santalum album* and *O. lanceolata.* It was found that ray constitution, type of crystalliferous cells and abundance of extractives are the best wood anatomical features useful for distinguishing *S. album* from *O. lanceolata*. The wood of Sandalwood was found to be distinct from *O. lanceolata*, i.e., the former has 1–2 seriate rays with the presence of crystals in the axial parenchyma cells and scanty extractives, while the latter possess 1- to 3- seriate rays, crystals in ray cells and relatively higher amount of extractive contents. The same study also differentiated both species based on the colour of hot water extract, chemical composition and DNA fingerprinting tools and standardized the species identification techniques to check wood adulteration.

As per the above study, the wood anatomical characteristics that are helpful in distinguishing Sandalwood from *O. lanceolata* include structure of rays, particularly their seriation, occurrence and distribution of crystals, and abundance of extractives within parenchyma cells. Samples of solid wood of Sandalwood and *O. lanceolata* can thus be distinguished from each other based on microscopic features (Figs. 6.7 and 6.8) are as follows:

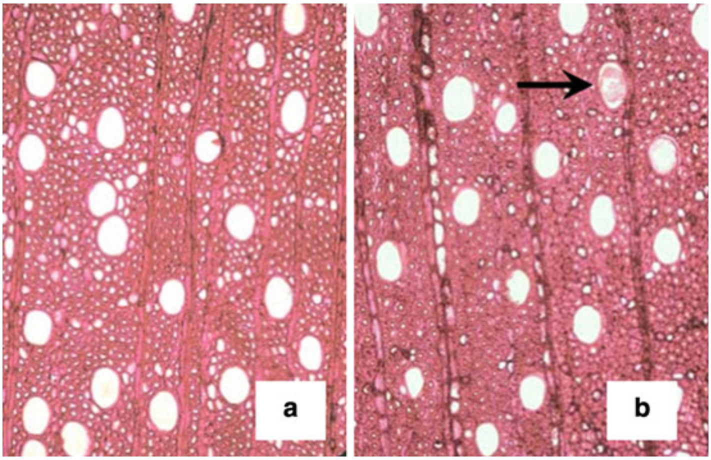


Fig. 6.7 Transverse sections (TS; 90X) of *Santalum album* (**a**) and *Osyris lanceolata* (**b**) (Source: Bhat et al. (2006))

S. No.	Wood anatomical feature	*Santalum album*	*Osyris lanceolata*
1.	Ray structure	Rays 1–2 seriate	Rays 1–3 seriate
2.	Rhomboidal crystals	Confined to chambered axial parenchyma; never found in ray cells	Crystals abundant and found usually in ray cells; rare in chambered axial parenchyma
3.	Heartwood extractives	Extractives scanty in parenchyma cells	Extractives abundant in parenchyma cells

Bhat et al. (2006).

Dev et al. (2014) have attempted the identification of marketplace adulterants of Sandalwood by means of DNA barcoding application. The customary DNA barcode regions of chloroplast genomic sequences (rbcL, trnH-psbA, and matK), acclaimed by the COBOL (Consortium of Barcode of Life) were examined to differentiate wood adulterants of Sandalwood. The outcomes have disclosed that Single Nucleotide Polymorphisms (SNPs) identified with trnH-psbA and rbcL sequences of *E. monogynum* as well as with matK sequences of *O. wightiana* could be resourcefully exploited for identifying Sandalwood adulterants. Amongst these two major adulterants, *O. wightiana* was more similar to Sandalwood, and grouped together in the dendrogram. Their investigation recommended for the use of DNA barcoding technique involving customary barcodes for tracing Sandalwood timber adulterant samples.

A more recent study stated the use of wood anatomy and DNA barcoding for detecting timber adulteration samples in Sri Lanka (Kannangara et al. 2020). According to them, the DNA barcodes, matK-trnT and atpB-rbcL can provide unique polymorphic DNA sequences, having unambiguous lengths for each species.

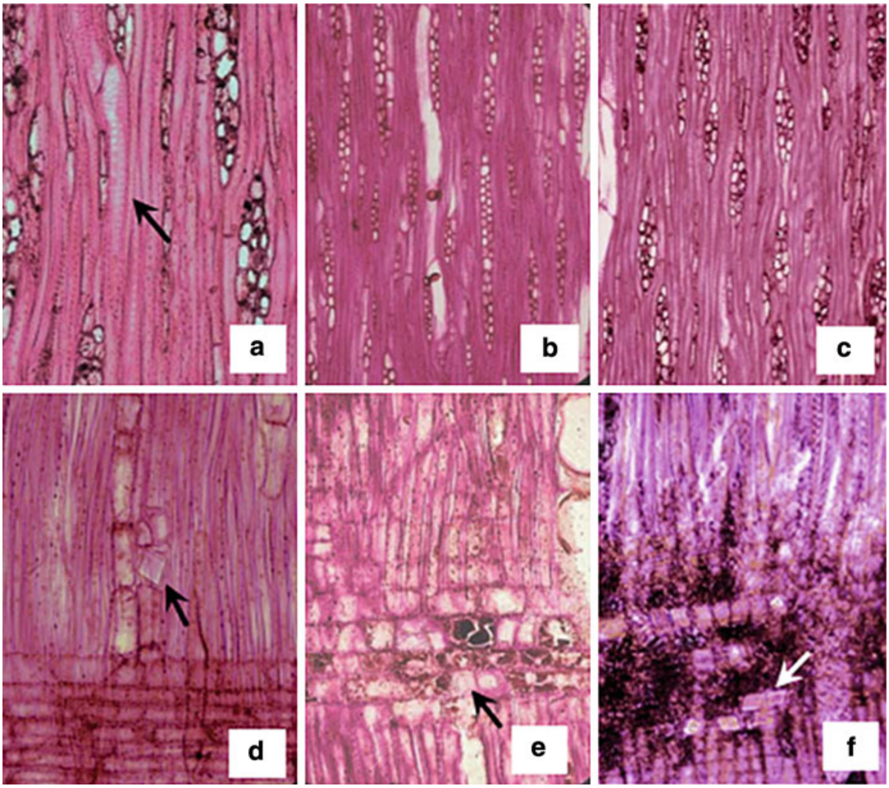


Fig. 6.8 (**a**) TLS of *O. lanceolata* showing tracheids (at arrow). x150. (**b**) TLS of *S. album* showing uni and biseriate rays. x90 (**c**) TLS of *O. lanceolata* showing 1 to 3-seriate rays. x90 (**d**) RLS of *S. album* showing rhomboidal crystals in chambered axial parenchyma cells. x180 (**e**, **f**). RLS of *O. lanceolata* showing rhomboidal crystals in ray parenchyma cells (at arrow). x180 (Bhat et al. 2006)

This approach may permit to authenticate species, and thus preventing the possibilities of timber adulterations.

6.6 Conclusions and Future Line of Work

The need of the hour is to maximize the growth of seedlings, raising plantations of Sandalwood and expanding their distribution range across the country. Unlike plantations of other commercial tree species, those of Sandalwood could act as the core starting point for reinitiating Sandalwood tree improvement programmes. Consistent investments in research, vigilance and dependable plant protection methods are inevitable for the same. It is noteworthy to mention that the tree improvement initiatives on Sandalwood has to widen its scope to the realm of both applied and action researches with a targeted plan of approach, along with the active collaboration of entrepreneurs, end-users, scientific institutions, local bodies, non-governmental organization (NGOs), self-help groups (SHGs), etc. Therefore, a deeper understanding of the relationship between Sandalwood variations will effectively bridge the domestic and global demand–supply gap for Sandalwood. There is a pertinent need to undertake long-term breeding programmes for this high value species, considering its value, uniqueness, and restricted natural populations. Sandalwood acts and legislations that acts as disincentive enacted in the sandal growing states of the country also needs to be done away with to encourage more planting of this species outside the forests, including homesteads.

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Silviculture, Growth and Yield of Sandalwood

7

Sudhir Chandra Das

Abstract

Sandalwood (*Santalum album* L.) tree flourishes well from the sea level up to above 1800 m altitude in different types of soils and climate. Sandalwood is a valuable forest tree, however, its disappearance from the natural habitat is at an alarming rate. Attempts have been taken to cultivate the species in farmlands to increase its production. The productive establishing of Sandalwood plantations and the increase of heartwood and oil extraction from these trees is very critical. The growth of Sandalwood is better in presence of a host plant, though it can grow without a host. Tree growth is the outcome of numerous and enormously complex processes, and it could be in terms of tree height, diameter at breast height, basal area or volume. In many instances, the growth takes place in a certain pattern, and it takes a considerable period to obtain information on growth behavior and to estimate expected yield based on the growth. Yield is proportional to heartwood girth which is dependent on site quality, type of soil, etc., and essential oil's yield and quality vary depending on the area of cultivation and age of the plant. In this chapter, details of geo-climatic factors, climatic conditions, geology, topography and soil, where this tree species is habitually distributed are discussed, comprising natural regeneration, phenological details, and vegetative methods of propagation. Further, aspects of seed dormancy, seed germination, and host-sandalwood parasitism are also detailed. Silvicultural practices like inter-cultural operations and tree improvement are highlighted.

Keywords

Dormancy · Germination · *Santalum* · Silviculture · Heartwood · Hemi-parasite · Collar girth · DBH

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7.1 Introduction

Silviculture is the practice of monitoring the establishment, growth, health, and quality of land covered with trees or forest to meet diverse prerequisites and values of landholders and the public on a sustainable basis (Adams et al. 1994). Silviculture deals with the growth, health, and quality of forests so that forests could be regenerated and managed for the desirable products. It is a set of approaches that are applied for attaining a definite forest managing objectives and to accomplish the application of objectives via manipulating composition and structure of a forest. In some cases in wood production plantations, the aim of silviculture is to increase the growth and quality of prospective crop trees. The term is derived from the Latin silvi (forest) + culture (as in growing) and the silvicultural concept should express the basic principles to local foresters or managers.

Sandalwood is the aromatic heartwood of the genus, *Santalum,* and belongs to family Santalaceae, which includes 30 genera and about 400 species, and many of them are completely or partially parasitic (John 1947). The word Sandal has been derived from Chandana (Sanskrit), Chandan (Persian), Savtador (Greek), and Santal (French). There are references of Sandalwood in Indian mythology, folklore, and ancient scripts. 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 the certain roots of Sandalwood and not on all of them. This plant forms a non-obligate relationship with a number of host plants (Nagaveni and Vijayalakshmi 2004). Wood is used in the treatment of major diseases like fever, piles, hemorrhagic conditions, diabetes, dropsy, mental disorders, management of poisons, and skin disorders. Sandalwood products uses are being widely reported in many literatures. Sandalwood fumigation is indicated in warding off evils and organisms, which contaminate the wounds and hasten the wound healing and keep surgical wards aseptic. There are at least three kinds of Sandalwood, namely White Sandal (*Santalum album*) also called "Sweta Chandana," Red Sandal (*Pterocarpus santalinus*), also called "Rakta Chandana" and interior Sandal, called Ku-chandana (*Adenanthera pavonina*). These plants belong to different species and families and have different properties according to their synonyms. Sandalwood is moderate sized evergreen large shrubs or small tree (*S. spicatum*) to tall tree of 12–15 ft minimum height (*S. album* in India and *S. paniculatum* in Hawaii) and the girth of 1.0–2.4 m (Sen Sarma 1982). Ecologically, Sandalwood adapts well in varied agro-climatic and soil conditions, except in waterlogged and very cold areas. It is believed that Sandalwood is an exotic in India, having been taken there from East-Indonesia by traders of the fragrant wood, and holding a pre-eminent position in the Indonesian island (Malay Archipelago), Timor (Ajaubaki, Siso, Buat, Niki –Niki, Kokoi, and Netpala districts) and to a small extent in Alor, Roti, Sumba, and Flores Islands.

Sandalwood plant is a root parasite in its early stage. It ensures its survivality when host plants are available in its surrounding root zone. It has also been found that host is no more required for its growth and development after 3–4 years (Das et al. 2018). A study was carried out by Jain et al. (1988) on the influence of soil properties and their relationship to Sandalwood's growth in three places. They observed that lime status, water holding capacity, pore space, volume expansion on wetting, exchangeable calcium and magnesium and available potash exert positive influence on the increment in girth and height of trees. Das et al. (2018) found that the higher the organic carbon and macro-nutrients (N, P and K) content of the soil, the better is the growth (both height and girth) and survival of the Sandalwood seedlings.

The silviculture of Sandalwood is very much important to understand growth behavior of the species. The present chapter describes silvicultural features, host-parasite relationship, growth and yield of Sandalwood. Information on growth pattern and expected yield could be of immense importance in selecting appropriate management practices for the desired output.

7.2 Distribution

Sandalwood is spread across the Hawaiian Archipelago in the North (30° N) to New Zealand in the South (40° S). Also, it is distributed through Indonesia in the West to Juan Fernandez Islands in the East. It is assumed that Sandalwood was introduced to India from the Timor, Indonesia (Shetty 1977), though some are of the opinion that it is indigenous to Peninsular India. In the Republic of India, Sandalwood is largely distributed in the Deccan Plateau and the total extent of its distribution is about 9600 km^2 of which 90% (8200 km^2) are in the southern states, mainly Karnataka and Tamil Nadu (Srinivasan et al. 1992). In Karnataka, it covered about 5245 km^2 which account for more than 50% area of the country. It is distributed in the southern part of the state as well as in the northern part of the state. In Tamil Nadu, it is distributed over an area of 3045 km^2, mainly in North Arcot (Javadis and Yelagiri Hills), Salem, Periyar, Coimbatore, and Vellore districts. The dense population exists in Chitteries, Javadis, parts of Shevaroys and Tenmalai hills. Also, Sandalwood is found to be distributed in Andhra Pradesh, Maharashtra, Madhya Pradesh, Orissa, Gujarat, Rajasthan, Uttar Pradesh, and Manipur. In Andhra Pradesh (175 km^2), it is mainly distributed in Chittoor, Kadapa, and Kurnool districts. In Madhya Pradesh (33 km^2), it is found scattered in Forest Divisions of Sehora, Sagar, and Seoni, and in Kerala (15 km^2) in Wynad, Marayoor, and Tenmalai. In Maharashtra (18 km^2), they are spread in small pockets only. In Orissa (25 km^2), it is found in Jeypore, Kalahandi, and Paralakhemundi Forest Division. In Uttar Pradesh, Sandalwood trees occur naturally in small patches in forests, and attempts have been made for its artificial regeneration, i.e., implanting Sandalwood seedlings or seeds after harvesting timber. Only a few thousand trees are located in Kangra valley near Jwaladevi of Himachal Pradesh. Occurrence of Sandalwood has also been reported in Manipur and Gujarat states (ICFRE 1992). The state of West Bengal is cited in the map of occurrence and distribution of *Santalum album* L. in India (Srinivasan et al. 1992). In West Bengal, Sandalwood was introduced in 1960s in the forest complexes, and now it is naturally coming up in parts of Bankura (Hirbundh) and Medinipur (Arabari) districts from the bird droppings in forest and adjoining non-forest areas.

The distribution of Sandalwood is also found outside India, mainly in Sri Lanka and South East Asia (Timor, Indonesia, Malaysia, Cambodia, Vietnam, Myanmar, Thailand, and China), the Pacific (Papua New Guinea, Fiji, New Caledonia, and Hawaii), and to some extent northwest of Western Australia (Kanunurra). This important species is categorized as "vulnerable" by International Union for Conservation of Nature and Natural Resources (IUCN), due to the over exploitation. The tree flourishes well from sea the level up to 1800 m altitude in different types of soils and climate.

7.3 Geology, Rocks, and Soils

Red ferruginous loam is the best suited soil for Sandalwood tree growth. The underlying rock often is metamorphic, and is predominantly gneiss and frequently found on the rocky grounds and on stony or gravelly soils (Troup 1921). Sandalwood is able of grow in varied soil types, especially sandy, clayey, lateritic, loamy, and black cotton soil avoiding waterlogged conditions. The Working Plan for the Sandalwood forests of the Khanapur, Nagargali, and Gujnal Ranges of Belagavi Division in Karnataka described laterite as the most common underlying rock in the higher hills with schist and trap rock on the northwest and an out crop of crystalline limestone on the south-west, respectively. In Malwa plateau of Gulbarga, Bidar in Karnataka and Bhir and Aurangabad in Maharashtra, the principal geological formation is Deccan Trap, consisting of basalt and dolerite capped up in places by laterite (Khan 1957). The soil in the Sandalwood tract is black cotton except in the districts of Bidar and parts of Gulbarga and Bhir, where Deccan Trap being of metamorphic origin contains ferruginous loams commonly called lateritic soils (Khan 1957). The Working Plan of Sarsi-Siddapur Sandalwood growing areas of Karnataka reported the geologic formation as archaic with characteristic features of laterisation. In Coimbatore Central Division of Tamil Nadu, Sandalwood is found in almost every type of soil. It is found in stony red soil along the higher reaches of Moyar valley, on alluvial soil along Hallurhalla, on rich loams in Hulical, Kallar, Jacanare Reserve Forest and shallow gravelly soil on the Melur and Pillurslopes (Jayaraman 1973). Also, it has been reported that Sandalwood occurs on sandy soil of Quilon in Kerala. In a study on soil properties and their relation to Sandalwood growth it was observed that lime status, water holding capacity, pore space, volume expansion on wetting, exchangeable calcium and magnesium, available potash exerts positive influence on the increment of girth and height. Sandalwood requires good drainage and does not withstand waterlogged ground. It is assumed that the heartwood with superior aroma is extracted from the tree growing in dried regions, mostly on red or stony ground. In addition, the yield of essential oil will be relatively higher than those trees grown in fertile regions (Gunther 1952).

7.4 Morphology and Phenology

Sandalwood is an evergreen tree, and being a complete or partial root parasite at the early age, generally grows in the dry deciduous forests of the Deccan Plateau and attains a height of 12 of 15 m and a girth of 1.0–2.4 m with slender drooping along with erect branching (Fig. 7.1a). In the early stage, it grows well under partial shade, but in middle and late stages, it cannot tolerate heavy overhead shade. Its tap root is moderately long and delicate. Lateral roots are fibrous, delicate, and distributed down the main root. Stem is initially green and tender, gradually turns brownish and hard. Bark is reddish brown or dark brown in color, smooth in young trees and becomes rough with deep vertical cracks as the tree matures. Leaves are opposite and decussate, and sometime show whorled arrangement. The shape of leaf varies and six morphological forms have been extensively recognized. They are ovate, lanceolate, elliptic, linear, big, and small (Kulkarni and Srimathi 1982). Color of

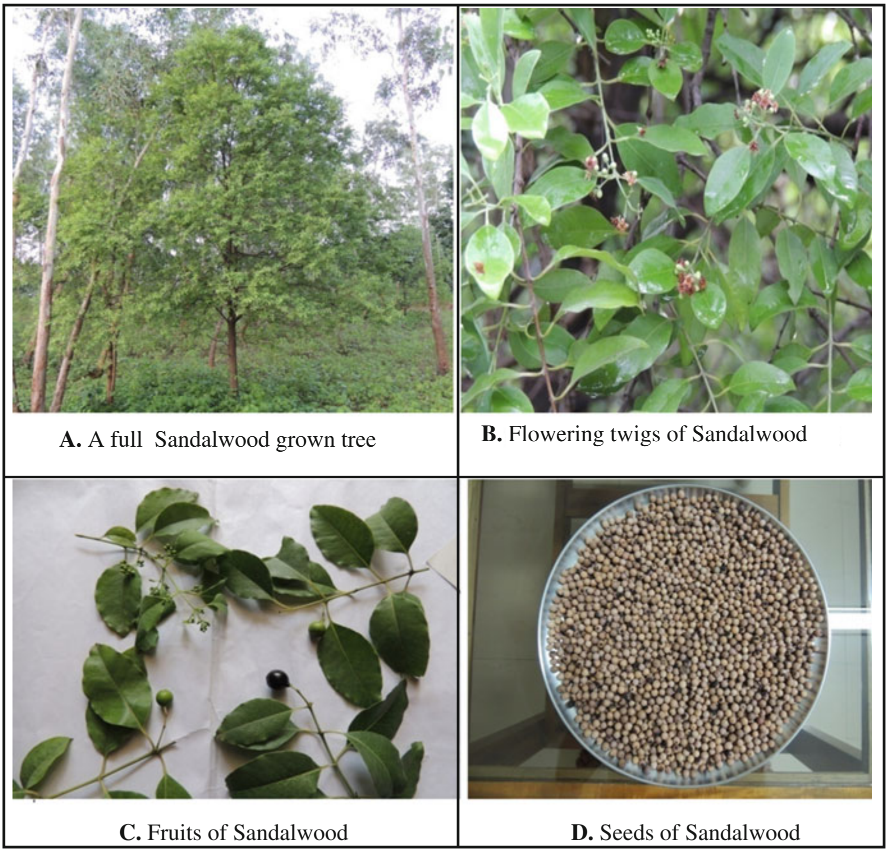

Fig. 7.1 Sandalwood morphology (Photos by: Sudhir Chandra Das). (**a**) A full grown Sandalwood tree. (**b**) Flowering twigs of Sandalwood. (**C**) Fruits of Sandalwood. (**d**) Seeds of Sandalwood

leaves varies from greenish yellow to deep green. Leaf is dorso-ventral, palisade and spongy parenchyma is clearly distinguishable, epidermis is single-layered on both the surfaces and is covered with thick waxy cuticle. Flowers are unscented straw yellow colored at initiation but turns to deep purplish brown on maturation (Fig. 7.1b). They occur in axillary or terminal cymose panicles. The floral organs develop in acropetal succession. Flowers are tetra to pentamerous and hermaphrodite. Flowering sets in at early stage, after 4–5 years of age. Generally, tree flowers two times in 1 year, (1) between March and May; and (2) between September and November. It takes about 30–35 days from initiation of bud to the opening of flower, and the period necessary from the initial stage to ripening of fruit is about 85–95 days. After the sunrise, anthesis is observed, and continues up to midday. Pollen remains viable at room temperature up to 7 days. The stigma remains receptive for 20–48 h. It is a cross-pollinated species.

The fruit is a succulent drupe, purplish black when fully mature and single seeded (Fig. 7.1c). The shape of the fruit varies from globose, ovate to elongate. The color of the fruit changes from green to purplish black at maturity. Fresh purple colored fruits are preferably collected from the trees or those fallen on the ground. The fruits are collected during April–May and November–December. Seeds are obtained by removing the fleshy portion of the fruit (Fig. 7.1d) and are covered by testa. Seeds show polymorphic characters, varying in size and shape. The seeds of both the season are similar in quality. Seeds of all members of Santalaceae possess santalic acid which is a characteristic feature of the family. Sandalwood seeds which exhibit polymorphic form maintain its identity in respect of germination, occurrence, and other characters. Seed weight is 6000 seeds/kg. The seed viability can be maintained for longer period when stored at low temperature (5 °C) in air tight container.

7.5 Seeds and Seed Dormancy

The matured purplish black fruits are collected during March/April and November/December. Fruits are de-pulped by rubbing, dried in shade, treated with fungicide, and stored in air tight container. Freshly collected seeds are dormant for a period of 2 months and remain viable up to 9 months. The failure of apparently ripe seeds to germinate in a suitable environment may be due to single factor or a combination of factors. The main causes of seed dormancy are (1) impermeable seed coat, (2) mechanically resistant seed coats, (3) rudimentary embryos, (4) physiologically immature embryos, and (5) morphologically mature but physiologically dormant embryos. The dormancy in Sandalwood seeds is due to the hard (impermeable) seed coat and presence of phenolic compounds in the seed coat, which hinders germination of the seeds. Physical pretreatments of seeds by soaking in water, alternate wetting and drying, or hot and cold water treatment will not be able to break the dormancy. However, chemical pretreatments of seeds by soaking in 0.05% gibberellic acid overnight can break dormancy and sowing of treated seeds ensures uniform germination up to 60% in 60 days (Nagaveni and Srimathi 1980). It was also reported that chemical treatment of seeds in hydrogen peroxide (1%), indole acetic acid (100 ppm), hydrochloric acid (0.5%), or gibberellic acid (500 ppm) can effectively break the dormancy of seeds and enhance germination. A scarified seed with concentrated sulfuric acid also induces early germination breaking seed dormancy (Nagaveni and Srimathi 1981).

7.6 Seed Germination and Seedlings Raising

Germination is epigeal, radical emerging out by breaking the false seed coat after 20–30 days. The hypocotyl elongates by very pronounced arching, the loop appearing above ground while cotyledons remain underground. Germinations of seeds are very low (15–20%) when the seeds are sown in mother bed (sand beds) after hot and cold water treatment, or alternate wetting and drying due to its hard seed coat and dormancy. Sandalwood seeds have been found to germinate fast when the seed coat is completely removed or seeds are soaked in 0.05% gibberellic acid for 12–16 h (Nagaveni and Srimathi 1981). The duration of germination is much prolonged after the dormancy period in Sandalwood seeds and starts in 25–30 days and reaches hardly 60–70% in 90 days with 0.05% (500 ppm) GA_3 soaking (Table 7.1) for 16–24 h (Das and Tah 2013), but rate of germination is faster from 30 to 60 days and most of the germination takes place within 60 days (Fig. 7.2). Germination of seeds will continue up to 90 days but rate of germination is very slow. Gunaga et al. (2014) found that overnight soaking of seeds in GA_3 solution @300 ppm (68%) and 500 ppm (63%) resulted in better germination over the control (38%) and observed that germination of bird dispersed seeds achieved highest seed germination within short time as compared to de-pulped seeds. The treated seeds are sown in the sand beds (germination beds) @400–500 g/m^2. Traditionally the seedlings at 2–3 leaf stage are transferred to poly-bags of 500 cc capacity or hycopots of 300 cc capacities with a potting mixture of sand, soil, and farm-yard manure FYM in 2:1:1 ratio with *Cajanus cajan* or *Mimosa pudica* as a pot (primary) host. Host plants are to be pruned periodically at monthly intervals to encourage the growth of Sandalwood seedlings. The germination media in beds or in trays must be treated with fungicide (0.25% Dithane M45) periodically as prophylactic measure. The physical and genetic quality of seedlings greatly influences survival, growth,

Table 7.1 Treatment of Sandalwood seeds with different concentration of GA_3

Sample size—300 seeds/treatment				
GA_3	No. of seeds germinated 90 days after sowing		Germination %	
Conc.	16 h soaking	24 h soaking	16 h soaking	24 h soaking
100 ppm	101	154	33.67	51.33
300 ppm	125	165	41.67	55.00
500 ppm	162	201	54.00	67.00
1000 ppm	171	209	57.00	69.67
0.0 ppm	25	30	8.33	10.00

Source: Das SC, Tah J (2013) Effect of GA3 on seed germination of sandal (Santalum album L.). Int J Curr Sci 8: 79–84.

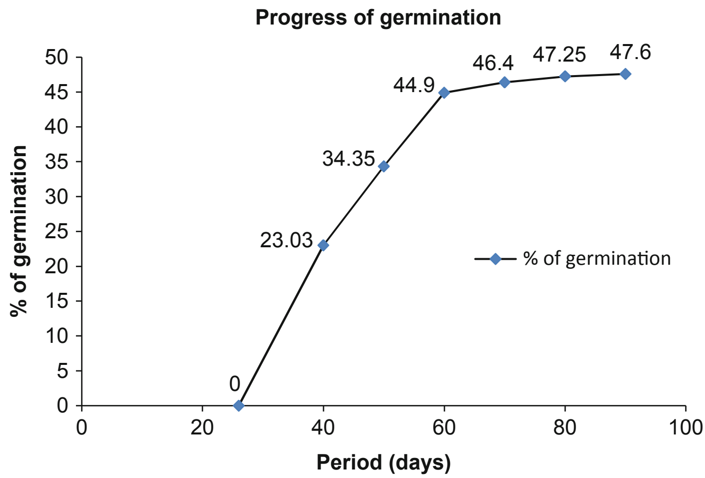

Fig. 7.2 Progress of germination over time (Das 2014)

and productivity. "Quality of seedlings" integrates genetic, morphological, and physiological characters which ultimately determine the seedling performance. Seedlings are sensitive to both drought and sunlight but needs lateral shade. Plantable seedlings of 30–40 cm height with dark brown stem can be produced within 6–8 months.

7.7 Vegetative Propagation

Batabyal et al. (2014) suggested that the use of 15 cm long stem cuttings obtained from 3- to 4-year-old Sandalwood trees are better for propagation. Noteworthy to mention that treating stem cuttings with indole-3-acetic acid (IAA) (1.5 mg/L) and gibberellin (GA_3) (1.5 mg/L) results in an increased number of leaves per branch, though rooting frequency amongst the treatments were not reported. Moreover, increase in the number of branches per cutting was observed with the application of 1.5 mg/L indole-butyric acid (IBA) and kinetin, each. Batabyal (2015) has studied different methods of vegetative propagation. Vegetative propagation of Sandalwood is done through (1) air layering, (2) root suckers, and (3) stem cuttings. Air layering is not promising but root suckers showed greater success. In air layering, branches of 1.5–2 cm diameter are chosen during June–July, when there are frequent showers. 1 cm ring of bark is removed and the exposed branch is treated with Seradex B and covered with moss. The wound is kept moist, within 35–50 days callus formation occurs and roots emerged in 15–20% cases. When the roots develop to about 8 cm, the branchlets are separated from the tree and planted with a host in a pit or pot. For root suckers, a trench of 30 cm wide and 30 cm deep is dug around a mature Sandalwood tree at a distance of 1.5–2 m from base. The cut ends of the radiating root put forth shoots profusely in about 40 days. The shoots having roots are cut off from mother shoots at 10–15 cm distance and cuttings are treated with Indole-butyric acid (IBA) (100 ppm) and planted with host in pots. In about 3–4 months root system gets established. Cleft grafting method adopted for clonal multiplication using 12 month old root-stock gave 60% success. Winter is the best time for cleft grafting. Success rate of this technique largely depends on age of root-stock, period of grafting, diameter of scion and genotype. Vegetative propagation using root cuttings is also useful. Secondary roots of 5 cm long obtained during April and treated with Seradex and planted horizontally in nursery bed and watered regularly resulted in sprouting in 30–40 days. The cuttings with shoot and roots are transplanted to pots along with hosts. The success rate was found to be up to 60% in this method. There is no report of successful vegetative propagation through stem cuttings till date.

Tissue Culture technique is also used to multiply Sandalwood plants, but it is not popularized due to its initial stage of parasitism. Yeast extract was found to initiate and stimulate the proliferation of Sandalwood endosperm. However, for a satisfactory proliferation an auxin (2,4-D) and a cytokinin (Kinetin) in conjunction with yeast extract are required (Rangaswamy and Rao 1963). Studies in culturing of lateral buds, root tips and haustoria of Sandalwood were also carried out. Induction of embryonic proliferation in Sandalwood was studied and it was found that similarity existed in the morphogenetic potentialities of the embryo of Sandalwood and other angiospermic parasites. Somatic embryogenesis in seedling callus of Sandalwood has been observed by Bapat and Rao (1979). Lakshmi Sita et al. (1982) induced Sandalwood somatic embryogenesis from shoot callus cultures derived from 20 to 25 year old trees. Rathore et al. (2007) described micropropagation methods through axillary shoot proliferation and is having high potential for rapid and mass production of clonal planting material of Sandalwood from plus trees. Scientists conducted field trial of micropropagated plants of Sandalwood and found that the survival is 70% by the end of 6 months. Mamatha and Rathore (2014) studied the effect of sucrose, agar-agar concentration, and pH of the media on somatic embryo induction, maturation, and germination from the explants of the mature trees and found that during maturation, size of the somatic embryos increased with increase in the concentration of sucrose in the medium favoring adventitious shoot induction and embryo creaking.

7.8 Natural and Artificial Regeneration

In natural regeneration, germination of Sandalwood seeds is found profuse from the bird droppings in the forest floor as well as in the village yards and bunds of the agricultural fields. In Tamil Nadu bush sowing is practiced in which about five seeds are sown in a bush. Germination takes place in about a month's time. These young seedlings will be benefitting from the moisture available during the entire Northeast monsoon rains. By the time the moisture in the upper layer of soil reduces considerably during January–February, the stem of the seedlings would turn to brown from green, thus enhancing its endurance. These robust seedlings would withstand successfully the moisture stress of the first summer they encounter. It would take

5–6 years for the Sandalwood saplings to emerge strikingly 3–4 m over and above the bushes. Rai and Kulkarni (1986) have reported that dibbling of seeds in bushes and sowing of seeds on the mounds in the trench-mound method were the most commonly followed in the past, success rate was normally around 30–40%. Natural regeneration is generally good but population density is poor due to biotic and abiotic interferences. It is capable of regenerating profusely in the absence of fire and grazing. Most of the populations are devoid of large girth class mostly due to smuggling. Hanumantha et al. (2014) conducted studies pertaining to phenology and natural regeneration of Sandalwood (*Santalum album* L.) under different plantations like Bamboo, Eucalyptus, Acacia, medicinal plants garden, and natural forest where several birds are involved in dispersal of seeds and their result showed that the overall regeneration was highest in medicinal plants garden followed by natural forest and bamboo plantation.

In artificial regeneration, the following methods are commonly adopted: (1) dibbling of Sandalwood seeds in bushes, (2) sowing of seeds on mounds in trench—mound technique, (3) planting of polypot or hycopot raised seedlings. Seeds are collected either from identified seed stands or from plus trees, processed and stored in seed processing units for dibbling in forest areas or raising seedlings in nurseries. In nurseries the Sandalwood seedlings are raised in "5 × 8" polypots or 300 cc hycopots, which are maintained for 6–8 months before planting. The polypot or hycopot raised 6–8 months old seedlings in nursery is transplanted to the main field in the pits dug well in advance after getting a good rain at a spacing of 2.5 m × 2.5 m or 3 m × 3 m. Transplanting of seedlings raised in the nursery is one of the commonly used methods for raising plantations. This method is costly; however, high success rate offsets the cost factor. After pit planting, a host plant (Arhar/*Cajanus cajan*, Tulsi/*Ocimum sanctum* or Nayantara /*Catharanthus roseus*) is to be planted at the side of the Sandalwood seedlings. Four different host species, which were the best as reported by different scientists, may be selected as secondary host plants for the main field. These are *Cynodon dactylon, Albizia saman, Casuarina equisetifolia,* and *Pongamia pinnata* (Das 2014). Sandalwood plants established haustorial connections with the secondary hosts in the main field to draw nutrition. Nagaveni and Vijayalakshmi (2014) observed the symbiotic relationship of Sandalwood plants with that of Arbuscular Mycorrhizal (AM) fungi revealed that plants growing in different places showed diverse AM species association and the intensity of colonization were higher in Sandalwood roots than the host.

7.9 Host–Sandalwood Parasitism

Sandalwood is a hemi–root parasite, firstly reported by Scott (1871). The importance of this fact was realized, when Barber (1906) reported the details of haustorial formation, growth and development of haustoria. The formation of haustoria is more or less confined to younger roots and they arise from external layers of rootlets, unlike lateral rootlets, which are formed deep in its tissues. The establishments of connection and histological changes that take place during contact have been explained in detail by Barber (1906), Bhatnagar (1965), and others. Brandis (1903) suggested that though Sandalwood is a root parasite, it may derive part of its nutrition from the soil as well. It was also reported that Sandalwood requires a primary host at nursery stage (Annapurna et al. 2006), and secondary long term host in the field. Being a hemi-parasite, the silvicultural requirements are unique, and there is no adequate understanding of the same. Its regeneration and establishment has been problematic because of the poor understanding of host–parasite relationships. Sandal plants in agro-forestry or forestry systems may have to tolerate varying levels of competition and complementary interactions from the component crops or plants. So an understanding of the complementary and competitive influence of the host on sandal is necessary for a successful growing of Sandalwood. When host is introduced in the pots at the early phase there is possibility of competition for soil moisture and nutrient between Sandalwood and host. The plant with a haustorial adaptation on its own roots, parasitize the roots of other tree but without major harm to its hosts. This plant forms a non-obligate relationship with a number of other plants like *Pongamia pinnata* and *Casuarina equisetifolia* (Nagaveni and Vijayalakshmi 2004). Subbarao et al. (1990) worked on nodule haustoria and microbial features of *Cajanus* and *Pongamia* parasitized by Sandalwood. They concluded that the parasitic dependence of Sandalwood saplings on nodulated host plants was apparent with the steady improvement in their nitrogen content. In natural surroundings, the survivability of Sandalwood trees is exclusively reliant on other woody plant species, which serve as host in their surrounding area. However, nodulated nitrogen fixing trees are superior hosts for Sandalwood when compared to non-nodulated trees is a question, and requires more research studies to answer this question.

Sandalwood can parasitize with more than 300 host species, ranging from grasses to leguminous trees in nature. This tree species exhibits varied growth patterns with diverse host species. Lack of understanding of the host–plant relationship causes the failure of sandal seedling production. It has been reported that *Cajanus cajan* is the best host plants for Sandalwood in nursery. Four different host species, which were the best as reported by different scientists, were selected as secondary host plants for the main field. These were *Cynodon dactylon, Albizia saman, Casuarina equisetifolia, Pongamia pinnata*. It depends on its host for phosphorus (P), potassium (K), and magnesium (Mg). Sekar et al. (2000) opined that combined application of *Azospirillum*, Phosphobacteria, and Vesicular Arbuscular Mycorrhizal (VAM) fungi provide better growth in Sandalwood by improving the nutrient uptake under nursery condition. Hayman (1986) highlighted that VAM fungi augment plant mineral nutrition, particularly phosphorus. In addition to their impact on plant nutrition, their communication with plant pathogens, such as bacteria, fungi, and nematodes might reduce the disease severity. Nagaveni and Vijayalakshmi (2007) studied on resistance of Sandalwood to determine the bio-protective effect of arbuscular mycorrhizal fungi in Sandalwood plant infected with wilt causing pathogen *Fusarium oxysporum.* They also studied the differential response in the haustorial formation as growth of Sandalwood plant (*Santalum album*) in respect to different host. Rocha et al. (2014) conducted anatomical studies of haustoria with host *Casuarina* reveals that vascular connections between the host and the Sandalwood tree became so close that the host and the parasitic route became almost a single physiological unit catering to the nutritional requirement of Sandalwood tree. Their study with ^{32}P radio tracer technique suggested that the host plants need not be present in the same pit of Sandalwood tree as it can extend its root to distance of 1.5–3 m to form haustoria on neighboring plants.

7.10 Inter-Cultural and Tending Operations

Subsidiary silvicultural operations are very important for the proper growth and development of a plant, and the host plants are to be pruned periodically when they overgrow Sandalwood saplings. All Sandalwood trees are to be pruned once in 4 years. Shrubs and plants useful as hosts are retained and other unwanted plants like Lantana should be removed to provide more space for development of Sandalwood trees. Fencing may be erected to protect young regenerating plants against grazing. Full overhead light should be allowed by judicious lopping of overtopping branches of surrounding trees. Thinning may be carried out as and when required to give Sandalwood trees a space of 5–6 m depending on the size of the trees retained. Only best and healthy Sandalwood trees should be retained in thinning for the final harvest and tending is better done from June to November.

7.11 Tree Improvement

Tree improvement in Sandalwood was initiated in 1978 with an aim of establishing trees that can produce well-developed thick heartwood and essential oil in a short period of time. Studies so far done are mainly focused on (1) genetics and genetic improvement, (2) variation and conservation of genetic resources, (3) production of improved planting stock, and (4) breeding for resistance to spike disease. Genetics and genetic improvement studies showed that the number of chromosomes in Sandalwood root tip is $2n = 20$. Nevertheless, 40 chromosomes could be observed in the haustorium part cells. Two to five-fold rise in the chromosomes size was also detected, and was accredited to endopolyploidy (Srimathi and Sreenivasaya 1962). The variation in the magnitude of standard error from tree to tree suggests that they are governed by genetic factors. For delimiting different types of Sandalwood it was suggested that results of biometric analysis could be helpful. Variations in leaves, flowering behavior, germination, and 3-phenotypes have also been reported. For genetic conservation, in situ conservation has been undertaken at Janiguda in Orissa and Thindlu in Karnataka. For ex situ three clonal banks at Gottipura, Bangalore Division (Karnataka), Karvetinagar, Chittoor Division (Andhra Pradesh), and Kurumbapatti, Salem Division (Tamil Nadu) with 50, 10, and 31 plus trees and one germplasm bank at Gottipura have been established. A clonal bank over 1 ha was established in Gottipura, Hoskote, Bangalore. The clonal bank consisted of rametes collected from 60 plus trees identified in Karnataka, Tamil Nadu Kerala, and

Andhra Pradesh. For production of improved planting stock (a) selection of plus trees, (b) identification of seed stands, (c) establishment of clonal seed orchards, (d) progeny trials, and (e) tissue culture were carried out. As a continued effort, four seed stands have been identified at Achalpatty (Kerala), Chitteri (Tamil Nadu), Rayalpad (Karnataka), and Juniguda (Orissa). Clonal seed orchards have also been established at Nallal (Karnataka) and Tirupati (Andhra Pradesh) for raising quality plantations and obtaining maximum genetic gain.

The common breeding system of *Santalum* species could be designated as facultatively allogamous (incompletely outbreeding) with dissimilarity amongst individuals and families at the level of self-incompatibility (Ma et al. 2006; Tamla et al. 2011) and with inability for parthenocarpy or apomixis (Ma et al. 2006; Tamla et al. 2011). The favored outcrossing nature of the breeding system, and the capability for self-fertilization is beneficial. Across all *Santalum* species investigated, only low proportions of controlled cross-pollinated flowers productively developed into mature seeds. The proportions ranged differently, i.e., 7.5% in *S. lanceolatum* (Tamla et al. 2011), 1.3% in *S. spicatum* (Rugkhla et al. 1997) and between 9.4 and 14% in *S. album* (Rugkhla et al. 1997; Ma et al. 2006).

Breeding for resistance to spike disease is one of the several control measures suggested. It has been reported that there is no natural resistance to spike disease, it is possible to obtain some resistant strains by selection and screening. The apparent resistance is likely to be due to absence of adequate spike inoculums and other climatic factors. In another tree improvement program, Shankaranarayana et al. (1997) had shown a highly significant and positive correlation between optical density (O.D) and oil content ($r = 0.929$) and concluded that this method should be useful in rapid screening of Sandalwood plants for their oil content and in selection of plus trees among different provenances. In order to increase essential oil content and monetary profits from Sandalwood, Zhang et al. (2010) induced polyploidy in this tree species. Polyploidy is one of the largely applied methods for plant breeding. Polyploid plants usually have bigger cells, and plants are frequently superior with thick shoots, bigger leaves, fruits, and higher nutritional contents, etc. The karyo-morphological features of Sandalwood were reported by Zhang et al. (2010). According to them, a simple chromocenter type was noticed in the interphase nucleus, while chromosomes in the prophase were of the interstitial type. The meristematic cells in few *Santalum* species shoot-tips were found to be mixoploid, i.e., 2n = 2x = 20 and 2n = 4x = 40. Two dissimilar karyotypes were noticed, i.e., one diploid (2n = 2x = 20) and one tetraploid (2n = 4x = 40); their karyotypic formulae were 2n = 20 = 18 m + 2sm and 2n = 40 = 32 m (2SAT) + 8sm, respectively. The chromosomes of both karyotypes presented the occurrence of centromeres mostly in a median position, and a few sub-median centromeres, of 2B type, of a primitive and symmetrical nature.

7.12 Conservation of Sandalwood

In India, eight Sandalwood growing areas have been recognized as prospective sources of Sandalwood on the basis of population density, phenotypic characteristics, latitude, longitude, and eco-climate. The provenances vary in climate and edaphic preference since they are located in different localities of South and Central India. The extraction and disposal of Sandalwood came under the Forest Department in 1864 in Mysore state. In Karnataka (formerly Mysore) the forest working plan for Sandalwood extraction were prepared for Hunsur Taluk in 1910, Heggadadevanakote in 1920, and Narasimharajapura in 1926. Ecologically Sandalwood has adapted various agro-climatic and soil conditions for in situ regeneration with an exception of waterlogged areas and very cold places. It is clear that distribution and abundance of Sandalwood is mostly confined to Deccan Plateau. The demand for Sandalwood and oil is increasing day by day and the gap between demand and supply are widening. Difficulty in the seed germination due to dormancy coupled with the hemi-parasitic nature of Sandalwood plants creates serious problems in their artificial regenerations. Illegal felling of Sandalwood trees for smuggling also poses other threats to its survival. Protection and management of forests are the primary responsibility of State Forest Department and they are performing that by integrating modern technology including wireless network, remote sensing, geographical information system, information technology, and global positioning system and better mobility of the field staff by providing vehicles for patrolling and constructing check posts but people's awareness is a major factor which is needed very much for the conservation of Sandalwood plantations. So people's awareness is very much needed to protect our shrinking wealth of Sandalwood (which is so difficult to regenerate). Now-a-days local communities are encouraged and involved in conservation, protection, and management of forests through joint forest management committees (JFMCs) or village level committees.

7.13 Growth and Yield of Sandalwood

There are many internal and external factors which influence growth of any biological system. Tree growth can be analyzed by dividing the process into two components, positive and negative. Biotic potential, photosynthetic activity, soil nutrients, etc. contribute to the positive component while limited resources, harsh environmental conditions, aging, etc. contribute to negative component of growth. In order to study growth pattern and habits, one has to collect data regularly on increase in height and girth with respect to time. Trees are perennials and continue to grow in height and girth to a considerable extent, given the favorable conditions. In many instances, growth takes place in a certain pattern and it takes considerable period to obtain information on growth behavior and to estimate expected yield based on the growth. Tree growth could be in terms of tree height, diameter at breast height (DBH), basal area or volume. Information on growth pattern and expected yield at the early stage of plantation could be of immense importance in selecting appropriate management practices for the desired output.

