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A Short Review on White Sandalwood (*Santalum album* L.)

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ABSTRACT

Sandalwood *(Santalum album L.*) is a valuable tree associated with Indian culture. It is the second most expensive plant in the world. Sandalwood referred to as "Chandana" in Sanskrit and is commercially known as "East Indian Sandalwood" and its essential oil known as "East Indian Sandalwood Oil". The Species is hemiparasitic, having photosynthetic capacity but water, mineral nutrients and organic substances are acquired via the host plant. In Indian tradition, sandalwood trees has a special place and it is used from cradle to cremation. The commercial value of sandalwood tree or oil is very high in the Indian market. There are many varieties of sandalwood, all of which are available in the world wide. The heartwood of the tree is treasured for its aroma and is one of the finest natural materials for carving. Sandalwood oil is used in perfumes, cosmetics, aroma therapy and pharmaceuticals. Sandalwood is an evergreen tree that is indigenous to India, the sandal oil and paste of sandal is used in medicines, skin and beauty treatments and numerous industrial products including mouth fresheners, edibles, incense sticks, room fresheners, deodorants, perfumes, soaps, lotions, creams and others. It has some really remarkable medicinal properties. The medical properties reside in the oil, which can be pressed from the wood or extracted with alcohol or water. The fragrant parts of sandalwood oil constitutes of α and β santalols. The health benefits of Sandal Wood Essential Oil can be attributed to its properties like anti septic, anti-inflammatory, anti phlogistic, anti-spasmodic, astringent, cicatrizing, carminative, diuretic, disinfectant, emollient, expectorant, hypotensive, memory booster, sedative, anti-bacterial, anti-viral, insect repellent property etc., *S.album* has also gained huge attention towards cosmetic and beauty therapy like curing dark spots, rashes, pimples, acne scars etc. Hence the *Santalum album* has great potential in pharmaceuticals, cosmetics and many other industries in present and future. This review paper mainly focuses on the importance of sandalwood tree, problems associated with its cultivation and the new techniques and approaches which can be implemented to increase the healthy sandalwood plantation and maintain the record of India being in the first position in the export of raw materials of *Santalum album.*

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INTRODUCTION

Santalum album L. is a small to medium-sized, evergreen semi parasitic tree of family Santalaceae[1,2]. *S. album* commonly known as Indian Sandalwood is one of the oldest and precious sources of natural fragrance with immense medicinal and commercial significance [3-5]. The species is recognized due to its fragrance and significant social and economic values[6]. The word sandal has been derived from Chandana (Sanskrit) and Chandan (Persian). It is called Safed Chandan in Hindi, Srigandha, Gandha in Kannada, Sandanam in Tamil, Chandanamu in Telugu. Historical review reveals that sandalwood has been referred to in Indian mythology, folklore and ancient scriptures. It is generally accepted that sandal is indigenous to peninsular India as its history of recorded occurrence dates back to at least 2500 years. Historical review reveals that sandalwood has been referred in Indian mythology, folklore and ancient scriptures. Certain cultures place great significance on its fragrant and medicinal qualities. Its main component is *'Santalol'* which has two isomeric forms, α santalol (41-55%) and β-santalol (16-24%), both of which are volatile compounds with a unique aroma and are the primary active components. α-santalol has proved to be a potential chemopreventive agent against UVB-induced skin tumor development in mice [7], while β-santalol was investigated for its antiviral activity against influenza A/HK (H3N2) virus in MDCK cells [8]. Additionally, purified α-santalol and β-santalol were able to suppress secretion of key cytokine-related factors and proinflammatory arachidonic acid metabolite production in skin cells. Lipopolysaccharides stimulated the release of 26 cytokines and chemokines, 20 of which were substantially suppressed by simultaneous exposure to either of the two sandalwood compounds and to ibuprofen [9.] In a study on a cohort of radiotherapy patients, turmeric- and sandal oil-based cream was effective in preventing radiation-induced dermatitis. The damage is mainly mediated via indirect effects, where the generation of free radicals, resulting from the radiolysis of water, causes damage to macromolecules such as DNA, proteins and lipids [10.] SO showed insecticidal activity with LD50 values (µg/fly) of 2.18 and of 5.61 against male and female drosophila flies, respectively[11.] *In vivo* analysis using a rodent model confirmed the anti-plasmodial potential of subcutaneously administered sandalwood oil[12]. It also is an effective repellent against spider mites [13.] Other minor molecules are derivatives such as the aldehydes santalal and cyclo-santalal, and traces of santalene, curcumene and bergamotene. Traditionally, sandalwood oil used to treat skin diseases, acne, dysentery, and in number of other conditions. In traditional Chinese medicine, its oil is considered an excellent painkilling agent, alleviate itching and inflammation, cools, calms and cleans the blood. The medicinal properties of sandalwood exist in the oil, which can either be pressed from the wood or extracted with alcohol or