Sandalwood is considered as a slow growing tree under forest conditions. Kushalappa (1995) reported that Sandalwood responses well to lime application. Application of bio-fertilizers to trees will greatly improve Sandalwood growth (Harley and Smith 1983). Rajagopal Shetty (1977) reported that growth rate of Sandalwood in Javadis is 1 cm girth at breast height per annum (0.33 cm DBH). Similar growth behavior had also been reported by Ranganathan and Wilson (1934). More or less the same growth rate was observed on the trees in plantations also (Srimathi and Kulkarni 1983). The mean annual diameter increment in trees each from Andhra Pradesh (Horsleykonda, Chittoor district) and Tamil Nadu (Sanamavu R. F., Salem North) was found to be around 0.287 and 0.195 cm, respectively (Sarma and Rai 1986). Venkatesan (1980) has reported that though earlier studies had indicated a growth rate of 1.23 cm girth per year, it could vary from 1 to 5 cm per year. The relationship between DBH (X) and yield of scented heartwood (Y) per tree in different DBH classes of sandal at Belgaum-Karnataka is expressed in the form of a power curve, $Y = 0.001476X\ (X^{3.3564})$ (Rai and Sarma 1986). Karnataka Forest Department also computed expected weight of actual Sandalwood (Heartwood) at various girths of sandal trees. Studies indicate that a healthy Sandalwood tree growing under ideal conditions show an increment of 1.0 kg per year with a girth of 1.5 cm (Rai 1990). Growth reported by Lahiri (2010) from Ballavpur in Mohammad Bazar Range of Birbhum Forest Division that Sandalwood trees attained 60 cm bhg (over bark) in 21 years and height is 7.0 m. and heartwood girth at breast height is 26 cm. Somashekar et al. (2014) studied the field performance of tissue culture raised Sandalwood plants as Agro-forestry models and found that tissue culture through axillary proliferation and somatic embryogenesis offers highest clonal propagation efficiency. It was also observed that from 1st to 4th year the plants are growing vigorously attaining height 5.5 m and collar girth 34 cm at the end of 4th year. Nagaveni and Vijayalakshmi (2002) opined that microbial inoculation to the seedlings of *Eucalyptus camaldulensis, Wrightia tinctoria,* and *Bombax ceiba* improved the growth and biomass under nursery conditions which may further result in better performance of seedlings in field planting.

7.14 Growth Study

The growth of sandal trees was influenced by the presence of host plant to a great extent both in nursery and in main field. Field experiments were conducted at Bagaldhara and Rangamati of Hirbandh Block under Bankura (South) Forest Division (Das 2014). In his study, the sandalwood seedlings were planted in the field along with host plant both singly as well as in combination. Some seedlings were planted without host in the month of July 2011. Soil work was done periodically and inter-culture operations were done 3 times after planting at 3 weeks interval. Manure (cowdung/vermicompost) @ 500 g/pit was applied at the time of pit filling. Fertilizer (NPK—10:26:26) was applied twice @ 40 g/plant at 3 weeks interval after planting.

Table 7.2 Growth of Sandalwood seedlings with and without host plants at Bagaldhara and Rangamati 2011 plantation

Type of host	Growth in 1st year (Bagaldhara)			Growth in 1st year (Rangamati)		
	Av. height (Cm)	Av. girth (Cm)	Survival %	Av. height (Cm)	Av. girth (Cm)	Survival %
T_3:Arhar + Tulsi	110.58	4.51	82%	60.50	2.31	76%
T_1:Arhar (*Cajanus cajan*)	99.32	4.45	80%	61.57	2.78	74%
T_5:Arhar +Akand	84.23	3.78	72%	x	x	x
T_9:Tulsi + Nayantara	x	x	x	51.85	2.07	68%
T_2:Tulsi (*Ocimum sanctum*)	85.58	3.75	70%	59.22	2.28	66%
T_8:Nayantara (*Catharanthus* sp.)	x	x	x	51.00	1.75	50%
T_4:Akand (*Calotropis* sp.)	63.67	2.42	40%	x	x	x
T_0:Without host	48.28	1.71	34%	35.75	1.15	30%
Type of host	Growth in 3rd year (Bagaldhara)			Growth in 3rd year (Rangamati)		
	Av. height (cm)	Av. girth (cm)	Survival %	Av. height (cm)	Av. girth (cm)	Survival %
T_3:Arhar + Tulsi	325.10	16.42	76%	158.0	9.10	70%
T_1:Arhar (*Cajanus cajan*)	300.25	15.23	74%	155.0	8.73	68%
T_5:Arhar + Akand	258.57	12.71	68%	x	x	x
T_9:Tulsi + Nayantara	x	X	x	106.87	6.50	64%
T_2:Tulsi (*Ocimum sanctum*)	289.67	13.50	66%	123.8	7.08	62%
T_8:Nayantara (*Catharanthus* sp.)	x	X	x	97.50	5.33	40%
T_4:Akand (*Calotropis* sp.)	223.30	9.60	32%	x	x	x
T_0:Without host	131.20	6.60	20%	70.12	3.50	20%

Source: Das and Tah (2016).

Plant height, collar girth, and survival percentage were measured after 12 months, 24 months, and 36 months of planting. The following Table 7.2 shows that growth (viz. plant height and basal girth) of Sandalwood saplings are better with Arhar + Tulsi combination of hosts followed by Arhar (*Cajanus cajan*) as single host followed by Arhar + Akand combination of hosts followed by Tulsi (*Ocimum sanctum*) as single host followed by Tulsi + Nayantara combination of host followed by Nayantara (*Catharanthus roseus*) and Akand (*Calotropis procera*) as single host both in 1st year, 2nd year, and 3rd year at Bagaldhara. The survival percentage also follows the same trend. The survival percentage varies from 70 to 82% in 1st year and 66 to 76% in 2nd year and 3rd year depending on the type of host at Bagaldhara whereas the survival percentage varies from 66 to 76% in 1st year and 62 to 70% in

2nd year and 3rd year depending on the type of host at Rangamati. The Sandalwood seedlings, which were planted without host, have survived 34% in 1st year and 20% in 2nd year and 3rd year at Bagaldhara whereas it has survival 30% in 1st year and 20% in 2nd year and 3rd year at Rangamati (Table 7.2).

The average height in 1st year at Bagaldhara is 110.58 cm, 99.32 cm, 85.58 cm, 84.23 cm, 63.67 cm with Arhar+Tulsi, Arhar, Tulsi, Arhar+Akand and Akand (*Calotropis procera*) host, respectively, whereas without host species, the average height is recorded as 48.28 cm. In 2nd year, it is recoded as 213.33 cm, 196.83 cm, 158.33 cm, 148.57 cm, 124.17 cm with above hosts, respectively, and 95.32 cm without host. In 3rd year, the corresponding heights are 325.1 cm, 300.25 cm, 289.67 cm, 258.57 cm, and 223.3 cm with above hosts, respectively, and 131.2 cm without host. The average basal girth at Bagaldhara also various from 2.42 to 4.51 cm with hosts and 1.71 cm without host in 1st year, 4.31 to 8.08 cm with hosts and 3.21 cm without host in 2nd year, 9.6 to 16.42 cm with hosts and 6.6 cm without host in 3rd year.

Table 7.2 also shows that growth of sandal saplings (viz. plant height and basal girth) at Rangamati are better with Arhar as single host followed by Arhar + Tulsi combined host, followed by Tulsi as single host followed by Tulsi + Nayantara combined host followed by Nayantara (*Catharanthus roseus*) as single host both in 1st year, 2nd year, and 3rd year. The survival % also follows the same trend. The survival percentage varies from 50 to 76% in 1st year and 40 to 70% in 2nd and 3rd year depending on the type of host. The sandal saplings, which were planted without host, have survived 30% in 1st year and 20% in 2nd and 3rd year, respectively. The average height at Rangamati varies from 51.0 to 61.57 cm with hosts and 35.75 cm without host in 1st year, 70.33 to 109.33 cm with hosts and 42.5 cm without host in 2nd year, 97.5 to 158.0 cm with host and 70.12 cm without host in 3rd year. The average basal girth also varies from 1.75 to 2.78 cm with hosts and 1.15 cm without host in 1st year, 2.67 to 4.33 cm with hosts and 2.0 cm without host in 2nd year, 5.33 to 9.10 cm with hosts and 3.5 cm without host in 3rd year.

The growth of Sandalwood saplings are better (almost double) in Bagaldhara than in Rangamati because the soil of Bagaldhara is loose and contains more of mica but the soil of Rangamati is slightly rocky, compact and full of laterite. Akand (*Calotropis procera*) and Nayantara (*Catharanthus roseus*) seem to be poor host as survival percentage is 40% and 50%, respectively, though combination of host of Arhar + Akand (76%, 70%, and 70% in 1st year, 2nd year, and 3rd year, respectively) and Tulsi + Nayantara (68%, 64%, and 64% in 1st year, 2nd year, and 3rd year, respectively) performed better (Das 2014).

It has been observed that Tulsi (*Ocimum sanctum*) combined with Arhar (*Cajanus cajan*) gave the best performance as host plants in all the locations for the growth and development of the Sandalwood plants. In some cases, Nayantara (*Catharanthus roseus*) gave the significant result for the growth and development of the sandal plants, though it has also been proved that Sandalwood plants can survive without any host plant association. This might be the effect of soil environment which will be explored in near future. However, it is clear that there is a certain edaphic factor for the growth and development of Sandalwood plant.

Table 7.3 Average Plant height and girth of Sandalwood trees at different age

S. no.	Age (year)	Plant height (m)	Girth of the plant (cm)	Remarks
1	1st	0.45	0.4	Basal girth
2	2nd	0.93	1	Basal girth
3	3rd	1.35	3.2	Basal girth
4	4th	1.75	5	Basal girth
5	5th	2.2	6	B.H.G.
6	6th	2.8	8	B.H.G.
7	7th	3.4	11.5	B.H.G.
8	8th	3.85	15.2	B.H.G.
9	9th	4	20.5	B.H.G.
10	10th	4.6	24.4	B.H.G.
11	13th	5	32	B.H.G.
12	15th	6.2	40.3	B.H.G.
13	20th	7.5	53	Av. b.h.g of 21 trees
14	25th	8.8	64.5	Av. b.h.g of 10 trees
15	30th	9.7	72	Av. b.h.g of 8 trees
16	35th	10.2	83	Av. b.h.g of 10 trees

Das (2013)

The survival percentage of Sandalwood did not decline in 4th year and were growing well even after the removal of host plants after 3rd year of planting. It proves that sandal needs the support of host plants for its better growth and establishment in the initial stage due to its parasitic nature. In another field investigation in different forest gardens of the Bankura (South) Division, a lot of Sandalwood population in different age have been observed and enumerated for height and girth of the plants (Das 2013). Those observations were taken into consideration for highlighting the magnitude towards edaphic factors of this region especially for the growth and development on the yield of Sandalwood. All these observations have been exhibited in the following tabular form (Table 7.3).

The study shows that at Hirbundh nursery of Khatra Range under Bankura (South) Forest Division, Sandal trees attain a height of 2.2 m, 4.6 m, 6.2 m, 7.5 m, 8.8 m, 9.7 m, and 10.2 m and a girth of 6.0 cm, 24.4 cm, 40.3 cm, 53.0 cm, 64.5 cm, 72.0 cm, and 83.0 cm in 5th, 10th, 15th, 20th, 25th, 30th' and 35th year of age, respectively. Age—height and age—girth curves were drawn and shown in Figs. 7.3 and 7.4, respectively (Das 2014). The sigmoid curves reflect the growth of Sandalwood trees with age.

7.14.1 Factors Affecting Growth

The following factors generally have important effects on growth in most plantations.

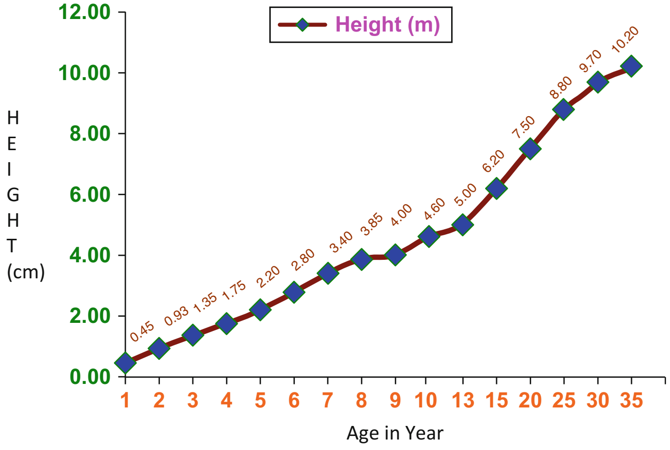

Fig. 7.3 Age—height curve (Das 2014)

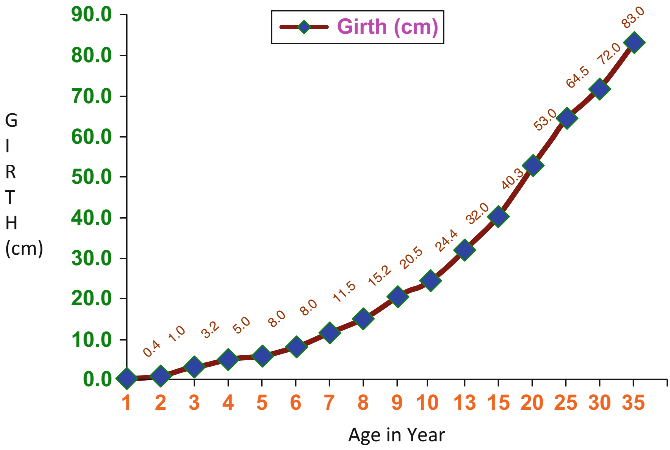

Fig. 7.4 Age—girth curve (Das 2014)

- Site condition and soil,
- Climatic condition,
- Initial specing and treatment,
- Silvicultural operations,
- Artificial thinning and pruning,
- Internal condition (genetic and physiological).

7.14.2 Influence of Soil on Growth and Heartwood Formation

Red ferruginous loam is the most common soil on which Sandalwood trees occur, the underlying rock is often metamorphic and is chiefly gneiss. Sandalwood requires good drainage and does not withstand waterlogged ground. Best growth of tree is on rich fairly moist soil such as garden loam and well drained deep alluvium on river banks (Troup 1921). In a study carried out by Jain et al.(1988) on soil properties and their relationship to the growth of Sandalwood in three locations, it was observed that lime status, water holding capacity, pore space, volume expansion on wetting, exchangeable calcium and magnesium and available potash, exerts positive influence on the increment in girth and height.

Heartwood in Sandalwood is the economically important product, and is the source of oil. It is believed that the heartwood with premium scent can be obtained from the trees, growing in dry regions, especially on red or stony grounds (Gunther 1952) and quantity of oil will be comparatively higher when compared to those grown in the fertile territories (Bhatnager 1965). The growth of Sandalwood seedlings is better in porous and well drained soils which help the seedlings for better root respiration and root-shoot growth in comparison to the soils which is hard specially when dry, slightly rocky, compact, and full of laterites (Das et al. 2018). Their experiment also proved that the availability of organic compound in the soil was responsible for stimulating the Sandalwood plant's growth and development. It is also reflected that higher the total nitrogen (N) and available nitrogen (N) content, better is the growth both height and girth (Das et al. 2018).

7.15 Yield of Sandalwood and Revenue

7.15.1 Heartwood Formation

Heartwood formation starts from 10 to 12 years of age and is rapid up to 20 years and reached its peak when the trees are 30 years and above (Kumaravelu et al. 2007). The yield of heartwood varies from locality to locality and with the age of the tree. In India, trees of 100 cm girth have been reported to yield between 85 kg and 240 kg of heartwood according to the locality from which they come (FAO 1995). Cameron (1894) reported that the tree attains commercial maturity at 27–30 years and at this period the heartwood is well developed at a depth of 5 cm below the surface. Ranganathan and Wilson (1934) observed that trees obtained from edges of plantation or open fields harvest more heartwood compared to those of proportional size obtained from the neighboring forests. Rama Rao (1911) from his investigations inferred that hosts influence heartwood formation also, in addition to growth and development. Srimathi and Kulkarni (1980) were of the view that heartwood formation is dependent on genetic factors of the individual tree and the phenotypic factors play only a secondary role.

Heartwood/sapwood ratio in sandal trees in different sandal tracts of Tamil Nadu was studied by Nayar (1984). He found that in the higher elevations of

Table 7.4 D.B.H and volume of wood, heartwood diameter, and volume of Sandalwood

S. No.	Diameter at breast height (cm)	Volume of 1 m log (m^3) (i)	Diameter of heartwood at breast height (cm)	Volume of heartwood of 1 m log (m^3) (ii)	Volume of sapwood (i – ii)
1	16	0.0201	10 cm	0.0078	0.0123
2	14	0.0154	8 cm	0.0050	0.0104
3	10	0.0078	5 cm	0.0020	0.0058
4	12	0.0113	8 cm	0.0050	0.0063
Total		0.0546		0.0198	0.0348

Source: Das (2013).

Table 7.5 Total and average volume of stem timber, small timber, volume and weight of Sandalwood trees

No. of sandalwood trees felled = 51 no.	
Total volume of stem timber = 7.2584 m^3	Average volume of stem timber/tree =0.1423m^3…(i)
Total volume of small timber = 2.7416 m^3	Average volume of small timber/tree =0.0537m^3…(ii)
Total weight of stem timber = 8845 kg	Average weight of stem timber/tree =173.43 kg… (iii)
Total weight of small timber = 2095 kg	Average weight of small timber/tree =41.08 kg…. (iv)
Weight of stem timber/m^3 = 1218 kg.	Average weight of timber/tree =214.51 kg.... (iii + iv)
Weight of small timber/m^3 = 764 kg	Average volume of timber/tree =0.196 m^3….. (i + ii)

Source: Das (2014).

Mettupalayam Range where soils are fairly rich and trees are of good proportion, the heartwood formation is relatively poor. In Coimbatore where xerophytic conditions prevail even in the trees of smaller girth class (10–18 cm), the heartwood formation was good. But in Forest college campus, where the soil is shallow and has pebbles and boulders, the sandal trees of even 30–45 cm girth had little or no heartwood (Nayar 1984).

In convention, the yield of timber is expressed by means of volume of wood. The volume of 1 m log (m^3), diameter of stem at breast height, and the diameter of heartwood at breast height denote the volume of heartwood and sapwood in this case. A brief tabulated form is given below (Table 7.4).

From the above table, it was calculated that the ratio of Sapwood: Heartwood = 1.75:1 and Total Wood: Heartwood = 2.75:1.

A small observation of 51 Sandalwood trees when felled, crosscut, and converted into stem timber, small timber and their weights were noted and presented in Table 7.5.

7.15.2 Girth Vs. Yield

Tree girth of Sandalwood is directly proportional to yield of heartwood. Venkatesan (1980) reported that probable average heartwood yield that can be expected under Tamil Nadu Forest conditions and suggested that each tree can yield at least 1 kg of heartwood per year after 20 years. His estimation of heartwood with girth is presented below.

The Sandalwood trees attained a height of 12–15 m and a girth of 1–2.4 m in dry deciduous forest of Deccan Plateau (Singh and Shankar 2007). Growth of Sandalwood tree was reported by Lahiri (2010) from Mahammad Bazar Range of Birbhum Forest Division that Sandalwood trees attained 60 cm B.H.G (over bark) in 21 years and the height revealed 7.0 m and heartwood girth revealed 26 cm. Heartwood formation was rapid in 20 years and reached its peak when the trees were above 30 years (Kumaravelu et al. 2007). The yield of heartwood varies from locality to locality and with the age of the tree. In India, trees of 100 cm girth have been reported to yield between 85 and 240 kg of heartwood according to the area from which they come (FAO 1995).

7.15.3 Revenue to Exchequer

The above Sandalwoods are sold in open auction in 2009 and in tender in 2010. Price of Sandalwood stem timber (including sapwood) in 2009 and 2010 was Rs. 750–950 per kg and Rs. 900–1400 per kg, respectively, depending on the quality (average price = Rs. 982/kg.) and price of small timber varies from Rs. 450 to 650/kg. (Average price = Rs.485/kg). So average price per tree is coming Rs. 1,90,000.00 and revenue earned from the sale of the above Sandalwoods is Rs. 97,00,000.00 (Das 2013).

7.15.4 Rotation Age

Under natural conditions, Sandalwood tree at 27–30 years would yield 25–30 kg of heartwood. But, under managed plantation conditions, rotation period of Sandalwood is considered as 15 years because with scientific approach like initial watering at seedling stage, periodical pruning, and fertilizer application, Sandalwood trees easily yield at least 15 kg of heartwood at the age of 15 years with the diameter at breast height (dbh) of approx. 15 cms (Mishra et al. 2018). According to recent studies, heartwood initiates at the age of 6–8 years and sizable heartwood is formed at 15 years which is worth harvesting. As per Viswanath et al. (2014), comparison of overall financial indicators at 15 and 20 years proved that a rotation period of 15 years is more economically viable than 20 years for all the Sandalwood cultivation models under study.

7.16 Production of Sandalwood in India

In its natural zone of occurrence in southern states and other states large tracts of plantations have been raised. The price trend in the international market has increased drastically. In 1999 the rate of Sandalwood (heartwood) in International market was Rs. 650.00/kg, whereas this rate has gone up to Rs. 3700/kg in 2007 and Rs. 4100/kg in 2010–11 and Rs. 9000/kg in 2019–2020. The average sale value for the wild Indian Sandalwood's heartwood increased from US$ 9400 per tonne in 1990 (Rai 1990) to around US$ 150,000 per tonne in July 2014 (on small volumes based on an auction held in Tamil Nadu, India), indicating a momentous yearly compounded growth rate (TFS 2015b). It is projected that the world demand for Sandalwood is about 5000 to 6000 tonnes per year, and for its oil, it is about 100 to 120 tonnes per year (Gairola et al. 2007). The country's production during 1930s through 1950s was around 4000 tonnes of heartwood per year which has now decreased to a meager 500 tonnes of heartwood per year. Karnataka and Tamil Nadu together accounting for nearly 90% of total Sandalwood production in India while Andhra Pradesh, Kerala, Orissa, Madhya Pradesh, and Maharashtra contribute the rest. All India Sandalwood production figures show substantial decline over the years. Mortality due to spike disease and other factors, extensive smuggling from restricted zone to free zone, dwindling forest cover and existence of non-uniform legislative provisions on movement of Sandalwood from one state to another, are some of the causes for decline in the production of Sandalwood. As a result the present production of sandalwood is very low.

Annual production of Sandalwood in Karnataka from 1958–1959 to 2010–2011 and the annual production of Sandalwood in Tamil Nadu from 1980–1981 to 2011–2012 was given by Kumar et al. (2012) along with its sky rocketed price for the same period.

According to unofficial reports, compared to 89 tonnes of smuggled Sandalwood in 1982–1983 in Karnataka, the seizure during 1987–1988 increased to 370 tonnes. The stock of wood in depots which was 100 tonnes in 1984–1985 has risen to 213 tonnes in 1988–1989. The fact is that extraction of trees is not taking place in an organized or prescribed manner. The production of Sandalwood has come down to 450–900 tonnes/year from 1990–1991 to 2010–2011. It was only 300 tonnes in 2011. The shortage is so severe that there was no auction of Sandalwood in Karnataka in the past 2 years. There is some recognition of this at the Government level. State-owned Karnataka Soaps and Detergents Ltd., maker of Mysore Sandal Soap, has launched a Grow More Sandalwood campaign that involves the company entering into agreements with farmers to increase Sandalwood cultivation.

The age of sandalwood tree and color of heartwood influences the content and quality of sandalwood oil. Heartwood from young trees (around 10 years of age, height <10 m, girth <0.5 m, heartwood diameter 0.5–2 cm) contains 0.2–2% oil and that from the mature trees (30–50 years of age, height 20 m, girth 1 m, heartwood diameter 10–20 cm) contains 2.8–5.6% oil (Zhang et al. 2012). Further, sandalwood oil from young trees contains 85% of santalol and level of santalones is higher compared to oil from mature trees (ICFRE 1992). Sandalwood oil content markedly decreases along the length of the tree (from root to tip) and across the diameter of heartwood (from core to periphery) in various proportions. In general, it has been reported that nearly 45% reduction in oil content from root to tip, and approximately 20% reduction from core to periphery is observed (Shankaranarayana and Parthasarathi 1987). The root contains 3.5–6.3%, stem 3–5%, and branches 1–3% oil. The quantity of oil within the heartwood of a matured Sandalwood tree varies amongst trees, ranging between 0.5 and 5% in *S. album* (Veerendra and Padmanabha 1996), 0.05–8% in *S. austrocaledonicum* (Page et al. 2010), and 0.1–8.2% in *S. lanceolatum* (Page et al. 2007). The price of Sandalwood oil in 1975–1976 was Rs. 899.25/kg whereas in 2005–2006 it has gone up to Rs. 15,992.99/kg. Current rate of Sandalwood oil is Rs. 70,000 to 1,00,000 per kg. As per the Tropical Forestry Services, heartwood is used for extracting essential oil via hydro-distillation. The price for Sandalwood oil was about US$ 5000 per kg in the global market, which further raised to US$ 8000 per kg in 2014–2015 (TFS 2015a). The cost of Indian Sandalwood is ten times higher than that of Australian Sandalwood. The heartwood of Indian Sandalwood produces higher oil, constituting increased levels of α- and β-santalols, the important aromatic compounds of Sandalwood oil compared to any other Sandalwood species (Baldovini et al. 2011; TFS 2015a).

7.17 Conclusions and Future Direction

The growth of sandalwood plant without host was observed in some cases the experiment conducted by Das in 2014. In parallel, it was also observed that in some cases, sapling mortality was noticed without host plant. The reason behind this might be the soil environmental factors. From the soil analyses report, it was remarkable that the differences of macro- and micro- soil nutrients were distinctly exhibited. Those organic compounds were responsible for stimulating the sandalwood plant growth and development (Das et al. 2018). Probably fungal and bacterial colony grow in organic matter for their life cycle in each soil environment, though it is a varied factor which depends on the soil characteristics of each and every forest garden. There has been fluctuation in production of Sandalwood year after year due to so many reasons; however, the trend clearly shows a drastic reduction in production. Sandalwood resources in India especially the wild populations is presently under threat, largely due to illegal felling, forest fire, grazing and to some extent spike disease combined with heavy domestic and international demand and with inadequate uniform regulation in the Southern States of the Country. Presently Sandalwood has been categorized as “vulnerable” by International Union for Conservation of Nature (IUCN) in 1998 (IUCN 2015). The dwindling population severely eroded the genetic base and is a cause of concern for initiating tree improvement work. Identifying spike resistant genotypes breeding for disease resistance is to be given equal impetus. Forestry research with reference to tree improvement, forest genetics and breeding should be given priority.

The excessively high demand in the international market of sandalwood has led to continued cost escalations for Sandalwood-based products and accumulative interest in Sandalwood cultivation, both as a commercial crop and on a smaller scale within agro-forestry systems. Effective cultivation of Sandalwood depends on a detailed knowledge about its basic biology and propagation. Knowing fully the conditions like soil types, seed treatments, host-parasite relationship, etc., raising large scale plantations in the natural sandalwood bearing areas as well as in farmlands will add up to the resource building of the valuable tree species.

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8

Cultivation of Sandalwood Under Agro-Forestry System

Sudhir Chandra Das

Abstract

Santalum album L. (Sandalwood) is a small tropical evergreen tree, and is one of the major sources of fragrant heartwood and essential oil. The plant is extensively cultivated and has a long life. Commonly, the mature tree is harvested after many years to obtain fragrant heartwood and to extract its oil. It is an important component of agro-forestry systems. Considering the growing demand and dwindling supply of Sandalwood, it has a great potential for cultivation not only in the forest areas but also in home gardens and other agro-forestry systems. The demand for Sandalwood and its oil is growing, and there is a wide gap between demand and supply. For bridging this gap, afforestation and plantation program should aim at increasing the productivity of Sandalwood. For an effective farming of Sandalwood, a strong knowledge on its basic biology and propagation is needed. Sandalwood, being a hemi-parasitic tree necessitates the implanting of host plants for supporting its growth, and this makes its cultivation very difficult. Many appropriate host species are mentioned in this chapter to support Sandalwood's growth. Technical aspects include the identification and supply of quality germplasm, nurture in the tree establishment phase and interactions with other components in an agro-forestry system, assuming the latter provides the most interesting option for small holders who want to get involved in growing the tree. In this chapter, we will explore how a generic simulation model of tree–soil–crop interactions can be adapted to the specific properties of Sandalwood in possible agro-forestry systems.

Keywords

Agro-forestry · Heartwood · Host plant · Nursery · Parasite · Regeneration

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8.1 Introduction

Sandalwood (*Santalum album* L.), the most valuable tree in India, is a source of expensive Sandalwood oil and scented heartwood that are used in aromatics, perfumery, medicine and religious purposes. The finest Sandalwood and oil have been produced in India for traditional uses, in addition to medicinal uses. The species being indigenous to India, the country enjoyed a niche market for its highly priced Sandalwood oil. India accounts for 85% of more than $1 billion international Sandalwood market as the foremost producer and consumer of Sandalwood (Viswanath et al. 2007). The annual production of Sandalwood has deteriorated from 4000 tonnes in 1965–1970 to nearly 1000 tonnes in 1990–1999, which further reduced to 500 tonnes in 2005–2006 (Gairola et al. 2007). Sandalwood prices have skyrocketed due to its increased demand in internal and external markets. In India, though Sandalwood tree finds its distribution all over the country, more than 90% is mainly located in the states of Karnataka and Tamil Nadu (8200 km^2 out of 9600 km^2). In Kerala, Sandalwood trees are seen in about 14.98 km^2 in the Reserve Forest and in the adjoining private lands distributed within 65 km^2 in and around Marayoor. Sandalwood is also found growing wild in some farmlands, homesteads and wastelands in Kerala. The area constituting Sandalwood is decreasing rapidly, due to the pilferage and smuggling, posing difficulties in establishing additional Sandalwood forests. Considering the growing demand and dwindling supply of Sandalwood, there is an enormous potential for raising Sandalwood not only in forest areas but also in the home gardens and other agro-forestry systems. To overcome the problem of demand and supply gap, afforestation and plantation program should aim at increasing the productivity of Sandalwood. Sandalwood can possibly be developed through a range of environments, only if locally acquainted appropriate host species are used from the nursery stage to harvesting. Thomas (2017) identified more than 70 species of host plants of Sandalwood (as it is a non-obligate root parasite and it has a wide range of host), but their influence varies greatly on the growth and development of Sandalwood. The host plant consists of primary host (nursery level), secondary (medium term) and tertiary (long term). The selection of host plants should pay attention to the size, shade nature, economic value, and its contribution to Sandalwood. Several species of host plants in investigation results are *Capsicum frutescens*, *Alternanthera nana*, *Acacia spirorbis*, *Duranta repens*, *Desmanthus virgatus, Solanum melongena*, *Lycopersicon esculentum, Acacia villosa*, *Acacia auriculiformis*, *Annona squamosa*, *Cassia siamea*, *Cajanus cajan, Citrus aurantifolia*, *Dalbergia sissoo*, *Ficus elastica*, *Gliricidia sepium*, *Jatropha curcas*, *Musa paradisiaca, Sesbania formosa, Tamarindus indica*, *Ziziphus mauritiana*, etc. (Thomas 2017). It is apparent that Sandalwood favorably forms haustorial networks with N_2-fixing legumes, and uses as a significant source of nitrogen (N) and carbon (C) from these hosts (Da Silva et al. 2016). The sensible use of biotechnology and cultivation could offer a sustainable alternate to natural habitats, and help in conserving valued *Santalum* species. Sandalwood has to rapidly make the transition from an over-regulated "forest product" (Rohadi et al. 2000) to a commodity grown in plantation forestry or agro-forestry systems if future supply is to keep up with the demand that is expected to persist.

High demand and remunerative prices of heartwood have motivated the farmers/stakeholders to take up Sandalwood farming in non-traditional areas in many states across India since the past decade. This chapter emphasizes on various agro-forestry systems, nursery practices, site selection, cultivation and host–parasite relationship, maintenance and protection of plantation, in addition to details on the economics of raising Sandalwood plantation. It has to be mentioned here that till date, there is a dearth of published literature and reviews on Sandalwood cultivation practices, challenges, and current economic status in the present date. Considering the above parameters, this chapter has illustrated detailed information on these aspects of Sandalwood cultivation under agro-forestry system.

8.2 Seeds, Seed Treatment, Germination, and Seedling Growth

Seeds are obtained by removing fleshy portion of the fruit. The dicotyledonous embryo occupies nearly the entire length of the albuminous seed. The stony endocarp is generally known as a seed coat although it is the false seed coat (Nagaveni and Padmanabha 1986). Seeds are dried and stored in gunny bags or in poly bags. They can be stored up to 12 months under normal condition and viability decreases after 12 months. Seeds are one amongst the imperative organs of plant species as they comprise the zygotic embryo, an important fragment of the reproductive life cycle, which renews with the dispersal of seeds, followed by the germination of seeds. Sandalwood species seeds are indeed distributed via bird-based endozoochory, i.e., by defecation or regurgitation (Batabyal et al. 2014). The germination of seeds can be done artificially under organized environmental circumstances, however is influenced by the stages of fruit's development, and also the seed's source and size, typically after breaking dormancy (Jayawardena et al. 2015). Sandalwood seeds are epigeal, radicle emerging out by breaking the false seed coat after 20–30 days. Fresh seeds display dormancy up to 60 days, and the obligatory dormancy of seeds is because of the occurrence of hard seed coat or may be because of the existence of chemicals in the seed coat that are impermeable to water and air. Soaking of seeds in gibberellic acid (0.05%) for 12–16 h and removal of the testa improved the germination of seeds (Nagaveni and Srimathi 1981; Das and Tah 2013).

Liu et al. (2009) stated that a substrate mixture, i.e., peat, burnt soil and coconut dust in the ratio of 1:1:1 (w/w) and calcium superphosphate (2%) results in increased survival rate (98%) with a greater height and biomass of Sandalwood seedlings, when *Kuhnia rosmarinifolia* Vent. was used as the main host plant. Further, the surface-sterilization of seeds with mercuric chloride (0.1%) for 5–6 min and three washes in sterilized distilled water, in addition to the addition of 1 mg/L GA_3 for 24 h was effective in improving the seedling growth and development. The seedlings are sensitive to both drought and sunlight, but needs lateral shade.

Annapurna et al. (2004) conducted a study on the container type and size on Sandalwood's seedling quality. According to them, the best container was found to be root trainers containing compost as the main component of the potting media for producing better quality healthy seedlings. Later, Annapurna et al. (2007) also studied to optimize different factors like seed source, seed pretreatment, germination medium, type of container, potting mixture, bio-fertilizer, host species to be used and stage of introduction of host for the quality seedling production. Integration of the results of their studies on individual components showed that quality planting stock of sandalwood can be produced in 270 mL block type root trainers or 600 ml polythene bags within 5–6 months period. Gogoi et al. (2014) opined that Sandalwood is being cultivated in Assam for its better economic prospects and its luxuriant growth proves that the geo-environmental conditions are suitable for this species. Sudhakar et al. (2014) conducted experiment for two decades on Indian Sandalwood to standardize nursery technology and their results indicated that treating the seeds with gibberellic acid (GA_3) 25 ppm and indole-acetic acid (IAA) 100 ppm can be recommended for the better germination and production of vigorous seedlings. They prescribed *Casuarina* as the best secondary host followed by *Terminalia, Albizia, Dalbergia,* and *Pongamia* in the field. Das and Tah (2014) conducted an experiment in different soil environments of South-West Bengal, India both in the nursery and field condition after transplantation of Sandalwood saplings with different hosts singly and in combination of hosts and found that *Cajanus cajan* is the best host followed by *Cajanus cajan* and *Ocimum sanctum* combination followed by *Ocimum sanctum* singly. They advocated that though Sandalwood plants survived without host, the girth and height growth was much better with the presence of hosts. Binu et al. (2014) demonstrated that the nutrient status of the Sandalwood seedlings inoculated with Arbuscular Mycorrhizal Fungi (AMF) was higher compared to the non-inoculated seedlings and colonization of the roots was higher for the seedlings inoculated with *Glomus mosseae*, an average root colonization was observed to be 68%. However, in general, the host species did not show any significant influence on the growth of Sandalwood seedlings.

8.3 Agro-Forestry Systems

Agro-forestry is the land utilization managing system, in which multiuse trees and shrubs in farmlands are grown. It is a potential approach to minimize unsustainable withdrawals from forests and promote the production of fuel wood, fodder, and timber in conjugation with agricultural crops on non-forest lands. The benefits generated by agro-forestry practices are both commercial and environmental. Agro-forestry can surge the farm profitability, and helps to conserve natural resources. There are four main types of agro-forestry system: (1) Agro-silvicultural systems are a grouping of trees and crops, such as alley cropping, i.e., implanting rows of trees at wide positioning with a companion crop grown in the alleyways between the rows or home gardens, (2) Silvi-pastoral systems combine forestry and pasture development, (3) Agro-silvi-pastoral systems combine crops, trees, and animals and are illustrated by home gardens, comprising animals and scattered trees on crop-lands used for grazing after harvests, and (4) Silvi-horticultural systems where forest trees and horticultural crops are grown together.

The high demand and remunerative prices of Sandalwood have motivated private individuals to take up Sandalwood cultivation in a big way as a pure crop as well as in agro-forestry system. Farmers have shown a distinct preference for horticultural species rather than conventional forestry species as long term secondary host with the objective of getting intermediary returns during the long gestation period of Sandalwood. However, information on the performance of Sandalwood under managed conditions in agro-forestry system is inadequate. Afforestation programmes have suffered from technological weaknesses, which have restricted the productivity and impact of these efforts are clearly visible. There is a need of quality planting materials, appropriate models and modalities of management techniques, and primarily lack of private participation. Sandalwood trees have been successfully grown as commercial crop in different countries including India and the harvesting period has been reduced significantly compared to the wildly grown trees. The fragrant heartwood and oil obtained in 15 years have all the qualities of a well grown tree and it can be commercially harvested (Padmanabha 2014). Agro-forestry systems with appropriate commercially important trees with Sandalwood offer promising options.

Indian sandalwood is a highly adaptable species that grows in varying soil conditions and weather, amid temperatures ranging from 5 to 50° C.

While selecting host plants in agro-forestry system for Sandalwood it should be kept in mind that it can apparently parasitize a wide range of host plants, but little is understood of the reasons why some hosts turn out to be better than others. Effective host plants include: *Capsicum frutescens, Acacia villosa, Desmanthus virgatus, Crotalaria juncea, Alternanthera* species (Fox et al. 1995; Fox and Barrett 1995). Sandalwood is not shade tolerant, and a vigorously growing host can easily outshade the parasite. Agro-forestry systems of potential interest include food crops in early stages and leguminous host trees that yield potentially viable products (fodder) while pruned and regulated in vigor to allow the sandalwood to gradually reach harvestable size. Some income stream in the early years is probably essential to maintain farmers' interest in tending the plot while waiting for the payback through sandalwood in 30 years (Noordwijk et al. 2001).

Singh et al. (2014) studied 6 years old sandalwood trees cultivated in association of *Citrus aurantium, Punica granatum,* and *Casuarina equisetifolia* trees in semi-arid region of North Gujarat, India for their relation with host species under agro-forestry system in terms of growth and heartwood formation. They found that height, collar diameter, crown size, clear bole, and survival of Sandalwood trees were greater with *Citrus aurantium* as compared to *Casuarina equisetifolia* and *Punica granatum* as hosts. Another study by Viswanath et al. (2014) conducted in semi-arid and tropical humid conditions in Karnataka, India on grafted Amla (*Emblica officinalis*), Mango (*Mangifera indica*), and Coffee (*Coffea arabica*) and suggested that the best growth of Sandalwood recorded with *Mangifera indica* as the host under intensively managed condition and least was with *Emblica officinalis* host under slightly less intensively managed conditions. Their study revealed that under managed conditions in agro-forestry, it is possible to attain mean annual increment in excess of 4 cm in a year. Padmanabha (2014) suggested agro-forestry systems/ models with appropriate commercially important trees with Sandalwood, which offers promising options. These models are not only commercially viable but has an impact on the micro-climate changes of the regions, influencing air temperature, radiation flux, wind speed, and saturation deficit of understorey crops. Hanumantha et al. (2014) conducted studies pertaining to the phenology and natural regeneration of Sandalwood under different plantations like Bamboo, Eucalyptus, Acacia, medicinal plants in garden and in the natural forest, where several birds are involved in dispersal of the seeds and their result showed that the overall regeneration was highest in medicinal plant's garden followed by natural forest and bamboo plantation.

Another model of agro-forestry system with one or more seasonal crops is illustrated here. The main priority of the agro-forestry system is the selection of appropriate host species. This system is done by utilizing the hedgerows that produce food, fruits, and animal feed. The fence plant is grown in the form of a line in association of Sandalwood. This system can be called a fence cultivation system. Plants that are considered suitable for this system are: *Cassia siamea*, *Schleichera oleosa*, *Sesbania formosa*, *Ceiba pentandra,* and *Aleurites moluccana*. In addition to planting side crops and hedgerows, the community can utilize the land in between rows with food crops such as *Zea mays* (corn), *Arachis hypogaea* (peanut), *Phaseolus radiatus* (green beans), *Cajanus cajan* (red gram) (Thomas 2017). The farmers in the state of Gujarat have been one of the most enterprising farmers and have started raising Sandalwood plantations way back in 2006–2007. The oldest private plantation of 15 years noticed was in Bhavnagar, Gujarat with grafted mango as secondary host. Grafted mango will provide some intermediate benefit to the farmers every year till Sandalwood is harvested. The Gujarat Sandalwood Growers Association claimed that they have planted nearly 20,000 ha of sandalwood in the State till date (Mishra et al. 2018).

8.4 Nursery Practices for Quality Planting Stock

Large-scale plantation programs have necessitated a demand for good quality planting stock from nurseries and it has to be established in different States. Nursery stock is the pre-requisite for raising successful plantations. Nurseries are either temporary or permanent depending upon the duration of their use. Temporary Nursery is established in a short term basis to meet the requirements of seedlings for a difficult and limited area. Permanent Nursery is established to supply nursery stock on a long term basis. Cost of production of seedlings in a permanent nursery is considerably less than a temporary nursery.

In artificial regeneration of Sandalwood, Kala et al. (2007) carried out an investigation on 14 nutrition levels to standardize the nutrition for establishment of sandalwood seedlings in nursery at Forest College and Research Institute, Mettupalayam, Tamil Nadu during the year 2004–2005 and found that nutrition plays a vital role in the establishment phase of Sandalwood seedlings in nursery. Among the 14 nutrition treatments tried in the experiment, T_1 (sandalwood + red gram), T_2 (Azsophos + VAM), and T_{12} (Azsophos + VAM + DAP + Micronutrients) had significantly better response to the growth parameters, quality parameters, biomass production, and chlorophyll content. Hence, these treatments could be adopted for quality seedling production in the nursery with or without host. The integrated application of organic, inorganic, and bio-fertilizers also proved good due to continuous supply of nutrients by the quick release of inorganic fertilizer at initial stage and the slow release of organic and bio-fertilizers at the later stages. This has created a sustained supply of nutrients to sandalwood seedlings for better shoot and root growth and development.

The ideal time to start raising Sandalwood seedlings in the nursery is during November–December so that disease free proper sized seedlings are available during monsoon (July). Sandalwood seeds have post-drop dormancy of 50–60 days due to the impermeable seed coats. Seeds have been found to germinate fast when the seed coat is completely removed, or seeds are soaked in 0.05% gibberellic acid for 12–16 h (Nagaveni and Srimathi 1981). Annapurna et al. (2007) conducted a study to standardize the various factors like seed source, seed pretreatment, germination medium, stage of transfer of seeding, type of container, potting mixture, supplementary nutrition, bio-fertilizer, and host species for nursery and stage of introduction of host responsible for mass production of quality seedlings of Sandalwood. They recommended that by integrating the best treatments for the above factors, quality seedlings of 25–30 cm height, 3.5–4.5 mm collar diameter, and 3–3.5 quality index with good fibrosity can be produced in 270 mL root trainers or 600 mL polybags within 6 months. Das (2014) studied the progress of germination of Sandalwood and found that the duration of germination is much prolonged after the dormancy period and starts in 25–30 days and reaches hardly 60–70% in 90 days with 0.05% (500 ppm) GA_3 soaking for 16–24 h but rate of germination is quicker from 30 to 60 days and most of the germination takes place within 60 days. The treated seeds are sown in the sand beds (Fig. 8.1), i.e. germination beds @400-500 g/ m^2. Traditionally, the seedlings at 3–4 leaf stage are transferred to hycopots of 300 cc (Fig. 8.2) or poly-pots of 500 cc (Fig. 8.3) capacity with a potting mixture of sand, soil, and FYM in 2:1:1 ratio with *Cajanus cajan* or *Mimosa pudica* as pot (primary) host. Host plants are to be pruned periodically at monthly intervals to encourage the growth of Sandalwood seedlings. The germination media in the beds or in the trays must be treated with fungicide (0.25% Dithane M-45 or Bavistin) at monthly intervals as prophylactic measure. Seedlings are sensitive to both drought and sunlight but needs lateral shades. Seedlings of 30–40 cm height having lush green leaves (Fig. 8.4) with dark brown stem can be produced within 6–8 months.

Many private nurseries are supplying Sandalwood seedlings across India.

Fig. 8.1 Sand bed for germination of sandal seeds (image by author)

Fig. 8.2 Shifting of sandal seedlings to hycopot (image by author)

Fig. 8.3 Shifting of seedlings to polypot (image by author)

Fig. 8.4 Nursery stock ready for planting (image by author)

8.5 Site Selection for Sandalwood Cultivation

Ecologically, Sandalwood trees have acclimatized to different agro-climatic and soil conditions for in situ regeneration with an exception of waterlogged areas and very cold places. Sandalwood requires good drainage and does not tolerate water stagnations. Sandalwood trees grow well on red ferruginous loam soil. It is not exacting as to the depth of the soil and is frequently found on rocky ground and on stony or gravelly soils (Troup 1921). Best growth of tree is found on the fairly moist soil such as garden loam with well drained deep alluvium on the river banks. A significant relationship between available nitrogen content in “A” horizon and annual growth increment was observed in the soil of the Talamalai ranges (Krishnamurthy et al. 1983). Jain et al. (1988) studied on the soil properties and their relationships to the growth of Sandalwood in three areas and observed that lime status, water holding capacity, pore space, volume expansion on wetting, exchangeable calcium and magnesium and available potash, exert positive influence on the increment in girth and height. It is assumed that the heartwood with a finest scent is attained from the dry regions, predominantly on red or stony ground (Gunther 1952). The yield of essential oil will be relatively higher than those grown in on the fertile zones (Bhatnagar 1965). Sreenivasaya and Rangaswamy (1931) are of the opinion that Sandalwood growing on rocky soil and in association with xerophytic conditions having higher proportion of heartwood than the one thriving on fertile soil enjoying good rainfall and nourished by vigorous hosts. The heartwood of trees growing in dry rocky mountainous soils is harder and richer in oil than those growing on fertile ones. It was also clear that the only factor which appears to influence the percentage of oil is the soil (Singh 1915). In Pachamalai forests of Tiruchirapalli forest division, the trees on the lower slopes and plains are generally stunted and poor in heartwood while those on the higher slopes and particularly those on the plateau have good growth with better development of heartwood (Baskardoss 1968). In Coimbatore where xerophytic conditions prevail even in the trees of smaller girth class (10–18 cm), the heartwood formation was good. But in the forest college campus where the soil is shallow and has pebbles and boulders, the Sandalwood trees of even 30–45 cm girth had little heartwood (Nayar 1974). Das et al. (2018) conducted experiment on two locations of laterite soil, viz. Bagaldhara and Rangamati of Bankura (South) forest division, West Bengal, India for cultivation of Sandalwood and found that the porous and well drained soils of Bagaldhara helped the saplings with better root respiration and root-shoot growth in comparison to the soils of Rangamati which is hard specially when dry, slightly rocky, compact and full of laterite. From the above discussion, it is clear that sandalwood prefers a well-drained moderately fertile, slightly acidic to neutral soil. Heartwood formation and the oil content in the wood seem to be better under drier conditions..

8.6 Sandalwood Cultivation and Impact of Hosts on Its Survival

Sandalwood can grow in comparatively poor agricultural soil and also in derelict forest areas of laterite tract but cannot withstand the water-logging. The hemi-parasitic nature of Sandalwood was not fully understood and silvicultural techniques to establish it are not fully known. Padmanabha et al. (1984) reported that Sandalwood plants establish haustorial connections with the secondary hosts (e.g. *Pongamia pinnata*). Though Sandalwood plants can survive without a host, their experiment has proved beyond doubt that the host plants are absolutely necessary for the better growth of sandal plants. Sandalwood can grow with a wide range of host (non-obligate) species depicted in Table 8.2 (Das 2014). Analysis of soil and leaf samples from this species has shown that Sandalwood depends on its host for potassium, phosphorous, and magnesium. It can draw other nutrients directly from soil as its roots have good cation exchange capacity (Parthasarathi et al. 1971). Study conducted by Das and Tah (2016) revealed that combination of host plants, Arhar (*Cajanus cajan*) + Tulsi (*Ocimum sanctum)* is always found to be better than that of single host treatment. Noordwijk et al. (2001) revealed in their study that as a relatively slow growing root parasite, sandalwood will interact with other components in a complex pattern of competition and host–parasite relationships, depending on root distribution and rooting depth of potential hosts (Noordwijk et al. 2001). Simple schemes for analyzing the balance of impact of positive and negative interactions between tree, soil, and crop components have contributed to our understanding of agro-forestry systems. For simultaneous tree-crop systems, such as hedgerow intercropping where most of the direct value for the farmer is to be derived from the annual food crops, the focus is on the tree effect on crop yields.

Viswanath et al. (2007) assessed the viability of domestication of sandalwood in Karnataka through a financial analysis using indicators like: Net Present Value (NPV), Benefit Cost ratio (B/C), Internal Rate of Return (IRR), Equivalent Annual Income (EAI) and Land Expectation Value (LEV) at different discount rates (10% and 15%) for sensitivity analysis. They have analyzed different Sandalwood based agro-forestry models, viz. sandalwood monoculture plantations and sandalwood intercropping with amla (*Phyllanthus emblica*) and horse gram (*Dolichos uniflorus*) for two different rotation periods (15 years and 20 years) to determine the financially optimal model and period of rotation. They concluded that Sandalwood block plantation with a rotation period of 15 years gives the highest NPV, B/C ratio, EAI, and LEV at different discount rates (10% and 15%) due to high returns from selling Sandalwood which is substantial compared to the expenditure incurred.

In Block Plantation, field experiment was conducted by Das (2014) in Bagaldhara Forest Protection Committee (FPC) and Rangamati FPC of Hirbandh Block, Bankura (South) Division, West Bengal, India. Planting pits of size 60 cm × 45 cm × 45 cm were dug in the field in March–April for planting of the potted seedlings. The pits may be aligned either in square manner (Model-1) or in

x—x—x—x—x—x—x—x—x—x—x	x—x—x—x—x—x—x—x—x—x—x
x—x—x—x—x—x—x—x—x—x—x	x—x—x—x—x—x—x—x—x—x
x—x—x—x—x—x—x—x—x—x—x	x—x—x—x—x—x—x—x—x—x—x
x—x—x—x—x—x—x—x—x—x—x	x—x—x—x—x—x—x—x—x—x
x—x—x—x—x—x—x—x—x—x—x	x—x—x—x—x—x—x—x—x—x—x
x—x—x—x—x—x—x—x—x—x--x	x—x—x—x—x—x—x—x—x--x
Model-1. Pit alignment in square	Model-2. Pit alignment in staggered

Fig. 8.5 Pit alignment in square and staggered manner

staggered manner (Model-2) (Fig. 8.5). Square manner looks good but staggered manner is more effective in controlling soil erosion particularly in sloppy ground.

The pits were filled with soil and 500 g of cow dung manure or farm yard manure (FYM) in the month of May–June after a good pre-monsoon shower. Planting was done early in the rainy season. The potted seedlings (6–8 month old) raised in nursery were planted in the field in July after getting a good rain at a spacing of 3 m $\times$ 3 m. As it is a hemi-(root) parasite, it needs host (non-specific) plant to grow in the initial stage. The Sandalwood seedlings were planted in the field along with host plants like *Cajanus cajan*, *Ocimum sanctum*, *Catharanthus roseus*, *Calotropis procera* either singly or in combination. Some seedlings were planted without host. Fertilizer (NPK–10:26:26) was applied twice @ 40 g/plant at the time of cleaning and mulching at 3 weeks interval after planting. Growth parameters (plant height and collar girth) and survival % were measured after 12 months and 24 months, respectively, for study of growth of Sandalwood saplings in 1st year and 2nd year. The following Table 8.1 shows that growth of Sandalwood saplings is better with Arhar (*Cajanus cajan*) and Tulsi (*Ocimum sanctum*) combination of hosts followed by *Cajanus cajan* followed by *Cajanus* and *Calotropis* combination of host followed by *Ocimum sanctum* as single host both in 1st year and 2nd year (Das and Tah 2016). The survival percentage also follows the same trend. The survival percentage varies from 70 to 82% in 1st year and 66 to 76% in 2nd year depending on the type of host. The Sandalwood seedlings, which were planted without host, have survived 30% in 1st year and 20% in 2nd year. The growth of Sandalwood saplings are better (almost double) in Bagaldhara than in Rangamati because the soil of Bagaldhara is loose and contains more of mica but the soil of Rangamati is slightly rocky, compact and full of laterite. *Calotropis procera* and *Catharanthus roseus* seem to be poor host with a survival rate of 40% and 50%, respectively, though the combination of host of *Cajanus* + *Calotropis* (72% and 68% in 1st year and 2nd year, respectively) and *Ocimum* + *Catharanthus* (68% and 64% in 1st year and 2nd year, respectively) performed better (Fig. 8.6, 8.7, 8.8, and 8.9).

Farmers have shown a distinct preference for horticultural crops like Amla, Tamarind, and Mango instead of conventional host trees with an objective of obtaining intermediate benefits during the long gestation period of Sandalwood. It

Table 8.1 Growth and survival of sandalwood seedlings without and with hosts in 2011 plantation (Source: Das 2014)

Type of host (2011 plantation)	Growth in 1st year (sample size: 30–40/treatment)				Survival %
	Height (cm)	Av. height (cm)	Collar girth (cm)	Av. girth (cm)	
Cajanus cajan	70–170	99.32	3–7	4.45	80%
Ocimum sanctum	52–115	85.58	3–5	3.75	70%
Calotropis procera	50–95	63.67	2–4	2.42	40%
Cajanus + *Ocimum*	75–183	110.58	3–7	4.50	82%
Cajanus + *Calotropis*	63–110	84.00	2.5–6	3.78	72%
Without host	33–64	48.28	1–2.5	1.71	34%
Type of host (2011 plantation)	Growth in 2nd year (sample size:30–40/treatment)				Survival %
	Height (cm)	Av. height (cm)	Collar girth (cm)	Av. girth (cm)	
Cajanus cajan	130–295	196.83	4–11	6.88	74%
Ocimum sanctum	120–200	158.33	4–8	6.17	66%
Calotropis procera	110–150	124.17	3–5	4.30	32%
Cajanus + *Ocimum*	140–295	213.33	6–11	8.08	76%
Cajanus + *Calotropis*	125–180	148.57	4–7	6.00	68%
Without host	80–110	95.00	2.5–4	3.00	20%

Das (2014).

Fig. 8.6 Plantation of 2011 at Bagaldhara (image by author)

is a form of multiple land uses for maximization of production for the diverse requirements of the rural communities. In agri-silvicultural systems, one or two lines of Sandalwood saplings can be alternated with one line of *Casuarina, Terminalia, Dalbergia, Pongamia, Albizia, Melia,* or *Cassia* saplings which will act as secondary hosts and help Sandalwood saplings to establish as it is a root parasite in the initial stage. In silvi-horticultural system, one line (Model-3) or two lines (Model-4) (Fig. 8.10) of Sandalwood saplings can be alternated with one line of

Fig. 8.7 Plantation of 2012 at Rangamati (image by author)

Fig. 8.8 Sandal seedling with *Cajanus cajan* host (image by author)

Orange (*Citrus aurantium*), Mango (*Mangifera indica*), Pomegranate (*Punica granatum*), or Amla (*Emblica officinalis*), which are suitable for the sites/areas. These will help Sandalwood saplings to establish and provide intermediate income every year after 3–4 years of planting till the final harvest of Sandalwood.

Field experiments were conducted in Kerala Agricultural University (KAU 2006) by Ashokan and Krishnambika (2007) in different agro-forestry systems (sandal + coconut, sandal + cashew, sandal + cocoa, sandal + rubber, sandal + teak, sandal + casuarina, sandal + coconut + casuarina, sandal + cashew + casuarina, sandal + cocoa + casuarina, sandal + rubber + casuarina, sandal + teak + casuarina) indicated that maximum height of the Sandalwood seedling was found when

Fig. 8.9 Sandalwood seedling with *Ocimum sanctum* host (image by author)

Casuarina was grown as the host plant. Height of Sandalwood seedlings in the planting systems of Sandalwood+teak +casuarina, Sandalwood + teak and Sandalwood + cocoa + casuarina was equivalent. Except Teak, all other crop plants, viz. coconut, cashew, cocoa, and rubber reduced the height of the Sandalwood seedlings. The height and girth of the Sandalwood without the host were only half of that of Sandalwood + casuarina. Thomas (2017) studied on the selection of host plants paying attention to the size, shade nature, economic value, and its contribution to sandalwood. They have tried several species of host plants like *Annona squamosa, Citrus aurantifolia*, *Ziziphus mauritiana*, *Musa paradisiaca,* etc. fruit species and *Capsicum frutescens*, *Alternanthera nana, Solanum melongena*, *Lycopersicon esculentum,* etc. vegetable species as short term, medium term, and long term hosts in Indonesia and advocated that by knowing the types of host plants, both at the nursery level and planting in the field (medium and long term), farmers/ communities can have a choice in cultivating sandalwood in the future.

8.7 Maintenance of Plantation

Tending is mostly concerned with preventing the plants from being suppressed by competing weeds in the most plantation sites. *Chromolaena odorata* (Syn. *Eupatorium odoratum*), *Lantana camara, Mikania* spp. (climber), *Parthenium hysterophorus*, *Saccharum spontaneum* are some of the obnoxious weeds of the plantation which needs to be uprooted or cut manually before they seed. Host plants are to be pruned periodically when it overgrows Sandalwood saplings so that

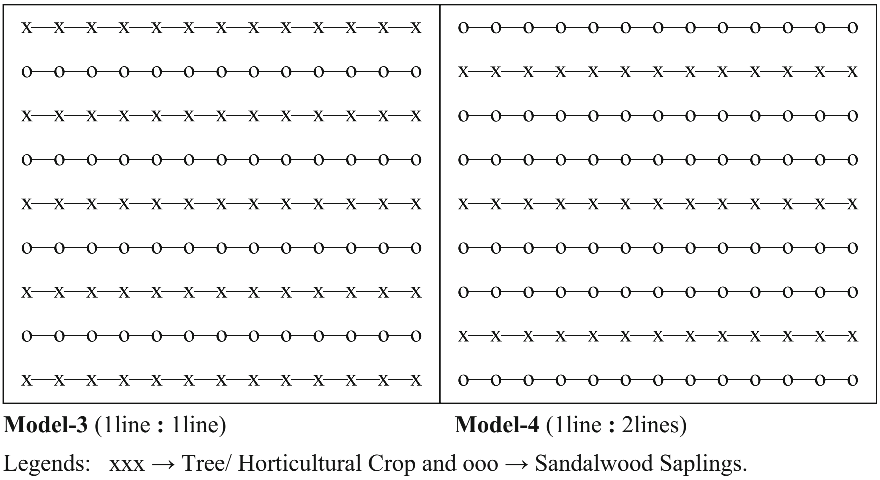

Fig. 8.10 Proposed agro-forestry models with sandalwood (by author). Legends: xxx → tree/ horticultural crop and ooo → sandalwood saplings

Sandalwood trees get maximum light. Climber cutting will be necessary from third year onwards. All Sandalwood trees are to be pruned once in 4 years. Shrubs and plants useful as hosts are retained and other unwanted growths like *Lantana* and other unwanted species should be removed to provide more space for development of Sandalwood trees. Fencing may be erected to protect young regenerating plants against grazing. Full overhead light should be allowed by judicious lopping of overtopping branches of neighboring trees. Thinning may be carried out as and when required to give Sandalwood trees a space of 5–6 m depending on the size of the trees retained. Only best and healthy Sandalwood trees should be retained in thinning for final harvest.

8.8 Protection of Plantation

Causes for failure of plantation are mainly the lack of technical knowledge, lack of planning, inadequate supervision, and insufficiency or untimely availability of fund. It is very important to investigate the reasons of failure thoroughly and to take all practicable steps to prevent failures in future. Sandalwood plantations should be protected against grazing, fire, pests (diseases and insects), and illicit felling.

8.8.1 Protection Against Grazing

Grazing is the most destructive factor for failure of plantation and consequent deforestation. Young plantations should be protected against grazing by keeping watcher or by live-hedge fencing or erecting barbed wire fencing around the plantation.

8.8.2 Protection Against Fire

Fire do incalculable harm to the plantations especially in the drier climatic regions but examples are many in the relatively moist or high rainfall areas where during warm and dry spells, fires have done extensive damage. Plantations should be protected against fire by engaging fire watcher and/or cutting fire lines 3 m wide along the periphery of the plantation and within the plantation 20 m apart.

8.8.3 Protection Against Disease and Pests

Pests and Diseases (Thomas 2017), the constraints faced in the rebuilding of sandalwood forest is pest control. When there is a great pest attack so that Sandalwood becomes bald and severe, should be destroyed so that it will not attack other Sandalwood. Some types of diseases that attack Sandalwood are (Sinaga and Dan Surata 1997):

- Caterpillar leaves: damage the leaves. Attacks are usually in the dry season. Control by spraying insecticide.
- Flea scales: the formation of lumps on the leaves, shoots, and crushes. Control by pruning, spraying with a carbonyl insecticide and chlorpyriphos.
- Sooty mushroom: attacking twigs and leaves, covered with soot hi-tam so as to disrupt.
- assimilation. Control by washing the affected part, or sprayed with a detergent solution.
- Stem blight: roots rot. Control by spraying fungicides.
- When in the growth and development of Sandalwood, there are host plant that died then another to be planted again as a substitute. Host plants should be always grown with Sandalwood (Details will be discussed in Chap. 9).

8.8.4 Protection Against Illicit Felling

Illicit felling will not be a problem till heartwood formation starts in Sandalwood trees. As heartwood formation starts after 10th year of plantation, so protection problem against illicit felling comes after the 10th year. Sandalwood trees are highly prone to theft due to their high economic values of heartwood. Power fencing works to some extent but due to vast area of forests and farmlands, fencing and electrification are not much useful in providing security to Sandalwood trees. The use of various sensors and wireless technology developed by Electronics and Communication Department, Bangalore Institute of Technology, India, the possibility of identifying any illegal logging activities can be detected. The sensor picks up the illegal logging activity, transfers the signal to the transmitter which further transmits the signal to the router and finally to the control station.

8.9 Benefits of Agro-Forestry Systems

8.9.1 Improving Soil Fertility

Plant fences grown on the sidelines of sandalwood plants can deposit soil organic matter so that the soil remains loose and moist. The deciduous leaves, the pruning of the branches, and the remnants of food crops re-enter the soil that can become manure and are the source of organic matter. The high content of this organic matter can maintain soil moisture and humidity.

8.9.2 Increase the Efficiency of Nutrient Uptake

Farmers generally do fertilization for food crops. In the agro-forestry system, this fertilizer will also be absorbed by the root of the sandalwood plant, thereby increasing the efficiency of fertilizer use.

8.9.3 Provide Shade to Young Sandalwood

Young sandalwood sapling is in need of shade so that the hedgerows can help to provide shade.

8.9.4 Assist the Parasitism Process for Sandalwood

Seasonal crops and hedgerows/intercrops among the sandalwood trees generally have soft roots that can act as a potential host for Sandalwood.

8.9.5 Suppressing the Spread of Pests and Diseases

Sandalwood plants, generally susceptible to caterpillars. The leaves of planted fencing plants and host plants are preferred by caterpillars and thus the pest does not quickly attack the sandalwood plant. Hence, fencing and host plants can act as pest-catchers.

8.9.6 Intermediate Benefits to Farmers

The economic benefits that can be gained by the farmers or community in the development of sandalwood crops with agro-forestry system are additional income to them besides sandalwood.

8.10 Economics of Raising Sandalwood Plantation

Divakara et al. (2018) have given the economics of Sandalwood cultivation under semi-arid tropics of Karnataka, India. They made an attempt to find out the economic viability of Sandalwood cultivation as a sole crop and along with the combination of Pigeon pea/Red gram (*Cajanus cajan* L.) under semi-arid conditions of Karnataka. The economics of cultivation of Sandalwood compares input cost and anticipated returns of three scenarios; an annual cropping system and two plantations of Sandalwood regimes over a 15 year period are considered. The economic analysis compares three management regimes;

1. Growing only red gram cropping system: using a continuous red gram rotation for simplicity.
2. Sandalwood plantation with generation of revenue from timber harvest only.
3. Sandalwood plantation with red gram, generation of revenue from sale of Sandalwood plus annual red gram harvest for 15 years.

The details of expenditure incurred in cultivation of Sandalwood as a sole crop, red gram as sole crop, and red gram-Sandalwood combination on per hectare basis are given in Table 8.2 (Divakara et al. 2018).

Income from Sandalwood plantation is calculated assuming that out of 400 trees planted, 10% of trees died during the period of 15 year, therefore 360 trees survived healthy (Table 8.3).

The actual cost in cultivation of Sandalwood per hectare is Rs. 34.36 lakhs (including interest at 9% rate), whereas when Sandalwood is grown with red gram as intercrop, cost of cultivation is Rs. 35.75 lakhs. Though the inter-cultivations (Sandalwood + red gram) have slightly lower income compared to pure Sandalwood plantations, the possibility of yielding *Cajanus cajan* dal in inter-cultivation makes farmers comparatively more attractive as it give some income every year. Added to this, combination of Sandalwood and *Cajanus cajan* advocates that the recommended investments will provide income up to 29% of returns over the life of the venture, considering the amount and timing of the anticipated money inflows and outflows are explicit to the investments (Divakara et al. 2018).

According to Mishra et al. (2018), international price for Sandalwood oil is Rs. 2 lakhs/kg. The average auction price of Sandalwood in the Salem depot of Tamil Nadu during 2013 was Rs. 6500/kg. The average price paid to farmer by Karnataka Soaps and Detergents Ltd., Bangalore (KSDL) on procurement of sandalwood in the year 2020 is Rs. 9000/kg of heartwood. But, in 2016 the average

Table 8.2 Details of cost of cultivation of sandalwood and red gram (Divakara et al. 2018)

S. No.	Item of activities	Cost (Indian Rupees)
	First year plantation cost of sandalwood	
1.	Site preparation (JCB@Rs. 800/h for 10 h)	8000.00
2.	Cost of 400 seedlings/ha (spacing 5 × 5 m) @ Rs 30/seedling	12000.00
3.	Cost of digging pits@20 pits/day/labor (Rs 350 × 20DL)	7000.00
4.	Cost of sowing primary host (*Cajanus*) @4DL/ha (Rs 350 × 4DL)	1400.00
5.	Cost of *Cajanus cajan* seeds/ha 1 kg @Rs 250	250.00
6.	Cost of farm yard manure (FYM-Rs 5/kg)@2 kg/plant(800 kg × Rs 5)	4000.00
7.	Labor charge for FYM application@4DL/ha	1400.00
8.	Cost of barbed wire fencing (Rs 650,000/km)@400 m/ha × Rs 650/m	260000.00
9.	Watering: cost of bore well, pipe line, transformer, pump set—5 HP motor, drip system @Rs 350000/ha	350000.00
	Next 14-years maintenance costs of sandalwood	
1.	Fertilizer: cost of fertilizer (Rs 25/kg) for 5 years @250 g/plant/year (400 plants × 250 g × Rs 25 × 5 year)	12500.00
2.	Security: 2–3 years: cost of one security guard per month @Rs 5000 × 24 months	120000.00
	Security: 4–9 years: cost of two security guards per month @Rs 6000 × 2 nos × 72 months	864000.00
	Security: 10–15 years: cost of three security guard per month@7000 × 3nos × 72 months	1512000.00
	Sub-total	3152550.00
	Cost of agriculture crop (Cajanus cajan cultivation)	
	Site preparation (JCB @ Rs 800/h for 10 h)	8000.00
	Cost of disc ploghing @ Rs 800/ h for 10 h	8000.00
	Cost of *Cajanus* seeds 12.5 kg/ha @ Rs 250/kg	3125.00
	Cost of sowing @ 10 MD/ha @ Rs 350/MD	3500.00
	Cost of FYM 5 tractors/ha @ Rs 3500/tractor	17500.00
	Cost of fertilizer (25–30 kg N, 50–75 kg P_2O_5) and pesticides L.S	10000.00
	Cost of harvesting processing (2500 kg/ha)	10000.00
	Cost of security @Rs 5000 × 12 months	60000.00
	Sub-total	120125.00
	Total	32,72,675.00

e-auction price of Sandalwood in Marayoor forest of Kerala was Rs. 12,000/kg. Though the costs of heartwood are high, on procurement of Sandalwood from farmers, they paid an average price of Rs. 6400/kg from Karnataka Soaps and Detergents Ltd. (KSDL), Bangalore.

Table 8.3 Details of income from cultivation of sandalwood and red gram (Divakara et al. 2018)

S. no.	Item of activities	Cost (Rs.)
	Income from sandalwood plantation	
1.	Cost of 5400 kg heartwood @ 15 kg heartwood/tree (360 trees × 15 kg heartwood × Rs 6000/kg	3,24,00,000.00
2.	Cost of 10,800 kg sapwood @ 30 kg sapwood/tree (360 trees × 30 kg sapwood × Rs 70/kg)	7,56,000.00
3.	Total income earned from sandalwood/ha (heartwood + sapwood)	3,31,56,000.00
4.	Net income of sandalwood/ha (after deducting 10% as processing and transportation charge from total income)	2,98,40,400.00
	Income from pigeon pea/tur dal/red gram (Cajanus cajan L.)	
1.	Red gram (*Cajanus cajan*) production @ 2500 kg/year in sole crop @ Rs 100/kg	2,50,000.00
2.	Red gram (*Cajanus cajan*) production @ 2000 kg/year in intercrop @ Rs 100/kg	2,00,000.00

8.11 Conclusions

Considering the future potentials of Sandalwood in the world market, the very high demand and prices of Sandalwood and its products, intensive research programs are needed to develop techniques to regenerate Sandalwood trees and to manage its cultivation. The present shortage in supply of Sandalwood can only be reduced by cultivation of Sandalwood in more forest areas as well as in farmlands like homesteads or other agro-forestry systems. The high profitability of Sandalwood trees in agro-forestry will undoubtedly spark interest among private growers, provided the policy environment is conducive.

According to the prevailing rules in the southern states of Karnataka and Tamil Nadu, except Kerala, even when the tree is located on private land, it belongs to the State Government and the owner of the land is required to make a declaration on the number of trees on his land (Rao 2002). The wood can only be sold to the forest department or any public sector undertaking as notified by the government from time to time. Moreover, the delay in payment due to bureaucratic red tapes will further bring down the financial indicators if the time lag in payment is also accounted for. Thus, the present policy of the financial profitability of Sandalwood cultivation are varied by the restrictive policies which deny farmers the full market value for their produce and compel them to go through elaborate bureaucratic procedures to receive the benefits. Hence, revamping of legal provisions related to Sandalwood is urgently needed to felicitate free trade and the markets to ensure higher and speedy returns to farmers, thereby encouraging private domestication of this priced resource (Divakara et al. 2018).

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9 Diseases and Insect Pests of Sandalwood

Sudhir Chandra Das

Abstract

Sandalwood (*Santalum album* L.) grows naturally under suitable conditions in different parts of India. Large-scale plantation programmes are taken up to reduce the gap between demand and supply as the natural stocks are dwindling. Its cultivation in agroforestry system is increasing day by day. Sandalwood seedlings and grafted plants face problems from insect pests and diseases, which take a heavy toll and sometimes the whole stock is wiped off. Hence, to raise a healthy plantation of this economically important plant, knowledge on its diseases and insect pests are of utmost importance. More than 150 insects are known to occur on Sandalwood, but only a few have been recorded as serious, causing huge economic losses. The most important pests are defoliators, sapsuckers, stem borers and termites. The seedling diseases (damping off and wilt) of Sandalwood are found to take a heavy toll in the nurseries. The causal organisms have been identified as *Fusarium oxysporum* and *Phytophthora* species and nematodes. Spike disease is an important disease of Sandalwood, which has attracted attention of scientists, foresters and economists. A few number of control measures are standardized for pest and disease management in Sandalwood. Eco-friendly, environmentally non-degrading and economically viable biological control of insect pests has also been tried in recent past for the pest management in Sandalwood.

Keywords

Plantation · Spike disease · Insect pests · Stem borer · Sap sucker

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9.1 Introduction

Sandalwood (*Santalum album* L.), a culturally and commercially valued tree species belongs to Santalaceae family. It is commonly identified as the East Indian Sandalwood. Sandalwood has a great importance in the Indian culture. The heartwood of Sandalwood is valued for its fragrance, and is one of the supreme natural solids preferred for wood carving (Kumar et al. 2012). Also, the tree heartwood yields fragrant essential oil, which has high commercial value. The heartwood upon steam distillation yields the oil, which is regarded very high for its sweet scent, tenacious, warm, spicy, woody note, non-varying composition and fixative properties. Sandalwood essential oil contains in excess of 200 chemical constituents, and thus make it interesting biologically active source of phytochemicals (Misra and Dey 2013). Apart from its importance as a supremely satisfying source of fragrance, it finds uses in medicine as an antiseptic, antiscabietic, antipyretic, diuretic, stimulant, expectorant, and for treatment of bronchitis, gonorrhoea, dysuria, and urinary tract infections (Okasaki and Oshima 1953; Jain 1968). Being a medicinal plant, it also acts as a storehouse of endophytic fungi that are significant sources of different types of bioactive compounds appreciated by the pharma industry (Khan et al. 2010).

There are some endophytes which can mimic the secondary metabolism of host species and secrete compounds of human interest. These endophytes are basically fungal and bacterial species, which live inside the plant tissue without affecting any harm to the host. Krings et al. (2007) reported that endophytic fungi are allied with plants since a long time. In 2010, Shekhawat et al. also reported that nearly ten lakh species exist ubiquitously in plants. Endophytes play significant ecological (Tintjer and Rudger 2006) and physiological (Malinowski et al. 2004) roles in plant symbiosis, thus protecting their hosts from infectious agents and stressful environment by secreting bioactives (Márquez et al. 2007).

Good quality seeds and grafts of superior clones are commonly used as the planting materials. Sandalwood seedlings and grafted plants face problems from insect pests and diseases which take a heavy toll and sometimes the whole stock is wiped out. The problem exists in the plantations also. Knowledge on various insects and diseases of this precious plant shall be highly useful for the economic management of healthy plantations.

Various insect pests damage Sandalwood species (Sundararaj and Muthukrishnan 2011), mainly the coccids and stem/wood borers (Sundararaj 2011). All these pests invade and harm erect Sandalwood trees, and the affected trees display deprived growth and yield poor quality timber. It has been reported that more than 150 insect pests occur on Sandalwood but only a few cause serious damage and economic loss. This includes defoliators, sapsuckers, stem borers and termites. The sap-sucking pests of family Coccidae is very deleterious to the normal health, growth and reproduction of Sandalwood plants. The adult beetle, *Mylabris pustulata* Thunberg (Coleoptera: Meloidae), generally feeds on the floral parts of the plants. The polyphagous weevil *Sympiezomias cretaceus* Faust was reported as a defoliating agent to several species of forestry importance including Sandalwood seedlings in nurseries (Sivaramakrishnan et al. 1987b). Bugs like *Saissetia nigra* Nietner and

S. coffeae Walker cause damage to immature fruits of Sandalwood leading to fall off and fail to germinate. *Ceroplastes ceriferus* Anderson has been observed earlier singly or in groups on Sandalwood trees, causing leaf drop, reduction in plant vigour leading to dieback of the plants (Remadevi and Sivaramakrishnan 1997). The coccid, *Inglisia bivalveta* Green was reported to cause dieback of branches and leads to death of saplings and young trees in severe cases. Seedling disease of Sandalwood has been identified as a serious threat to the raising of plants in nurseries (Nayar et al. 1980). Muthukrishnan et al. (2014) conducted a survey on population dynamics of insect pests in Indian Sandalwood–based silvi-horticultural plantations from 2008 to 2013. The study revealed that mainly sap suckers followed by stem borers, *Zeuzera coffeae* Nietner and *Indarbela quadrinotata* Walker are the dominant insect pests in almost all Sandalwood based silvi-horticultural plantations.

Different diseases and pests may harm trees at all phases of growth and development as well as affect the productivity of both plantations and natural forests. Some of the fungi and insect pests can affect seedlings during nurseries stage, while others attack fully grown trees in natural forests and plantations. A number of indigenous and exotic pests or diseases are reported to cause devastating losses to forests, leading to changes in management practices or forcing forest managers to switch over to alternative tree species. For example, in a complex tropical rain forest where as many as a thousand plant species occupy per unit area, only a limited amount of suitable host material will be available to a population of host-specific phytophagous caterpillar, thereby limiting their population. On the other hand, agro-ecosystems often cover large areas and provide an unlimited amount of suitable host biomass (FAO 2001), resulting in population explosion of host-specific organisms. The lack of ecosystem diversity leads to a marginal habitat for the natural enemies of the organisms that are using the crop plant as host materials. In terms of diversity and stability, forest plantations tend to be more susceptible like agro-ecosystems than natural forests.

Defoliators and sapsuckers are the most devastating pests of Sandalwood in plantations. Seedling diseases (damping off and wilt) are the serious one which takes heavy toll in the nurseries; causal organisms identified are *Fusarium oxysporum* and *Phytophthora* spp. and nematodes. Both chemical and biological control measures are developed and standardized for pest and disease management in the Sandalwood nurseries and plantations. This chapter deals with the fungal association, occurrence of insect pests and diseases of Sandalwood and their control measures.

9.2 Sandalwood and Fungal Association

Interesting fungal associations are found with Sandalwood plants. These plants are not affected by large number of bio-deteriorating organisms like bacteria and fungi but the few that infest Sandalwood cause very serious damage and are of great economic significance. Study conducted by Nagaveni and Vijiyalakshmi (2007) to determine the bio-protective effect of Vesicular–Arbuscular Mycorrhizal (VAM) fungi in Sandalwood plants infected with wilt-causing pathogen, *Fusarium oxysporum*, showed that addition of Arbuscular Mycorrhizal fungus helped the plants to achieve the boosted growth with good vigour and health (less mortality) by putting more biomass when compared to that of uninoculated plants. Vesicular Arbuscular Mycorrhizal (VAM) associations have reduced damages triggered by soil- and root-borne pathogens to a great extent by offering tolerance of the plants to wilt disease. The interaction of VAM fungi with plant pathogens like bacteria, fungi and nematodes could lead to lessening in the severity of wilt disease (Schench 1981). Such a tolerance, because of VAM association might be conveyed by one or many ways of molecular mechanisms, such as improvement of the plant nutritional status, alterations in the physiology of the host, anatomical changes and release of phenolic compounds (Krishna and Bagyaraj 1983).

Another example of the bioprotective measures against the pathogens of Sandalwood is endophytic fungi. They are basically the endosymbionts that survive inside the plant intercellular and intracellular spaces for at least part of their life cycle without affecting damages to their host (Wilson 1995). Endophytes secrete various volatile organic compounds that are lethal to pathogenic bacteria and fungi. Endophytes also produce some chemicals that act as growth inhibitors to their competitors as well as pathogenic organisms (Woropong et al. 2001). Sun et al. (2014) isolated and identified 25 fungal endophytes linked with roots of *Santalum album* and *Kuhnia rosmarinifolia*. Among them, the most frequent ones were found to be the species of *Fusarium* and *Penicillium*.

9.3 Sandalwood Diseases

9.3.1 Nursery Diseases

Seedling diseases (damping off and seedling wilt) were found to take a heavy toll (up to 100%) in nurseries (Remadevi et al. 2005). The mortality in seedlings was found in all the three stages during their growth, due to pre-emergence blight, post-emergence mortality, root rot and wilting of older seedlings. The diseases are caused by a several fungi and nematodes. Species of *Fusarium*, *Rhizoctonia, Phytophthora* and *Pythium* were found most commonly in infected seedlings (Barbour et al. 2010). *Fusarium oxysporum* is a common and the most virulent fungus found in all the infected Sandalwood seedlings, affected by pre-emergence blight and vascular wilt. In vascular wilt, nematodes attacked seedlings along with *Fusarium* causing serious problems to seedlings. The fungus spreads rapidly in the tissues and the seedlings either wilt completely or rot off at ground line. The fungus attacks on succulent root tips in older seedlings and transplants are usually not fatal. If soil moisture is favourable, new roots develop and the seedlings continue to live. If such damage is followed by drought or by excess soil moisture, both of which discourage formation of new roots, seedling mortality may eventually occur (Remadevi et al. 2005). Wilt is a systemic disease in Sandalwood seedlings caused by *Phytophthora* spp., where the entire individual or its parts exhibit wilting of the foliage in acropetal succession up to the shoot. The leaves become yellow, lose turgidity and fall off. The affected plant or the branch soon dies. Dwarfing, stunting and necrosis were also a common symptoms found in seedlings. In all cases translocation of water and nutrients was adversely affected (Remadevi et al. 2005).

The control measures include (1) pre-emergence rot can be controlled by selection of seeds which are free of fungi and seed dressing with organo-mercuric compounds (0.2% Agallol or Ceresan); (2) drenching of mother bed with a combination of 25 g of nematicides and 0.25% of fungicides will effectively control the source of infection from soil; (3) damping off can be checked by controlled watering and good drainage in containers or nursery beds; and (4) *Fusarium* wilt can be controlled by drenching the potting medium with copper fungicide and nematocide (Blitox/Bordeaux mixture and Quinalphos or Phorate) and controlled watering of plants.

9.3.2 Main Field Diseases

9.3.2.1 Spike Disease of Sandalwood

Spike disease is an important disease of Sandalwood, which has attracted attention of scientists, foresters and economists. Teixeira da Silva et al. (2016) gave an excellent review on Spike disease of Sandalwood. Spike disease was first reported by McCarthy from Kushalnagar, Tamil Nadu, in 1899. He named the disease as 'spike' on account of the resemblance of shoots to a spike. Spike disease of Sandalwood also appeared in the literature during 1898–99 released by Forest Administration, Coorg, Karnataka. Since then the disease was considered as the most prevalent and destructive disease of the sandal species, hence attained global notice. The disease is characterized preliminarily by severe reduction in size of leaves and internodes. In advance stage, the new leaves become smaller and show a tendency to stand stiffly which gives a spike inflorescence appearance to the entire shoot (Figs. 9.1, 9.2, and 9.3). The tree ultimately dies after a year or two from the time of appearance of visible symptoms. The diseased plants do not bear any flowers/fruits or develop only abortive flowers (Muthu Kumar 2014). Over a million trees have been removed as a result of sandal spike disease from Mysore and Coorg states during 1903–1916.

Causes of Spike Disease

Coleman (1917) of Mysore Agriculture Department reported that spike disease is transmissible by grafting. Deficiency of lime in the spiked leaves was observed by him, but the same could not be traced to deficiency of the element in the soil. It has also been found that the disease is not due to want of soil aeration (Dorairaj 1958). The relationship between soil nutrients and incidence of the spike disease was studied by Iyengar 1928a, b, 1937a, b, 1938, 1955, 1960). Hence, it was viewed that calcareous nature and low amount of available nutrients in the soil may serve as predisposing factors for the onset of the disease (Khan and Yadav 1962). Parthasarathi et al. (1973) made the similar study in Sandalwood-bearing areas of

Fig. 9.1 Sandalwood spike disease: partially infected plant showing symptoms of reduced leaves (Source: Muthu Kumar 2014)

Karnataka to see whether deficiency of any major or minor elements in soils would serve as a predisposing factor for the onset of the disease. In Hunsur plantation of Tamil Nadu, where red sandy soil overlies the granite boulders at an altitude of 300–500 m with consequent low temperature favourable for growth of pathogen, the spike disease is absent or rare, perhaps due to heat released by granites (Nayar 1974). Hole (1918) and Howard and Howard (1919) believed that the disease is caused due to the unbalanced sap circulation. While Rao (1965) felt that the disease is not infective and questioned the theory of insect transmission. Kunkel (1926), McKinley (1923) and Smith (1931) suggested that the infective principle is an ultramicroscopic organisms which confirmed Coleman's earlier theory. Norris (1930) and Venkata

Fig. 9.2 Sandalwood spike disease—completely infected plant (Source: Muthu Kumar 2014)

Rao (1935) suspected that the associated rank vegetation of sandal plays decisive role in the spread of disease in nature. Even in abandoned holdings, incidence of spike is more due to herbaceous undergrowth. Even presence of *Lantana camara* was considered to be predisposing factor to spike disease (Hart and Rangaswamy 1926; Sreenivasaya 1930a, b, 1931, 1932, 1933a, b, c, 1934). Nayar and Srimathi (1968) Sreenivasaya (1933b) confirmed that *Lantana* is a symptomless carrier. Kumar and Joshi (2012) also expressed the opinion that presence of undergrowth of weed *Stachytarpheta jamaicensis* may be responsible for the spike disease. External symptoms of spike have been reported on *Eucalyptus tereticornis, E. citriodora, Ocimum* sp.

Fig. 9.3 Sandalwood—healthy plant (Source: Muthu Kumar 2014)

Earlier it was considered that a virus was responsible for sandal spike disease. During 1969, Dijkstra and Ie and Hull et al. established individually that the disease was caused by phytoplasma. Phytoplasma affect the sieve tubes of phloem tissues of petioles, leaves, stem and roots, thereby giving the plants a witches' broom–like appearance. Spike disease is one of the significant diseases of Sandalwood which is caused by mycoplasma-like organisms (MLO). MLO has also been reported on *Sesamum indicum*, *Arachis hypogaea*, Cowpea, Pigeon pea, *Argemone mexicana* and sunhemp (Muniyappa et al. 1980; Ghosh et al. 1985). Spread of the disease is sporadic and it is transmitted in nature by insect vector namely *Nephotettix virescens*. It can occur at any stage of development of the tree. As the disease progresses, the new leaves become smaller, narrower or more pointed and fewer in number with each successive year until the new shoots give an appearance of fine spike. At the advance stage, the intermodal distance on twigs become small, haustorial connection between the host and Sandalwood tree breaks, and the tree dies in about 2–3 years.

Pollen Theory

Hart and Rangaswamy (1926) observed that spike disease spreads in east to north-eastern direction towards Salem district in Tamil Nadu corresponding to the general direction of the south-west monsoon. They also observed that pollen from partially spiked trees is the causal entity which gives the impression that sandal under nature conditions has never become spiked before flowering. However, it was felt that the pollen theory could not explain adequately the initial attack of spikes on further no experimental transmission by pollen could yield successful results.

The onset of spike disease in Sandalwood results in a number of physiological changes. Some of the prominent changes are increase in levels of carbohydrate, particularly starch (Iyengar 1928a), total nitrogen, phosphorus (Rama Rao and Sreenivasaya 1928), nitrate content (Parthasarathi et al. 1962), phenolic bodies (Parthasarathi and Ramaswamy 1961), tannins (Iyengar 1937a), acidity (Iyengar 1938) and ascorbic acid (Parthasarathi et al. 1963), and a lowering in levels of ash, potash and lime levels (Iyengar 1928b) and iron content (Parthasarathi and Rao 1962).

Control of Spike Disease

Control of spike disease of Sandalwood is the most important aspect of the investigations and unlike diseases in agricultural crops, many practical difficulties are encountered since it is a perennial and growing into many hectares both in natural forests and man-made plantations. So far, no permanent remedial measures have been prescribed for control of spike disease; however an integrated approach of clearing of scrubby bushes, timely spraying of insecticides, soil working, protection against grazing and fire has successfully prevented further spread of disease (ICFRE 1992). Attempt to control spike disease by chemotherapy, immunological control, vector–host plant control and by imparting resistance through host plants had helped to control the spread of this disease. In Arbithittu of Hunsur Forest Division, which was recorded to have incidence of spike disease, no trace of disease was noticeable in the late 1970s. It is reported by the officials of Forest Department that the area is prone to frequent forest fires, which had changed the ecosystem and microclimate, by elimination of tall trees and bushy undergrowth from the area. It is likely that the pathogen and the vectors get killed due to frequent fires (heat therapy) and consequently the new generation of trees developed remained healthy and free from spike disease.

9.4 Insect Pests of Sandalwood

Many species are serious pests of cultivated crop plants and forest trees. While feeding, some species of pests introduce toxic chemicals into plants, and few species transmit diseases, and a few heteropterans are vectors of diseases of warm-blooded vertebrates (Triplehorn and Johnson 2005). Mathur and Singh (1961) reported 17 species of hemipterans and Varshney (2002) reported 2 species of scales and mealy bugs infesting Sandalwood trees. Remadevi et al. (2005) reported 8 species of sucking pests infesting sandal in nurseries. Sundararaj et al. (2006a) reported the occurrence of 23 species of scales and mealy bugs on Sandalwood. Sundararaj et al. (2006b) in their review indicated the presence of 411 species of hemipterans under 43 families in sandal ecosystem, which included phytophagous insects, predators and casual visitors and 18 species of Thysanoptera under 4 families infesting Sandalwood trees. *Ascotis selenaria imparata* Walker (Geometridae: Lepidoptera) is a serious pest in irrigated plantations. There are five generations in northern India and six generations in southern India (Chatterjee 1935). Beeson (1941), Mathur and

Singh (1961) and Brown (1968) recorded *A. octofasciculata* boring small branches and stem of saplings of Sandalwood.

The insects which have been recorded as serious and bearing economic importance for Sandalwood are defoliators, sap suckers, stem/wood borers and termites. The important insect species which cause damage to Sandalwood belonging to different types are (1) nursery pests, (2) stem borers, (3) sap suckers and (4) wood borers in storage and in dead wood and (5) termites. Each category is discussed below in detail.

9.4.1 Nursery Pests

Sandalwood seedlings in nursery are attacked by defoliators and sapsuckers (Remadevi et al. 2005). The important defoliators found to feed on seedlings are also encountered in plantations on mature trees. The species of insects of economic importance are described below:

9.4.1.1 *Cryptothelia cramerii*

Westwood (Psychidae: Lepidoptera): Male small, greyish brown with bipectinate antennae. Wings and body light brown. Expanse of wings is 2.25 cm. Female wingless and canary-yellow in colour, consisting of a simple sac-like body resembling a miniature queen ‘white-ant’. Body swells up after fertilization. Female remains in the case (case is formed of small pieces of stem of Sandalwood placed side by side so as to form a cylindrical bag open at both ends) and male pairs with her in this position. This insect cuts down the young seedlings almost at the ground level and such seedlings tend to dry up. The feeding by young larvae results in total defoliation. A total of 19 species of collateral hosts of forestry and agricultural crops are reported for this insect (ICFRE 1992).

9.4.1.2 *Ascotis selenaria imparata*

Walker (Geometridae: Lepidoptera): It is a serious pest in irrigated plantations. The moth is dark brown on a whitish grey or pale fuscus ground, abdomen with dark dorsal specks and expanse 4.5 cm. Caterpillar is a true looper with two pairs of sucker feet on the last abdominal segments; occur in two colour forms—green with dark lines or reddish brown with darker lines and patches. Full size is 4.5–6 cm. Pupa reddish-brown, naked about three-fourth of an inch. The species feeds on 12 collateral hosts of forestry plants including Sandalwood (Beeson 1941).

9.4.1.3 *Acanthopsyche moorei*

Heyl (Psychidae: Lepidoptera): Male moth is grey brown and wings coppery brown. Expanse is 1.6–2 cm. The female is without visible wings or legs, resembling a grub rather than a moth, and it does not leave the bag. The larva lives in a flesh-coloured conical bag. The young bagworm carries its bag upright at right angles to bark of leaf but in later instars the bag is too heavy and is carried in a pendant position. Usually found from December to April depending upon the climate. In epidemic situation, total defoliation and drying up of young plantations of Sandalwood is recorded. The larva feeds on the leaves of collateral hosts like *Albizia*, *Santalum*, *Lagerstroemia* and *Dodonaea* (ICFRE 1992).

9.4.1.4 *Sympiezomias cretaceus*

Faust (Curculionidae: Coleoptera): It is a polyphagous feeder on a number of species of plants like *Coffea, Morus, Santalum, Pongamia, Acacia, Cassia, Gliricidia* and *Ziziphus* (Sivaramakrishnan et al. 1987a). Beetles are 6–7 mm long and 2–3.5 mm broad, black coloured with a uniform yellowish chalky white scaling on the dorsal surface, mainly distributed in Karnataka and Tamil Nadu. The beetle feeds on the leaves mostly at night from the edges towards the midrib. The beetles may be seen on under surface of leaves or inside leaf curls or in between webbed leaves during day.

9.4.1.5 *Eupterote geminata*

Walker (Eupterotidae: Lepidoptera): Polyphagous species feeding on foliage of forestry and agricultural crops; recorded forest species include *Bombax, Gmelina, Tectona* and *Santalum* (Mathur and Singh 1961). Moth is orange yellow with dark transverse bands. Wing expanse is 6–8 cm. Eggs are laid in mass encircling a twig of the host and the young larvae feed gregariously often moving in a single line and assembling in clusters to moult but older larvae tend to scatter. Fully grown larva is 3.5–4 cm long with longitudinal yellow stripes, a bright reddish-yellow candle spot and tuft of long white or grey-black-tipped hairs and tubercles bearing short stiff hairs, the pupa lies loosely in the soil. Generation annual in north India with moth on wing in June–July but in south two generations are recorded.

9.4.1.6 *Natada nararia*

Cramer (Limacodidae: Lepidoptera): It is frequently a serious pest of tea and Sandalwood. Eggs are laid singly on leaves, mature larvae apple green, marked with brown or pink tubercles, armed with four rows of fleshy spiny processes. Pupation takes place in cocoon on top of soil. Moth with forewing pale brown to reddish brown, a central dark spot and transverse band and hind wing ochreous. Earlier instars skeletonise, later instars feed by making irregular holes and ragged edges. There are five overlapping generations in a year. The collateral hosts are *Toona, Erythrina, Santalum, Lagerstroemia, Pithecellobium* and *Thea* (ICFRE 1992).

9.4.1.7 *Holochlora albida*

Kirby (Locustidae: Orthoptera): These insects are usually of large size (2.2–4.5 cm), green coloured and the veins of the tegmina resemble veins of a green leaf. They live upon bushy plants and are so well concealed to their habitat that they can scarcely be seen until they are in motion. The antennae are very long and fine, functioning as delicate organs of touch, the mandibles short and powerful, the palpi is well developed. These hoppers usually gnaw on tender shoots of Sandalwood seedlings and saplings, very serious in nursery and young plantations.

9.4.1.8 *Teratodus monticollis*

Gray (Acrididae: Orthoptera): Adult band nymph are dull green or dry grass coloured with brighter colouring under the wings; the pronotum is produced up as a sharp hood over the body giving it a most striking appearance, in flight it is extremely beautiful, the bright colours showing out. They look like green leaves and feed on Sandalwood leaves both in nymphal and adult stage. It is a serious defoliator of young Sandalwood plants in nursery and plantations.

9.4.1.9 Control of Nursery Pests

Sap suckers can be controlled by spraying Monocrotophos @ 0.02–0.05% or Quinalphos @0.5% or Chloropyriphos @ 0.2–0.3%. For controlling defoliators 0.05% Ekalux 25EC @ 1 L/ha may be sprayed.

9.4.2 Stem Borers

The insect stem borers play a major role in the damage of Sandalwood. These stem borers include *Indarbela quadrinotata*, *Zeuzera coffeae* (Cossidae: Lepidoptera), *Sahyadrassus malabaricus* (Hepialidae: Lepidoptera) and *Aristobia octofasciculata* (Cerambycidae: Coleoptera) in south India. All these borers infest and harm fully grown Sandalwood trees, and their damage lead to die-back and mortality in smaller trees. Trees infested by these borers show poor growth and poor-quality timber. Sandal *koties* in south India showed sandal logs with hollowed heartwood and average logs of 198.6 kg of heartwood was found lost to every tonne of timber produced by these trees (Remadevi et al. 1998). The red stem borer *Zeuzera coffeae* Nietner and heartwood borer *A. octofasciculata* Aurivillius were established as more predominant species, infesting Sandalwood in the usual forest zones of Karnataka. In plantations of rural districts of Bengaluru, Karnataka, *Purpuricenus sanguinolentus* is more prevailing, while in all the districts of Karnataka, *Z. coffeae* is noticed (Sundararaj et al. 2019).

9.4.2.1 *Indarbela quadrinotata*

Walker (Indarbelidae: Lepidoptera): It is a polyphagous pest of many trees and its incidence on Sandalwood is also very high. It is found to breed on *Mangifera indica* and *Xylotrechus quadripes* (Sundararaj and Muthukrishnan 2007b). Its larval stage is dangerous, that's why it is called 'bark feeding caterpillar'. Eggs are laid in clusters of 15–20 directly on bark of branch or bole. The larva bores a short shelter tunnel downwards in the wood from which it emerges to feed upon the outer surface of bark at night excavating broad irregular patches which are roofed with silk, bark and excrement. Pupation takes place in the shelter tunnel, and pupal period is 3 weeks. Life cycle is annual with moths appearing in May–July. The moth has the forewing with rows of dark rusty red spots. Collateral hosts reported are about 40 species of forestry, agricultural and horticultural importance. Young, attacked saplings die-back and develop epicormic shoots. It is a very serious pest of young and older plantation of Sandalwood (ICFRE 1992).

9.4.2.2 *Zeuzera coffeae*

Nietner (Cossidae: Lepidoptera): It is called 'Red Borer'. It is found to breed on *Coffea* spp. and is found as an aggressive pest responsible for serious damage of heartwood of Sandalwood in Thangali Sandalwood provenances, India (Sundararaj and Muthukrishnan 2007b). Eggs are laid in strings on the bark of small stems or branches. Hatched larvae spin a silken shelter which is easily carried away by wind to longer distances and later settle on suitable host plants and bore into leaf axil or axil of the stem and branch. The younger larvae make tunnels while older ones form irregular cavities and cut circular holes on the outer surface at various distances through which the borer ejects frass. Excrements can be seen adhering to the plant in the form of pellets or falling to the ground below in a heap round the plant. Larval feeding period extends from 60 to 120 days. Pupal period lasts for 3–4 weeks. Moth emerges leaving the empty pupal case protruding from the bark. It is more prevalent in younger plantation than older plantation (Sundararaj et al. 2019).

9.4.2.3 *Sahyadrassus malabaricus*

Moore (Hepialidae: Lepidoptera): It is called 'Phassus Borer'. Moth with wing span of 5–10 cm, forewing greyish or brownish with some mottling and white dots. When at rest, it hangs vertically resembling a withered leaf. Mature larva attains 7–8 cm, yellow with a black corrugated head and is injurious to the stem of saplings of numerous trees including Sandalwood. Stems of about 10–12 mm diameter attacked, the tunnels in the larger hosts being relatively short and restricted to sapwood. The species is an important pest of *Eucalyptus*, *Tectona* and young Sandalwood saplings (Beeson 1941).

9.4.2.4 *Aristobia octofasciculata*

Aurivillius (Cerambycidae: Coleoptera): It is called 'Heartwood Borer of Sandalwood'. It appears to be monophagous as its infection is reported only from *Santalum album*. The dead and living Sandalwood trees in various sandal *koties* and forests showed that 35–40% of old and middle-aged trees had several bore holes due to this insect. The beetle is 1.7–2.9 cm long, elytra and head brick red in colour dorsally; abdomen, legs and ventral portion of head black; antenna seven segmented and black. The beetle is on wing immediately after first rains during April–May and appears in numbers by day feeding on bark of living shoots and stems (Sivaramakrishnan and Venkatesan 1980). The larva feeds its way into the branches or main stem through the bark and sapwood and excavates long tunnels downwards from 1 to 3 m. The bore hole is about 2 cm in diameter. The larva before pupating reverses its position from its head downwards and gnaws a thin part of the sapwood very near the bark for the exit of the adult. The beetle gnaws its way out through a circular hole. The life cycle is annual. It is more prevalent in older plantation than younger plantation (Sundararaj et al. 2019).

9.4.2.5 Control of Stem Borers

Introducing fumigant and plugging the borer holes or spot application of Monocrotophos @ 0.1% or Quinalphos @ 0.1% to drench the borer holes, sleeving the surrounding barks will effectively control wood borers.

9.4.3 Sap Suckers

It is reported that 73 species of Hemipteran and two species of Thysanopteran pests occur in Sandalwood with different level of infestation (Sundararaj and Muthukrishnan 2007a). The pests of Hemiptera and Thysanoptera damage plants by inserting their mouthparts into plant tissue and drain the sap. Heavily infested plants become yellow, wilted, deformed or stunted and may eventually die. Among the sapsuckers, members of Aleyrodidae, Cicadellidae and Membracidae as well as scales and mealy bugs were found highly polyphagous breeding on other host plants. Among the tree species, *Pongamia pinnata* seems to be a common host for many sucking pests, hence planting *Pongamia pinnata* as host plants in Sandalwood-planting programme may be avoided. The important coccids observed in nurseries and plantations are:

9.4.3.1 *Saissetia coffeae*

Targioni-Tozzetti (Coccidae: Hemiptera): It is known as ‘Brown Bug’, distributed widely in India. Adult female bug is shining brown, convex, elliptical in outline measuring 2 mm across. Approximately 500–1000 eggs are laid and protected by a female beneath the cup of the dome-shaped body. They rarely move from the point where the young nymphs settle; growth is slow and two generations per year is reported. Both the species *Saissetia coffeae* and *Saissetia nigra* occur invariably together on the same plant, feeding on the sap of tender stems, leaves, flowers and fruits of many collateral plants, viz. *Cajanus, Citrus, Hibiscus, Ixora, Jacaranda, Psidium guajava, Terminalia catappa*, etc. (Sundararaj and Muthukrishnan 2007a). Feeding by such nymphs and adults in large numbers leads to a severe drain of sap resulting in drying and ultimate death of the particular plant part (ICFRE 1992).

9.4.3.2 *Saissetia nigra*

Nietner (Coccidae: Hemiptera): It is known as ‘Black Bug’, distributed widely in India. The adult female bug is smooth shiny black, narrowly elongated, measuring 4 mm across. Female lays 2000 eggs at a time. Most of the young nymphs settle on the leaves and migrate to twigs and branches when partly grown. Adults are active, two-winged insects and have three generations in a year. Feeding by nymphs and adults in large numbers leads to a severe drain of sap resulting in drying and ultimate death of the particular plant part. The feeding insects excrete ‘honey dew’ when the ant attenders tickle these scales. This honey dew secretion causes black sooty mould fungus formation on the leaves. The direct injury to the host is usually aggravated by the development of the sooty mould (Sivaramakrishnan et al. 1987b).

9.4.3.3 *Ceroplastes actiniformis*

Green (Coccidae: Hemiptera): This insect is pale white. It is found along the folded inner surface of the leaves on coconut; attacked branches and leaves dry up. *Cocos nucifera, Mangifera indica, Vinsonia stellifera, Alstonia scholaris, Ficus* and *Canna* are recorded as collateral hosts (Sundararaj and Muthukrishnan 2007a).

9.4.3.4 *Ceroplastes ceriferus*

Anderson (Coccidae: Hemiptera): This insect is known as the 'Great Indian wax scale', the presence of which can be easily made out on a plant. The mature insects resemble irregular masses of pale white wax attached to the leaves and shoots. The bark peels off from the attacked portions and the young tree ultimately succumbs to the attack of the scale. *Boswellia serrata, Buchanania latifolia, Casuarina equisetifolia, Santalum album, Syzygium cumini, Pongamia pinnata* were recorded as collateral hosts (ICFRE 1992).

9.4.3.5 *Inglisia bivalvata*

Green (Coccidae: Hemiptera): *Thespesia populnea* and *Pongamia glabra* are the collateral hosts besides many agricultural, horticultural and forestry species. The body of the insect is covered by two glass shell–like plates along median longitudinal line like a 'bivalve mollusc'. Sandalwood plants dry up as a result of the epidemic infection by this scale.

9.4.3.6 Control of Sap Suckers

Since these bugs have many collateral hosts, they can spread very rapidly to the neighbouring plants. The branches, heavily infested by these coccids should be lopped and burnt. The tree may be sprayed in the first instance with 0.5% Ekalux to kill the existing infestation. After the initial spraying is dried, that is, after 2 days, 0.5% BHC (50% WP) should be sprayed to prevent any future attack by bugs. Young seedlings in the nurseries may be sprayed with 0.02–0.05% Ekalux or Nuvacron once a month beginning from May for 4 months.

9.4.4 Insects Attacking Wood in Storage and Dead Wood

The important insects which feed on dead wood and Sandalwood in storage are described below:

9.4.4.1 *Sinoxylon atratum*

Lesne (Bostrichidae: Coleoptera): This insect occurs in the Indian peninsular region; emergence from May to September. It is one of the bostrichids that bore into the living saplings of Sandalwood, making an axial tunnel and causing the upper part of the affected shoot to die back. *Acacia catechu, Artocarpus hirsuta, Casuarina equisetifolia, Lagerstroemia microcarpa, Phyllanthus emblica, Pongamia pinnata, Terminalia arjuna, Trewia nudiflora*, etc. are the reported collateral hosts.

9.4.4.2 *Xylopsocus capucinus*

Fab (Bostrichidae: Coleoptera): This insect is widely distributed in the tropics, emergence between May to October, inactive in cold weather. Life cycle is 1 year and may extend to 2–3 years depending in the favourable conditions. It is an important pest to sapwood. *Anacardium occidentale, Mangifera indica, Morus alba, Delonix regia, Santalum album, Shorea robusta, Tectona grandis, Terminalia myriocarpa,* etc. are the important collateral hosts.

9.4.4.3 *Purpuricenus sanguinolentus*

Oliv (Cerambycidae: Coleoptera): This insect is reported to attack dead branches of Sandalwood and wood in storage, distributed throughout India (Beeson 1941). Adult beetle is 12–20 cm long, prothorax black, elytra orange with broad transverse median and apical black bands. The adult is on wing from April and reaches a peak by July. It bred from dry bamboo and has been recorded to gnaw the dead or drying shoots of Sandalwood. The collateral hosts are *Acacia nilotica* and *Dendrocalamus strictus*.

9.4.4.4 *Xylocopa latipes*

Drury (Xylocopidae: Hymenoptera): It is a very serious pest especially in the depots where sandal sapwood is stored. The wood is tunnelled by the insect which become powdery and the quality is also deteriorated. Collateral hosts are *Amoora wallichii, Santalum album, Syzygium cumini, Toona ciliata* and *Terminalia chebula.*

9.4.4.5 Control Measures

Bark sprays target egg-laying females or the adult stages emerging from the host plants. They may kill small larvae. Bark sprays generally use residual insecticides such as bifenthrin or permethrin. Dinotefuran also provide some control of wood-boring beetles.

9.4.5 Termites

Arboreal termites, *Odontotermes* spp. are often observed in Sandalwood plantations. The attack leads to loss of bark, poor health and infestation of stem-boring insects. The infestation is highest (about 50%) in winter. Experiment shows that use of Chlorpyriphos 20EC (1.5%) give adequate protection up to 4 months.

9.5 Control Measures of Pests of Sandalwood

9.5.1 Chemical Control

Chemical control measures of different types of insect pests of Sandalwood are given in Table 9.1.

Table 9.1 Chemical control measures of different types of insect pests of Sandalwood

Sl. no.	Type of insect pests	Chemical control
1	Nursery pests	Sap suckers can be controlled by spraying Monocrotophos @ 0.02–0.05% or Quinalphos @0.5% or Chloropyriphos @ 0.2–0.3%. For controlling defoliators 0.05% Ekalux 25EC @ 1 L/ha may be sprayed
2	Stem borers	Introducing fumigant and plugging the borer holes or spot application of Monocrotophos @ 0.1% or Quinalphos @ 0.1% to drench the borer holes, sleeving the surrounding barks will effectively control wood borers
3	Sap suckers	In the first instance tree may be sprayed with 0.5% Ekalux to kill the existing infestation. After the initial spraying is dried, i.e. after 2 days, 0.5% BHC (50% WP) should be sprayed to prevent any future attack by the bugs. Young seedlings in the nurseries may be sprayed with 0.02% to 0.05% Ekalux or Nuvacron, once a month beginning from May for 4 months
4	Insects attacking wood in storage and dead wood	Bark sprays target egg-laying females or the adult stages emerging from the host plants. They may kill small larvae. Bark sprays generally use residual insecticides such as bifenthrin or permethrin. Dinotefuran also provide some control of wood-boring beetles
5	Termites	Use of Chlorpyriphos 20EC (1.5%) give adequate protection up to 4 months

9.5.2 Biological Control

Biological control is an effective, eco-friendly, technically appropriate, economically viable and socially acceptable method of pest management. Generally there are three types of biological control strategies, viz., conservation, classical and augmentation, among which the last one is the most popular. Augmentative biological control involves a supplemental release of natural enemies. Owing to the prey–predator relationship, predaceous natural enemies like coccinellids feed on coccids, aphids, whiteflies and other injurious insects and mites which keep the insect population under control. Economically important crops, particularly woody species including Indian Sandalwood are mostly damaged by coccids. Detailed survey conducted by Sundararaj et al. (2014) revealed that Sandalwood is being grown with many agricultural, horticultural and commercial crops in addition to other tree species as per the choice of farmers and 25 species of coccids were found breeding on Sandalwood under different farming systems. Coccids are 'hard to kill pests' and cause damage by sap drainage which results in dieback symptoms. They also secrete copious amount of honeydew which attracts black sooty mould fungus. Eggs of the coccids are protected by waxy filamentous secretions of ovisacs and are almost impossible to come in contact with insecticides. Late instar nymphs and adult female mealybugs are not affected by foliar application of insecticides as they are covered with waxy coatings. They have also reported 24 existing species of coccinellids in these Sandalwood-growing areas which are actively predating on these coccids thereby keeping their population under control. The observations outlined above emphasizes to develop ecologically and environmentally sound insect pest management in Sandalwood plantations by augmenting more effective coccinellids like *Cryptolaemus montrouzieri* Mulsant and *Chilocorus nigrita* as their multiplication technology is available.

9.6 Conclusions

Indian Sandalwood, acclaimed as a 'Royal Tree' of India for centuries, owing to its fragranced heartwood, and its curative and commercial significance have been revealed in many literatures of age-old literatures. The wood has great demand in the national and international trade for handicraft and perfumery industries. Our efforts are for making the best quality wood in higher quantity. Steps are to be taken to control diseases and insect pests' infestation in Sandalwood in the important stages of its growth and during storing. There are many natural enemies to insects, which help in the biological control of different coccid pests. The percentage of parasitism varies from 4 to 10 in the different coccids. Though the parasites and predators exert effective check on the pest populations, at times, pest outbreaks are observed to occur which needs attention of the growers for its effective control to save the crop. Different control measures are discussed in this chapter; still some more studies are required to develop disease resistant varieties of Sandalwood.

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The Sandalwood Trade: An Overview

10

S. Noorunnisa Begum and K. Ravikumar

Abstract

Sandalwood (*Santalum album* L.; family: Santalaceae), one of the highly valued commercial tree species, is harvested largely for its aromatic heartwood and essential oil. The tree is referred to as "Chandana" in Sanskrit, and is commercially known as "East Indian Sandalwood." The oil extracted from the trees is considered to be unique, and is preferred over other ingredients for the preparations of perfumes, flavors, formulations, cosmetics, toiletries, beauty utilities and medicines. The species is one the highly threatened, traded, and important medicinal plant species and the part traded is wood. The trade of sandal is about 500–1000 MT traded during 2014–15 @ Rs. 10,000/kg. This chapter provides details of the part traded, classification of the traded part, overview of trade from brief on the historical trade, export, and import of the Sandalwood and Sandalwood oil.

Keywords

Export · Import · Sandal wood · Sandalwood oil · Trade

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10.1 Introduction

Sandalwood (*Santalum album* L.; family: Santalaceae), one of the highly valued commercial tree species, is harvested largely for its aromatic heartwood and essential oil. Sandalwood, called as “Chandana” in Sanskrit, is commercially known as “East Indian Sandalwood.” The oil extracted from the Sandalwood trees is considered to be unique and is preferred over other options for the preparations of perfumes, flavors, formulations, cosmetics, toiletries, beauty utilities, and medicines. The species is habitually spread across from 30° N to 40° S, from the north Pacific Ocean (Hawaiian Archipelago) to south (New Zealand) and from east (Indonesia) to west (Juan Fernandez Island, Chile). It is believed that Sandalwood was introduced into India from Timor, Indonesia (Shetty 1977). More than 90% of the Sandalwood is distributed in the states of Karnataka and Tamil Nadu, covering around 9000 km^2 (Jain et al. 2003), of which more than 70% occurs in Karnataka (Srinivasan et al. 1992). The species is mostly found in dry deciduous and scrub forests. In Karnataka, *Santalum album* is estimated to be spread over an area of 5245 km^2 (Singh and Shankar 2007). The fragrant oil is extracted from the heartwood only from the matured trees. Sandalwood finds its applications in various fields, including religious purposes, medicinal purposes, incense sticks (*agarbattis*), perfumes, handicraft, carvings, etc. The value of a Sandalwood tree is largely determined by the weight of its heartwood and the concentration and composition of the oil contained within it (Doran et al. 2005). As per Goraya and Ved (2015) 500–1000 MT was traded during 2014–15 @ Rs. 10,000/kg. The chapter is going to provide an overall understanding of the sandalwood trade, the botanical identity of the species being traded, as well as educating the readers about the possible adulterants and substitutes. It also give insight to export, import, and commerce of wood and sandal oil.

10.2 About Sandalwood Tree and Current Situation

The present government policy pertaining to the management of Sandalwood goes back to the king’s rule in Mysore, during which it was declared as a royal tree and the Sandalwood trade was monopolized in 1792. According to the prevailing rules in the southern states, except Kerala, Sandalwood continues to be a royal tree and trade in the wood is the monopoly of the state. Places such as Karnataka–Kerala–Tamil Nadu border have become havens for illegal trade in Sandalwood. Due to the extensive illegal cutting of native Sandalwood trees, this species has become vulnerable to extinction. In Karnataka, Sandalwood populations are sparse and devoid of larger girth classes; matured trees have been nearly vanished. Despite favorable conditions for its growth and natural regeneration in many forests of Karnataka and Tamil Nadu, both production and export of Sandalwood and its products have shown a steep decline. Sandalwood genetic resources in the regions are under threat, due to a variety of factors, including its high economic value both inside the country as well as in the international market (Rao et al. 2001). Sandalwood production in the country was found to be reduced from ~4000 tons/year in the 1960s to

<1000 tons during the 1990s (Ananthapadmanabha 2000) and 500 tons in 2007 (Gairola et al. 2008). Sandalwood oil has virtually disappeared from the international market and its place has been taken over by synthetic substitutes. Sandalwood bio-resources depletion at a rapid pace is due to various reasons, the gap between demand and production has widened tremendously. During 2001 and 2002, Karnataka and Tamil Nadu governments relaxed the existing rules and regulations related to Sandalwood in an effort to boost its production by encouraging private domestication. Despite the policy amendments favoring private growing of Sandalwood and its advantages as an agroforestry species, there prevail considerable skepticism on the economic prospects of Sandalwood cultivation due to the time lag in accruing returns from the tree and the high investments required for its protection.

10.3 Sandal Tree and Part Traded

The traded part in sandal tree is its wood. The Sandalwood is harvested as either green logwood or deadwood. Wood is cleaned using jet of water or mechanical chain and classified into different groups before selling. Soundararajan et al. (2017) reported that commercialization of Sandalwood starts from extraction of mature trees from field, hammer marked and transportation to the nearest 'Final Cleaning Depot' under proper permit. Sandalwood trees are cleaned and stored in the depots and the particular regarding the weight of the 'final cleaned wood' is recorded. The quality of final cleaned wood including sapwood and sawn dust is classified based on government rules and regulations. According to the Karnataka Forest Manual Rule No. 95, Sandalwood is classified into 21 classes, namely Vilayat Budh, China Budh, Panjam, Ghotla, Ghathadla, Bagardad, Roots—Class I, Roots—Class II, Roots—Class III, Jaipokal—I, Jaipokal—II, Ain Bagar, China Sali or Large Chilta, Ain Chilta, Milwa Chlta, Hattari Chilta, Basola Bukni, Saw dust, White chips, Bark.

10.3.1 Adulterants

Adulterants of Sandalwood are dealt in detail in Chap. 6. Briefly, the most common materials used to dilute Sandalwood oil are the essential oils of other species of Sandalwood (resulting in a blended Sandalwood essential oil), as well as fractions of *Copaifera* species oil, *Cedrus atlantica* (Atlas cedar), and *Amyris balsamifera* (Amyris) oil. Sandalwood aroma chemical compounds that are synthesized chemically are often added to other oils to recreate Sandalwood oil's natural fragrance. Adulteration of Sandalwood oil can also often involve a technique called "stretching," where odorless solvents are added to Sandalwood oil to increase its quantity (Anonymous 2020b). Owing to its sensual quality, wide-ranging uses, and increased cost, Sandalwood oil is frequently adulterated with low-grade, cost-effective essential oils and synthetic or semisynthetic substitutes, for example Sandalore. Sandalwood oil adulteration is a major concern for regulatory organizations, oil merchants, and also it is dangerous to human consumers. Mixing of synthetic additives may impact on the chemical configuration and physical characteristics of the Sandalwood oil, and thus could affect oil's quality and cause allergic reactions in consumers. The most frequent adulterants informed till date include cedarwood oil, castor oil, and low-grade oil from other species of *Santalum.*

10.3.2 Consumption of Sandalwood and Oil

The industries dealing with perfumery, medicine, attar preparations, scented chewing tobacco, mouth fresheners, soaps and toiletries, and incense sticks or joss sticks use Sandalwood and Sandalwood oil (Ananthapadmanabha 2011). Domestic use of Sandalwood is depicted in Fig. 10.1.

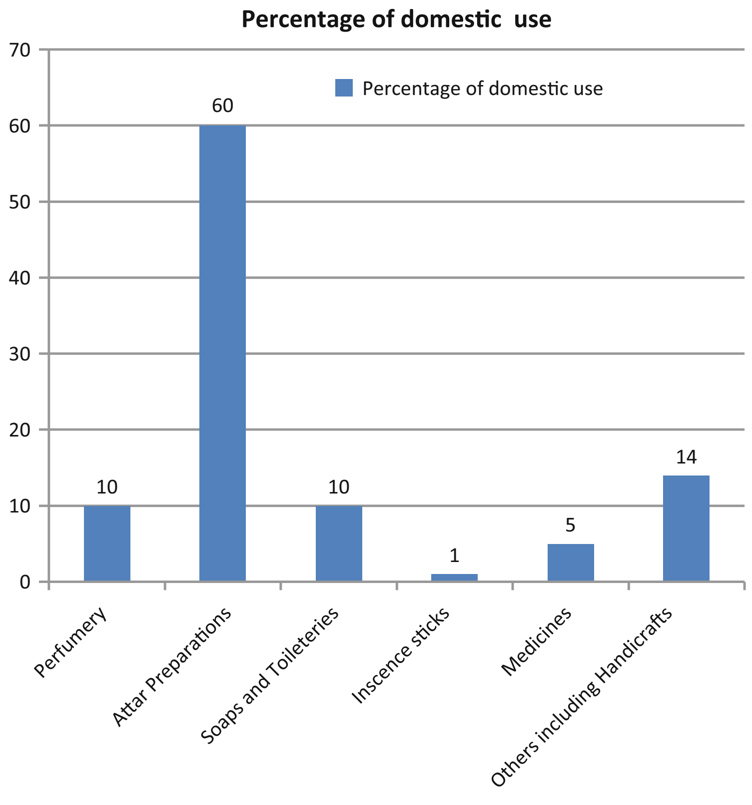

Fig. 10.1 Percentage of domestic use of Sandalwood

10.4 Sandalwood and Brief on Pricing Trend

10.4.1 Historical Trade in Price

The earliest Sandalwood trade was conducted during 1885–86. The Mysore Government (presently Karnataka state) had Sandalwood stock worth Rs. 1,56,321 (US $ 78,160) and selling realized a revenue of Rs. 74,598 (US$ 3730). During 1885–86, the Government of India exported Sandalwood stocks worth Rs. 4,44,241 (US$ 222,120) and imported value-added products worth Rs. 16,404 (US$ 8202) (Ananthapadmanabha and Gupta 2016).

During 1889–90, the export of wood increased to Rs. 10,08,152 (US$ 504,576), out of which the stock worth Rs. 7,70,791 was ported through Madras and the rest from Bombay port. At that time, the selling price for wood at Bombay was Rs. 120–180 per mound (10 lb). The price for Sandalwood oil was Rs. 8.5 (US$ 4.25) for 1 pound. During the beginning of twentieth century, that is 1907–08, around 85,000 lb. of wood was exported to different countries at value Rs. 10,00,000 (US$ 500,000). After the advent of the First World War, the export of wood was restricted to 2500 tons, of which 52% was sent to Germany, 18% was sent to the USA, and the rest to England and other countries (Ananthapadmanabha and Gupta 2016).

10.4.2 Price Trend During Twentieth Century

At the commencement of twentieth century, Sandalwood fetched a little over Rs. 400 per ton, which in the next few years scrambled to Rs. 500. In 1913, the prices shot up to Rs. 1000 per ton, which doubled Rs. 2000 per ton in the year 1914. The price of wood prior to the Second World War had aggrandized to Rs. 5000 a ton, which remained almost stable till 1957–58. The average price of Sandalwood has been pooled to 5-year period from 1962 to 2005. Average auction price of Sandalwood per metric ton (MT) from 1962 to 2005 and 2008 to 2015 in India are given in Tables 10.1 and 10.2, respectively.

Table 10.1 Average auction price of Sandalwood per MT from 1962 to 2005 (Source: Ananthapadmanabha and Gupta 2016)

Year	Rs.	US$	US$
1962–65	6874	1718	US$ 4
1965–70	10,910	2727.6	
1971–75	20,371	4074.36	
1976–80	33,776	2251.7	US$ 15
1991–95	2,20,000	8800	US$ 25
1995–2000	6,46,000	21,533	US$ 30
2000–06	21,50,000	56,578	US$ 38

Table 10.2 Average auction price of Sandalwood per MT from 2008 to 2015 (Ananthapadmanabha and Gupta 2016)

Year	Rs.	US$	US$
2008–10	54,00,000	103,864	US$ 52
2011–12	55,00,000	101,905	US$ 55
2013–14	82,67,887	135,917	US$ 60.8
2014–15	1,09,34,181	177,376	US$ 61.6

The average auction price from 2008 has increased very sharply due to high demand and short supply.

An e-auction conducted by Karnataka Forest Department in April 2016 gave a shocking news of the steep increase in the average price of heartwood to over 1.25 crores per ton (US$ 189,393) and it was likely that within next few years the average price of heartwood may reach over 1.40 crores (US$ 200,000). The increase in price is due to short supply against demand with this trend in increase in price the Sandalwood oil price may also go up to 3,60,000/kg (US$ 5300), prohibiting use in many formulations (Ananthapadmanabha and Gupta 2016).

As per Karnataka Government, fixed price per kilogram of various classes of the Sandalwood during 2014–2015 are Vilayat Budh (Class I billets) sold at highest price @ Rs 6050, followed by China Budh (Class II billets) @ Rs. 6410, Panjam @ Rs. 5810, Ghotla (billets of short length) @ Rs. 6410, Ghatbadla @ 5820, Bagardad @ Rs. 5600, Roots—Class I @ Rs. 4100, Roots—Class II @ 4150, Roots—Class III @ 4250, Jaipokal—I @ 5160, Jaipokal—II @ 4900, Ain Bagar @ 5500, China Sali or Large Chilta @ 4350, Ain Chilta @ 3655, Milwa Chlta @ 2350, Hattari Chilta 2153, Basola Bukni @ Rs. 1728, and Saw dust @ Rs. 750 (Soundararajan et al. 2017).

10.5 Price Trend of Sandalwood Oil

Sandalwood oil price during prewar was only Rs 5 per kg (US$ 3.5), the prices of Sandalwood oil was reasonable to some extent till 1960. During the period 1961 to 1973 the price remained to be about Rs. 99.6 to 293.6 (US$ 20 to 35) per kg. But in 1974, the price of Sandalwood oil shot up to Rs 1245 (US$ 150) per kg. During 1977–78 the price of oil came down to Rs 1132 (US$ 135); however the price stepped up again from 1980. From 1990 to 2000 the price of Sandalwood oil increased from Rs. 1678 to 26,065 (US$ 200 to US$ 580). The price of Sandalwood oil increased sharply from 2001 to 2008, Rs. 29,211 to 75,000 (US$ 650 to US$ 1500). With the increase of Sandalwood auction price, legal distilled Sandalwood oil price in 2014–2015 was more than Rs 2,30,000 (US$ 3500). The price of oil will increase further due to high demand and short supply.

Due to the progress in the developed and the developing nations, synthetic resolution is a perceived threat to continued use of natural products in the perfumery industry. This threat has been created by the presence of multinational companies dominating the fragrance industries; however, smaller companies still provide specialist services to the industry and to its customers.

Since Indian Sandalwood is in short supply, the users are buying natural Sandalwood oil obtained from different species, like *S. spicatum, S. lanceolatum, S. austrocaledonicum* and *S. yasi*, though the santalol content is less. *Osyris lanceolata* an East African wood also belongs to the family Santalaceae, the oil obtained from it is called East African Sandalwood oil, it contains less amount of santalol compared to Indian Sandalwood, and is used as one of the alternate for Indian Sandalwood.

Prior to 1970s, Karnataka, India was generating more than 2000 tons of Sandalwood per annum. Later, there was a collapse of the state's Sandalwood population, leading to obtaining of Sandalwood from the neighboring state, Tamil Nadu. In recent years, Indian Sandalwood export has decreased to 2550 cubic meters in the year 2011-–2012 and 800 cubic meters in the year 2014–2015. Indian Sandalwood has been exported to Canada, China People's Republic, France, Guyana, Hong Kong, Japan, Malaysia, Nepal, Philippines, Saudi Arabia, Singapore, Sweden, Switzerland, Taiwan, Thailand, Trinidad, the United Arab Emirates, the United Kingdom, and the United States of America. The major importers of Indian Sandalwood are Hong Kong, Japan, Saudi Arabia, Singapore, the United Arab Emirates, and the United States of America. The export of Indian Sandalwood in 2003–2004 was 1.78 cubic meters (thousands) for a value of Rs. 192.67 lakhs and it was noted drop exports during the year 2014–2015, wherein 0.8 cubic meters (thousands) was exported for a value of 188.69 lakhs.

Indian Sandalwood import is also increasing every year. Above 20 cubic meters of Sandalwood has been imported from various countries in the year 2011–2012; 790 cubic meters of Sandalwood has been imported in the 2014–2015. Sandalwood has been imported from Australia, Fiji Island, Gabon, Germany, Hong Kong, Indonesia, Kenya, Malaysia, Russia, Taiwan, Tanzania Republic, Tunisia, the United Arab Emirates, and Vanuatu Republic. The major exporter of Sandalwood is Australia, Tanzania Republic, and Vanuatu Republic. Australia and Tanzania are two countries from where Sandalwood is imported.

The Sandalwood oil trade is being carried out from ancient times and used to be exported to Egypt, Greece, and Rome. Hence the demand for the oil of Sandalwood was limited. India continued to export Sandalwood and its oil till 1914 without any hindrance in its trade. Most of the Sandalwood was exported to Germany, where oil used to be distilled by modern steam distillation techniques and supplied to different parts of the world. With the outbreak of the First World War, exports to Germany completely stopped due to lack of shipping space for more bulky wood.

The Sandalwood oil was fetching handsome prices in those days. Therefore, Australia also extracted Sandalwood oil from different species of the tree and referring it to be Sandalwood oil, entered into the world market. They tried to market it as Sandalwood oil, but it could not compete with the Indian produce.

To face this stiff competition, the Indian traders agreed to sell their oil jointly to foreign countries. In this way, the fall in prices of Indian oil was checked for the time being. This arrangement, however, did not last long. The United States was one of the important buyers for Indian Sandalwood oil. Although, there was an import duty of 20%, it was not charged on the Sandalwood oil exported from India. This facilitated Indian Sandalwood oil to compete with the other countries operating in the US markets. However, the import duty on oil was further increased from 20% to 25% in September 1922. The Mysore Government, therefore, entered into an agreement with M/s Bush & Co., in New York, to distil the oil in the US, on its behalf from the wood exported by the Mysore Government.

During the period, oil of Sandalwood from a number of species was also available in the market. Despite this, India maintained its monopoly in this trade till 1950. Later on, the Indian government banned the export of Sandalwood with the result; Oil industry was set up in Indonesia and 8 to 7 tons of Sandalwood oil was produced.

In Indonesia, there are two factories situated in Kupang. Their production of Sandalwood oil during 1978 was reported to be about 6 tons. These two units have a total export potential of producing about 30 tons of Sandalwood oil per annum. During early 1920, the quality of Indonesian Sandalwood oil was very inferior as Indonesian factories were distilling the heartwood along with the bark and sapwood. But after acquiring the technical knowhow from the USA and Germany, the factories in Indonesia are reported to be producing quality oil which is almost similar to that of the east Indian Sandalwood oil. Thus, Indonesia has emerged as a new competitor to India in the world markets. The Sandalwood oil exported from Indonesia being cheaper, the USA is prompted to import bulk of its requirement from Indonesia.

It has also been reported that a firm, namely, Singapore Essential Oils Distillation Ltd., Singapore, has also come up in November 1967 and now it is distilling Sandalwood oil from Sandalwood chips obtained mainly from Indonesia. They are exporting the Sandalwood oil to West European countries and their production capacity is stated to be 6–10 tons per annum. Another firm namely Indah Co. Ltd., (I.C.L.) was also established in Singapore as a joint venture with Singapore in early 1969 by Mr. Tsai, a business from Indonesia (in Indonesian language *Indah* means “beautiful”). This factory has a total distillation capacity of 18,000 L of Sandalwood oil and envisages a production of 20,000 L of Sandalwood oil per annum in the near future. The oil so obtained is reported by a London analyst as “in our opinion this is a genuine Sandalwood oil of East – Indian type” and is satisfying the requirements of British Standards specification No 2999/30/1939.” Singapore is reported to be going better in production of Sandalwood oil. Some Chinese interests in Singapore have installed stainless steel equipment and as a result are offering a comparatively better produce to the US market. They are also offering a variety called U.S.P. oil with over 90% percent of santalol contents as total alcohols. A Singapore firm has installed stainless steel equipment with over 90% of santalol contents as total alcohols.

Yugoslavia is another new exporter, through their performance in 1970 was reported to be not as high as it was in 1969, when they exported 7855 lbs. of oil. Nepal also made some shipments of Sandalwood oil, but the interest of buyers appears to be falling off in their produce. Market sources confirmed that most suppliers do not have Agmark certification which in other words explains the establishment of Indian quality mark. Apart from Indonesian Sandalwood oil, New Caledonian Sandalwood oil has also entered the world market and is competing with the Sandalwood oil of Indian origin. However, the detailed information on new Caledonian Sandalwood oil is not readily available.

10.6 Domestic Market

The first factory was started at Bangalore in May 1916 and the other at Mysore in 1917. Since then, the Mysore Government stopped auctioning of Sandalwood in 1917. By 1921, for every ton of Sandalwood distilled and sold as oil by the state government, it is estimated that it obtained nearly 50% more price than the auction price of 1 ton of Sandalwood. This attracted attention of other Indian distillers, some of whom started factories with modern techniques of steam distillation. One such factory was started at Kuppam (Andhra Pradesh) and another at Kannauj near Kanpur by the year 1921. Thus, the Mysore Government's factories were the pioneers in modern distillation. In 1930, high pressure steam distillation was tried. This gave higher output and was more economical, saving both time and fuel. Later on, the Mysore Government started another factory at Shimoga, with a supplementary distilling at Bhadravati where surplus steam was available (Anonymous 1984).

In the world markets, a new substitute (a product commercially synthesized and commonly known as Sandela) has also entered and is available at cheaper rates than common Sandalwood oil offered by any country and being used only in the cheap oriental types of perfumes. Chemical hazards of this substitute have not yet been studied (Anonymous 1984).

10.7 Production in Trade

According to Directorate of Marketing & Inspection, Ministry of Rural Development, Karnataka, contributed to the extent of 74% to the total production of Sandalwood oil in India in the year 1963–84, when its production was about 116.29 tons. In the year 1969–70, it reached the peak when India produced about 165 tons of Sandalwood oil. The contribution of Karnataka state was about 73% and Andhra Pradesh contributed around 11%, while Tamil Nadu and Uttar Pradesh contributed only about 5.2% and 9.1%, respectively. After 1969–70, the country's production looked downward and it decreased to about 156 tons in 1970–71. In the year 1972–73, it increased slightly to 163 tons. Thereafter, the production declined continuously to be 133, 97.73, and 90 tons during 1973–74, 1975–76, and 1976–77, respectively. In 1977–78 about 112 tons of Sandalwood oil was estimated to be produced in the country. But during 1978–79 and 1979–80, the trend remained downward with production declining to only 82 and 69 tons, respectively (Anonymous 1984).

As per the Soundararajan et al. (2017), the Indian Sandalwood oil export started as early as in the 1960s. During the period 1996–97, 11.52 kg of Sandalwood oil was exported at the value of Rs. 95.48 lakhs. After a decade, during 2006–2007, the export decreased to 3.07 kg at the value of Rs. 737.83 and in 2014–2015, 0.64 kg

Table 10.3 Indian Sandalwood oil exports

Sl. no.	Year	Quantity in kg (thousand)	Rupees in lakhs	US$ in million
1	1996–97	11.52	95.48	0.27
2	1997–98	27.93	110.56	0.3
3	1998–99	2.75	29.29	0.07
4	1999–2000	7.03	66.59	0.15
5	2000–01	17.67	51.2	0.11
6	2001–02	4.77	35.47	0.07
7	2002–03	13.65	76.56	0.16
8	2003–04	3.14	521.34	1.13
9	2004–05	9.67	1047.90	2.33
10	2005–06	5.71	913.2	2.06
11	2006–07	3.07	737.06	1.61
12	2007–08	6.48	606.83	1.5
13	2008–09	2.49	719.35	1.69
14	2009–10	3.78	29.65	0.06
15	2010–11	2.13	25.36	0.06
16	2011–12	1.11	105.07	0.22
17	2012–13	0.25	30.85	0.06
18	2013–14	0.42	56.26	0.09
19	2014–15	0.64	314.28	0.51
20	2015–16	0.01	0.64	0

Source: Export Import Data Bank Version 7.1 Tradestat, Government of India, Ministry of Commerce and Industry, Department of Commerce

exported for a value of Rs. 314.28 lakhs and 2015–2016 further declined to 0.01 kg at a value of 0.64 lakhs (Table 10.3).

Soundararajan et al. (2017) provided import data from 1996 to 2016. They quote that Sandalwood imports has been imported during the 1996–2016 (Table 10.4). Maximum quantity of Sandalwood oil has been imported in the year 2009–2010, weighing 43,270 kg and 34,440 kg in 2013–2014, and least amount of Sandalwood oil was imported during the years 1998–2000 (Table 10.4).

Indian Sandalwood oil has been exported to several countries of the world and also imported Sandalwood oil from some other countries.

10.8 Import and Export Policy on Sandalwood

Sandalwood and its product related import policy contains three chapters in Schedule–I. There is Section II, Chapter–12: Oil Seeds and Oleaginous Fruits, Miscellaneous Grains, Seeds and Fruit; Industrial or Medicinal Plants; Straw ad Fodder; Section–VI, Chapter–33; Essential Oils and Resinoids; Perfumery, Cosmetic or Toilet Preparations, Sections IX; Wood and Articles of Wood; Wood Charcoal; Cork and Articles of Cork; Manufacturers of Straw of Esparto or of

Table 10.4 Indian Sandalwood oil imports

Sl. no.	Year	Quantity in kg (thousand)	Rupees in lakhs	US$ in million
1	1996–97	0.96	10.32	0.03
2	1997–98	26.74	75.52	0.2
3	1998–99	0	1.31	0
4	1999–2000	0	0	0
5	2000–01	2.05	9.53	0.02
6	2001–02	0.41	1.74	0
7	2002–03	3.15	5.85	0.01
8	2003–04	5.3	150.44	0.33
9	2004–05	3.2	96.92	0.22
10	2005–06	1.41	140.02	0.32
11	2006–07	3.18	299.2	0.67
12	2007–08	19.64	1597.95	3.98
13	2008–09	61.1	2061.88	4.53
14	2009–10	43.27	1879.29	3.97
15	2010–11	27.15	4087.82	8.97
16	2011–12	29.19	5326.18	11.11
17	2012–13	30.75	7669.07	14.09
18	2013–14	34.44	9865.11	16.44
19	2014–15	26.95	7590.71	12.42
20	2015–16	2.24	621.4	0.99

Source: Export Import Data Bank Version 7.1 Tradestat, Government of India, Ministry of Commerce and Industry, Department of Commerce

Other Plating Materials; Basket ware and Wickerwork; Chapter-44: Wood and Articles of Wood; Wood Charcoal.

Sandalwood and its product related export policy contain three chapters in Schedule–II. There is Chapter–12. Oils Seeds and Oleaginous Fruits; Miscellaneous Grains, Seeds and Fruits; Industrial or Medicinal Plants; Straw and Fodder; Chapter–33. Essential Oils and Resinoids; Perfumery Cosmetics or Toilet preparations; Chapter–44. Wood and Articles of Wood; Wood Charcoal.

10.9 Case Study from the Industry, Karnataka Soaps and Detergents Limited (KSDL), India

Karnataka Soaps and Detergents Limited (KSDL) is an unlisted public company with its registered office of the company at Bangalore, Karnataka, and classified as a state government company. The company manufactures and markets toilet soaps, detergents, cosmetics, *agarbattis* (incense sticks), and Sandalwood products. Other major products are *agarbattis*, Sandalwood oil, detergents, talcum powder, and soaps. The makers of the iconic Mysore Sandal Soap, a household brand across south India, Karnataka Soaps and Detergents Limited (KSDL) is on a higher growth trajectory. The KSDL is eyeing a robust 20% topline growth during the current fiscal, as its popularity and profitability, predominantly on account of the consistent production of its pure Sandalwood oil–based soap, proceed with great strides. In 2019, Karnataka Soaps and Detergents Limited's operating revenues range is over INR 500 crores. Its EBITDA has increased by 57.81% over the previous year (Anonymous 2020a).

10.9.1 KSDL History: High and Low

The Karnataka government–owned company was set up in 1916 by Nalwadi Krishnaraja Wodeyar, the then Maharaja of Mysore, and Mokshagundam Visvesvaraya, the then Dewan of Mysore, for Sandalwood oil extraction and export. An idea to use this oil to manufacture soaps took root in the mind of the Maharaja, supported by the Dewan, and validated by an industrial chemist Sosale Garalapuri Shastry, which led to the formation of the Mysore Sandal Soap In 1918.

The company was under loss between 1980 and 1990 when the marketing of its products was done by another state enterprise Mysore Sales International Limited (MSIL). However, the company got back control over its sales in 1990. It also received an interest-free, unsecured loan from the government of Karnataka during the year 1990–1996 amounting to Rs 3.5 crore. The company recovered losses and became profitable again. It has been 10 years now that the company has been consistently making profits. Its product portfolio consists of 91 products across categories (Anonymous 2020a).

10.9.2 KSDL Turnover

For the year 2017–18, KSDL reported a turnover of Rs 583 crore and increased it further to Rs 672 crore in 2018–19, a growth of 15.3% year-on-year. The net profit of the company almost doubled from Rs 67 crore in the year 2017–18 to around Rs 123 crore as in March 2019, a growth of 83.5% over the previous year. The company's top line growth is around 16.5% annually, which is much higher compared to the industry growth of 8–9%. In FY19, KSDL produced 13,000 metric tons of soaps across all brands and the company is aiming at a turnover of Rs 800 crore by March 2020. KSDL's market share in the soap market is a minuscule 1.8–2.5%. However, its share in the premium soap category is 12%, while the premium soap as a category accounts for 20% of the overall soap market in the country.

Mr. M. R. Ravikumar, MD, KSDL, quotes "The company holds 40% market share in Southern markets and commands huge popularity in the markets of Tamil Nadu, Andhra Pradesh and Telangana followed by Karnataka. Mysore Sandal Soap (75 g) remains to be the company's star product, contributing the most to its revenues." The company has obtained geographical indication (GI) tag for Sandalwood soaps.

10.9.3 Challenges Faced by KSDL

Being a government-owned company, KSDL is facing several challenges, such as a negligible marketing and advertising budget, which is limited to Rs 12–13 crore a year. However, this year, it has been hiked to Rs 20 crore (Anonymous 2020a).

10.10 Conclusion

There is a continuous decline in the production of Sandalwood, but the demand for natural products is increasing. The wood and the value-added products are not adequately available in the market. Sometimes the policies of the government also hinder the free flow of raw materials and the dependent industries have no option other than to seek alternatives. Due to these reasons, the sale price of wood and oil is fluctuating in both domestic and international markets. Due to progress in the developed and the developing nations, there is shift in the use of synthetic substitutes. Because of the synthetic revolution, there is a perceived threat to continued use of natural products in perfumery industry. This threat has been created by the presence of multinational companies seeking maximum profit at low cost, although these companies dominate the fragrance industry; however, smaller companies still provide specialist services to the industry and its customers. Customer market demands an imperative and an ever-increasing requisite.

Consumers have become more educated and knowledgeable and hence discerning with regard to chemical names on the product labels and feel more secure with natural products, especially in skin care and health products. This is attributable to both an inherent desire for the use of natural derivatives and adverse publicity resulting from sensitivity and allergic responses in some people to synthetic products. They have fear of adverse allergies due to synthetic usages**.**

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Sandalwood Smuggling and Illegal Trading in India 11

Subbiah Karuppusamy

Abstract

Santalum album L. (Sandalwood) is one of the most valuable tree species in Indian forestry. It is an important export product, and is highly traded illegally in the international market. It provides significant cash incomes, and adds a considerable value to the national economy. This wood is highly expensive, and used not only in medicinal uses, but also in various industrial purposes. Hence, it is being overexploited from their natural habitats, since the past centuries. Though these trees naturally grow in the forest, there is no systematic cultivation, and at the face of increased exploitation, Sandalwood has become an endangered species in India. As a prohibited item for the export, Sandalwood is included in the list of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This chapter highlights the illegal trade of Sandalwood, smugglers and Sandalwood mafias, exploiting wood from the forest with a few incidents of smuggling stories and controlling measures for illegal trade.

Keywords

Sandalwood · Wood · Tree · Smuggling · Illegal trade · Essential oil

11.1 Introduction

Santalum album L., commonly known as Sandalwood or sandal is a small tropical tree, is widely accepted as the most precious and commercial timber species with an estimated market volume of more than $1 billion (Srinivasan et al. 1992; Viswanath et al. 2008). The species is indigenous to India and its distribution is limited to an

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area of about 9600 km^2, mostly in the deciduous forests of the Deccan region of Peninsular India (Gairola et al. 2008). The southern Indian states of Karnataka and Tamil Nadu together account for more than 90% of the natural population of Sandalwood. India has traditionally enjoyed a niche market for the premium prized Sandalwood oil, which has excellent medicinal properties, and is widely used as a fixative in the manufacture of world-class perfumes and aromatic oils, owing to its intrinsic blending properties (Baruah 1999). Sandalwood also finds extensive applications in the wood carving and turnery and possesses religious significance (Parthasarathi and Rai 1989). Despite the value of the resource and its status as India's brand ambassador in the international markets, a recent data on production of Sandalwood in India shows a declining trend, due to its overexploitation by illegal traders. India's Sandalwood production dropped from 4000 megagram (Mg—1 metric tonne) heartwood per year in the 1950s to a mere 500 Mg in 2007 as against the global annual demand of about 5000–6000 Mg wood and around 100–120 Mg oil for perfumery industries (Gairola et al. 2008). Despite its traditional advantage of being a frontrunner in Sandalwood trade, India has now lost the potential economic opportunity in Sandalwood and sandal oil trade to Australia and Indonesia. Indonesia produced 1000 Mg Sandalwood annually in the 1980s (McKinnell 1990) and Australia had 830 ha of Indian Sandalwood plantation in 2001, which was projected to expand to 2300 ha by 2011 (Awasthi 2007).

Studies also indicate a substantial loss of genetic diversity of natural sandal populations in the major Sandalwood-bearing regions of India in recent decades (Venkatesan et al. 1995). Owing to its rapidly declining status, Sandalwood has been accorded the vulnerable status by the International Union for Conservation of Nature and Natural Resources (IUCN) in 1998 (Awasthi 2007). In addition to the erosion of sandal gene pool and loss of adaptive gene complexes that might have evolved through the process of natural selection (Meera et al. 2000), depletion of sandal resources has become a major concern for the *Gudigars* (Sandalwood carvers of Uttar Kannada district, Karnataka, India) whose livelihoods are dependent on this resource (Chandrasekhariah and Dabgar 1998; Bhaskar et al. 2010). For example, in Karnataka, between 1980 and 1997, Sandalwood recovered from poachers accounted for just about 30% of the gross sandal yield (Meera et al. 2000), while in 2006–2007, the quantity of recovered wood was about 78% more than the gross yield (Government of Karnataka 2007). Till recently, overall response of the state governments to the threat of smuggling has been limited to imposing stringent controls over Sandalwood extraction and trade through monopolistic laws and regulations (Viswanath et al. 2009). However, it has not deterred illegal and indiscriminate harvesting of Sandalwood nor has it helped to conserve the species in its natural habitat and its sustainable utilization. Paradoxically, the restrictive policy labyrinth has resulted in the perverse outcome of discouraging legitimate interest in sandal growing (Rao 2002; Bhaskar et al. 2010). The rate of Sandalwood smuggling and illegal trading has not stopped or reduced till date, even though we have enforced stringent actions against the smugglers and illegal traders. This chapter highlights the illegal trade of Sandalwood, smugglers and Sandalwood mafias, exploiting wood from the forest with a few incidents of smuggling stories and controlling measures for illegal trade.

11.2 Illegal Sandalwood Trade

The trade of Sandalwood started from Vijayanagar Dynasty in sixteenth century and Tipu Sultan's kingdom of Mysore in 1792, and later on Maharajas of Mysore, and subsequently all the governments after independence until now. Only one thing has changed, that is, the extraction and disposal of sandalwood under the jurisdiction of the Forest Department from 1864 to till date (Arunkumar et al. 2012). The forest department official estimate that the Karnataka forest areas show a dramatic rise in number of sandalwood offences from 302 to 1982–83 to 2338 in 1990–91. In Tamil Nadu, the number has gone up from 677 in 1988–89 to 2107 in 1991–92. Officials admit most cases come to light as a result of tipoffs from disgruntled gang members. Otherwise, it is very difficult to detect the crime though every year, officials confiscate Sandalwood worth crores of Rupees. Karnataka and Tamil Nadu together account for about 90% of India's Sandalwood stock. The Sandalwood forests are spread in about 50,000 ha in Karnataka and 30,400 ha in Tamil Nadu located mainly along the Western Ghats. Average annual Sandalwood production is 700 tons in Karnataka and 807.50 tons in Tamil Nadu and the total accumulated stock in the two states are 6000 tons. Until the ban on export of Sandalwood billets and chips came into force, the entire Sandalwood business revolved around exports.

Most of the Sandalwood used by distillers and illegal exports is mainly sourced from the smugglers. There are two major routes by which smuggled Sandalwood is normally traded illegally. One goes to sandal oil distillery units in Kerala and the other to Uttar Pradesh, which also has sandal oil units, and to Delhi, from where it is smuggled out to other parts of India. The smuggled wood is sometimes taken to Mumbai and Chennai as well to export other countries through the international smugglers. Sandalwood is being smuggled even in log form to Southeast Asia and the Middle East nations, and to perfumeries in Europe. It is possible that quite a large quantity of Sandalwood is being smuggled out of the country because of the ban of trade. The demand for Sandalwood has created dangerous backward linkages down to the grassroots level, encouraging crime and smuggling in forest products in the villages near the Sandalwood forests. It has also resulted in the distortion of the relationship between forest-dwellers and forests (https://www.downtoearth.org.in/indepth/when-alienation-ruins-31741).

11.3 Sandalwood Smuggling

Smuggling of Sandalwood requires a sophisticated organization. It involves traders and a variety of agents and labour contractors, who are capable of monitoring the collection of wood illegally form the reserve forest areas. Once the wood is cut, the logs are hidden in safe places, and then loaded into trucks with a fake registration.

The police checkpoints need to be crossed during transportation to the ports, and port customs inspection also need to be escaped. Finally, for the transportation via sea, ships need to be found and managed illegally. Importantly all these operations require the active participation of police and custom officers as well. Smuggling of prohibited natural sources requires political support and control, and bureaucrats committed to getting things done for the 'Sandalwood mafia'.

Smuggling processes primarily start from the woodcutters. The business relies heavily on male migrant labour from tribal and unemployed schedule castes, originating mostly from the neighbouring states of Karnataka, that is, Tamil Nadu and Andhra Pradesh. These labourers are widely known to have the special skills needed to work with timber, and are well experienced to work in difficult forest conditions. However, there are also other factors that explain the use of labourers from Tamil Nadu and Andhra Pradesh rather than local ones. Primarily, the local labourers do not get involved in the wood-cutting business, because they are aware of the dangers that working for the Sandalwood mafia involves. The local labourers are well aware of the consequences, the stakes and the tensions regarding Sandalwood smuggling. It has become a highly political issue and dangerous. Many local people refuse to work in the forest. Secondly, unemployed youths and tribal migrant labourers from Tamil Nadu are considered special for this act. They are viewed as fearless, due to their alleged history of criminality and linkages with the famous Sandalwood mafia like Veerappan. It follows that labour contractors use the brand 'name of mafia group forest' to promote the skills of their labourers and negotiate better wages for them. This branding, while being an advantage when negotiating labour wages, also facilitates criminalizing migrants. Going back to the Sandalwood mafia organization, labour contractors are in charge of organizing shelter, food and water in the hamlets and villages in the reserve forest areas, and manage the working schedules. The labourers cut the trees, then carry and hide the logs in the local ravines. Most labourers are paid by weight of logs cut off. Once a patch work is over, they removed from the place and return to home.

11.4 Sandalwood Mafias

'Sandalwood Veerappan' was an Indian bandit and dacoit who was active for several years in the forest lands, covering about 6000 km^2 in the states of Tamil Nadu, Karnataka and Kerala. He maintained a small army for his all activities of poaching, hunting and smuggling of illegal trade material from the forest sources, where he stayed. He was wanted for killing approximately 184 people, about half of whom were police officers, including senior police and forest officials, who were all against his activities in the forest. While his initial days of dacoity were restricted to satisfying his financial needs, his later actions included demand of release of militants from jail in exchange of the hostages. He was said to have poached his first elephant at the age of 14 and committed his first murder at 17 years of age. Later, he joined a gang of poachers and expanded their operations to include Sandalwood and ivory smuggling, murder and abduction (Manoharan 2004).

Veerappan first came in news when he murdered Sathyamangalam district forest officer Mr. Chidambaram, who was against his illegal trade of Sandalwood and ivory. In 1991, he shot Mr. P. Srinivas, a Karnataka Deputy Conservator of Forests and beheaded in a Kali temple. During the subsequent years, he killed tens of police officers and tribal people, whom he felt were against his illegal trade of forest products. In 1997, he kidnapped Karnataka forest officers, tourists, Kannada actor Rajkumar and several others. His last big crime was in 2000, when he abducted Nagappa, a retired minister of Karnataka. Nagappa was found dead in the forest later, but Veerappan denied his killing. He was involved in poaching about 200 elephants and smuggling ivory worth US$ 2,600,000 and about 10,000 tons of Sandalwood worth approximately US$22,000,000. A special task force dedicated to Veerappan's capture was convened by the Tamil Nadu and Karnataka governments in 1990. Veerappan evaded being caught partly, thanks to a vast information network that he had established, bolstered by his financial contributions to impoverished locals. Because of the political instability, Veerappan could easily escape from one state to another. The state jurisdiction problems also prevented police officers from entering other states to apprehend Veerappan's area (India Today 1997).

Veerappan's activities over the years attracted stringent policing. On the flip side, authorities have also come up with economic censures such as a total ban on Sandalwood exports. But the ban imposed in the year 2003 by the ministry of environment and forests (MoEF) had negligible results, apart from making Sandalwood prices crash, and causing revenue losses running into crores of rupees for Karnataka and Tamil Nadu, the two principal Sandalwood-producing states in the country (Down to Earth 2004). Some forest officials contend that Veerappan was distracting public attention from more serious and organized smuggling of Sandalwood. Also, the subtle transition from a single, all-powerful anti-hero to a collective enterprise, involving entire villages, went almost unnoticed. In the Sandalwood-rich Western Ghats in the two states, the names of villages, such as Vachati now evoke greater terror for the authorities than Veerappan. Smuggling, not only cuts into the legitimate profits of the Sandalwood and state revenue, but it also threatens a valuable natural resource and threatens the communities living around the forests.

Today, villagers in Karnataka and Tamil Nadu stand totally alienated from the Sandalwood trees and either participate in its open loot or shun it to the extent that they uproot Sandalwood saplings from their private land, fearing encroachment by smugglers or dictates from the forest department. Ironically, in Sandalwood-rich Kollegal forest division, where Veerappan ruled the roost, only 80 residents have declared their Sandalwood trees. Small wonder then that despite its religious uses, the tree now evokes reactions that from a Soliga tribal in a village near Rampura in Kollegal. They believed that Sandalwood is a government tree. Curiously enough, the nature and scale of smuggling operations vary across the Sandalwood-rich districts of Mysore, Shimoga and Chikmagalur in Karnataka and Salem and Dharmapuri in Tamil Nadu. The spectrum moves from an all-powerful, anti-hero, such as Veerappan, to group smuggling by villagers as in Vachati in Salem, with a large number of peddlers in villages and towns linked with the wider market through a chain of middleman (Times of India 2001).

Veerapan's system worked in a top-down fashion. According to the vigilance record, the smugglers have nodal agents in Bangalore, Mysore, Chennai and a few other towns in the two states. The bigger kingpins have agents at all levels. The vigilance record of Karnataka, for instance, notes two major gangs, the Khuddus gang and Shameer gang, operating from Bangalore and establishing contact through telephone with their agents in different places for organizing transportation of the wood. Sandalwood smuggling has become a way of life in some villages near the forest areas where Veerapan operated. For instance, Dharmapuri district in Tamil Nadu, where about 73 tons of Sandalwood were seized, and more than 400 village people prosecuted between 1985 and 1987. The gravity of the problem came to light later on when within a space of 3 days, 63 tons of Sandalwood worth INR 1.25 crore were seized and more than 100 people arrested from just two tribal villages in Vachati and Salur divisions of Tamil Nadu. Usually Sandalwood smugglers are well armed and when the forest officials or spy men enter in the area, they scare away.

Political involvement in Sandalwood smuggling is very common. Apart from Veerappan and other gangs known to deal in Sandalwood are said to be politically well connected. Recently, when the forest department apprehended a vehicle carrying a load of Sandalwood, a minister rang up the forest department and had the vehicle released. According to most observers, there are probably many other smugglers and poachers who are carrying on business as usual with support of politicians. Where Veerappan went wrong, they insist, was that he killed forest officers and guards and police personnel. So there could well be several other low-key operators who are cleaning the forests of Sandalwood. Observers feel that Veerappan may have been a smokescreen that many vested interests wanted and needed. With the massive local people support, it was no surprise that Veerappan evaded capture so long and so successfully. At Marthahalli village, close to the spot where the officials recovered an estimated 65 tons of Sandalwood in 1990 from one of Veerappan's hideouts, villagers say that they are proud of Veerappan. They feel that he is a hero, one of them who made it very big. Veerappan's story ended on 18 October 2004 after three decades and he and two of his associates were killed by the Tamil Nadu Special Task Force near Paparapatti village of Dharmapuri district in Tamil Nadu (Rediff News 2004; Times of India 2004).

11.5 The Ghost of Veerappan and Criminalization of Labour

A well-known Sandalwood mafia and illegal smugglers of Sandalwood haunts pervades the representations and practices of criminal economy from labour organization to long-time police investigation. Veerappan was a powerful element in the local cultural repertoire of models of authority. A Robin Hood figure (Seal 2009) and protector of forests for some, the figure of Veerappan in South India epitomized the dangerous criminal for the state and the police forces. In doing so, it also contributed to legitimizing the criminalization of labourers and the use of state violence against labour in the context of the Sandalwood criminal economy. But the career of

Veerappan also mirrors the changing alliance between politics, markets and violence in later forms of capitalism. These dynamics can be seen in two events in April 2015: the massacre of 20 labourers by the Red Sanders Anti-Smuggling Task Force, followed by the decision to remove Red Sanders (*Pterocarpus santalinus*) from the endangered list to make the business easier (Vadlapatla 2015). As early as July 2014, the Andhra Pradesh government was ready to sell Red Sanders at auction through global tenders (Economic Times 2014). In October and November 2014, the government prepared the first phase of the e-auctions of 4000 tons (seized by police) to be sold at an average of INR 25 lakh per tonne. The change of rules in the business cannot be dissociated from the massacre of woodcutters. It is the combination of the private use of state violence with the manipulation of market regulations that unravels how electoral democracy is crucial in determining who is ruling and controlling the business (Picherit 2019).

11.6 Current Commercial Trend of Sandalwood Trade

The price of Indian Sandalwood of good heartwood class at present is over INR 9000 per kilogram and that of oil is over INR 1,23,000 per kg, from the legal and ethical sources. The price at the international market is about 15–20% higher than the domestic market. Though there is ban on the export of bigger logs of wood from India, these nevertheless reach the world market. The annual increase of price is going at a premium of more than 30% (Venkatesha Gowda 2011). The Sandalwood being realized from the Sultan of Mysore was declared as a royal tree in 1792. It continues to retain that place even today also, although individuals are entitled to receive 75% of its value as a bonus for growing and protecting the trees. Due to its high value and steeply rising demand both in internal and external markets, Sandalwood prices have skyrocketed, as can be seen from the price per tonne. Sandalwood production in the country has fallen from about 4000 tons per annum in the 1960s to <1000 tons during the 1990s (Rao et al. 2001). Sandalwood oil has virtually disappeared from the international market and its place has been taken over by synthetics. With Sandalwood bio-resources depleting at a rapid pace due to various reasons, the gap between demand and production has widened tremendously. These factors are demanding the commercialization of Sandalwood and hence local mafias and gangs formed to start illegal export with support of politicians.

11.7 Recent Policies on Sandalwood Trade

During 2001 and 2002, Karnataka and Tamil Nadu governments have relaxed the existing rules and regulations related to Sandalwood in an effort to boost production through encouraging private domestication of Sandalwood. Despite the policy amendments favouring private growing of Sandalwood and the advantages of cultivation of Sandalwood as an agroforestry species, there prevail considerable scepticism on the economic prospects of Sandalwood cultivation due to the time lag in accruing returns from the tree and the high investments required for its protection. Against this backdrop is the problem to assesses the viability of Sandalwood cultivation practices in southern India through a benefit–cost analysis (BCA) using financial indicators like net present value (NPV), benefit–cost ratio (B/C ratio), internal rate of return (IRR), equivalent annual income (EAI) and land expectation value (LEV) (Divakara et al. 2018). Some places in Bellary district of Karnataka and Dharmapuri district in Tamil Nadu are engaging commercial cultivation of Sandalwood through genetically improved varieties provided by tree breeding institutes of India.

11.8 Conclusions

This chapter illustrates how current criminal economies, based on alliances between markets, politics, state and violence, have led to a criminalization of labour and a marked shift from political violence to economic violence in south India for Sandalwood trade. The history of Sandalwood traffic highlights the transformation of the local Sandalwood economy into a criminal, international mafia-like activity. The latter is further illustrated by the ways the mythical figure of Veerappan is used to negotiate labour, violence and justice in the region. The local criminal economies are further entrenched in the local socio-political contexts through the logics of intermediation typical of the local informal economy. Such dynamics help to maintain the silence and secrecy necessary to protect the workings of the Sandalwood mafia. Finally, it showed that how the Sandalwood business is unstable and always dependent on local politics and changes in the laws. However, these uncertainties are also the basis for the making of personal fortunes and for making the Sandalwood business a ‘gamble’ worth hundreds of crores of Indian rupees.

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Tissue Culture Studies in Sandalwood (*Santalum album* L.)

12

Mallappa Kumara Swamy

Abstract

Sandalwood (*Santalum album* L.) is one of the highly valued Indian tree species in the world, and economically valued for its essential oil, extracted mainly from heartwood and roots. Its products are used in fragrance, cosmetic, and therapeutic industries. These slow-growing Sandalwood trees have been overharvested in the past centuries, leading to a condition of being endangered. However, the conventional mode of large-scale afforestation of Sandalwood is hindered by many difficulties, including low seed germination rate, seedling mortality, and diseases. Establishing a reproducible and cost-effective plant regeneration system under in vitro conditions, using cell, tissue, or organ culture is very useful for a large-scale Sandalwood plant production. This chapter reviews on the micropropagation and conservation, and also addresses several issues related to Sandalwood tissue culture.

Keywords

Germination · Propagation · Plant cell culture · Somatic embryogenesis · Tree

12.1 Introduction

Sandalwood (*Santalum album* L.; family Santalaceae) is one of the highly valued Indian tree species in the world and well known as "East Indian Sandalwood." The *Santalum* species, including *S. spicatum*, majorly occur in India, Bangladesh, Nepal, Indonesia, Sri Lanka, Australia, Hawaii, and other Pacific Islands. In Karnataka and Tamil Nadu states of India, the distribution of Sandalwood is more than 90%,

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covering about 9000 km^2 area, of which over 70% is observed in Karnataka, mainly in the southern Western Ghats. This tree species is chiefly observed in dry deciduous and scrub forest areas (Jain and Shankaranarayana 2003; Divakara et al. 2018; Tewari et al. 2014). The economic value of Sandalwood is for its essential oil, extracted mainly from the heartwood and roots. Noteworthy to mention that Sandalwood is the second-most costly wood in the biosphere, only after African Blackwood (Kumar et al. 2012), and India is the major supplier of Sandalwood and its produces. The extracted essential oil content ranges from 0.9% to 8%, chiefly constituted with α-santalols (41–55%) and β-santalols (16–24%) as the major volatile chemical constituents (Howes et al. 2004; Jones et al. 2007; Zhang et al. 2016). The heartwood and its oil possess a distinct aromatic fragrance, which is the reason for its higher value since from centuries, and have pharmaceutical and industrial uses. It is widely employed in the flavor and perfume, cosmetic, and medical industries (Divakara et al. 2018). Traditionally, Ayurvedic, that is, the folk medicine of India and traditional Chinese medicine (TCM) have utilized it for treating various health problems, and the present medical investigations also suggest that Sandalwood may perhaps help in curing numerous health issues. In addition, it is used in handicrafts, wood carvings, religious purposes, etc. (Tewari et al. 2014). This promising commercial perspective allows commercial growers to consider Sandalwood as an attractive option, targeting at global fragrance, cosmetic, and therapeutic markets (Da Silva et al. 2016). An estimated global market for Sandalwood oil is more than $1 billion (Divakara et al. 2018; Viswanath et al. 2010). To produce an economically vital Sandalwood tree with greater levels of fragrant essential oils need Sandalwood trees to be of at least 10–15 years old (Tewari et al. 2014). These slow-growing Sandalwood trees have been overharvested in past centuries, leading to a condition of being endangered. Further, to support the scarcity, they are being cultivated widely in different parts of the world, mainly India, China, and Australia.

Sandalwood is primarily an outbreeding species, and thus the qualities of progenies are obviously separated. Selection of improved varieties of Sandalwood species is difficult as it takes a minimum of 10–15 years to mature after planting. Unfortunately, these tree species display higher genetic variability, and therefore as a feasible way, the large-scale afforestation was adopted to select superior distinct trees (Kumar et al. 2012). Hence, propagating Sandalwood trees with preferred traits is very imperative for a sustainable expansion of the Sandalwood commerce. Naturally, Sandalwood regeneration happens by means of seeds that are commonly dispersed by birds and generally take about 2–4 months to germinate. Seeds show a post-dormancy period up to 2 months because they possess impermeable outer covering. Their viability varies between 6 and 12 months. However, low seed germination rate and seedling mortality due to various reasons pose a major challenge. The germination rate can be improvised by soaking seeds in gibberellic acid (0.05%) (Das and Tah 2013). The regeneration is succeeded artificially by dibbling seeds in pits, sowing on mounds. Also, wounds are caused to roots to induce root suckers production by trenching around the mother tree. Tissue culture–raised seedlings are also used for propagating Sandalwood. Though conventional vegetative propagation methods, such as rooting of the excised branches and grafting, are effective to a certain extent, they still possess limitations. These traditional approaches for the production of clones are ineffective, laborious, and extremely reliant on the season (Rao and Raghava Ram 1983; Veerendra and Padmanabha 1996; Li 1997; Rugkhla and Jones 1998; Uniyal et al. 1985; Bapat and Rao 1992a).

Establishing a reproducible and cost-effective plant regeneration system under in vitro conditions, using cell, tissue, or organ culture is very useful for various biotechnological applications, including crop improvement of plants (Swamy et al. 2014; Kaushik et al. 2015; Kumar and Srivastava 2016). The tissue culture of Sandalwood has been studied since 1963 and somatic embryogenesis in woody plant species was firstly reported in Sandalwood. Significant advancements have been accomplished by using different responsive explants, including zygotic embryos, hypocotyls, nodes, internodes, and immature leaves. In vitro propagation has been achieved through shoot organogenesis and somatic embryogenesis with a varying degree of success of its mass propagation. In addition, cell culture, protoplast culture, and synthetic seed cultures have been proposed by different researchers (Rugkhla and Jones 1998; Muthan et al. 2006; Zhang et al. 2016; Da Silva et al. 2016; Bele et al. 2019). In spite of all these achievements in Sandalwood, there are few impediments that hamper its complete practical use. Some of these problems include abnormalities in somatic embryos (SEs), low responses to in vitro shooting and rooting, low survival percentage of the regenerated plantlets in the field condition (Da Silva et al. 2016). To date, the commercial production of Sandalwood tissue culture is yet to be achieved. This chapter reviews on the micropropagation and conservation, and also addresses several issues related to Sandalwood tissue culture.

12.2 Tissue Culture Applications in Sandalwood

Though, Sandalwood is cultivated all around the world, its market demand is yet to be fulfilled, due to ever-increasing applications of Sandalwood products. Hence, it is imperative to cultivate Sandalwood trees in a large scale and to enhance the area of cultivation. In this regard, conventional approaches, like multiplication by means of seeds sowing and vegetative propagation, are found to be ineffective (Rao and Bapat 1993; Muthan et al. 2006). The reasons could be correlated to various reasons, including the impact of seeds' vigor, physiological responses, and agronomical factors. For instance, the seeds of Sandalwood remains dormant up to 60 days, and the viability of seeds gradually decrease after 10 months. Moreover, seeds stored for more than 1 year lose viability progressively, and seed germination fails after 2 years of storage (Bapat and Rao 1992b). In contrast, the vegetative propagation methods consume more time and are not always successful (Peeris and Senarath 2015; Viswanath et al. 2009). The mortality rate of plantlets is very high, because of high temperature, fire, unnecessary weed growth, trampling, grazing, diseases, and incidence of insects and pests attack (Bapat and Rao 1992a; Teixeira da Silva et al. 2016). Furthermore, and in general, the practicability of large-scale production is limited because of diseases and climatic conditions (Swamy and Sinniah 2016). In spite of different conventional investigations, the link among host and parasite is yet to be understood properly in Sandalwood species. Thus, tissue culture approach can be very effective in overcoming these issues, as it offers the possibility of propagating disease-free and genetically uniform plantlets with high-vigor compared to conventional approaches (Parthiban et al. 1998; Swamy and Sinniah 2016; Krishnakumar and Parthiban 2018).

There are few reviews on Sandalwood biotechnology, including tissue culture (Bapat and Rao 1989, 1992a, b; Redenbaugh 1993; Da Silva et al. 2016). Micropropagation techniques involve different stages, that is, mother plant selection, aseptic culture establishment, in vitro shoot multiplication, in vitro or ex vitro rooting, acclimatization, and establishment of plantlets in the field. In the following chapter, we provide an up-to-date information on these aspects till date.

12.2.1 Tissue Culture Studies in Sandalwood

There are numbers of investigations on the in vitro regeneration and growing of Sandalwood accomplished via organogenesis or embryogenesis (Table 12.1). Nonetheless, the sources of explant, methods of disinfection, culture media formulations, and growing conditions, etc., remarkably influence the micropropagation of Sandalwood, and these factors are discussed in the following sections. Previously, few review papers have been published on the tissue culture of Sandalwood (Bapat and Rao 1992a; Rao and Bapat 1992, 1993; Muthan et al. 2006; Da Silva et al. 2016). However, this chapter provides an updated and more comprehensive information related to various aspects of Sandalwood tissue culture.

12.2.1.1 Explant Sources

For an effective in vitro culture initiation through direct organogenesis in Sandalwood, wide-ranging explants, such as seeds, zygotic embryos, seed endosperm, leaves, shoot tips, hypocotyl segments, nodal segments, internodal segments, etc., are being used. Explants with predetermined meristems, especially nodes or shoot tips, hypocotyls derived from elite trees or germinated seedlings are being largely employed for in vitro propagation of Sandalwood. Further, internodal segments, stem segments, and leaf discs were commonly used for inducing in vitro somatic embryos or adventitious shoots (Table 12.1).

12.2.1.2 Surface Sterilization

For an effective in vitro aseptic culture establishment, majority of Sandalwood tissue culture studies have used $HgCl_2$ for surface sterilization, and the concentration commonly ranged between 0.05% and 0.5% (w/v) (Lakshmi Sita et al. 1980a, b; Rao and Raghava Ram 1983; Bapat and Rao 1984, 1988; Bapat et al. 1985; Muralidharan 1997; Sanjaya and Rai 2003; Mujib 2005; Sanjaya et al. 2006a, b; Mo et al. 2008; Shekhawat et al. 2008; Nikam and Barmukh 2009; Singh et al. 2016; Tripathi et al. 2017; Bele et al. 2019; Akhtar and Shahzad 2019). In few studies, 15% Clorox™, 2–3 drops of Tween 20, 2.5% NaOCl, soap water, 70% EtOH, low concentrations (0.2–1 g/L) of microbicides (bavistin, cefotaxime, kanamycin) were

Table 12.1 A detailed report on various tissue culture studies of Sandalwood tree till date

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
Seeds	mWBM + CM (20%) + CH (400 mg/L)	Seeds germinated but failed to produce seedlings	Rangaswamy and Rao (1963)
Endosperm and ZE	mWBM + CM (20%) + CH (400 mg/L)	Friable callus after 4–6 weeks; Zygotic embryos failed to show response	Rao (1965)
Cotyledon, endosperm and ZE	For cotyledon culturing: mWBM + CM (20%) or CH (400 mg/L). For endosperm and ZE culturing: mBM + KIN or 2,4-D or YE (0.25%) alone or in combinations. For excised ZE: mBM + CH (400 mg/L) CM (20%)	Embryoids were produced from cotyledon-derived callus, which later formed plantlets. Both endosperm and ZE failed to show response. Excised ZE showed seedlings formation after 28 days, and later produced plantlets after 14 days	Rao and Rangaswamy (1971)
Hypocotyls and stem segments from in vitro-derived seedlings	For callus induction: BM + 2,4-D or pCPA (1 mg/L) or 2,4-D + KIN (1 mg/L each) or 2,4-D + BA (1 mg/L each). For shoot multiplication: BM alone or BM + IAA/NAA/IBA/Kin/BAP/Zeatin (1 mg/L), NAA + KIN (0–2 mg/L) or NAA + BAP (0–2 mg/L). For root induction: BM + NAA (0.5 mg/L) + IBA (0.5–5 mg/L)	Stem segments failed to respond. Hypocotyls showed shoot multiplication on BM added with cytokinins. Mainly, BA at 2 mg/L induced up to 20 buds/explant. Rooting was evidenced only in few cultures. It took about 4–8 weeks for a complete plantlet regeneration. Acclimatization not reported. Callus was noticed on BM supplemented with 2,4-D + BA	Rao and Bapat (1978)
Stem segments	Liquid BM + IAA or NAA (1 mg/L), BAP (1 mg/L), 2,4-D (1 mg/L), GA_3 (1 mg/L), CM (10%), NAA and BA (1 mg/L each), or CH (400 mg/L) + CM (10%)	Globular SEs were produced after sub-culturing calli on media having 1 mg/L IAA after 28 days. Nearly, 30% SEs transformed to form plantlets. After 56 days, plantlets	Bapat and Rao (1979)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
		were acclimatized in soil	
Shoot tips and shoot segments	For callus induction: MS + 2,4-D (1 mg/L) + KN (0.2–0.5 mg/L) For embryoids induction and multiplication: MS + GA_3 (1 mg/L) or MS + GA_3 (1 mg/L) + IAA (1–2 mg/L) + 2,4-D (0.1 mg/L) or MS + BA (0.5 mg/L) + NAA (1 mg/L)	Both shoot tips and shoot segments induced calli that resulted to form embryoids after 4 weeks after subculturing	Lakshmi Sita et al. (1979)
Shoot tips and shoot segments	For callus induction: MS + 2,4-D (1–2 mg/L) or MS + BA (0.5–2 mg/L) + NAA (1 mg/L) For embryoids induction and multiplication: MS + 2,4-D (1 mg/L) or MS + GA_3 (1–2 mg/L) or MS + BA (0.3 mg/L) + IAA (1 mg/L) + KIN (0.3 mg/L) + GA_3 (1 mg/L)	Calli induction was noticed, and subsequent sub-culturing of callus resulted to form embryoids within 4–6 weeks	Lakshmi Sita et al. (1980a, b)
Juvenile shoots from matured tree, green fruits, and matured seeds	For callus induction: MS + 2,4-D (1 mg/L) or MS + 2,4-D (1 mg/L) + KIN (0.2 mg/L). For SEs induction: MS + IAA (1 mg/L) + BA (1 mg/L). For SEs multiplication: MS + IAA (1 mg/L) + IBA (0.5 mg/L) + GA_3 (0.5 mg/L)	Callus formation was evidenced within 3 weeks. Sub-culturing of callus induced SEs formation after 4 weeks, which later turned to plantlets having 2 to 3 pairs of leaves and well developed roots after another 4 weeks. Plantlets were acclimatized in pots consisting of vermiculate and soil	Rao and Raghava Ram (1983)
Hypocotyl segments derived from 4-week-old in vitro seedlings	For shoot induction: mBM + NAA (1 mg/L) or BA (1 mg/L) For root induction: NAA (0.5 mg/L) + IBA (5 mg/L). For acclimatization: Hoagland's nutrient	Shoot buds were initiated, well rooted normal plantlets (~20 cm in length) were obtained. After acclimatization for 3 weeks, plantlets were transferred to	Bapat and Rao et al. (1984)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	solution for 3 weeks (Hoagland and Arnon 1938)	field with 10% survival without host plant	
Nodal segments and internodal segments from 30-year-old tree	For shoot induction: MS + BA (0.5 or 1 mg/L). For callus induction: MS + 2,4-D (1 mg/L) or MS + 2,4-D (1 mg/L) + KIN (0.2 mg/L). For SEs induction: MS + IAA (1 mg/L) + BA (1 mg/L)	In vitro shoots were developed. Nodal segment-derived shoot buds failed to root. Callus was initiated well from nodal explants. SEs were initiated from internode-derived callus, and successfully converted to plantlets, which when transferred to field condition showed 10% survival rate	Rao et al. (1984)
Stems and hypocotyls (4-week-old in vitro seedling)	For callus induction from hypocotyls: MS + 2,4-D or BA (1 mg/L) For callus induction from stems: MS + 2.4-D (1 mg/L) or MS + 2,4-D (1 mg/L) + KIN (0.5 mg/L). For SEs induction from stem calli: ½ MS + IAA (1 mg/L) or BA (1 mg/L)	Stem explants were effective in inducing callus. ½ MS added with 1 mg/L IAA induced the highest number of SEs. Plantlets were converted from stem calli-induced SEs	Bapat et al. (1985)
Shoot segments derived from 20-year-old tree	For SEs induction: MS + 2,4-D (0.5–2.5 mg/L) + folic acid (1 mg/L) or MS + BA (0.1, 0.5, 1.0, 2.0 mg/L) + 0.01 mg/L 2,4-D. For SEs multiplication: MS or 1/2 MS, alone or MS or 1/2 MS + BA (0.1 or 1 mg/L) or IAA GA_3 (1 mg/L) + BA (0.2 mg/L). For shoot growth: MS + filter-paper bridge or agar on WBM + IAA (0.5 mg/L) or combination of IAA	BA and 2,4-D supplemented media effectively produced SEs from callus. Club and heart shape staged SEs were observed. Cell suspension culture was obtained on MS media consisting of 1 mg/L BA. Further, cell suspension culture yielded secondary SEs. A successful conversion of SEs to plantlets was noticed	Rao and Ozias-Akins (1985)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	(0.1 mg/L) + IBA (0.5 mg/L) + GA_3 (0.5 mg/L). For protoplast culture: V47 medium. For SEs induction from protoplasts: MS + IAA (1 mg/L) + BA (1 mg/L) or casamino acid (400 mg/L). For germinating SEs from protoplasts: ½ MS or WBM + IAA (1 mg/L) or IBA (0.5 mg/L) or GA_3 (1 mg/L) For multiplication SEs from protoplasts: MS + BA (1 mg/L). For converting callus-derived SEs to plantlets: WBM + IAA (0.5 mg/L)		
Internodal stem segments of young shoots derived from 20 year old tree	For callus induction: MS + 2,4-D (1 mg/L). For SEs induction in suspension culture: MS + IAA (0.3 mg/L) + GA (0.5 mg/L). For synthetic seeds preparation: Individual SE was entrapped in calcium alginate gel beads. For secondary SEs: MS + BA (0.5 mg/L) + IAA (0.5 mg/L)	About 10–16% of encapsulated SEs showed germination, and subsequently it took 16 weeks to obtain a well-developed plantlets. Encapsulated embryos produced secondary SEs instead of germination. Further, encapsulated embryogenic cell suspension preserved at 4° C up to 6 weeks yielded embryos after re-culturing as suspensions	Bapat and Rao (1988)
Hypocotyl and stem segments	For shoot bud differentiation: MS + BAP (1 mg/L) For callus cell suspension culture: MS + 2,4-D (1 mg/L). For SEs formation: MS + IAA (2.85 μM) + BA (2.22 μM) + sucrose (87.6 μM).	Direct induction of multiple buds on hypocotyl explants after 3 weeks. The buds developed into young, green, leafy shoots, which attained a height of 25–30 mm after 8 weeks. Somatic embryos	Bapat and Rao (1989)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	For protoplast culture: Protoplasts were isolated leaf mesophyll, stem and hypocotyl callus using enzymes, such as cellulase, macerozyme, hemi-cellulase and pectinase at various concentrations along with mannitol (0.55 M) as an osmoticum. For synthetic seed preparation: Similar to Bapat and Rao (1988)	differentiated from callus. Plantlets developed from somatic embryos grew vigorously, and produced normal flowers within a span of 18 months. An acceptable yield of protoplasts was achieved. Optimal protoplast division was observed on V-47 medium containing BA and 2,4-D, resulting to form embryogcnic callus. The study demonstrated the possibility of retaining the viability of embryos after encapsulation	
Stem internodes of young shoots of a 20 year old tree	For callus culture: MS + 2,4-D (4.52μM) + sucrose (87.6 mM). For SEs establishment: MS + BA (2.22μM) + IAA (2.85μM) + sucrose (87.6μM). For plantlet conversion: WBM + ABS (18.92μM) + sucrose (58.4μM)	Both non-encapsulated and encapsulated desiccated embryos exhibited revival of growth upon rehydration on WBM, and developed into plants	Bapat and Rao (1992a, b)
Endosperm of 4-week-old fruits	For callus formation: MS + 2,4-D (1 mg/L) + BAP (1 mg/L) or 2,4-D (2 mg/L) + KIN (0.5 mg/L). For SEs establishment: MS + IAA (2.85μM) + BAP (2.22μM) + sucrose (87.6μM). For synchronous embryo differentiation:	Somatic embryogenesis events involves four phases. A distinctive morphological and biochemical changes occurs with progressing embryogenesis	Sankara Rao et al. (1996)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	MS + mannitol (2%). For maturation of bipolar embryos: ½ MS with or without mannitol		
Shoot tips, nodes and internodes of a mature tree	For shoot induction: MS + BAP (0.5μM) + KIN (0.5μM). For callus induction: MS + 2,4-D (0.5, 1, 2.4μM)	Nodal explants produced multiple shoots formation. Internodes showed better response to callus formation. Shoot tips failed to show any sprouting response	Muralidharan (1997)
Zygotic embryos of a mature tree	For SEs formation: MS + BAP (2 mg/L) or TDZ (4.5μM). For SEs multiplication: MS devoid of PGRs. For SEs conversion: ½ MS + GA_3 (2.8μM)	>90% of zygotic embryos produced about 14.2 SEs/explant after 56 days. Primary SEs induced nearly 20 secondary SEs/ primary SE after 56 days. Single SEs with distinct cotyledons converted into plantlets.	Rai and McComb (2002)
Nodal segments and seeds	For SEs induction: MS + TDZ (1–2μM) For SEs multiplication: MS + IAA (6μM) + KIN (1μM). For SEs germination/ elongation: MS + GA_3 (6μM)	Explants formed 100% globular SEs and friable embryogenic tissue with the use of 2μM TDZ within 2–3 weeks. Mature SEs (1–2 mm) having well-developed cotyledons were germinated and elongated on GA_3 media	Rugkhla and Jones (1998)
Seedling hypocotyls	For embryogenic callus induction: MS + IAA (1 mg/L). For bioreactor culture: MS + BAP (1 mg/ L) + ABA (0.5 mg/L)	About 3000 somatic seedlings were produced with less abnormality (59.3%) per liter of medium as compared to only 800 seedlings on the solidified medium with high rate of	Das et al. (1999)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
		abnormality (88.9%) in 12 weeks' time	
Seedling hypocotyls	For callus induction: MS + 2,4-D (4.52 mM). For SEs induction: MS + IAA (2.85 mM) + BAP (3.99 mM). For SEs production: WPM + IAA (2.85 mM) + BAP (3.99 mM) + glutamine (40 mM) + nitrate (11.6 mM) + ammonium (7.89 mM) + mannitol (0.33 M) + ABA (1.31 mg/L)	The optimization improved the embryogenesis efficiency up to 57.35%, and produced higher number of SEs	Das et al. (2001)
Nodal segments from mature 20-year old trees	For callus/shoot induction: MS + BAP (4 mg/L). For root induction: MS + IBA (1,2 or 3 mg/L)	Callus formation (27.7%) was observed after 3 weeks. 18% of callus differentiated into 2.59 shoots with 3.85 cm in length. Rooting was observed only with the addition of 3 mg/L IBA	Radhakrishnan et al. (2001)
Seedling hypocotyls and nodal stems	For callus induction: MS + 2,4-D (2.26μM) or pCPA (2.68μM). To produce embryogenic mass: Liquid or solid MS + NAA (2.7μM) + BAP (2.22μM) For maturation and development of embryo: Solid or liquid WPM devoid of PGRs. For root induction: MS + IAA (5.71μM)	The induced callus transferred to embryogenic media differentiated to form SEs. At the initial stage, liquid media was found to be more responsive than the solid media. High rate of abnormality (up to 68%) was noticed by the appearance of quite a few irregularities in SEs. 83.3% of rooting was observed	Ilah et al. (2002)
Seeds and nodal segments collected from 50 to 60-years-old candidate plus trees	For seed germination: Overnight soaked seeds in GA_3 (2711μM) cultured on MS media devoid of PGRs. For shoot induction: MS + BAP (11.12μM)	For micrografting, 45-days-old seedlings were used as rootstock. The shoot apex grafting frequency was observed to be highest	Sanjaya and Rai (2003)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
		in rootstock and in vitro derived shoots. A high success rate of grafting (60%) was noticed when 1–2 cm long scions were used	
Young and immature leaves obtained from aseptically germinated seeds (3–4 weeks old)	For shoot induction: MS + BAP (0.44, 2.22, 4.44, and 8.87μM) or KN (0.46, 2.32, 4.65 and 9.29μM)	Shoot bud formation was effective on media supplemented BAP at lower concentrations (0.44 and 2.22μM). Leaf sections positioned vertically failed to respond, while leaf lamina placed horizontally showed a high frequency of shoot bud formation	Mujib (2005)
Seeds and nodal shoot segments (as scions) derived from 50 to 60-years-old candidate plus trees	For shoot growth of rootstock (45-days-old seedlings): MS media devoid of PGRs. For shoot induction: MS + BAP (11.09μM) + NAA (0.53μM). For post-grafting: Liquid MS + sucrose (2%) on paper bridges	In vitro micrografting was accomplished. In vitro developed shoots as scions offered 60% of grafting success rate. 1–2 cm sized scions and hypocotyl united to develop into a complete plant with 2–4 leaves after 6–8 weeks	Sanjaya et al. (2006a)
Nodal shoot segments (as scions) derived from 50 to 60-years-old candidate plus trees	For shoot induction: MS + BAP (11.09μM) + NAA (0.53μM). For shoot multiplication: MS + BAP (4.44μM) + NAA (0.53μM) or MS + BAP (4.44μM) + NAA (0.53μM) with additives, i.e., ascorbic acid (283.93μM) + citric acid (118.10μM) + cysteine (104.04μM) + glutamine (342.24μM) + coconut milk (10%).	About 4.92 shoots measuring 3.23 cm length were induced. Media supplemented with NAA and BAP in addition to additives significantly improved the shoot number (4.63)/shoot segment in comparison to medium devoid of additives. In vitro rooting was accomplished from microshoots pulsed	Sanjaya et al. (2006b)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	For root induction: MS + IBA (1230μM)	with IBA for 30 min in soilrite media	
Young shoots from elite mature tree	For adventitious shoot induction: MS + BAP (5μM) + NAA (0.5μM). For root induction: MS + IBA (250μM)	Multiple shoots (5.7 shoots/explant) were formed. Only 8% of in vitro shoots rooted well. After acclimatization, 95% plantlets showed survived	Ma et al. (2005)
Immature seeds and mature seeds from a 10 year-old tree	MS + GA_3 (14μM)	82.5% seedling rate was attained after 45 days of culturing	Mo et al. (2008)
Fruits/seeds collected in May month from elite tree	For seed pre-treatment: 2, 4, 6 and 8 mM GA_3. For shoot growth: MS + BAP (4μM)	Pre-treated seeds showed 80.7% germination rate compared to only 46% in control treatment	Nikam and Barmukh (2009)
Seeds, cotyledons and internodal segments	For seed germination: BAP (4.44μM) + NAA (2.69μM) For SEs induction: MS + 2,4-D (13.50μM)	80% response of seed germination. About 60% SEs formation response was noticed	Revathy and Arumugam (2011)
Fruits/seeds collected from a mature tree	500 ppm GA_3	500 ppm GA_3 treatment for both scarified and non-scarified seeds considerably improved the germination	Janarthanam et al. (2012)
Seeds	For germination of seeds: MS + BAP (4.44μM) + NAA (2.69μM). For direct SEs development: MS + 2,4-D (13.5 μ M). For shoot elongation: MS + BAP (2.22μM) + GA_3 (1.44μM). For root induction: ½ MS + IBA (2.46μM)	80% seed germination was noticed within 35 days. Direct somatic embryogenesis was noticed from inter-nodal explants of in vitro germinated seeds. 70% rooting was observed with an average 5.3 roots/shoot	Revathy and Arumugam (2011)
Leaves from 3 to 4-weeks-old seedlings, leaf discs	For callus induction: MS + 2,4-D (1 mg/L) + TDZ (0.5 mg/L). For indirect	54.23% indirect somatic embryogenesis, 11.44% direct somatic	Bele et al. (2012)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	organogenesis: MS + 2,4-D (2 mg/L) + TDZ (0.5 mg/L). For direct organogenesis: TDZ (2 mg/L) + NAA (0.5 mg/L). For plantlet regeneration via somatic embryogenesis: MS + TDZ (2 mg/L) + GA_3 (1.0 mg/L). For plantlet regeneration via indirect organogenesis: MS + TDZ (1 mg/L) + GA_3 (0.5 mg/L) + NAA (0.5 mg/L). For plantlet regeneration via direct organogenesis: MS + 2,4-D (2 mg/L) + NAA (0.5 mg/L)	embryogenesis, 20.38% indirect organogenesis, and 9.48% direct organogenesis was noticed. 163.63% plants regenerated via somatic embryogenesis, 141.25% plants regenerated via indirect organogenesis, and 36.69% plants regenerated via direct organogenesis	
Young hypocotyl segments obtained from aseptically germinated seeds	For seed germination: B_5 + sucrose (3%). For callus induction: B5 or MS + 2,4-D (0.5μM) + KIN (10μM)	95% of healthy seedlings were obtained after 5 weeks. Different calli types, namely white and friable, hard and green, yellow were obtained. Predominantly, green and compact callus was noticed	Crovadore et al. (2012)
Leaf tissue	For callus induction: WPM + TDZ (0.4 mg/L). For shoot induction: WPM + BAP (2.5 mg/L) + NAA (0.4 mg/L). For root induction: WPM + IBA (1.5 mg/L)	100% callus formed, 24.6 shoot buds were differentiated from callus, 24.6 shoot buds per callus; 91.7% of shoots rooted	Singh et al. (2013)
Mature and immature seeds, leaf discs and nodal segments	For callus induction: MS + 2,4-D (2.5 mg/L) + KIN (3 mg/L). For SEs induction: MS + BAP (0.5 mg/L) + IAA (1 mg/L) + KIN (0.5 mg/L). For SEs germination: MS + GA_3 (2 mg/L). For plantlet regeneration:	Nodal segments found to be the best explants for embryonic callus production. Callus was induced within 8 weeks. 10 SEs were formed from 1.0 cm^2 of callus mass within 2 week. SEs germinated best on	Peeris and Senarath (2015)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	MS + BAP (0.4 mg/L) + IAA (0.2 mg/L)	GA_3 supplemented media within 2 weeks	
Nodal segments	For callus induction: WPM + 2,4-D (1.5 mg/L) + TDZ (0.6 mg/1). For shoot induction: WPM + BAP (2.5 mg/L) + NAA (0.4 mg/L). For shoot multiplication: WPM + KIN (3.0 mg/L). For root induction: WPM + IBA (1.5 mg/L)	Optimal callus was developed. The highest number of shoot buds (16) per callus was initiated from the surface of callus. 82.37% rooting was achieved. The in vitro raised plantlets grew well in greenhouse without showing any growth abnormalities	Singh et al. (2016)
Leaf discs	For callus formation: MS + BAP (2.5 mg/L) + 2,4-D (1.5 mg/L)	Callus formed from leaf disc explants	Barpanda et al. (2017)
Mature cotyledons, hypocotyls and mature embryos	For callus induction: MS + 2,4-D (mg/L). For direct SEs induction: MS + 2,4-D (0.5 mg/L) + BAP (0.5 mg/L) or MS + 2,4-D (2 mg/L) + BAP (0.5 mg/L). For indirect SEs induction: MS + 2,4-D (1 mg/L) + BAP (0.5 mg/L) or MS + 2,4-D (2 mg/L) + BAP (1 mg/L). For direct organogenesis: MS + NAA (2 mg/L) + TDZ (0.5 mg/L). For indirect organogenesis: MS + NAA (1 mg/L) + TDZ (0.5 mg/L). For plantlets regeneration via indirect organogenic mode: MS + TDZ (1 mg/L) + GA_3 (1 mg/L) + NAA (0.5 mg/L). For plantlets regeneration via direct organogenic mode: MS + TDZ (1 mg/L) + GA_3 (1 mg/L)	Acceptable callus was induced. 144.92 SEs were produced directly. Both direct and indirect way of somatic embryogenesis was noticed. Plantlets regenerated via both direct and indirect organogenic mode	Tripathi et al. (2017)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
Nodal and intermodal segments	For shoot initiation: MS + KIN (5.0 mg/L) + BAP (2.0 mg/L). For multiple shoot formation: MS + BAP (3 mg/L). For rooting: MS + IBA (3 mg/L)	Multiple shoots were best induced from inter-modal segments on MS media. The highest morphogenic response (59.82%) was observed by nodal segments. 50.75% cultures induced multiple shoots with an average number of 3.05 shoots and 5.08 cm in length. Optimal root induction was observed with higher average number of roots per shoot	Krishnakumar and Parthiban (2018)
Nodal segments	For callus induction: MS + 2, 4-D (1–7 mg/L) or MS + NAA (4 mg/L). For direct SEs induction: MS + TDZ (1.0 mg/L) + NAA (0.5 mg/L). For indirect SEs induction: MS + BAP (1 or 2 mg/L) + NAA (0.5 mg/L)	Callus formed in higher frequencies at higher concentrations of 2,4-D. Higher frequency of somatic embryogenesis, maximum SEs and plantlet regeneration via direct/direct organogenesis were demonstrated	Bele et al. (2019)
Aseptic seedling derived hypocotyl and hypocotyl + root junction	For shoot buds induction: MS + BAP (2.5μM). For SEs induction: MS + BAP (7.5μM). For SEs growth: MS + BAP (7.5μM) + NAA (0.5 or 1.0μM) or silver nitrate (5.0 or 10.0μM).	Directly differentiated shoot buds and SEs. 30.27 SEs per explant were produced directly, and showed better growth. Rhizogenesis was attained	Akhtar and Shahzad (2019)

(continued)

Table 12.1 (continued)

Explant/s	Culture media + plant growth regulators (PGRs)	Response/s	References
	For root induction: ½ WPM + IBA (5μM) + silver nitrate (15μM)		

2,4-D: 2,4-dichlorophenoxyacetic acid; ABA: abscisic acid; B5: Gamborg's medium (Gamborg et al. 1968); BAP: 6-benzylamino purine; BM: Basal medium (in mg/L): NH_4NO_3 (1650), KNO_3 (1900), $MgSO_4.7H_2O$ (370), KH_2PO_4 (170), $MnSO_4.4H_2O$ (25), $CaC1_2.2H_2O$ (440), $ZnSO_4.7H_2O$ (13.9), H_3BO_3 (10), Na_2EDTA (18.6), nicotinic acid (5), myoinositol (100), glycine (2), folic acid (5), thiamine-HCl (0.5), pyridoxine-HCl (0.5), biotin (0.05), sucrose (20 g/L), agar (6 g/L) as per Rangaswamy (1961)); CH: Casein hydrolysate; CM: Coconut milk; GA_3: Gibberellic acid; IAA: Indole-3-acetic acid; IBA: Indole-3-butyric acid; KIN: kinetin; mBM: modified BM; MS: Murashige and Skoog (1962) medium; mWBM: Modified White's basal medium (White 1963); NAA: α-naphthaleneacetic acid; *p*CPA: *p*-chlorophenoxyacetic acid; PGRs: Plant growth regulators; SEs: Somatic embryos; TDZ: Thidiazuron (N-phenyl-N0–1, 2,3-thiadiazol-5-ylurea); V47 medium: 3 mM 2-(N-morpholino)ethanesulfonic acid + 2,4-D (0.5 mg/L) + BAP (0.5 mg/L); WBM: White's medium (White 1963); WPM: Woody plant medium (Lloyd and McCown 1980); ZE: Zygotic embryo

used (Muralidharan 1997; Rugkhla and Jones 1998; Radhakrishnan et al. 2001; Rai and McComb 2002; Mo et al. 2010; Janarthanam et al. 2012; Baiculacula 2012; Crovadore et al. 2012; Singh et al. 2013; Peeris and Senarath 2015). In general, the duration of sterilization treatment ranged between 5 and 8 min for $HgCl_2$ and up to 15 min for detergents.

12.2.1.3 Culture Medium

For tissue culture studies in Sandalwood, largely MS (Murashige and Skoog 1962) basal salt medium (either full or half strength), with or without PGRs, and/additives was used for in vitro initiate cultures, multiple shoots induction, somatic embryogenesis, and rooting. In few investigations, Woody Plant Medium (WPM; Lloyd and McCown 1980) supplemented with PGRs was employed for callogenesis, indirect organogenesis, somatic embryogenesis, and rooting (Das et al. 2001; Ilah et al. 2002; Singh et al. 2013; Singh et al. 2016; Akhtar and Shahzad 2019). For in vitro seed germination, B5 Gamborg's medium (Gamborg et al. 1968) was used by Crovadore et al. (2012). Also, White's Basal Medium (WBM) (White 1963) or modified WM was used in few studies for seed germination, shoot induction, callus induction, and somatic embryogenesis (Rangaswamy and Rao 1963; Rao 1965; Rao and Rangaswamy 1971; Rao and Ozias-Akins 1985; Bapat and Rao 1992b) (Table 12.1). In general, most studies used agar (0.8%) as the gelling agent to solidify the culture medium. About 1–3% sucrose concentration was used as the preferred carbon source. However, for somatic embryogenesis, liquid culture medium was used by Lakshmi Sita et al. (1980a, b). Some additives, such as coconut milk (20%), casein hydrolysate (400 mg/L), silver nitrate (5.0 or 10.0μM), and yeast extract (0.25%) to induce seed germination, callogenesis, and somatic embryogenesis (Rangaswamy and Rao 1963; Rao 1965; Rao and Rangaswamy 1971; Bapat and Rao 1979; Akhtar and Shahzad 2019). *p*-Chlorophenoxyacetic acid was used by Rao and Bapat (1978) and Ilah et al. (2002) to induce callus and somatic embryos (SEs). In most of the studies, cytokinins (TDZ: thidiazuron; BAP: 6-benzylamino purine; KIN: kinetin) either alone or in combinations with auxins (NAA: α-naphthaleneacetic acid; IAA: indole-3-acetic acid; IBA: indole-3-butyric acid) and other additives at different concentrations were used to induce various morphogenetic responses, including seed germination, callogenesis, somatic embryogenesis, shoot multiplication, and rooting (refer Table 12.1). For embryoids induction and multiplication, gibberellic acid (GA_3) and abscisic acid (ABA) were also used in many studies (Bapat and Rao 1979; Lakshmi Sita et al. 1979; Lakshmi Sita et al. 1980a, b; Rao and Raghava Ram 1983; Rao and Ozias-Akins 1985; Bapat and Rao 1988; Rai and McComb 2002; Rugkhla and Jones 1998; Das et al. 1999; Das et al. 2001; Sanjaya and Rai 2003; Mo et al. 2008; Nikam and Barmukh 2009; Janarthanam et al. 2012; Peeris and Senarath 2015; Tripathi et al. 2017).

12.2.1.4 In Vitro Regeneration of Sandalwood

In the case of Sandalwood, majority of the authors have used somatic embryogenesis as a pathway for micropropagation. Somatic embryogenesis is one of the tissue culture procedures, and used widely for in vitro regeneration of plant species in large scale. Also, it is suitable for producing synthetic seeds, protoplasts, and cryoconservation of plants species (Da Silva et al. 2016).

As early as 1963, the first study on Sandalwood tissue culture was reported by Rangaswamy and Rao (1963), where the authors have reported that about 30–40% seeds cultured on modified White's Medium (mWM) added with 20% coconut milk (CM) and 400 mg/L casein hydrolysate (CH) germinated within 45 days, but failed to convert into seedlings. In studies of Rao (1965) and Rao and Rangaswamy (1971), endosperms, cotyledons, and zygotic embryos (ZE) were used to obtain plantlets. Both endosperms and ZE failed to show any response, however, embryoids were obtained from cotyledon-derived calli, which later formed plantlets. Stem segments and hypocotyls (5 mm size) derived from in vitro derived seedlings were cultured on basal medium for callus culture and plant regeneration (Rao and Bapat 1978). From the study, it was observed that stem segments failed to show any response. Hypocotyls exhibited shoot multiplication on BM media supplemented with cytokinins, especially BA at 2 mg/L induced higher multiplication, that is, up to 20 buds/explant and in vitro rooting was evidenced only in few cultures. To generate a complete plantlet, it took about 4–8 weeks. In the same study, BM supplemented with 2,4-D + BA (1 mg/L each) induced callus formation. Further, their study continued to induce somatic embryos by subculturing callus for 4 weeks on BM medium added with 1 mg/L IAA (Bapat and Rao 1979). About 30% globular SEs were converted to plantlets, and later planted in soil for acclimatization after 56 days. Lakshmi Sita et al. (1979) cultured shoot tips and shoot segments on MS + 1 mg/L 2,4-D + 0.2–0.5 mg/L KIN for inducing callus. SEs were induced in MS liquid culture medium added with GA_3 within 4–5 weeks. Likewise, a series of studies also evidenced the formation of calli on MS medium supplemented with different plant growth hormones. When callus was subcultured, embryoids were formed within 4–6 weeks (Lakshmi Sita et al. 1980a, b). Likewise, callus was also induced on MS media fortified with either 1 mg/L 2,4-D or 1 mg/L 2,4-D and 0.2 mg/L KIN within 3 weeks. Further, subculturing of callus induced SEs formation after 4 weeks, and subsequently produced plantlets consisting two to three pairs of leaves and well-developed roots. Plantlets were acclimatized in pots consisting of vermiculate and soil (Rao and Raghava Ram 1983).

Bapat and Rao (1984) cultured hypocotyl segments derived from 4-week-old in vitro seedlings to initiate shoot buds on mBM supplemented with 1 mg/L NAA and BA, each. According to authors, about 90% of the explants differentiated to form shoot buds. Addition of 0.5 mg/L NAA and 5 mg/L IBA induced rooting. In another study, in vitro shoots were developed on MS media supplemented with 1 mg/L BA using nodal segments and internode segments derived from 30-year-old tree (Rao et al. 1984). However, nodal segment–derived shoot buds failed to root in vitro. Internode explant–derived callus induced SEs formation, which successfully converted to plantlets. About 10% of plantlets showed 10% survival rate in the field condition. Muralidharan (1997) reported the induction of multiple shoots, that is, four shoots per nodal explant on MS media supplemented with 0.5μM of BAP and KIN, each. While internodes cultured on MS media added with 2,4-D-induced callus from their cut ends. However, shoot tip explants failed to exhibit any differentiation.

A study by Bapat et al. (1985) used stems and hypocotyls from 4-week-old in vitro seedling to induce callus and SEs and reported that stem explants effectively induced callus on MS medium supplemented with either 1 mg/L 2.4-D alone or in combination with 0.5 mg/L KIN. For inducing SEs, half-strength MS added with 1 mg/L IAA was found effective. Further, calli-induced SEs from stem explants converted to plantlets. Another investigation showed the formation of SEs from shoot segments–derived callus on MS medium fortified with BA and 2,4-D in combinations (Rao and Ozias-Akins 1985). Mostly, the SEs were in the stages of club and heart shapes. In the same study, cell suspension culture was obtained by culturing callus in liquid MS media added with 1 mg/L BA. Additionally, cell suspension culture yielded secondary SEs. A successful conversion of SEs to plantlets was noticed by these researchers. In a study by Bapat and Rao (1988), an attempt was done to establish well-developed plantlets from synthetic seeds using SEs. They used both SEs and embryogenic cells and encapsulated in calcium alginate gel beads. However, the results showed only about 10% of synseeds germinating only after 16 weeks, and converted to produce well-developed plantlets. Some of the encapsulated embryos resulted to form secondary embryos instead of showing germination. Moreover, the encapsulated embryogenic cell suspension conserved for about 45 days at 4° C showed the formation of embryos, when re-cultured in suspensions. Later, Bapat and Rao (1989) investigated on the in vitro regenerative potentials of sandalwood organ, callus, cell suspension, and protoplast cultures. Nodal stem segments and hypocotyls derived from a mature tree (20-year-old) directly differentiated to yield multiple buds. Callus formation and SEs induction was well noticed from internodes. Further, cell suspensions were obtained through embryogenic callus, which later differentiated into SEs. A successful isolation of protoplasts was noticed from different explant sources. Protoplasts isolated from stem callus and cell suspension cultures underwent multiple divisions to form colonies, which further regenerated into SEs. These derived SEs via different morphogenetic pathways successfully produced plantlets that were effectively established in the field. Synthetic seeds were also produced by encapsulating SEs in the calcium alginate matrix, and the results were in concordance with the earlier report of Bapat and Rao (1988). Overall, their study concluded the possibility of utilizing in vitro approaches to multiply and preserve Sandalwood germplasms. Bapat and Rao (1992b) carried out a research to establish Sandalwood plantlets regeneration from nonencapsulated and encapsulated desiccated SEs. For encapsulation, sodium alginate matrix was used. Both nonencapsulated and encapsulated desiccated SEs were shown with growth revival capabilities when rehydrated on White's medium, and established into plantlets. The sustainable plantlets regeneration and desiccation tolerance was reported to depend on the pretreatments given to SEs. The reduced sucrose concentration (29.2 mM) in the medium was found to be effective in regenerating the complete plantlet. Likewise, 18.92μM abscisic acid (ABA) concentration was found effective in influencing the induction of enhanced desiccation tolerance. Also, SEs desiccated up to 30-day period continued to remain viable, and found to retain the regeneration capability to develop into plants. In another study, it has been revealed that the application of cyanobacterium, *Plectonema boryanum* extract can stimulate somatic embryogenesis and development of SEs to certain level, however less effective as compared to the regularly used plant growth regulators.

Researchers have investigated on various morphological and biochemical events that are linked to synchronous somatic embryogenesis process in Sandalwood (Sankara Rao et al. 1996). Somatic embryogenesis includes three distinctive phases, that is, pre-globular masse (phase 1), globular embryo (phase 2), and bipolar embryo (phase 3). Two polypeptides, each having the molecular weight of 15 and 30 kDa, specifically appear during the transition from phase 0 to 1. In primary callus extract, a polypeptide with 24 kDa was detected, however was not seen in phases 1, 2, and 3. Interestingly, during the transition from phase 2 to 3, there was a gradual reduction in the levels of a glycoprotein with 50 kDa. In addition, the activities of enzymes, such as glycosidase, protein kinase, and xylanase, increased remarkably with continuing embryogenesis process.

In another study by Rai and McComb (2002), zygotic embryos of mature Sandalwood tree were employed to regenerate plants via direct somatic embryogenesis. Culturing of zygotic embryos on MS media supplemented with either 4.5μM TDZ or BAP (2 mg/L) directly induced SEs formation without callus intervention after 8 weeks. They claimed these results as the first report of direct somatic embryogenesis in Sandalwood. Later, SEs were separated and implanted on MS media devoid of cytokinins to produce secondary embryos. Further, isolated SEs with distinct cotyledons were converted into plantlets by re-culturing them on half-strength MS media added with 1.4μM GA_3. Plantlets were initially acclimatized, before transferring them to greenhouse for full growth.

Rugkhla and Jones (1998) developed a reproducible method of somatic embryogenesis and plantlets establishment for Sandalwood. Explants such as nodal segments and seeds cultured on MS media added with TDZ (1 or 2μM) induced high frequency (100%) of SEs directly, while MS media supplemented with 2,4-D and TDZ induced 100% SEs indirectly. The cultured explants produced white globular SEs or friable embryogenic tissue within 56 days. After 2–3 weeks, mature SEs, measuring about 1–2 mm with well-established cotyledons were germinated by subculturing on GA3 (6μM) supplemented MS medium. After germination, transferring SEs to MS medium containing lower levels of GA3 (3μM) further encouraged the elongation of SEs up to 20 mm long.

Das et al. (1999) used for the first time to mass propagate Sandalwood via in vitro cultivation in liquid medium using airlift bioreactor. Using the same bioreactor, embryogenesis, development, and germination were carried out by replacing the drained medium with fresh medium without subculturing. Overall, this process increased the efficiency of propagation by reducing the time, when compared to the normal propagation in solid agar medium, and showed limited abnormalities. Within 6 weeks' time, almost 3000 somatic seedlings were produced with less abnormality (59.3%) per liter of medium. While, on the solidified medium, only 800 seedlings were obtained in 12 weeks' time, however with high rate of abnormality (88.9%). Most of the somatic seedlings (about 70%) matured to healthy plantlets and endured all hardening procedures, which was somewhat difficult to achieve for somatic seedlings raised on agar medium.

In a study, three major factors, that is, inorganic nitrogen, sucrose, and ABA levels were optimized statistically to improve the efficiency of embryogenesis process to produce more SEs (Das et al. 2001). The optimization improved the embryogenesis efficiency up to 57.35%, and produced higher number of SEs and nitrate (11.6 mM), sucrose (37.56 g/L), ammonium (7.89 mM), and ABA (1.31 mg/L) constituents were found to be optimal when used in Woody Plant Medium (WPM).

The investigation by Radhakrishnan et al. (2001) provides information on the callus formation and organogenesis in Sandalwood. They used nodal segments of length 1.5–2 cm obtained from 20-year-old, recognized candidate plus trees. After 3 weeks' time, about 27.7% callogenesis was noticed on MS media fortified with 4 mg/L 2,4-D. On the same media, and after repeated subculturing, nearly 18% of nodulated clump–like structure callus differentiated to produce 2.59 shoots that measured about 3.85 cm in length. The highest percentage of rooting (5.6%) was achieved only with the addition of 2 mg/L IBA to MS medium.

Irregularities in SEs differentiation in Sandalwood was detailed by Ilah et al. (2002). On the MS medium supplemented with 2.26μM 2,4-D or 2.68μM p-chlorophenoxyacetic acid (pCPA) induced callus, which exhibited a strong inclination toward developing SEs after transferring on to embryogenic media, that is, MS nutrients added with 2.7μM NAA and 2.22μM BAP. The SEs maturation and growth were practically blocked if produced SEs were not separated and transferred on to the solidified media. Compared to the solid media, liquid media was found to be more responsive at the initial stage of embryogenesis. A higher rate of SEs abnormality (up to 68%) was noticed by the appearance of quite a few irregularities, which included less developed root, secondary callusing from embryo, fused somatic embryos at the base, etc. Though, WPM was effective in maturation and SEs development, root degeneration was noticed. Hence, excised in vitro shoots transferred on MS media consisting of 5.71μM IAA induced nearly 83.3% rooting.

A simple and efficient in vitro micrografting procedure was explained by Sanjaya and Rai (2003) in Sandalwood. They used 45-days-old seedlings for micrografting as the rootstock, the highest shoot apex grafting frequency was observed in rootstock and shoots derived from in vitro culture. A high success rate of grafting (60%) was noticed when 1–2 cm long scions were used. Similarly, influence of factors on in vitro micrografting of Sandalwood was reported (Sanjaya et al. 2006a). In vitro micrografting was accomplished by inserting 1–2 cm long scions collected from nodal shoot segments obtained from a candidate plus tree of 50–60 years of age onto the hypocotyl of 45-days-old in vitro rootstocks. The grafting success rate was lower when scions collected directly from field-grown trees were used, while in vitro developed shoots as scions offered enhanced grafting success rate (60%). Further, different sizes of scions and rootstock age significantly influenced in vitro grafting process. Under favorable environments, both scion and hypocotyl united to develop into a complete plant, which formed 2–4 leaves after 56 days.

For the first time, an effective induction of adventitious shoot buds on leaf explants (0.5–1.5 cm) of Sandalwood was reported by Mujib (2005). They observed the induction of de novo shoots directly on leaf tissue without the intervention of callusing stage of on MS media added with 2.22μM BAP with 13.95% shoot bud formation frequency. Shoot bud initiation was observed on both WPM and MS media devoid of PGRs, though liquid media exhibiting more response. Interestingly, positioning of leaf explants on culture media showed a substantial effect on the development of shoot buds. Mainly, leaf sections positioned vertically failed to display any response, whereas leaf lamina kept horizontally showed a high frequency of shoot bud formation.

Sanjaya et al. (2006b) reported multiple shoots induction from nodal shoot segments collected from a 50–60-years-old candidate plus tree cultured on MS media fortified with 0.53μM NAA and 11.09μM BAP. Further, in vitro differentiated shoots showed the highest shoot multiplication rate on MS media supplemented with 4.44μM BAP, 0.53μM NAA, and additives, including ascorbic acid (283.93μM), citric acid (118.10μM), cysteine (104.04μM), glutamine (342.24μM), and coconut milk (10%). In vitro rooting was accomplished from microshoots pulsed with IBA (1230μM) for 30 min in soilrite media. After hardening, the plantlets were transferred to the field, and found that all seedlings (from seeds) and tissue culture–raised plants presented 100% survival rate with a steady growth. After 1 year, the stem girth and height of seed-derived seedlings and tissue culture–upraised plants were found to be almost same. Likewise, Ma et al. (2005) reported a rapid in vitro propagation of Sandalwood. They observed the adventitious shoot propagation from young shoots collected from an elite tree when cultured on MS media added with 5μM of BAP and 0.5μM of NAA. They observed about 5.7 shoots/explant within 1 month of culture. Further, subculturing on the same media for 1 to 3 months resulted to form adventitious roots. However, in vitro rooting of microshoots was better achieved on MS media supplemented with 250μM IBA.

Mo et al. (2010) cultured zygotic embryos of Sandalwood for its rapid in vitro propagation on MS media fortified with various plant growth regulators (PGRs). The results revealed that the use of GA_3 reduced the dormancy period and improved the germination of embryos. The matured zygotic embryos germinated on MS media containing 14μM/L GA_3 after 1 week, and about 82.5% seedling rate was attained after 45 days of culturing.

A rapid and reliable scheme was described by Nikam and Barmukh (2009) to ensure quick and uniform seed germination of Sandalwood. After removing endocarp under aseptic conditions, the seeds were pretreated with GA_3 (2, 4, 6, and 8 mM) for half day. Later, pretreated seeds were cultured on MS media contained with or without 2 or 4μM BAP. Overall, pretreatment with 4 mM GA_3 significantly shortened the mean germination period and enhanced germination rate (80.67%) in 30 days. In the case of nontreated seeds, only 46% germination rate was noticed. They proposed that this technique could be used successfully for nurturing enormous numbers of saplings in short time.

Janarthanam et al. (2012) conducted experiments to ascertain the class of dormancy in Sandalwood and 500 ppm GA_3 treatment for both scarified and non-scarified seeds considerably improved the germination. The germination was affected by both scarification and light regime. Only about 3.3% of scarified seeds germinated in light/dark, while no response was observed in the darkness. GA_3 significantly augmented the germination rate of both scarified and non-scarified seeds irrespective of the dry storage period.

A reproducible method of Sandalwood somatic embryogenesis and plantlet regeneration was proposed by Revathy and Arumugam (2011). MS media fortified with 4.44μM BAP and 2.69μM NAA exhibited 80% response of seed germination, and produced cotyledons having an average length of 3.9 cm plants within 35 days. They noticed a large number of direct SEs development from internodal explants of in vitro germinated seeds on MS media comprising 13.50μM 2,4-D. About 60% SEs formation response was noticed. In vitro rooting was achieved by supplementing 2.46μM IBA to MS media. A high rooting percentage (70%) with an average 5.3 roots/shoot were witnessed. Well-rooted plantlets were moved to paper cups encompassing sand, sterile soil, and vermiculite. In another study, in vitro morphogenetic response was observed by culturing leaf discs of Sandalwood on MS media fortified with different concentrations of PGRs (Bele et al. 2012). The results showed that organogenesis and somatic embryogenesis leading to regeneration of plantlets were subjective to the types and concentrations of PGRs used. Among different media evaluated, MS medium with 1 mg/L 2,4-D and 0.5 mg/L TDZ encouraged 54.23% indirect somatic embryogenesis, 11.44% direct somatic embryogenesis, and 160 mean numbers of SEs/explant. On the other hand, MS media comprising 2 mg/L 2,4-D and 0.5 mg/L TDZ endorsed 20.38% indirect organogenesis. MS media containing 2 mg/L TDZ and 0.5 mg/L NAA evidenced to be the best culture medium to attain 9.48% direct organogenesis, and 36.69% plantlets regeneration through direct organogenesis. MS media added with 1 mg/L GA_3 and 2 mg/L TDZ found superior for regenerating plantlets through somatic embryogenesis. The in vitro regenerated plantlets were successfully acclimatized and well established in the field.

Crovadore et al. (2012) induced callus using young hypocotyls (5 weeks old) acquired from in vitro germinated seeds of Sandalwood under diverse conditions. Different calli types, namely white and friable, hard and green, yellow were obtained. Largely green and compact callus was noticed on MS media containing 0.5μM 2,4-D and 10μM KIN, and was subcultured regularly on the same media. Later, Singh et al. (2013) proposed a reliable protocol to in vitro regenerate plantlets through indirect organogenesis from calli cultures using leaf explants of mature Sandalwood trees. Callus induction (100%) was observed on leaf tissues inoculated on WPM consisting of 0.4 mg/L TDZ. WPM media added with 0.8 mg/L TDZ showed the highest fresh weight (141.92 mg) and dry weight (47 mg) of calli. Addition of 2.5 mg/L BAP and 0.4 mg/L NAA to WPM media effectively produced 24.6 shoot buds per callus. Further, WPM medium fortified with 5.0 mg/L BAP and 3.0 mg/L KIN was used for shoot multiplication. In vitro rooting was achieved by culturing shoots on WPM medium with 1.5 mg/L IBA. All tissue culture–raised plantlets persisted acclimatization stage, and all plants were observed to be healthy in the greenhouse. Likewise, a simple and effective procedure to regenerate plant from nodal explants of Sandalwood was developed (Singh et al. 2016). Callus was induced from nodes on WPM supplemented with 1.5 mg/L 2,4-D and 0.6 mg/L TDZ. On shoot induction medium, that is, WPM added with 2.5 mg/L BAP and 0.4 mg/L NAA, the highest number of shoot buds (16) per callus was initiated from the surface of callus. Shoots were further proliferated on the medium consisting of 3.0 mg/L KIN. The highest rooting (82.37%) was attained on WPM medium consisting of 1.5 mg/L IBA. The in vitro propagated plantlets were successfully acclimatized, and developed fully in the greenhouse without any growth abnormalities. Similarly, Peeris and Senarath (2015) also developed Sandalwood plantlets regeneration via somatic embryogenesis. They used mature and immature seeds, nodal segments, and leaf discs as explants to induce embryonic callus. Mainly, nodal segments were found to be superior in inducing embryonic callus. Nodes on MS media added with 2.5 mg/L 2,4-D and 3.0 mg/L KIN prompted calli formation with a mean diameter of 3.2 cm after 8 weeks. The addition of 0.5 mg/L KIN, 0.5 mg/L BAP and 1 mg/L IAA to MS media encouraged differentiation of callus to produce SEs, and about 10 SEs were resulted from 1.0 cm^2 of callus mass within 2 weeks. SEs germinated better on MS media containing 2.0 mg/L GA_3. The transfer of germinated SEs onto MS media supplemented with 0.4 mg/L BAP and 0.2 mg/L IAA witnessed the highest percentage (76%) of plantlets regeneration with well-developed shoots and roots. Similarly, Sandalwood regeneration via somatic embryogenesis was described by Herawan et al. (2016) by utilizing leaves as explant source. MS media for embryo induction is MS containing 3 mg/L 2,4-D and 15 mg/L KIN induced embryogenic callus (69%) from leaf explant within 21 weeks. Average embryo induction rate of the nine clones evaluated was found to be 30%. The maturation of embryos was better evidenced on MA media added with 2 mg/L BAP.

An examination has been carried out to induce callus in Sandalwood using leaf disc explants (Barpanda et al. 2017). Their study results exposed that leaf discs cultured on MS media supplemented with different combinations of BAP (1.5, 2.0, and 2.5 mg/L), NAA (0.5 mg/L), and IAA (0.5 mg/L) induced callus with good callus spread. However, subculture of the calli mass the same media failed to promote further callus development, and the calli mass converted to brownish in color with a necrotic appearance.

A high frequency micropropagation was reported by Tripathi et al. (2017). In vitro morphogenetic response, that is, somatic embryogenesis and/or organogenesis, resulting in plantlets regeneration was significantly influenced by the use of different PGRs. MS media fortified with 2 mg/L 2,4-D demonstrated satisfactory callus formation. MS media with 0.5 mg/L 2,4-D and 0.5 mg/L BAP or MS media with 1 mg/L 2,4-D and 0.5 mg/L BAP induced direct somatic embryogenesis with an average 144.92 SEs per explant. While MS media supplemented with 1 mg/L 2,4-D and 0.5 mg/L BAP or MS media with 2 mg/L 2,4-D and 0.5 mg/L BAP improved the indirect somatic embryogenesis frequency. MS nutrient media fortified with 2 mg/L NAA and 0.5 mg/L TDZ promoted direct organogenesis and plantlets regeneration, whereas MS media containing 1 mg/L NAA and 0.5 mg/L TDZ supported indirect organogenesis. A high frequency of plantlets regenerated on MS media containing 2 mg/L TDZ and 1 mg/L GA_3 from SEs, while indirect organogenic mode of plantlets regeneration was accomplished in higher ratio on MS media fortified with 1 mg/L TDZ, 1 mg/L GA_3, and 0.5 mg/L NAA for the explant cultures. After hardening, the plantlets were successfully transferred to the field (Fig. 12.1).

A standardized micropropagation technique was proposed by Krishnakumar and Parthiban (2018). The highest morphogenic response (59.82%) was observed by nodal segments as compared to shoot tip explants (52.50%) when cultured on MS media supplemented with 5 mg/L KIN and 2 mg/L BAP. Among two different media (MS and White's), MS medium showed better morphogenic response the explants. About 50.75% shoot cultures induced 3.05 multiple shoots with an average 5.08 cm in length. Optimal root induction was observed with higher average numbers of roots per shoot (2.43) and root length (4.72 cm).

In vitro plantlets regeneration via somatic embryogenesis/organogenesis by culturing nodal segments of Sandalwood on MS medium added with different PGRs at varied concentrations was reported more recently (Bele et al. 2019). Higher frequency of direct somatic embryogenesis, maximum SEs, and plantlet regeneration via direct organogenesis were demonstrated on MS media containing TDZ at moderate levels (1 mg/L) in addition to low concentration of NAA (0.5 mg/L). At higher levels of BAP (1–2 mg/L) and low concentration of NAA (0.5 mg/L) encouraged indirect somatic embryogenesis. The regeneration media containing MS salts, 2 mg/L TDZ, and 1 mg/L GA_3 produced maximum number of plantlets regeneration via direct/indirect somatic embryogenesis. Lately, a study reports the comparative ontogeny of directly differentiating SEs and shoot buds (Akhtar and Shahzad 2019). MS media amended with 2.5μM BAP formed maximum number of direct shoot buds (32.21 ± 1.02) with 100% regenerative response. Higher frequency of SEs differentiation was induced on MS media constituting 7.5μM BAP and yielded 30.27 ± 0.05 direct SEs per explant. After transferring these differentiated structures on MS media containing BAP (7.5μM) in combination

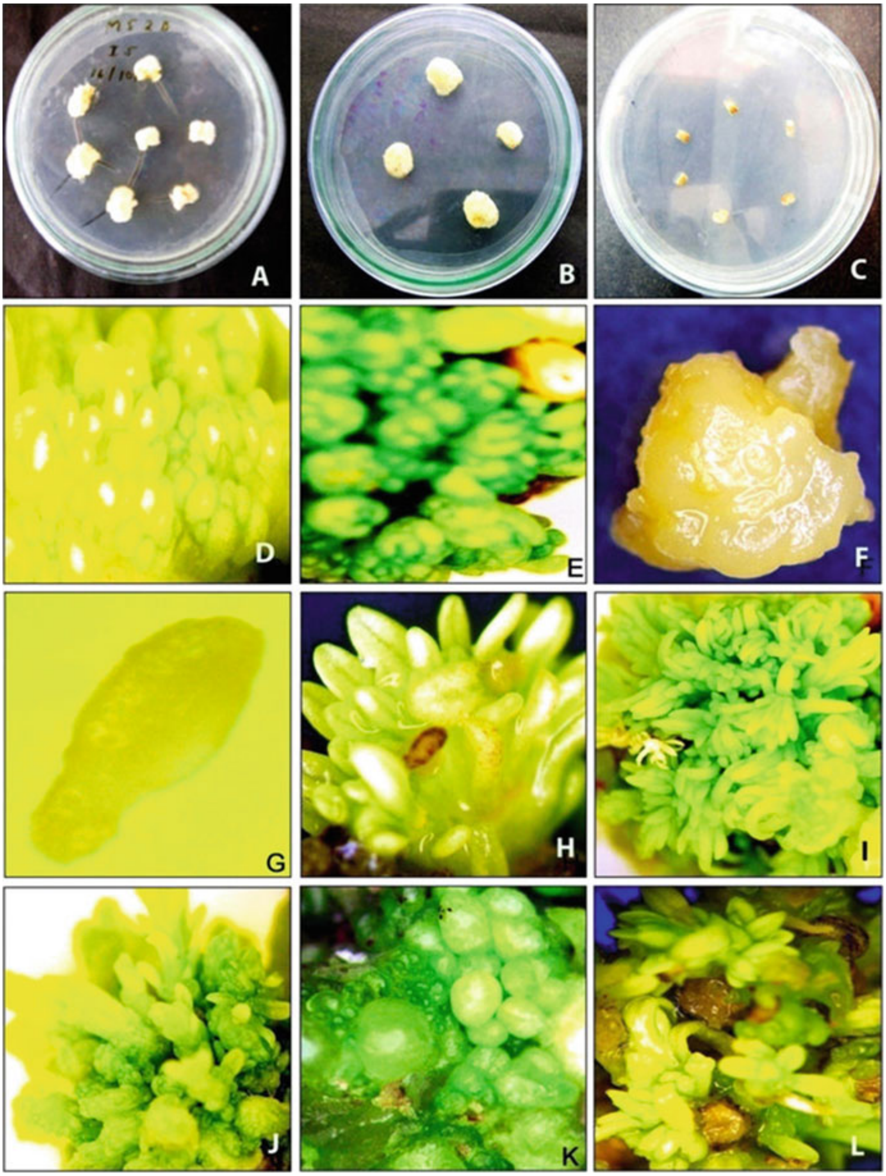

Fig. 12.1 Plant regeneration in sandalwood via somatic embryogenesis: (**a**) Cultured mature cotyledons after 10–14 days in culture; (**b**) Cultured hypocotyls after 10–14 days in culture; (**c**) Cultured mature embryos after 3–5 days in culture; (**d**) Somatic embryo of globular stage; (**e**) Formation of secondary embryos; (**f**) Somatic embryo of heart stage; (**g**) Somatic embryo of torpedo stage; (**h**) Somatic embryo of cotyledonary stage; (**i**) Germination of somatic embryo; (**j**) Plant regeneration from somatic embryo; (**k**) Formation of globular stage somatic embryo via indirect mode; and (**l**) Germination of somatic embryos via indirect mode (Adapted from Tripathi et al. 2017)

with NAA (0.5 or 1.0μM) or silver nitrate (5.0 or 10.0μM) encouraged better growth. The SEs reached mean shoot length of 3.68 ± 0.13 cm when cultured on MS media containing 2.5μM BAP and 1μM NAA. Likewise, MS media with 7.5μM BAP and 10μM silver nitrate produced shoots of 4.36 ± 0.14 cm in length. Rhizogenesis was attained better on half-strength WPM media constituting IBA (5μM) and silver nitrate (15μM).

12.3 Limitations

Though several numbers of plant tissue culture protocols have been proposed for Sandalwood by many researchers, its complete applications are yet to be overcome, due to few hindrances, for instance SEs irregularities, low rhizogenic responses in excised or in vitro developed shoots, low survivability of in vitro regenerated plantlets after transplanting in the field, etc. One of the main difficulties of Sandalwood tissue culture is the induction of callus and lower regularity of callus establishment. Also, different investigators have proposed protocols of callus development that are faces the difficulty of repeatability.

Some researchers have used MS media supplemented with only 2,4-D for inducing callus from stem segments or hypocotyls (Rao and Bapat 1978; Bapat and Rao 1979; Bapat et al. 1985; Bapat and Rao 1989; Rugkhla and Jones 1998; Das et al. 2001; Ilah et al. 2002; Crovadore et al. 2012; Peeris and Senarath 2015; Zhang et al. 2016; Tripathi et al. 2017). However, some researchers have mentioned that these media were inefficient in inducing callus from hypocotyls, and observed with low callus proficiency (~10–20%) (Rugkhla and Jones 1998; Crovadore et al. 2012). Some studies have stated that NAA- or IAA-supplemented nutrient media can be effective in callus induction (Lakshmi Sita et al. 1980a, b; Bele et al. 2019), and subsequent subculturing has resulted to cause drying up of callus and necrotic appearance (Lakshmi Sita et al. 1980a, b). Other studies have stated the use of callus induction medium, which is fortified with different concentrations of cytokinins and auxins in varied combinations for inducing callus (Lakshmi Sita et al. 1979, 1980a, b; Rao and Raghava Ram 1983; Sankara Rao et al. 1996; Das et al. 1999; Radhakrishnan et al. 2001; Crovadore et al. 2012; Bele et al. 2012; Peeris and Senarath 2015; Barpanda et al. 2017; Bele et al. 2019). Nevertheless, each experiment used different combinations of PGRs, and hence the success and reliability of callus induction remains uncertain. In the case of other researchers, the use of TDZ was reported to be the best PGRs to induce higher frequency of callus formation from nodal segments or young leaves. TDZ-supplemented medium was reported to induce a typical bright yellow–colored compacted, nodular calli (Rugkhla and Jones 1998; Singh et al. 2013, 2016). Hence, more reliable and reproducible callus-inducing protocols are yet to be developed, especially considering the fact of friable callus induction, which is appropriate for establishing cell suspension cultures.

In Sandalwood, two paths of somatic embryogenesis, that is, direct and indirect somatic embryogenesis were noticed, and frequently the process was reported to be asynchronous (Bapat and Rao 1984; Rao and Ozias-Akins 1985; Rugkhla and Jones

1998; Das et al. 2001; Rai and McComb 2002; Ilah et al. 2002; Bele et al. 2012; Tripathi et al. 2017; Bele et al. 2019; Akhtar and Shahzad 2019). Rai and McComb (2002) reported the direct somatic embryogenesis to produce secondary SEs, having higher potential for quick proliferation. In a study, secondary SEs were induced and isolated from synseeds cultured in BAP- and IAA-supplemented media, and later they were converted into plantlets (Bapat and Rao 1988). Studies have suggested the use of PGRs help in better induction of somatic embryogenesis (Bele et al. 2012; Tripathi et al. 2017; Bele et al. 2019; Akhtar and Shahzad 2019). The well-separated SEs moved to liquid culture media consisting of ABA increased the SEs multiplication, and when transferred back to solidified media additionally converted them into secondary SEs (Bapat and Rao 1979; Ilah et al. 2002). However, high rate of abnormality (up to 68%) was noticed by the appearance of quite a few irregularities in SEs (Ilah et al. 2002). The result of each researcher differs, particularly the production of SEs at different times. Somatic embryogenesis in many studies has been observed with SEs production with abnormalities, such as SEs showing no morphogenetic response, SEs with underdeveloped shoot axis, SEs without roots, SEs with an irregular cotyledons, etc. (Rao 1965; Ilah et al. 2002). Callus differentiated into globular, heart-shaped, cotyledonary SEs, immature torpedo-shaped SEs, and abnormal SEs on media added with different PGRs (Bapat and Rao 1979; Sankara Rao et al. 1996; Rugkhla and Jones 1998). SEs formed into plantlets after culturing on half-strength MS media added with low concentrations of GA_3 (Rai and McComb (2002). Some of the factors, such as inorganic nitrogen, sucrose, pCPA, polyethylene glycol, GA_3, and ABA levels were optimized to enhance the effectiveness of embryogenesis to obtain many SEs (Das et al. 2001; Ilah et al. 2002; Bele et al. 2012; Peeris and Senarath 2015). Further, the differences in the SEs differentiation, and time duration for SEs formation, variations in the developed SEs could be because of the use of different culture media and PGRs at varied levels by different researchers. Hence, these require more investigations in this regard to standardize a reliant protocol for somatic embryogenesis of Sandalwood.

Shoot organogenesis of Sandalwood is greatly affected by the problem of difficulty in rooting (Rao and Bapat 1978; Rao et al. 1984; Ma et al. 2005). In most cases, MS full-strength and half-strength media, B5 media, and WPM were used along with different types and concentrations of PGRs and additives were used for rhizogenesis. IBA is observed to be the best PGR for in vitro root induction (Radhakrishnan et al. 2001; Sanjaya et al. 2006b; Ma et al. 2005; Singh et al. 2013, 2016; Krishnakumar and Parthiban 2018; Akhtar and Shahzad 2019). However, rhizogenesis was achieved with a little success rate, and thus more studies are required in this direction.

In the final stage, micropropagated plantlets are hardened and transplanted in the field. The performance studies of field established in vitro regenerated Sandalwood plants is highly limited, due to the fact that rooting of plantlets is difficult, leading to raw materials scarcity. Rao et al. (1984) reported only about 10% survival rate of in vitro raised plantlets in the field condition. In another report, the tissue culture–raised plantlets when transferred to the field showed a normal and steady growth with 100% survival rate. The stem girth and height of seed-derived seedlings and tissue culture–upraised plants were found to be almost same after 1 year of evaluation (Sanjaya et al. 2006b). Though, many tissue culture studies have reported in Sandalwood, the field establishment of tissue culture–raised plants and their growth and morphological performances are highly limited.

12.4 Conclusions and Future Prospects

Sandalwood is a commercially valued tree species, and its products are being transacted since from many eras, throughout the world. Due to increased demand for Sandalwood products, natural trees were harvest from the wild, and due to this unwarranted misuse have resulted in its habitat loss, and it has been enlisted in endangered plants list. To meet the increasing global demand, Sandalwood cultivation in large scale was/is practiced, as an industrial produce. However, many challenges are faced in conventional cultivation, for instance unavailability of saplings to cultivate, low seed germination, seedling mortality, genetic variability, environmental adaptability, diseases and pests, etc. Thus, a reliable, reproducible and cost-effective plantlets regeneration under in vitro conditions using cell, tissue, or organ culture was/is practiced with a little success. In this regard, plant tissue culture approach can be a better option to mass propagate Sandalwood species. This chapter has reviewed all the published research articles on the tissue culture of Sandalwood and highlighted their findings. Protocols related to in vitro seedlings production, callus induction and proliferation, differentiation to yield SEs, in vitro plantlets regeneration via direct/indirect somatic embryogenesis organogenesis are being proposed. In specific, the future studies should be considered to evaluate the field establishment of micropropagated plants and their growth performances. Further, tissue culture protocols in Sandalwood have proven useful in large-scale plantlets regeneration without any morphological, biochemical, and genetic variations. Further, biotechnological applications of Sandalwood are detailed, for example, synthetic seeds production by encapsulating SEs to be useful for cryo-conserving germplasms. However, more reliable procedures for mass propagating Sandalwood tree species is yet to be warranted for commercial applications.

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Sandalwood Biotechnology: Challenges, Opportunities, and Outlook

13

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Abstract

Plants are well known as storehouses of numerous products, which have been employed for numerous applications continuously since a very long time. However, excessive cutting of plants, industrialization, biotic and abiotic stresses have greatly reduced the plant productivity and these adverse factors have considerably influenced the wealth of plants. The existing technologies are not adequate to execute ever-increasing requirements of plants which have created openings for novel, effective, and precise alternatives. Remarkable strides in plant biotechnology have facilitated for overcoming several diseases problems, cultivation of plants in unfriendly circumstances, changes in plant morphological properties, elucidation of metabolic pathways, improvement in composition of plants, rapid propagation of identified elite plant materials, better and novel isolation of drugs, and finally use of plants as bioreactors for edible vaccines, therapeutic proteins, and industrial products. One of the reasons for this progress is the noteworthy achievements in gene transfer strategies and precise understanding of gene regulation, which have tremendously assisted experts to integrate genes from any organisms to plants in a precise and targeted method for enhancement of a specific metabolite or a desirable trait. Molecular markers, DNA bar coding, DNA microarrays, metabolic engineering, nanotechnology, and synthetic biology are the other emerging areas currently being widely explored for their applications in plant biotechnology. The present chapter presents amalgamation and incorporation of these upcoming technologies to improve and save existing Sandalwood plant treasure. Sandalwood is an evergreen precious forest tree well acknowledged for its fragrant wood and oil, its medicinal properties, and extensively used in pharmaceutical, cosmetic, soaps, perfumes, furniture, and carvings

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industries. A comprehensive account of in vitro propagation, spike disease, host parasite relationship, and oil synthesis pertaining to Sandalwood in conjunction with the contemporary modern molecular and analytical technologies and their advantages has been presented.

Keywords

Genetic engineering · Genomics · Metabolomics · Molecular markers · Somatic embryogenesis

13.1 Introduction

The methodological improvements in genetics, genomics, proteomics, metabolomics, and other areas of modern biology have been developed substantially in cereals, legumes, horticultural and ornamental crops and the progress is much ahead than the forest trees. However, there have been remarkable changes in the genetic techniques and integration of recently acquired knowledge of hereditary mechanisms in the forestry (Meilan and Kirst 2020). A wider range of products have been exploited from the forest trees, and necessitate the judicious applications of various biotechnological technologies to improve the quantity and quality of the forest trees and the forest wealth. The dominant biotechnology gears the exploration of the distinctive biology of forest trees, comprising their intermittent reproductive characters, peculiar long duration of growth habits, changes in the properties of wood, and adaptation to abiotic and biotic stresses (Fig. 13.1). Biotechnology has now been integrated with the cutting-edge technologies of molecular biology for the rapid multiplication of elite clones, production of pulp, wood, useful metabolites, and energy products, pertaining to the trees (Meilan and Kirst 2020).

Kumar et al. (2012) outlined the traits unique to Sandalwood and emphasized that Sandalwood cannot be equated with the other commercial short-rotation or timber-yielding species in which improvement work has been considerably successful.

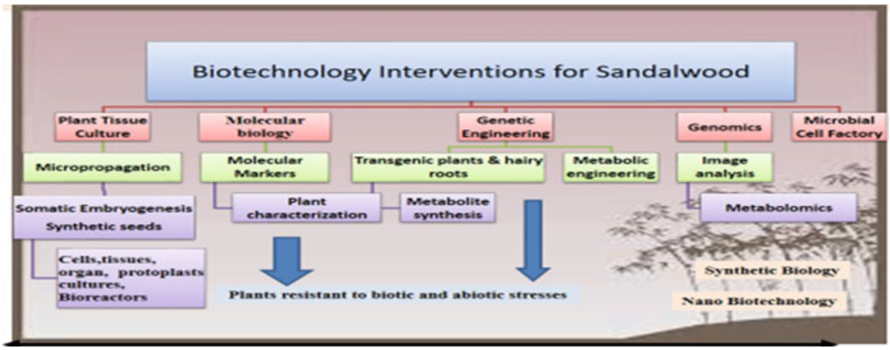

Fig. 13.1 Biotechnology interventions for Sandalwood

Sandalwood, an evergreen forest tree mainly from the tropics, is famous for its wood and fragrant oil that are expensive but have a plentiful of commercial demands. The wood is widely used for several articles and furniture whereas oil is used for making highly prized perfumes, soaps, and cosmetics (Sandeep and Manohara 2019). The oil is used for its therapeutic effects such as antimicrobial, anti-inflammatory, anticancer, antiviral properties, antiaging effects, etc. The oil also has been used in the traditional medical practices, such as Indian Ayurveda and traditional Chinese medicines, and found to be effective in treating neurological disorders like anxiety, insomnia, fatigue, bronchitis, liver disorders, high fever, high blood pressure, gall-bladder diseases, indigestion, diarrhea, and urinary tract infections (Kumar et al. 2012; Bommareddy et al. 2012; Santha and Dwivedi 2015). The plant is overexploited and disproportionately harvested without replacement of this priceless resource which has significantly affected the Sandalwood business, resulting in the worldwide scarcity and increasing of market rates (Rao et al. 2011; Kumar et al. 2012). The demand for high-quality Sandalwood and its oil has been ever-increasing, because of their extensive use in broad spectrum of fields ranging from perfumes, handicrafts to cosmetics, and medicine (https://qrius.com/Sandalwood-demand-crime-bio-tech/). A projected market demand for Sandalwood oil is greater than $1 billion (Divakara et al. 2018). Sandalwood is a rich source of very precious Sandalwood oil along with other metabolites, having several medicinal properties. The oil content is maximum in the roots and next in the stem at the base of the tree and gradually decreases toward the apex of the tree. Similarly, the heartwood at the core is denser with oil and the oil content decreases towards the periphery. Additionally, it being a slow-growing tree, requires 60–80 years of growth for harvest of the good quality heartwood that can yield maximum quantity of oil, is not able to meet the market's rising demand. Apart from illegal harvesting and smuggling, and spike disease have caused heavy economic losses, and also add up to the depletion of the native Sandalwood reserves. The other reasons of paucity of Sandalwood include forest fires, absence of adequate number of seed-bearing trees, lack of established plantations, and heavy demand by the "perfume, cosmetic, and pharma industries" (Daramwar 2014). As a prospective income-generating source, Sandalwood cultivation has attracted farmers with a hope of high income. However, commercial cultivations is affected by several challenges, especially low seed germination rate, seedling mortality, inefficiency and time-consuming, diseases and pests problems, slow-growing nature of the plant, and higher genetic variability (Daramwar 2014).

Against these backdrops, upcoming effective technologies have to be practiced and employed to save this treasure tree species (Teixeira da Silva et al. 2016a). Considering this, Sandalwood biotechnology would be the top-most priority, and multiple scopes of biotechnology are available to save and improve this high-quality plant material. Broadly, biotechnology of Sandalwood encompass tissue culture, micropropagation, somatic embryogenesis, bioreactors, genetic engineering, genetic markers, gene editing, and metabolic engineering. The forthcoming and imminent path-breaking technologies of "omics," synthetic biology, and nano-biotechnology are needed to be integrated for Sandalwood progress and expansion. However, Sandalwood, being a tree, it is necessary to contemplate clear understanding of its growth and development, morphological characteristics, genetic resources, breeding, oil and wood production, spike disease, and host–parasite relationship are needed to be addressed (Teixeira da Silva et al. 2016a).

13.2 Modern Biotechnology Strategies for Enhancing Sandalwood Bio-Prospects

13.2.1 Plant Tissue Culture

Micropropagation, somatic embryogenesis, anther and protoplast culture, somaclonal variations, and in vitro mutagenesis are some of the emerging areas of plant tissue culture which have been effectively used for plant improvement in a wide range of crops. Micropropagation technology is now employed commercially for rapid mass propagation of elite plant species and it could be utilized for the elite Sandalwood genotypes as well (Lakshmi Sita 1986; Rao and Bapat 1992; Sarangi et al. 2000; Sanjaya et al. 2006; Singh et al. 2013; Peeris and Senarath 2015) and has several advantages (Fig. 13.2). The system of somatic embryogenesis is very well standardized in Sandalwood (Rao and Bapat 1995; Rao et al. 1996; Herawan et al. 2014; Bele et al. 2012; Bhargava et al. 2018; Bele et al. 2019), allowing to multiply a large number of trees, although it has certain unsolved problems for transferring the plants to the larger areas with a high success rate (Cheng et al. 2017). The main

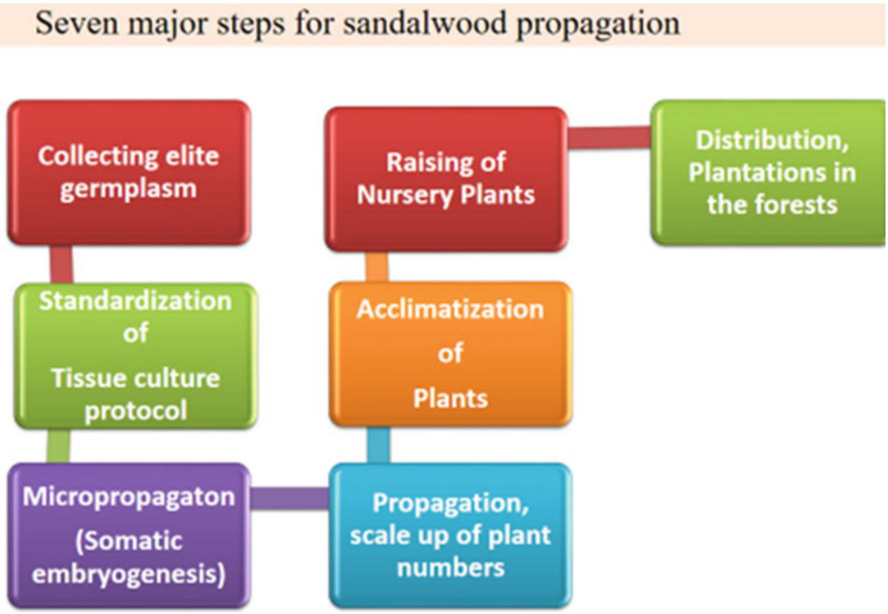

Fig. 13.2 Seven major steps for Sandalwood propagation

advantages of cell cultures and somatic embryogenesis are (1) Few embryogeneic cells, as a starting material. (2) Rapid propagation of selected elite material. (3) Space and system of propagation are economical. (4) Embryogenic cells can be screened in a large number in the mutagenic studies. (5) Scale up of embryogenic cells in a bioreactor for harvesting the maximum number of embryos. (6) Expedient system to study physiological, molecular, and biochemical changes in the developing embryos. (7) Through synthetic seeds, novel delivery of tissue culture plants. (8) Advantageous option in plant genetic engineering manipulations. (9) Convenient for the biotransformation studies. (10) Easy isolation and purification of the natural products. (11) Suitable platform for the studies on metabolic engineering. (12) Appropriate for the germ plasm storage.

Protoplasts culture has been reported in Sandalwood but so far it has remained only of academic interests (Rao and Ozias-Akins 1985; Bapat et al. 1985). Plant cell cultures for producing highly valued bioactive metabolites are promising potential alternative sources (Yue et al. 2016; Vidal and Sanchez 2019) and could be a promising alternative "chemical factory" (Sharma and Sharma 2009), but needs appropriate manipulations of the cell cultures in bioreactors (Mamun et al. 2018). The other advantages are incorporation of precursors or elicitors to the cell cultures to enhance the synthesis of targeted products which have been demonstrated in other plant species (Mendozaa et al. 2018). Cell suspension cultures of Sandalwood have been successfully scaled up in the bioreactors (Bapat et al. 1990; Das et al. 1999; Valluri 2009a) demonstrating scale-up production of Sandalwood cell cultures and somatic embryos. Valluri (2009b) demonstrated the utilization of variant cell strains and bio-transformation of added precursors that can positively improve the uses of Sandalwood cell cultures for the bio-production of preferred compounds. Eibl et al. (2018) discussed emerging trends of manufacturing cosmetics and other products produced from plant cell cultures, which have made their way into the industrial products, and Sandalwood cell cultures could produce oil after an extensive experimentation of attempting additions of precursors or elicitors and other factors to the active cell cultures (Fig. 13.3).

Encapsulation of Sandalwood somatic embryos in alginate gels has been attempted to prepare synthetic seeds (Bapat and Rao 1988), which are of advantageous for plant propagation and germplasm conservation, although inherent constraints have not been fully solved for its larger applications (Faisal and Alatar 2019; Ghosh and Haque 2019).

13.2.2 Plant Genetic Engineering

Need for plant improvement is a continuous research quest underway since many centuries. Plant breeding has helped to domesticate several wild plants for fulfilling the food demand of ever-increasing population. The existing technologies are not adequate to execute these requirements which have created openings for novel and precise alternatives (Chang et al. 2018). Plant genetic engineering expedites incorporation of foreign genes to generate novel genetic combinations, useful for

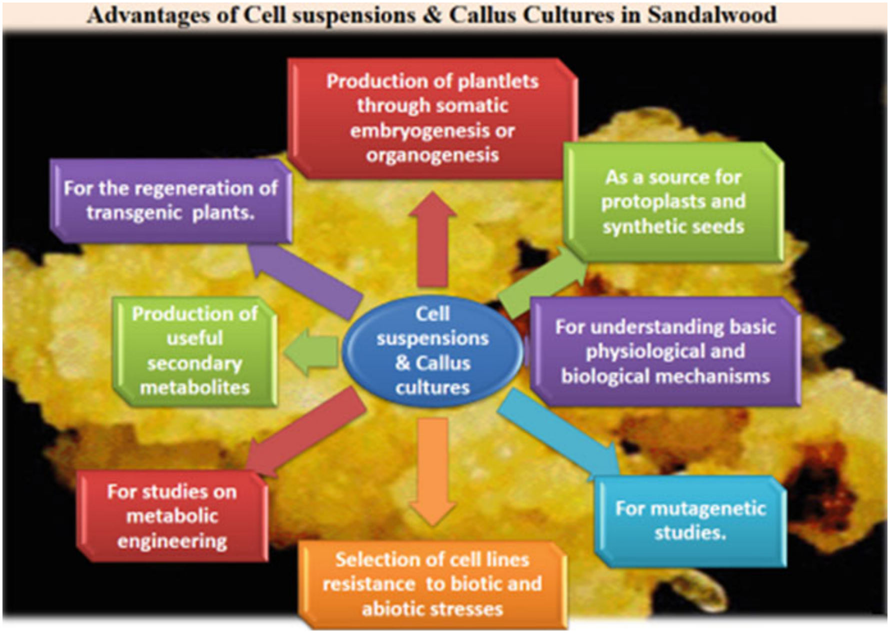

Fig. 13.3 Advantages of cell suspensions and callus cultures in Sandalwood

pathway modification (metabolic engineering) for enhanced biosynthesis of Sandalwood products, easier to study the structure and functions of genes, possibility of overproduction of metabolites present in the natural plant, generation of novel compounds absent in the parent plants, helps to obtain plants that are resistant to the biotic and abiotic stresses and production of fast-growing transgenic plants as demonstrated in other trees species (Harfouche et al. 2011).

Remarkable advances in the transgenic plant technology have facilitated to enhance food supply, overcome several diseases problems, cultivation of plants in unfriendly circumstances, changes in plant morphological properties, delaying of fruit ripening, improvement in the nutritional composition of edible plants, rapid propagation of an identified elite plant material, better and novel isolation of drugs, and finally use of the plants as bioreactors for therapeutic proteins and other industrial products production. Over the years, gene transfer methods have been advanced and several basic mechanisms have been deciphered. Thus, it would be advantageous for testing these technologies in the case of Sandalwood as well.

Nevertheless, there are a number of investigational prerequisites to be followed for delivering genes effectively. Each plant species has its own requirements and it is required to form distinct protocols of transformation, exclusively. Several parameters determine the success of genetic transformation in plants, including the choice of gene to be integrated, types of vectors, genotypes, promoter sequences, and reproducible regeneration systems. In this connection, work on Sandalwood transgenics has been reported earlier, and incorporated marker gene (Anil and Rao

1998), complete transgenic plant regeneration (Shekhawat et al. 2008), and afterwards hepatitis surface antigens were expressed in transgenic Sandalwood cell cultures (Shekhawat et al. 2010). All these new concepts have to be explored and implemented in Sandalwood for better growth, elite plant multiplication, disease free population, higher oil content, and better-quality wood products. A large pool of genes are available which have the prospects to improve traits in Sandalwood and can be incorporated to the Sandalwood genome using plant genetic engineering mechanism as discussed earlier.

13.2.3 RNA Interference Approach in Sandalwood Improvement

RNA interference (RNAi) as a novel approach has been identified for regulating gene expressions in all the higher organisms, and it promises greater accuracy and precision to plant improvement. The criticism of transgenic plants and Genetically Modified Organisms (GMOs) motivates research into effective GMO-free RNA delivery methods (Jagtap et al. 2011; Rosa et al. 2018; Dubrovina et al. 2019; Dalakouras et al. 2020). A better understanding about the plant insight and processing of exogenous RNAs could result in developing new biotechnological methodologies for plant protection. RNAi is an RNA-dependent gene-silencing procedure and is regulated by the RNA-prompted silencing complex (RISC) and is initiated by short double-stranded RNA molecules in a cell's cytoplasm. Mainly, RNAi researches have been performed in plant models, and have to be extended to the entire commercial plants for required traits. The conventional transgenic methods mostly need the expression of whole genes. In contrast, relatively a small-sized RNAi transgene is needed to silence, permit multiple genes to be targeted in a particular construct. For changing stages in a particular metabolic pathway pertaining to oil synthesis or resisting spike disease attack, this would assist to lessen the amount of manipulation and time required to accomplish the desired traits in Sandalwood (Jagtap et al. 2011). Moreover, the first-hand information about RNA stability in the environs, plant perception of external RNAs, and the mechanisms governing cross-kingdom RNA tracing between plants and attacking pathogens might increase the present knowledge of host–pathogen interactions and controlling of Sandalwood's spike disease (Dalakouras et al. 2020).

13.2.4 Transgenic Hairy Roots

The transgenic hairy roots are a prospective platform for Sandalwood since the oil synthesis is highest in the natural roots. Hairy roots (HRs) have been proven as a potential source of secondary metabolites and also for the biotransformation of desirable metabolites (Guillon et al. 2006; Mehrotra et al. 2015; Gutierrez-Valdes et al. 2020). The fast-growing HRs is unique in their genetic and biosynthetic stability and can be used as a continuous source for the production of valuable metabolites (Meng et al. 2019). HRs have the fast doubling time and are easy to maintain on a simple growth regulatory free medium. HRs have been found to contain higher levels of secondary metabolites than callus or cell suspension cultures. HRs does not lose the capacity to produce through successful generations and have more number of apical zones showing a high degree of cell divisions. HRs does not exhibit any environmental threat. Sandalwood metabolites are highest in the roots, and thus HRs would be an ideal option to synthesize these compounds in transgenic HRs.

HRs have been demonstrated to synthesize multifarious active metabolites from a wide range of living cells and are the new genetic tools accessible to enable an augmented production of tailor-made molecules (Gutierrez-Valdes et al. 2020). HRs provide advantages of superior genotypic and phenotypic stability than the dedifferentiated cultures, thus offering more consistent and reproducible systems, and even for the flexibility of inserting gene of interest to the HR gene construct for proficient uses. Additionally, absence of soil matrix and microbes are the key advantages in HRs for elucidating metabolic pathways. The feasibility of scale up of HRs in bioreactors offers an attractive avenue for industrial processes for the metabolite synthesis (Desai et al. 2014). The major compounds of interest in Sandalwood are located in the roots and induction of hairy roots might be a striking opportunity to examine the synthesis of desired products. HRs expressions systems can be conveniently employed in Sandalwood for the production of valued metabolites required by different industrial sectors including pharmaceuticals and cosmetics using fully controlled large-scale bioreactors.

13.2.5 Host–Parasite Relationship in Sandalwood

Studies on the decoding of host–parasite interactions using biotechnology would be of specific interest in Sandalwood. Generally, Sandalwood species parasitizes the roots of host plants and are hemi parasites as they have functional chloroplasts to perform photosynthesis while partially dependent on their host plants to take up water and nutrients through the haustorium and host preference is an important aspect from which the host could gain measurable benefit (Tennakoon and Cameron 2011; Lu et al. 2014). The knowledge gained from plant genetic engineering could improve understanding of the physiological and molecular interactions between Sandalwood and different host plants. The actions of genes responsible for selecting the specific hosts in Sandalwood would be possibly helpful deciphering host–parasite mechanisms. Accordingly, Zhang et al. (2015) in their remarkable work identified key genes using RNA sequence analysis that are associated with haustorial development in Sandalwood and suggested that genes encoding nodule-like proteins may be important for the haustorial morphogenesis. Deepa and Yusuf (2016) investigated the role of different hosts in ammonium transporter expressions and glutamine synthetase (GS) activity and their effects on the growth parameters in the Sandalwood and concluded that the relative increase in *Sa*AMT1;2 gene expressions and upregulated glutamine synthetase (GS) activity and positively affected the growth parameters in Sandalwood when associated with the leguminous hosts.

Growing in vitro Sandalwood seedlings with a wide range of host plant seedlings under aseptic conditions would be a good alternative to test and select the appropriate host suitable for the robust growth of sandalwood. This method is easier and a large host plants can be screened, and it would be profitable for the Sandalwood plantations. Sandalwood seedling establishing contact and penetrating roots of a legume seedling under in vitro condition has been demonstrated (Unpublished work).

13.2.6 Spike Disease in Sandalwood

Sandalwood is susceptible to attack by spike disease caused by mycoplasma and results in reduced productivity of the Sandalwood plantation. Teixeira da Silva et al. (2016b) elaborately reviewed Sandalwood spike disease and suggested various biotechnological methodologies such as tissue culture to derive disease-free clones and transgenic strategies to derive disease-resistant trees and realistic solutions for spike disease–free Sandalwood plantations. Genome sequencing, comparative genome analysis, and evolution of disease-causing organism have been studied by Khan et al. (2008). At the molecular levels, a plant's response to stress is complex and involves a coordinated expression of many genes (Meilan and Kirst 2020). The recent work in understanding the molecular basis for the stress tolerance in model plants is assisting a rapid progress in tree plants in conjunction with genetic engineering which will hasten the production of tolerant Sandalwood plants to the spike disease. Reports of high-quantity sequencing, genomics, transcriptomics, metabolomics, and proteomics in several forest trees are giving tools and resources that will expedite the improvement in Sandalwood to fight the spike disease (Xue et al. 2015; Dong and Ronald 2019; Meilan and Kirst 2020).

These new technologies empower speedy identification of novel immune receptor genes, and directed molecular evolution. Further, the number of genes for increased resistance to microbial infections has expanded considerably. In parallel, advancements in molecular stacking and targeted gene insertion through genome editing are expected to play a major role in generating broad-spectrum resistance against microbial pathogens. The progressively multipurpose, precise, and competent genome-editing tools facilitate accurate modification of endogenous genes for the disease resistance, and would be extremely advantageous for controlling the spike disease in Sandalwood. In this context, as discussed earlier, plants can uptake and process externally applied double-stranded RNAs (dsRNAs), hairpin RNAs (hpRNAs), and small interfering RNAs (siRNAs) designed to silence important genes of plant diseases (Guo et al. 2016). Concurrently, understanding the plant perception and processing of exogenous RNAs could result in the development of novel biotechnological approaches for Sandalwood protection from the spike disease.

13.2.7 Plant Metabolic Engineering and Metabolomics

A large number of metabolic pathways functions in plant cells to synthesize many complex metabolites and make available a seemingly vast pool of structurally assorted chemicals. Due to the diversity and complexity, detection, identification, and quantification of all the metabolites are impossible to underpin the total number of metabolites contributing using conventional analytical techniques (Chownk et al. 2019). However, recent progress in the chromatographic and mass spectral techniques and generation of consortia between analytical techniques and bioinformatics platforms have helped in the documentation of numerous unknown compounds in a plant (Srivastava et al. 2015). Accessibility of the latest technologies in gene sequencing coupled with bioinformatics, it is now possible to decipher the role of the individual genes involved in the biosynthetic pathways and using them appropriately to make use of the wealth of compounds and biocatalysts present in the plants. Many factors make Sandalwood essential oil expensive hence the logical option is to use genetic engineering and molecular biological methods to heterologously express the related synthetic genes of santalene and santalol chemical constituents in the microbial host (Wang et al. 2018).

For overproduction and isolation of high-value plant-derived chemicals, plant pathways can be reconstituted in other hosts, mainly microbial systems. Using this approach, it has been demonstrated to synthesize artemisinin, a plant drug, in yeast cells in the recent times. Sandalwood oil is a blend of mono and sesquiterpenoids, of which, santalols (α- and β-), the mono-hydroxylated sesquiterpenes constitute a major part, and also decide the odor and consequently the quality of the oil. About 90% of Sandalwood essential oil is composed of the sesquiterpene alcohols α-, β, and epi-β santalol and α-exobergamotol, and α- and β-santalols are the most important contributors to Sandalwood oil fragrance. Lanceol and α-bisabolol are also found in modest concentrations (Diaz-Chavez et al. 2013; Srivastava et al. 2015). Using transcriptome database, Diaz-Chavez et al. (2013) pointed nine genes that were functionally characterized using in vitro assays and yeast in vivo assays to encode santalene/bergamotene oxidases and bergamotene oxidases. Rani et al. (2013) isolated santalene sequences encoding farnesyl diphosphate synthase and santalene synthase from Sandalwood using suppression subtraction hybridization and 2D gel electrophoresis technology and reported molecular regulation, and tissue-specific expression of the genes involved in santalol biosynthesis. Misra and Dey (2013) worked on the detailed insights into sesquiterpenoid metabolism across several in vitro and in vivo developmental stages and several genes encoding enzymes participating in early and critical steps of isoprenoid biosynthetic have been isolated. Results indicated that the isoprenoid biosynthetic pathway is differentially regulated with development and in tissue-specific manner and predicted that the results would facilitate characterization of routes of Sandalwood oil biosynthesis and for future improvement of sesquiterpenoid content in this tree. Srivastava et al. (2015) characterized novel sesquiterpene synthases with varying kinetic parameters and expression levels and predicted that it may help to produce of Sandalwood sesquiterpenes in genetically noticeable heterologous systems.

These results would be the foundation for metabolic engineering for synthesis of Sandalwood oil from other sources, thus reducing pressure on supply of Sandalwood from native forests. Studies on the metabolic engineering in Sandalwood would generate new data leading to the higher production of the oil and other related products. Zhang et al. (2017a) categorically summarized multiple strategies for enhanced sandal oil synthesis and discussed various biochemical and molecular approaches involved in the oil metabolic pathways. In a novel work, Yin and Wong (2019), considering insect-repellent properties of Sandalwood oil, expressed genes responsible for santalenes and bergamotene in tobacco plants and these transgenic tobacco plants emitting santalenes and bergamotene showed increased attraction to the green peach aphid *Myzus persicae* (Sulzer), indicating that these transgenic tobacco plants have considerable potential as a trap crop to protect wild-type tobacco from *M. persicae* feeding damage. Such studies demonstrate the possibilities of synthesis of sandal oil outside the natural plants. Since over the past few years, natural Sandalwood resources around the world continue to decline due to the complex cultivation requirements, long growth periods, and continuous harvesting (particularly from illegal poaching and smuggling), combined with limited plantation. Celedon et al. (2016) worked on heartwood-specific transcriptome signature for sesquiterpenoid biosynthesis, and characterized a multi-substrate, which stereo-selectively produces (Z)-α-santalol, (Z)-β-santalol, (Z)-epi-β-santalol, and (Z)-α-exo-bergamotol, matching authentic Sandalwood oil and discussed further prospects of bioengineering of microbial systems for development of alternative industrial production systems for Sandalwood oil fragrances. Jones et al. (2011) cloned and characterized three orthologous terpene synthase (TPS) genes, SaSSy, SauSSy, and SspiSSy, from three divergent Sandalwood species necessary the encoded enzymes catalyze the formation of fragrance molecules and suggested these compounds have played a significant role in the evolution of Sandalwood.

Remarkable research in the use of metabolomics technologies for a wide range of plant metabolites have noticeably improved in the recent years. The blending of the competence of existing analytical platforms for the analyses of complex samples, simultaneously with the incorporation of metabolomics with other "omics" and functional genetics, is proficient to give original impending into the genetic and biochemical features of cellular function and metabolic network regulation. Metabolomics is particularly significant in the plant field, because plants produce an enormous diversity of metabolites and a broad coverage of metabolomics analysis is achieved not by a single specific analytical technology but by other complementary technologies.

Post-genomics era has generated the development of technologies that have offered metabolite-profiling assays on a large scale and a combination of metabolomics with other approaches mainly related to quantitative genetics, transcriptomics, and genetic modification have established its immense consequences to higher synthesis of phytochemicals. This leads to decipher the functional gene(s) responsible for downstream analyses as well as to the description of metabolites, to identify trait-specific markers to recover of desirable essential traits. Sandalwood would be an ideal tree plant to attempt these latest biotechnologies for extracting highly prized Sandalwood oil for the huge commercial gains. Zhang et al. (2017b) scrutinized physiological and transcriptomic analyses related to response mechanism to cold stress in Sandalwood leaves and identified significant genes involved in cold tolerance mechanism, and this work would be the pioneer work to interpret the molecular mechanisms responsible for this tree's response to the cold stress. Mahesh et al. (2018) explained an integrated genomic, transcriptomic, and proteomic approach to assemble and annotate the Indian Sandalwood genome and commented that genomic, transcriptomic, and proteomic data will enhance genomics-assisted breeding, germplasm characterization, and conservation of Sandalwood trees. Mishra and Dey (2018) reported studies on molecular docking studies of a natural product from Sandalwood against diseases and explicated interaction of natural molecules with the selected anticancer molecule for a rational drug design.

Considering these new remarkable research findings, there are abundant prospects to upsurge sandal oil synthesis through breeding and genetic engineering. Capitalizing on the molecular mechanisms and cell-to-cell signaling, have the potential to assist genetic engineering and targeted breeding to enhance oil and other metabolites in Sandalwood.

13.2.8 Molecular Markers

Molecular markers have a significant role to avoid the haphazard collection of valuable plants which need their proper authentication and conservation (Guo-Liang 2013). It is imperative to go for sustained efforts toward an appropriate germplasm cataloging at nucleotide level and to get genotype data, distribution of genetic diversity and population arrangement (Nadeem et al. 2018). Molecular markers such as Restriction Fragment Length Polymorphism (RFLP), Random Amplification of Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP), Selectively Amplified Microsatellite Polymorphic Loci (SAMPL), and Simple Sequence Repeat (SSR) are being extensively used to meet these objectives. The innovative marker technologies offer greatly reduced costs in marker screening and high multiplexing capabilities for metabolite production. The preference of the mainly suitable marker system, however, needs to be decided on a case-by-case basis and will depend on many issues including the availability of technology platforms, costs for marker development, species transferability, information content, and ease of documentation. The identification of the authentic plants and their proper establishment in the catalog as well as selection of elite plants using molecular markers will be extremely useful for the conservation of forest plants.

Chembath et al. (2012) analyzed Santalaceae and its adulterant wood species using rDNA sequencing and comparison studies which offered opportunities to understand their evolutionary and interfamilial relationships. In another study, the potential of DNA barcodes to differentiate market adulterants from the original Sandalwood have been documented. Single nucleotide polymorphisms observed in the adulterants of original Sandalwood clearly indicated the utility of DNA barcoding to track the wood adulterants in Indian Sandalwood industry (Dev et al. 2014). Being a tree, as Sandalwood exists as a heterogeneous plant population, molecular marker investigations would be of immense significance to identify elite plant, to assess their range of diversity, and tag the plants precisely (Nageswara et al. 2007) based on the latitude, longitude, population density, and phenotypic characteristics. Fatima et al. (2019a) studied morphological and genetic variability of 14 Sandalwood accessions collected from the southern states of India and using molecular markers estimated oil content and quality. These studies demonstrated no significant correlation between heartwood oil and genetic structures and this would facilitate tree improvement and conservation of Sandalwood populations.

Shashidhara et al. (2003) screened 51 genotypes of Sandalwood from India and Australia, and found rare and genotype specific bands identified which could be effectively used to distinguish the genotypes. RAPD analysis showed proper genetic diversity and relatedness among the screened populations. Patel et al. (2016) used RAPD, Inter Simple Sequence Repeats (ISSR), and SSR markers and observed genetic diversity good enough for the characterization of Sandalwood genotypes useful for the collection, conservation, and characterization of Sandalwood genetic resources. Fatima et al. (2019b) analyzed 177 genotypes of Sandalwood from 14 populations of three states in southern India and the genetic diversity and genetic structure were characterized through 25 SSR markers developed by cross-amplification of different species of Sandalwood. The highest range of polymorphism was detected with SSR markers developed and would help in the conservation of Sandalwood populations with high profile of genetic diversity and selection of clones for genetic improvement program. The precise advantages of molecular markers studies have been thoroughly pointed out by Teixeira da Silva et al. (2017) and advocated molecular marker studies for phylogenetic studies, correct identification of Sandalwood species, genetic diversity assessment and differentiation, as well as for marker assisted breeding added that these studies will also assist for finding out the trait loci for spike disease, oil and fragrance synthesis, RNA sequence analysis, and metabolic pathways.

Such studies are helpful for the ex situ and in situ conservation as well as selection for genetic improvement program (micropropagation, cloning, tissue culture). Sandalwood populations with high genetic diversity should be given preferential for developing in situ conservation strategies. Additionally, these markers would be a useful tool for investigating genetic diversity and genetic structure of other regions' natural and plantation populations of *S. album* or other Sandalwood species (Fatima et al. 2017, 2019b).

13.2.9 Genomics

The exploration of genomics in the forest tree is behind that of model plant systems. Because of the recent remarkable research, genomic research in forest trees is inflowing into an imperative and productive phase owing to the advent of next-generation sequencing technologies, the wide genetic diversity in forest trees, and the need to alleviate the effects of climate change. This is extending the molecular knowledge of complex life histories of trees and adaptations to the environment (Neale and Kremer 2011; Neale et al. 2017). The study of genomics decipher certain unique properties of the plant that have not been previously reported as in the case *Eucalyptus* and *Populus* trees (Meilan and Kirst 2020). The major thrust of genomics is on the gene sequencing, assembly, and annotation in addition to the computational analysis and other elements of the central dogma with omics studies (Meilan and Kirst 2020). The genome sequences encompass essential information of plant origin, evolution, development, physiology, inheritable traits, epigenetic regulation, etc., which are the premise and foundation of deciphering genome diversity and chemo diversity (especially various secondary metabolites with potential bioactivities) at the molecular level. Meticulous screening of sequencing of plants would help to decipher the biosynthetic pathways of phytochemicals, especially secondary metabolites, and their regulation mechanisms will play a major role in the molecular breeding of high-yielding cultivars. Due to the peculiar features of trees, it makes them more interesting to study compared to other plant groups. However, new and advanced genetic-sequencing techniques enable to sequence long-gene sequences of many trees. The genomic studies on Sandalwood offer an opportunity to uncover the genetic elements that contribute to biomass production, oil synthesis, and their interactions with the biotic and abiotic stresses.

A draft genome of Sandalwood representing the natural population from Kerala, India, was sequenced and assembled into 74,900 major scaffolds with N50 of 12,068 bp and the estimated genome size was 286 Mb. A total of 37,500 genes were predicted including 30 genes from terpene synthase gene family predicting further research in population diversity estimation and accelerated trait breeding in this species (Dasgupta et al. 2019).

Restriction site–associated DNA-sequencing (RADseq) methods have theatrically improved ability to bring population genomic perspectives to trees. The rapid recent increase in studies of trees utilizing RADseq suggests that it is likely to become among the most common approaches for generating genome-wide data for a variety of applications. RADseq offers a powerful and inexpensive technique for generating genome-wide SNP data that can significantly contribute to exploration spanning phylogenetic and population genetic inference, linkage mapping, and quantitative genetic parameter estimation for Sandalwood genetics (Parchman et al. 2018). Recently, chloroplast genome of Sandalwood has been completely sequenced forwarding our knowledge and insight into the genetic map of this plant for better learning of gene functions and their characteristics (Yang et al. 2020).

13.2.10 Image Analysis

Since the last several years, image analysis data has emerged as a powerful tool for analyzing various cell biology parameters in an unprecedented and highly specific manner. High-throughput analysis techniques have become state-of-the-art in the life sciences (Hartmann et al. 2011) and the novel technique developments are programmed for high-throughput plant phenotyping. The method does not destroy the plants and individual plant images are saved for the analysis. Disease detection and health monitoring on the plant are very critical for the sustainable forestry (Sethy et al. 2017). Detecting the disease in the earlier stages needs a reliable method and to overcome this problem it is necessary to develop image-detecting computer-based technologies. This specific technology would be very useful in Sandalwood for identifying the spike diseased plants among the population in the earlier stages of the infection. Sandalwood cell cultures are powerful tools for developing the high competence options for plant regeneration and metabolite production. Proper evaluations by image analysis of select cultured cells of cell lines having desirable properties are essential for the cell quality maintenance. Sorting of well-developed somatic embryos from the cell mass will augment high frequency plant regeneration. Robotics-based technology development has been attempted for isolation, selection, and handling of mature somatic embryos for quality assessment, sorting and orientation of mature embryos (Egertsdotter et al. 2019). Image analysis has also been employed for visualizing localization of metabolites (Nakabayashi et al. 2019) and locating the precise accumulation of metabolites in the plants. Image analysis of wood has been practiced to determine its quality and superiority (Wąsik and Michalec 2016) and this technique has application in testing percentage of synthesis of Sandalwood-scented oil in the wood.

13.2.11 Synthetic Biology and Nanobiotechnology

Synthetic biology is an emerging technology which merges science and engineering for developing and design novel biological functions (Zhu et al. 2020). The major thrust of synthetic biology is to construct new biological parts, devices, and systems and simultaneously change existing biological systems mainly for the desirable functions (Jagtap et al. 2017). The major advantages of synthetic biology are dependable off-the-shelf parts and devices provided with standard connections and versatile framework of yeast or bacteria that easily admits those parts and devices which can assemble various parts into sophisticated and functional systems. The desirable results of design and construction of the synthetic gene network established that engineering-based methodology could indeed be applied to build sophisticated, computing-like performance into the biological systems. The framework provided by synthetic systems, biological circuits can be built from smaller well-defined parts according to model blueprints, which can be studied and tested in isolation, and their activities can be evaluated against model predictions of the system dynamics. This line of attack has subsequently been applied in the synthetic construction of additional genetic switches, memory elements and oscillators, as well as of other electronics-inspired genetic devices, including pulse generators, digital logic gates, filters, and communication modules. Recently, several reports have been published on the integration of synthetic biology with yeast genetic engineering such as the rapid assembly of biosynthetic pathways, modulation of expression of heterologous genes, and localization of enzymes to a special subcellular region or scaffold.

Moreover, *S. cerevisiae* can provide a similar physical and physiological environment for the functional expression of diverse heterologous enzymes [e.g., cytochrome P450s and uridine diphosphate glycosyl transferases (UGTs)] from plants and mammals, as they allow endomembrane localization and post-translational modifications consisting mainly of protein glycosylation. Among the vast number of areas benefiting from synthetic biology, medicine is rapidly taking the lead in adopting the novel tools and strategies developed by this discipline. Notable achievements of synthetic biology primarily in microbes have opened up new avenues of research in the higher plants. Wilkerson et al. (2014) reported noteworthy success in the synthetic modification of trees using a single gene and incorporated chemical labile ester linkages into the poplar tree. A beginning has been initiated in tree synthetic biology and future attempts will demonstrate the utility of synthetic biology in trees including Sandalwood (Myburg et al. 2019).

Spectacular advancement in nanotechnology in recent years has changed the scenario of biological, chemical, engineering, physical, and biological sciences. Extensive work has been carried out on the synthesis and utilization of nanoparticles using various approaches in plant sciences (Fincheira et al. 2020; Misra et al. 2016; Shang et al. 2019). Several applications of nanoparticles in biological sciences have been recorded including agriculture, medicine, food industry, and in other assorted industrial sectors (Duhan et al. 2017; Verma et al. 2018). According to Zahedi et al. (2020), nano fertilizers used in plant nutrition participate in various metabolic pathways, affect their usefulness, and alter their properties which evoke many advantageous responses in the plants.

Considering its significance, the synthesis of nanoparticles has been successfully accomplished using biological, chemical, and physical techniques. Additionally, the chemistry of nanoparticles has certain distinctive properties which have been judiciously and thoughtfully exploited by researchers (Jagtap and Bapat 2013). The advantageous role of nanoparticles includes improved seed germination, augmented root and shoot length, fruit and crop yield, and considerable increase in vegetative biomass of seedlings and plants of Sandalwood. The experimental evidences for enhancement of secondary metabolites through nanoparticle treatment under in vivo and in vitro conditions have been confirmed (Misra et al. 2016) and would facilitate Sandalwood metabolite synthesis. However, currently the work has not yet been translated to practical applications, and in the near future world will witness incomparable and consummate prospective of nanoparticles for plants in many ways and Sandalwood would be one of the beneficiaries and future studies in Sandalwood nanoparticles would be focused for the technological innovations.

13.3 Conclusions

It is evident from the available data that, biotechnology is of immense significance and makes a strong case for extending further its applications of various modern tools for the improvement of tree plants. This chapter explores how this breakthrough and the imminent outcome of the remarkable biotechnological research aimed at the Sandalwood plant improvement might accelerate further research on this precious tree. The understanding gained from the previous work will immensely help to comprehend the basic requirements for planning the future action plans for profitable exploitation for the commercial gains. Generated population from locally selected elite germplasm will be easier to test at the local orchards for performance of possessing desirable traits. Accumulation of constructive data and plant material will help to propagate local Sandalwood plants in conjunction with latest analytical tools. It is essential to adopt modern propagation techniques including tissue culture for the mass propagation of selected germplasms. The generated population of plants will be useful for studies on genetic diversity by using molecular markers. Successful protocols for genetic transformation of Sandalwood plants once established will be useful for incorporating the genes for enhancing synthesis of phytochemicals. Spike disease and host–parasite relationship are the specific targets of research in Sandalwood for which various biotechnological interventions would facilitate the clear understanding to raise disease-resistant plants and selection of the best host for Sandalwood. Impressive strides have been made in plant metabolic engineering, which involve the changing of operating metabolic pathways for synthesis of the products as well as knowledge from metabolomics will constructively be helpful in Sandalwood plants for phytochemical production. The past few years have endorsed tremendous expansions and advancements in "omics," viz. genomics, transcriptomics, epigenomics, proteomics, metabolomics, and phenomics and a combination of these "omics" together would generate exhaustive information. Such information produced by these omics has increased thoroughness and strides of improving several traits in plants including Sandalwood. Salubrious nature is the most primary and important requirement of a tree, and modern omics approaches will help in unraveling certain biomolecules and altered metabolic pathways occurring in Sandalwood because of the spike disease. Similarly, transcriptome analysis will pinpoint role of a specific gene in sandal oil synthesis whereas metabolomics will characterize metabolite under the umbrella of expression of a particular gene. The genome-editing technology is growing rapidly and includes zinc-finger nucleases (ZFNs), transcription activator–like effector nucleases (TALENs), clustered regularly interspaced short palindromic repeat (CRISPR)-Cas (CRISPR-associated) system as genome engineering tools. These chimeric nucleases are composed of programmable, sequence-specific DNA-binding modules linked to a nonspecific DNA cleavage domain. The significance of these enzymes in research, medicine and biotechnology ascends from their capability to induce site-specific DNA cleavage in the genome, the restoration of which allows high-precision genome editing. However, these nucleases differ in several respects, including their composition, targetable sites, specificities, and mutation signatures, among other characteristics. Though, their applications are in their infancy, they open the doors for improvements of forest trees including Sandalwood.

Improvement in trees is a challenging task considering typical life cycle, peculiar morphological characters, seed dormancy, and several biochemical and genetic factors, which have not been clearly understood, hence plant upgrading has been a slow and a laborious process. Work on sequencing of genome of plants has already been achieved in several plants and now it has to be extended to the forest plants. This will increase the research on these plants considerably and will help to propagate elite genotypes for a large-scale utility. The new thrust of technologies will enhance the research on tree plants and will help to propagate elite genotypes for a large-scale utility. Databases are the vital component in the biotechnology and areas, such as genomic analysis, transcriptomics, metabolomics, and image analysis become reachable tools for genetic engineering and systems biology especially in the forest trees (Allona et al. 2019). As a result, the new millennium is likely to see a large and rapid change in the forest plant species which is useful for gaining many rewards.

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Sustainable Use, Threats, and Conservation of Sandalwood

14

Sudhir Chandra Das and Thammineni Pullaiah

Abstract

Conservation and improvement of Sandalwood is felt with the increased interest of farmers, plantation companies, research organizations, and State Forest Departments after amendment in Sandalwood cultivation norms during 2001 and 2002 by the Tamil Nadu and Karnataka State Governments. Apart from this, overexploitation of bio-resource of Sandalwood mainly due to illicit activities resulted in drastic decline in population of Sandalwood in natural habitats and IUCN in 2007 expressed its concern for its threatened status. Sandalwood (*Santalum album*) is listed by IUCN as threatened species. Some of the major menaces for this tree species include illicit and unjustifiable harvesting, loss of habitat, forest fire, grazing, pests and diseases, truncated fruit establishment, and poor regeneration potential. In this chapter, the dangers and approaches to conserve this valuable tree are reviewed and discussed.

Keywords

Sandalwood · Threats · Conservation · Endangered · Sustainable use

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14.1 Introduction

Sandalwood (*Santalum album* L.) is recognized globally as a valuable tree species. Owing to overharvesting from the wild and dearth of appropriate plantation establishment, Sandalwood resources have reduced rapidly in recent past throughout the world. For example, recent data on production of Sandalwood in India show a declining trend. India's Sandalwood production dropped from 4000 MT heartwood per year in the 1950s to a mere 500 MT in 2007 as against the world's yearly demand of around 5000–6000 MT wood and around 100–120 MT oil (Dhanya et al. 2010). In addition to that, grazing and land conversion to agriculture crops such as sugarcane and pineapple have caused the sandalwood resource to decline especially in Australia and Hawaii. According to Harbaugh (2006), one Sandalwood species has already been extinct due to overharvesting and many of others like *S. haleakele* are in highly threatened situation (Subasinghe 2013). As said above, besides today's existing Sandalwood species, the species *S. fernandezianum*, native to the Juan Fernández Islands, became extinct around 1908 after several decades of overharvesting (IUCN 2013 https://www.iucnredlist.org/species/30406/9544750).

Santalum album is native to India, Sri Lanka, eastern Indonesia, and Australia (Northern Territory; although its origin in this area is unknown). In the range of the species there is significant threat from overharvesting for timber and for essential oil, which can be extracted from the heartwood. Global demand for these products currently outstrips supply and is causing native stands of the tree to dwindle. Across Asia, the species is present in plantations, which has eased some pressure on the wild population but illegal harvest and trade still occurs, and the species is commercially exhausted in some sites in India and much of Indonesia. As the price for products of the species is so high, illegal trade is rife. There has been a marked decrease in the availability of Indian Sandalwood. There are also further threats to the species from habitat changes and, particularly in India, the species is affected by spike disease which causes the mortality of trees. It should be ensured that work is taken to maintain the genetic variability of the species and that plantation efficiency is investigated to expand cultivation and further reduce pressure on the wild population. The species is assessed as "Vulnerable." It is suspected that over the last three generations due to overharvesting and global trade the population of the species has declined by at least 30% (Arunkumar et al. 2019).

14.2 Liberalization of Legal Aspect of Sandalwood in India

Sandalwood trees are largely spread across the south regions of India, mainly Tamil Nadu, Karnataka, Andhra Pradesh, and Kerala states. Hence, Sandalwood is defined as a "forest produce," although the "Indian Forest Act" does not have any special provisions for Sandalwood. Meanwhile, the Indian government categorized *Chandana* as one of 32 recognized medicinal plants. However, the Government of India and the concerned departments have to decide whether these medicinal plants come under the Forest Act and Rules, as medicinal and aromatic plants do not. The legal disturbances generated by Sandalwood trade guideline are due to the fact that there is no inclusive regulatory guideline pertinent to the whole nation. Thus, it has encouraged the clandestine trade (see Chap. 11), and Sandalwood population is deteriorating, nearing to elimination. Sandalwood is now classified as one of the endangered plant species in India.

Realizing the sharp decline in the Sandalwood population in their states and having accepted that they cannot be the custodians of Sandalwood anymore, the Karnataka and Tamil Nadu Forest Departments amended the Sandalwood Act in 2001 and 2002, respectively, and made the growers themselves owners of the Sandalwood as per the Amended Act. Further, the government of Karnataka has already made amendments on the sale of Sandalwood through Forest Department and other government departments to eliminate the clandestine trade and to encourage farmers to take cultivation of Sandalwood on commercial scale during the recent years.

14.3 Sustainable Use

There are 16 documented Sandalwood species, occurring around the globe; largely they are clustered as East Indian Sandalwood, Australian Sandalwood, Hawaiian Sandalwood, and Sandalwood of the Pacific Islands. Due to overexploitation, several of them are under the danger of extinction. Steps are taken by some countries toward commercial cultivation using modern techniques to save these species. East Indian Sandalwood, *Santalum album* L., is the queen among Sandalwood species, yielding superior quality essential oil, hugely required by perfumery and related industries. Over the past decades, India was producing the largest quantity of Sandalwood oil, meeting over 80% of world demand (Gowda 2011). However, due to overexploitation, rampant smuggling, illegal trade of Sandalwood, and the declining in the area of cultivation, the quantity of production has declined drastically during recent years from 4000 MT in 1960s to <500 MT in 2010.

Many Sandalwood-based industries have sprung up recently in India as well as abroad due to a worldwide shift in customer preference toward natural products and a demand for legal, ethical sustainable supplies of natural Sandalwood and essential oil. Sandalwood oil is used for perfumes, fragrances, flavors, cosmetics, chewing materials (*pan parag* and *gutka*), among other applications. Many countries, such as Australia, Sri Lanka, Thailand, Cambodia, Costa Rica, etc., are involved in the commercial cultivation of East Indian Sandalwood (*Santalum album* L.) to meet global demand (Gowda 2011).

In the meanwhile, India remains competitive in its effort to cultivate more Sandalwood both in situ and ex situ by different plantation methods to bring back its lost glory as an emerging economy in the world with vast human resources potential. It is expected that this initiative will meet both domestic and international market demands. Further, this will increase green cover, reduce global warming, enhance economic empowerment of the grower, alleviate poverty, generate rural employment, and conserve the ecology and bio-diversity of the country.

The production of Sandalwood was picking up the momentum by the year 2011 onwards, since a major plantation company in Australia, M/s TFS Ltd., had planted about 5000 hectares of the Indian Sandalwood following scientific methods. They expect harvesting of first rotation in 2021. Further, they are also planning about 2000 hectares in the Kemberly region of Western Australia. There is a high demand for Indian Sandalwood because of its unique fragrance quality, its use in medicines, cosmetics, beauty aids, and paradigmatic shift of the consumers towards the natural products. Additionally, since 2003, Karnataka farmers have also been showing active interest in cultivating sandalwood on a commercial scale in view of the liberalization of the Sandalwood trade and amendment of the Forest Act and Rule and granting of ownership to the private *patta* landowners.

In India, the National Medicinal Plant Board and National Horticultural Mission are supporting Sandalwood farming and interplanting with other medicinal plants through their state agencies. A healthy response from the private landowners to cultivate Sandalwood commercially is normal from the year 2015 onwards, particularly in Karnataka. Besides, several planters and capitalists are establishing Sandalwood plantations in the states of Gujarat, Andhra Pradesh, Madhya Pradesh, Maharashtra, Rajasthan, and Assam on a large scale.

Assistance from the commercial banks and other financial institutions for the farmers and entrepreneurs in India is yet to pick up the momentum. Hence there is urgent need of intervention of the Indian government, particularly from the National Bank for Agriculture and Rural Development (NABARD) and even from Foreign Direct Investment (FDI). However, countries like Australia are encouraging companies who are entering into the plantation crops by extending huge rebates from income tax in the context of investment made toward the maintenance of eco-balance. Moreover, several countries such as China, Australia, Thailand, Costa Rica, Cambodia, and Sri Lanka are also venturing into Sandalwood farm, due to its aromatic features and monetary feasibility together with the enormous demand for its products, globally.

14.4 Threats to Conservation

As per the researchers, the main factors, causing Sandalwood's extinction is due to its habitat loss and degradation all over the world (Dani et al. 2011; Rao et al. 2007; Byrne et al. 2003; Warburton et al. 2000). A loss of habitat and substantial exploitation might lead to the disintegration of populations into patchy, small, and isolated remnants. In patchy population, there could be disruption in the gene flow via pollen grains and dispersal of seeds, resulting to strong genetic differentiation among populations as a result of genetic drift (Warburton et al. 2000). Investigations on *Santalum* spp. have specified self-incompatibility within the genus; and in *S. album* and *S. acuminatum*, partially self-compatibility has been testified (Warburton et al. 2000; Ratnaningrum and Indrioko 2014). *Santalum* species have been observed to accomplish vegetative regeneration by root suckers, in which the sprouting of new off-springs emerges from the roots. Clonality phenomenon occurs when most of off-springs in population are derivative of a distinctive single clone (Dani et al. 2011; Warburton et al. 2000). When there exists clonality and little genetic diversity in populations, and if gene flow fails to happen alongside populations, then the existence of self-incompatibility mechanisms lead to sexual reproductive failure (Indrioko and Ratnaningrum 2015).

Sandalwood is an economically important tree species bearing a scented timber. Due to high demand, there has been extensive harvesting of the trees. Besides, changes in land-use patterns and low regeneration, the Sandalwood populations have dwindled. Such drastic reduction in the Sandalwood populations could have drastic effect on the genetic diversity of the populations. Sandalwood's genetic resources in the India are threatened by a variety of factors because of its high economic value both inside the country as well as in the international market (Nageswara Rao et al. 2001a). Extensive extraction of heartwood has severely decimated the natural stocks of the tree in the forests and has rendered many populations fragmented. In the light of these threats to sandal resources, active management is required for its conservation and effective utilization.

Globally, 90% of the world's *S. album* comes from India, with most of the remaining 10% or so coming from the island of Timor. And within India, around 70% of *S. album* comes from the state of Karnataka, with an additional 20%coming from neighboring parts of Tamil Nadu largely falling within the erstwhile Kingdom of Mysore (Rashkow 2014). Sandalwood, though European colonists and foresters did overexploit the species and also failed to conserve it, the real watershed moment came not during the colonial period but rather in the independence period, when industrialization led to a major endangerment crisis for the tree. Though sandalwood smugglers were often blamed for the tree's precarious status since the 1970s, in fact illegal poaching only became an overwhelming problem after the state–industrial complex failed to effectively manage this precious resource, leading to its endangerment and skyrocketing prices.

Arunkumar et al. (2019) has discussed in detail the threats to the existence of *Santalum album*. In India in its natural habitat, subpopulations are not dense, devoid of larger girth classes, and mature trees are entirely or nearly absent in the forest areas of Karnataka and Tamil Nadu (Swaminath et al. 1998; Kumar et al. 2012).

The endangerment of Sandalwood in southern India was discussed by Rashkow (2014). Between 1950 and 1970, on an average over 480,000 Indian sandalwood (*Santalum album*) trees were harvested annually in the state of Karnataka in southern India. Then, in 1974, it was suddenly discovered that there were only approximately 350,000 standing trees left in the entire state. Overnight, India's sandalwood industry ground to a halt. The species was on the brink of extinction. Harvesting and trade in Indian Sandalwood, long considered the most precious wood in the world, was ineffectively banned. Smugglers could now make more money by felling sandal trees than by poaching elephants for ivory (Rashkow 2014).

Systematic studies on Sandalwood population status in terms of quantifying number of trees have not been carried out in India recently except for the information available during the first all India Sandalwood Survey that was carried out during the late 1970s. In case of Marayoor Sandal Reserve in Kerala, it was reported in 1976 that there were over 100,000 trees above 30 cm girth at breast height (gbh) (Varghese 1976). As per the census carried out in 2013–14, it is estimated that this reserve has ~60,000 trees. According to studies carried out by International Timber Trade Organization (2010), in Indonesia, the Province of East Nusa Tenggara (NTT) consisted of 51,417 mother trees and 199,523 seedlings in 1997 (ITTO 2010). The current status of these subpopulations is not known.

Santalum album is experiencing population decline from illegal harvesting and overexploitation. There is a declining 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 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).

Currently the demand for this species exceeds the rate of supply. The natural population of Indian Sandalwood had been continuously under threat from illegal harvesting and overexploitation for many years, if not decades. With the reduced availability of wood and the high value of the wood and oil in the international market, extensive smuggling of the wood is encouraged. With the population dwindling in its natural habitat states, that is, Karnataka and Tamil Nadu, it can be safely assumed that economically viable trees (>30 cm girth at breast height) were nearly absent by the end of twentieth century (Arunkumar et al. 2019). In India, the species is threatened by "spike disease," which leads to mortality of trees due to changes in the physiology of the species (Thomson et al. 2018). There are also more minor threats from a decline in habitat quality from overgrazing and fire which also puts the species at risk.

Sandalwood is a nationally protected resource in India. Despite the protection status the natural resources of sandal are being indiscriminately exploited, perhaps because of its extremely high export value. It has been extensively harvested and more intensively so in the latter half of the twentieth century (Meera et al. 2000; Nageswara Rao et al. 2002). The Sandalwood genetic resources in the country are threatened by variety of biotic and abiotic factors including logging of the trees, poaching, large-scale changes in land use, and poor natural regeneration (Srinivasan et al. 1992). As only natural populations of Sandalwood are used for the extraction, there exists a tremendous amount of ecological pressure on the surviving populations (Radomiljac et al. 1998; Nageswara Rao et al. 2001a, b; Suma and Balasundaran 2003).

In the Karnataka Government–owned Cauvery Handicrafts Emporium, presently 1 kg sandalwood costs ~US$300, while 1 kg of sandalwood oil costs ~US$6000. But these prices can be much more in global illegal markets. There has been a marked decline in the occurrence of the species in the market due to the decline in the number of commercially harvestable and available trees. The annual global demand for Sandalwood heartwood for handicrafts has been estimated to be approximately 5000–6000 tons, with the main markets in China, Singapore, Korea, and Japan but also Europe and the USA (Thomson et al. 2018; Arunkumar et al. 2019). India produces 85% of the world's Sandalwood oil, 80 tons per year is used domestically and the remaining 40+ tons is exported. Indonesia produces 10% of the world's supply, with the remaining 10% from multiple sources (Thomson et al. 2018).

In Tamil Nadu, Sandalwood trees are distributed over an area of 3045 sq km mainly in North Arcot (Javadis and Yelagiri Hills), Salem, Periyar, Coimbatore, and Vellore districts and sparsely in Nilgiris, Madurai, and Tiruchirappalli districts. Dense populations are found in Chitteries, Javadis, parts of Shevaroys, and Thenmala Hills. Higher girth classes are found in most of these populations. Natural regeneration is good in most of the areas. Durairaj and Kamaraj (2013) carried out a survey in Manamalai forest in Tamil Nadu and reported that *S. album* population showed a drastic decline in population due to various reasons. Though biotic the interferences are less in reserved forests, still sandal smugglers are the felling of Sandalwood trees of girth 20–30 cm to check the heartwood farming.

The genetic resources of *Santalum* species have affected due to severe exploitation of their natural population (Jain et al. 2003; Nageswara Rao 2004). This harmful influence of genetic resources has affected the improvement of Sandalwood trees for their heartwood and oil quality. Moreover, the declined resource of Sandalwood base has affected adversely on various businesses and the livelihoods of the customary craftsmen (Chandrashekharaiah and Dabgar 1998). In spite of years of wide-ranging reaping and poaching of Sandalwood, there are few investigations that address the geographical scattering and the genetic diversity of this species in diverse regions of India. Researchers have lately emphasized that disruption or logging has led to permanent losses of the treasurable genetic diversity and genetic resources of forest tree species.

14.5 Conservation of Sandalwood

The species is found in plantations across its native range and also outside of this area. For example during the past 10 years, there have been about 2000 ha of Indian Sandalwood plantations established in southern China. It is estimated that in Cook Islands, specifically Mangaia and Mitiaro islands, there are about 600 trees (aged 6–12 years) and 100 trees (aged about 6 years). A seed production area (0.14 ha) consisting of 150 trees has been established in Vunimaqo, Fiji Islands. Increasingly, especially from 2022 onwards, East Indian Sandalwood oil will be derived from plantation sources, especially from northern and western Australia, as it has more than 10,000 ha of Eastern Indian Sandalwood plantation (L. Thomson pers. comm. to Arunkumar 2019). Due to rampant smuggling, illegal trade of Sandalwood and the declining the area of cultivation, the production of Sandalwood may reach to 300–400 MTs per annum.

In this scenario for conservation of Sandalwood, identifying the genetic resources on the hotspots of the ecological niche of the species as well as its genetic diversity is utmost important. Using GIS and molecular marker tools, attempts have been taken (Nageswara Rao et al. 2007) to identify areas of habitat suitability of Sandalwood as well as identifying the hotspots of genetic variability of Sandalwood in southern India. A comprehensive conservation effort of the Sandalwood genetic resources has also been worked out by them. The genetic diversity of the Sandalwood populations has been estimated using isozyme markers. The conservation of the most genetically variable representative can best be achieved by identifying the hot spots of genetic variability in Sandalwood (Nageswara Rao 2004).

In view of the vanishing population of Sandalwood, the governments of Karnataka and Tamil Nadu relaxed the earlier stringent policies on Sandalwood cultivation and harvest. This has encouraged Sandalwood cultivation by the farmers, entrepreneurs, and NGOs. With the huge demand for wood and oil in the international market, in the last decade, extensive private plantations are now being established across India which, in a way, has paved the way for reviving the past glory of Sandalwood in India. Similarly, large areas are being brought into Sandalwood cultivation in other countries such as Australia and China. Some of the measures needed for its conservation and sustained utilization are as follows:

- An important factor that needs immediate attention from India's Sandalwood cultivation perspective is that there should be uniform rules and regulations across the country that encourages hassle-free harvesting and marketing of the Sandalwood and its products which would also support in its better utilization and conservation.
- Establishing regional-level seedling/clonal seed orchard of superior genotypes for obtaining quality seed material.
- Proper assessment of Sandalwood population at the country level especially in the case of India.
- Government must support farmers and Sandalwood plantation companies by making provision of insurance for Sandalwood trees like agricultural crops to motivate and promote Sandalwood cultivation.
- Genetic variability in provenances, clones, seedling seed orchards, and morphological variability should be verified by using DNA markers and identify markers of high oil-yielding clones.
- All Sandalwood-bearing states/countries should establish germplasm banks for ex situ conservation and clonal and seedling seed orchards as a source of improved seed for raising quality planting materials (QPM).
- Concerted research efforts should be undertaken to study early heartwood induction and understanding biosynthetic pathway for oil formation in Sandalwood.
- Reinitiating tree improvement strategies using plantation grown Sandalwood as the source/base population. Encouraging mass production of seedlings and distribution by various forest departments within the country so that Sandalwood cultivation is extensively encouraged.
- Encourage farmers to undertake cultivation of Sandalwood as "cluster farming" or "community farming," as cooperative venture ensures effective protection.
- Developing proper package and practices for Sandalwood cultivation that would enable in bringing financial gains to the farmers which can also help in conservation of the population.

- Role of genetic and environment on the heartwood and oil quality needs to be extensively studied.
- Local communities are to be encouraged and involved in conservation, protection, and management of forests through joint forest management committees (JFMCs) or village-level committees.
- Studies pertaining to important Sandalwood pests, conservation and augmentation of natural enemies and integrated pest management (IPM) should be taken up by the Research Institutes and Universities.

14.6 Conclusion

Sandalwood being dwindling resource should be used in restrictive and wise manner for its long-term use. As natural habitat of this species has shrunk, its cultivation in "cluster farming" or "community farming" should be encouraged to maintain its sustainable supply owing to its skyrocketed demand and price. Overexploitation and pilferage should be minimized as far as possible to achieve the far-reaching goals. Gene pool is also to be preserved for its in situ and ex situ regeneration, multiplication, and improvement.

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Success Stories of Sandalwood

15

Thammineni Pullaiah

Abstract

Sandalwood supply from India remains variable and fell to just 250 tons of wood a year in 2016 from almost 4000 tons a year in 1970 and more than 1300 tons in 2002. The governments of Karnataka and Tamil Nadu amended the sandalwood laws in 2001 and 2002, respectively, and made the grower an owner of the wood. This amendment encouraged the farmers to take up cultivation on a commercial scale. Several state governments have taken up several measures to encourage farmers to grow Sandalwood in huge quantities. The lure of Indian Sandalwood attracted both the farmers and corporates for growing Sandalwood not only in India but also in Australia and Indonesia. In this chapter the success stories of farmers and corporate farmers are given.

Keywords

Sandalwood farming · Sandalwood · Success stories · Corporate farming

15.1 Introduction

Santalum album L. (Santalaceae) 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. Overall, 60% of the Sandalwood oil is used in attar preparations, 10% in perfumes, 10% in soaps and toiletries, 14% in handicrafts, 5% in medicines, and 1% in incense sticks (Fig. 15.1).

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Fig. 15.1 Industries depending on Sandalwood oil (Source: https://thefederal.com/the-eighth-column/why-sandalwood-farming-is-losing-its-essence/#:~:text=%E2%80%9CKarnataka%2C%20once%20famous%20as%20the,forest%20fire%2C%E2%80%9D%20he%20says.&text=%E2%80%9CSmuggling%20wasn't%20the%20only,too%20exploited%20the%20forest%20resources)

Till recently, there were severe restrictions on cultivation of Sandalwood. If it happened to come up, the plant became the property of the state. Till the year 2001 Sandalwood trees growing in private lands were considered to be government property. The landowners of these lands, where Sandalwood trees grew were paid in the form of bonus and there were several restrictions to dispose of the Sandalwood tree that grew in private lands. The restrictions have been relaxed; cultivation is now allowed and one may apply for a government subsidy for doing so. Owing to this, farmers and owners of private lands were not showing interest in growing Sandalwood. The governments of Karnataka and Tamil Nadu amended the sandalwood laws in 2001 and 2002, respectively, and made the grower an owner of the wood.

This amendment encouraged the farmers to take up cultivation on a commercial scale.

The changes followed an alarming decline in natural plantations across southern states in the last decade, due to rampant smuggling and illegal trade. Supply from India remains variable and fell to just 250 tons of wood a year in 2016 from almost 4000 tons a year in 1970 and more than 1300 tons in 2002, according to government data (https://www.bloomberg.com/news/features/2017-02-21/australian-sandalwood-plantation-is-about-to-make-its-owners-a-lot-of-money) The governments of Tamil Nadu and Kerala collectively auctioned <300 tons during 2010–11. Tamil Nadu conducts auctions thrice a year, while Kerala holds it once a year. Karnataka, a leading producer, has not held any auction for the past 3 years. Till a few years ago, Karnataka Soaps & Detergents Ltd. was producing about 150 tons of sandalwood oil per annum. Now, we can hardly produce about 2 tons. This shows how fast the sandalwood tree is disappearing in India.

The price of Sandalwood has, correspondingly, seen a sharp rise, from ₹1 lakh per ton in 1990 to ₹90 lakhs per ton (2019–20). The sale of wood attracts 12% value-added tax and 14% excise duty when used as an ingredient in soaps by companies like KS&DL. Sandalwood oil has surged from ₹20,000 per kg in 2001–02 to ₹185,000 per kg in 2019–20.

Several state governments have taken up several measures to encourage farmers to grow Sandalwood in huge quantities. Farmers complain that protecting Sandalwood trees is harder than cultivating them. But several methods are being adopted for the protection of Sandalwood trees. Some of these methods include constructing high compound walls around the land where Sandalwood trees are cultivated, growing hedges all around, use of dogs to patrol, putting up solar electric fence, fixing chain-link mesh around the plantation, etc.

The government of Karnataka, one of the largest growers of Sandalwood in India, is backing cultivation in a bid to rebuild supply. Some 470 farmers have so far joined up to the plan covering an area of more than 2000 acres of land, according to the website of Karnataka Soap and Detergents Ltd., the state-backed company that oversees the program.

Half of the country’s 12,000 hectares under sandalwood cultivation is in Karnataka, though most of the trees are yet to mature. Heragu Vasu from a village near Hassan, Karnataka, who has begun growing sandalwood in three acres, believes theft can be minimized if sandalwood is grown extensively by several farmers since isolated farmers would not become easy targets. Sandalwood trees have been stolen from several high-security establishments, including minister’s quarters, Forest Department offices, and university campuses in Bengaluru. With increasing popularity, growers are pressing for a Sandalwood Board that could effectively use the steep 18% tax on wood sales to address security problems.

In Karnataka, over 1000 farmers have been cultivating Sandalwood under an initiative launched by Karnataka Soaps and Detergents Ltd. (KSDL), which produces oil from the wood for its premium brand “Mysore Sandal Soap.” The soap is made from sandal oil and exported to several countries. The KSDL initiative was launched in 2008 to encourage people to grow sandalwood saplings on their farms, estates, and gardens. The firm produces saplings at its nursery in Mysuru and Shivamogga and supplies them to interested persons at ₹12 a plant.

15.2 Success Story 1: Sirigiri Ravinder: The Farmer and Businessman Combined

Sirigiri Ravinder's story is typical rags-to-riches story. Born in 1965 in Hyderabad he did his graduation. He wanted to do something big. He went to New Zealand as a laborer and earned $100 a day. Through his savings he started the taxi services and later on expanded his business. He then entered farming. He purchased 400 acres of pine farm in New Zealand and developed the same. He also purchased 1700 acres of land in Australia and 1200 acres of land in New Zealand. He grew vegetables through hydroponics. He later on came to India and expanded his farming. He now farms 7.5 lakh acres which is owned, leased, and government-allotted land round the world. In the land purchased at Hyderabad he used hydroponics to grow vegetables. After knowing the value of Sandalwood, he later turned to Sandalwood farming. He grew Sandalwood in 10 acres of land in Shabad village near Hyderabad, Telangana State in India, and developed the same. In appreciation of his progressive farming of Sandalwood, he was made chairman of Telangana chapter of Sandalwood Society of India. He dug pits of 1.5 × 1.5 × 1.5 ft. and filled the same with soil mixed with farmyard manure and neem cake. He used mint as first host plant and later red gram (*Cajanus cajan*) as host plant. He used drip irrigation for the plants. He has grown 435 plants per acre with a spacing of 10 × 10 ft. He has grown 220 drumstick (*Moringa pterygosperma*) plants in between the rows as secondary host. He also grew Malabar neem (*Melia dubia*) and another secondary host. Later he has grown jamun plants as permanent host. He later on expanded his Sandalwood farming. Besides 10 acres of Shabad farm, he also planted Sandalwood in 1.5 acres in Shadnagar village near Hyderabad, 10 acres in Vemulakonda village in Nalgonda district, 14 acres in Jadcherla village in Mahabubnagar district, 5 acres in Mall village in Nalgonda district, and 4.5 acres in Achampet in Mahabubnagar district. He proposed to develop Sandalwood farming in 378 acres of land in Marrigudem in Nalgonda district. All this Sandalwood farming is in Telangana state of India. All these farms are different stages of growth from 1-year to 6-year-old plants. He would like to harvest these plants between 15 and 20 years.

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15.3 Success Story 2: Chava Chandrasekhar: The Farmer

Chava Chandrasekhar (49 years old) is from Nimmagudem village near Kothagudem town in Telangana state of India. He came to know about Sandalwood plant through the brochure of Mysore Sandal Soap manufacturers 15 years back. He was inspired by the prospects and bought a piece of land in Nimmagudem village. First, he planted Sandalwood in 2015 in 10 acres of land and another 5 acres in 2016.

The soil was red gravely. He planted 450 plants per acre. Saplings were procured from local private nursery. He has grown red gram (*Cajanus cajan*) and avise (*Sesbania grandiflora*) as primary hosts and Rosewood, Malabar neem, *Pongamia pinnata*, Red sanders (*Pterocarpus santalinus*), and other forest plants as secondary hosts. He used drip irrigation. There was 80% survival rate after 5 years of planting. Root rot and shortage of water in summer caused the death of some plants. In May 2017, his 2-year-old plantation suffered a fire accident and incurred huge loss in the growth of plants, and he suffered a lot to recover the growth. Farm ponds and bore well recharge mechanism (rainwater in to borewell) was made to provide proper water in summer for the plants. Lots of forest plants can be seen in this plantation with around 1000 varieties (fruit, flower, timber, herbs and shrubs, and many more). His aim is to create one best location to see all the forest plants, flora, and fauna.

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15.4 Success Story 3: Thangamuthu the Farmer

M. R. Thangamuthu is a 70-year-old farmer from Moonampalli, near Chennimalai in Erode district of Tamil Nadu, India. Of the 12 acres of his farm, he set aside 4 acres for Sandalwood tree cultivation (Fig. 15.2). It all started in 2009, when Thangamuthu procured 1000 seed balls free of cost under the forest department's 2001 scheme that promoted plantation of Sandalwood trees on private land. He planted Sandalwood sapling in 4 acres of land. Unlike other farmers, Thangamuthu was easily convinced to plant the trees as it required little effort to nurture and could be grown with other trees and vegetables. He had to initially overcome opposition

Fig. 15.2 Mr. Thangamuthu in his Sandalwood farm (Source: https://timesofindia.indiatimes.com/blogs/tracking-indian-communities/70-yr-old-farmer-becomes-states-sandalwood-icon/)

from a section of farmers and deal with fears of Sandalwood smugglers. Forest officials asked him to plant other crops along with the Sandalwood, as the latter won’t grow separately and needs support of other trees to grow. So, he cultivated neem trees, vegetables, and other greens in between. Of the 1000 sandalwood trees, Thangamuthu has lost 200 trees to severe drought that hit the state in 2017. He, however, could save the remaining 800 with guidance from the forest officials. After 8 years of hard work, Thangamuthu is today content.

15.5 Success Story 4: Rangaswamy, A Farmer

The story of Rangaswamy, a farmer of Ragibaikanahalli in Hassan district of Karnataka, is very interesting. He owns 150 acres of high-security farmland with sandalwood cultivation. After the change in government policy, anyone can grow sandalwood tree, one of the costliest wood in the world. Rangaswamy, one of the farmers out of more than thousand farmers, has started the cultivation of this highly endemic tree (Fig. 15.3). He has more than 15 security persons with guns along with dog squads to patrol these highly expensive trees to safeguard from the thieves. He is spending lot of money and technology to save these trees from thieves. Despite this, thieves stole three of his trees, resulting in a loss of a few lakhs.

There is much money in Sandalwood—a 15-year-old tree can have as much as 15 kg of heartwood, with each kg fetching at least ₹9000. With each acre supporting 300 trees, Mr. Doddamagge’s security concerns are obvious. The farmer now wants the government’s help in protecting his trees, especially with the use of technology.

Fig. 15.3 Doddamagge Rangaswamy at his Sandalwood plantation at Ragibaikanahalli (Source: https://www.thehindu.com/news/national/karnataka/lured-by-the-growing-fragrance-of-money/article25016775.ece)

"There is technology of embedding a microchip in trees, which can send alerts, if anyone is cutting it. But each chip costs around ₹400 and we need a government subsidy for this," says the 61-year-old. These concerns have prevented from the lucrative cultivation to 500 acres of his 600-acre holding.

The State Forest Department, which is encouraging the cultivation of the lucrative species, has found that in the 25 years that it takes for a tree to mature, a farmer will have to spend an estimated ₹50.75 lakh per hectare; of this, more than 80% will be on security and wages for guards. The average returns still work out to between ₹1.3 crores and 2.12 crores—revenue scarcely seen in other crops.

While the embedded chip, being developed by Hitachi and the Institute of Wood Science and Technology (IWST), is helping in security, practical problems have stalled its extension. For one, the chip and the battery are too large for the relatively diminutive sandalwood tree. And then, there are issues with battery life. Surendra Kumar, Director IWST, said that they thought the battery can last for 9 months. But, due to constant wind movement, it lasts for <3 months.

15.6 Success Story 5: Chinnegowda

Chinnegowda is a farmer from Kiragaalu village in old Mysore region of Karnataka. He purchased 225 acres of land in erstwhile Sandalwood-rich region of Kollegal costing ₹2 crore in 2005.

Chinnegowda planted about 3000 sandalwood trees, a highly endemic species, in about 100 acres of land in 2005–06 (Fig. 15.4). Depending on 11 borewells and 2 open wells, he cultivated bananas, pomegranates, and limes in the rest of the land. To his advantage, in 2012 the Kabini dam water reached his farm through the canals. Despite all that, Chinnegowda dreams are far from coming true anytime soon.

15.7 Success Story 6: Raghunath, the Farmer

B. S. Raghunath of Hariyabba village in Hiriyur taluk of Chitraadurga district is a progressive farmer. He has accomplished a lot in agroforestry. He planted 4500 sandal saplings in 15 acre of farmland. Tur (Pigeon pea, *Cajanus cajan*) was the host plant. Sandalwood plants were planted after growing of pomegranate plants. *Melia dubia* plants were also grown as permanent host plants. The sandalwood trees have grown well in 4.5 years and even *Melia dubia* has been growing well. If Sandalwood trees are nurtured for 15 years, he is expecting to get minimum of ₹1 lakh from each tree, that is, ₹3–4 crores from an acre.

Fig. 15.4 Sandalwood farmer Chinnalu Chinnegowda inspects his farm in Kiragavalu village in the old Mysore region of Karnataka (Source: https://thefederal.com/the-eighth-column/why-sandalwood-farming-is-losing-its-essence/#:~:text=%E2%80%9CKarnataka%2C%20once%20famous%20as%20the,forest%20fire%2C%E2%80%9D%20he%20says.&text=%E2%80%9CSmuggling%20wasn't%20the%20only,too%20exploited%20the%20forest%20resources)

15.8 Success Story 7: Ayyappa Thoranagatti, the Farmer

Ayyappa Thoranagatti, a retired teacher from Katakola village in the jurisdiction of Ramadurga forest range in Belagavi district, has cultivated Sandalwood plants in 10 acres. He had planted 1200 saplings and as they grew well, he planted another 4500 more saplings. He has cultivated mango trees as intermediate trees and the mango yield has already begun. He has plans to form a sandal nursery and sell the sapling. He has raised high compound wall and grown the traditional hedge fence. He has made arrangements to fix a solar electric fence upon the compound.

15.9 Success Story 8: Ramesh, the Farmer

Ramesh of Chowdadenahalli village in Chintamani taluk of Chikkaballapur district is renowned in this area for cultivation of Sandalwood. He has been growing mulberry and decided to plant Sandalwood because of scarcity of laborers. He has planted Sandalwood saplings in his land of 7.5 acres near his village. Nearly 5 years ago he had planted 1750 saplings and after 3 years 750 more were planted. He planted the saplings of Sandalwood at first with sapota. He used the sandal foliage as fodder for sheep and goats. He has cultivated neem, sapota, jamun, custard apple, etc., as a mixed crop. He has grown four to five varieties of trees without depending solely on Sandalwood. He has received financial incentive of ₹20,000 under the Krishi Aranya Protsaha Yojana of Forest Department.

15.10 Success Story 9: Corporate Sector Enters Sandalwood Plantation

Pragmatic loosening of state clamps encourages commercial plantation of Sandalwood, but much remains. The severe shortage of Sandalwood, hitting user industries like perfume, soaps, and medicine has encouraged pragmatic changes in the rules on cultivation, encouraging the corporate sector to embark on plantation of the endangered wood species.

There are no clear statistics on the extent of sandalwood cultivation in India. It is estimated, however, that in recent years, there has been new plantation on as much as 15,000 acres in southern states and parts of western and northern India.

Companies such as Surya Vinayak Industries, DS Group, and Namdhari Seeds Ltd. and a host of individual farmers with large landholdings have taken up commercial plantation of Sandalwood in the states of Madhya Pradesh, Rajasthan, Karnataka, Andhra Pradesh, Gujarat, and Maharashtra. Significant, since the sector was under strict government control; the wood can still be sold only through government auctions anywhere.

In natural conditions, the Sandalwood tree takes at least 7 years to produce scented heartwood and its growth is restricted due to climatic factors, soil, vegetation, fire, grazing, and human interventions. Under these conditions, a fully developed tree requires about 30–35 years for harvesting. Plantation-grown trees show heartwood formation in about 3–4 years and develop good heartwood, ranging in diameter from 15 cm to 25 cm, in about 12–15 years. Harvesting at this age is much more economical and commercially viable. The tree is a partial root parasite, requiring another host tree by its side, through which it draws nutrient for good growth. The trade is limited to a few companies. KS&DL and Delhi-based Surya Vinayak Industries Ltd. are major players, having been around for quite a while. There are some smaller trading firms, too, which participate actively in the auctions held by state governments.

At present, the Tamil Nadu forest department holds about 650 tons of sandalwood and releases 150–200 tons every 3 months. The forest department of Kerala holds less. The Maharashtra government has a direct sale arrangement with KS&DL. “We are ready to buy any quantity of sandalwood available from anywhere in the country at prevailing market prices, provided it is a legal sale,” Gowda said.

V. S. Mani, consultant for Surya Vinayak Industries, which manufactures sandalwood oil and perfumery compounds, said it had taken up the commercial plantation of sandalwood in a big way in Katni district of Madhya Pradesh. The Dharampal Satyapal Group, maker of Rajnigandha pan masala, has also undertaken plantations in Madhya Pradesh. Bangalore-based Namdhari Seeds has taken up cultivation at Pavagada in Tumkur district of Karnataka.

15.11 Success Story 10: Quintis Limited (Formerly Tropical Forestry Services Corporation Limited, Australia)

India was the largest producer of Indian Sandalwood (*Santalum album*) till 2018, but since 2018 Australia has become the largest producer of Indian Sandalwood. Quintis Ltd. (formerly Tropical Forestry Services corporation Ltd.), Australia founded in 1997 is the world's largest owner and manager of sustainable Indian Sandalwood plantations. Quintis has the world's largest custom-built Indian Sandalwood (*Santalum album*) nursery. Sandalwood seedlings are grown in the nursery with the pot host species (Fig. 15.5). Other host trees are also cultivated in separate pots in preparation for planting.

From the first planting in 1999, Quintis Ltd. (formerly TFS corporation Ltd) have dedicated nearly 20 years of mastering the art of hosting and cultivation of Sandalwood. By harvesting and replanting each year, Quintis Ltd. have created the world's first and only sustainable supply of this endangered species with 5.5 million *Santalum album* trees covering 12,564 hectares. The company manages about 5.5 million trees maturing at different stages and completed its first commercial harvest in 2014. Quintis plans to increase output 30-fold to 10,000 tons of timber a year from its 30,000 acres of plantations located in a strip of land running through the northern parts of Western Australian, the Northern Territory, and Queensland (Fig. 15.6). It is very beautiful, rugged, high rainfall, very fertile area; it's an oasis in the desert. The biggest growth in demand will come from pharmaceuticals and Quintis is in the process of developing dermatological products to treat conditions including acne and psoriasis.

Fig. 15.5 Quintis Sandalwood nursery

Fig. 15.6 A new multiacre planting; just one section of Quintis' 47 square miles of trees; (inset) plantation location in Kununurra (Source: Raj 2018)

Quintis Limited (formerly TFS Corporation Limited) Level 1, 87 Colin street, West Perth, Western Australia 6005 Phone: +61 864584700; +61 86 3233350. press@quintis.com

15.12 Success Story 11: Santanol Pty Ltd.

The company Santanol in Australia was founded in late 1990s. Santanol Pty Ltd. operates sandalwood plantation company. Santanol owns around 550,000 sandalwood trees in Queensland and Western Australia, and an oil distillation and refining facility in Perth. It is the world's second largest producer of Indian sandalwood. The company produces and supplies sandalwood oil products and serves clients in Australia. The group has been growing pure Sandalwood in the Kimberley region of Western Australia since the plantation industry's inception in the late 1990s. The company is only involved in Sandalwood of the *Santalum album* species, grown in sustainable plantations. Santanol manages about 2500 hectares of sandalwood in Kununurra. It first harvested trees in 2014 and is selling "tons" of oil a year.

Santanol Group, 17–21 Coulson Way, Canning Vale WA 6155, Australia info@santanol.com

Mercer International has announced that it has entered into an agreement to acquire the Santanol Group, which owns and leases approximately 2500 hectares of existing Indian Sandalwood plantations and a processing and extraction plant in North West Australia (Source: Timberbiz). The proposed acquisition will expand the company's operations to include plantation harvesting and the production of solid wood chemical extractives.

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