water. It relieves fever, thirst, burning sensation and stops sweating. It is good for fever or rejuvenates the skin to natural state harmed by overexposure to the sun, and it awakens the intelligence. Besides these, it is used in heart care, anti-dandruff shampoo, anti-wrinkle cream, baby cream, baby powder and chayvanprasha. The heartwood of Sandalwood is also used for making wood crafts and decorative furniture [14].It has been reported that Sandal seed oil could be reacted with zinc chloride, yielding a dark plastic solid which when dissolved in benzene forms an ideal base for insulation tapes. It reacts with sulphur at 220ºC yielding a dark sticky rubber like product, suggesting it to be vulcanizable oil. Resins like colophony and copal could be dissolved in oil at 200 ºC producing an orange coloured varnish, which may be used in the manufacture of pigmented enamels. By partial hydrogenation a semidrying oil of utility in soap industry could be obtained. A number of surface active products having excellent foaming capacity and foam suitability products which are commercially valuable as foam boosters, germicides plasticizers emulsifying, thickening and wetting agents and for use in liquid detergents have been reported[15]. The highest yield of sandalwood oil is from roots and lowest from the sap wood. In addition to oil, the wood and its powder are used for religious, cultural and medicinal purpose. Both wood and oil are used in incense, perfumes and in medicine and are of great commercial importance. It is used for making idols, boxes and other curios of exquisite beauty[16].

The sandal is known for its oil which is pronounced as the most famous East Indian sandal wood oil which is produced in large quantity from the heartwood and in small amount from seeds of sandal on distillation is rated very high for its sweet fragrant, persistent, spicy, warm, woody note, tenacious aroma and fixative property and is mainly used in perfumery industries and pharmaceutical industries[17].The aromatic oil, which is contained in the heartwood, is only produced when the trees reaches a certain maturity. 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 [16]. Determining the rate of heartwood development in sandalwood tree is important, since it will largely determine the length of its commercial rotation. The weight of the heartwood is invariably dependent on the size of the tree. Very little information has been published regarding the growth rate of *S. album*. It is reported that heartwood and oil formation in sandalwood are yet to be studied in detail[19]. Although *S. album* is grown in small quantities, India has a virtual monopoly over sandalwood production. Over 90 per cent of India's sandalwood is grown in Karnataka and Tamil Nadu. The present Government policy pertaining to the management of sandalwood goes back to King Tipu Sultan, erstwhile ruler of Mysore. King Tipu Sultan declared sandalwood a royal tree and monopolized the sandalwood trade in 1792. Till 2002, state

governments, especially Karnataka and Tamil Nadu have had monopoly control over all the sandalwood resources including those in private lands. 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. In Kerala, however, there is no restriction on storage and transportation. This has given rise to widespread smuggling and illegal trade especially between Karnataka and Kerala. Places such as Karnataka-Kerala-Tamil Nadu border have become havens for illegal trade in sandalwood. Due to extensive illegal cutting of native Sandalwood trees, this species has become vulnerable to extinction[20].

There are two main commercial species of Sandalwood in the world: Australian Sandalwood (*Santalumspicatum*) and Indian Sandalwood (*Santalum album*). Annual global demand of Sandalwood was estimated to be 6,000 tons in 2006 [19]. To fulfill this demand, Western Australia exports about 2000 tons annually [19.] The extremely high demand and reduced supply of Sandalwood is driving its price up all around the world. Sandalwood from Mysore region of southern India is generally considered to be of the highest quality available. The price of Indian Sandalwood fetches two third better prices than Australian Sandalwood. Other species are found in the Pacific region and Australia. The natural resource of Pacific sandalwood species has been heavily exploited since the early 19th century [22].and on some islands, the resource has been practically exhausted [20-22]. Some confusion exists over the taxonomy of these species due to variations in appearance and habit. For example, *S. insulare* from French Polynesia and *S. marchionense* from the Marquesas may be varieties of the same species[23]. Sandalwood has not enlisted as endangered flora by CITES but IUCN and the Government of India have included Indian Sandalwood trees in the list of endangered species in recent Years. The government of Indian has attempted to curb its possible extinction through limiting the exportation of sandalwood. Therefore, export of timber from India is totally banned except for handicraft pieces of Sandalwood up to 50g weight [24].

PLANT MORPHOLOGY

Santalum album is a small evergreen tree that grows to 4 m in Australia, but in India it is much larger and can grow to a height of 20 m; girth of up to 2.4 m, with slender drooping branchlets. Bark is tight, dark brown, reddish, dark grey or nearly black, smooth in young trees, rough with deep vertical cracks in older trees, red inside. Leaves thin, usually opposite, ovate or ovate elliptical, 3-8 x 3-5 cm, glabrous and shining green above, glaucous and slightly paler beneath; tip rounded or pointed; stalk grooved, 5-15 cm long; venation noticeably reticulate. Flowers purplish-brown, small, straw coloured,

reddish, green or violet, about 4-6 mm long, up to 6 in small terminal or axillary clusters, unscented in axillary or terminal, paniculate cymes. The ovary is semi inferior and unilocular. The tree starts flowering at an early age of 2 to 3 years. Generally, trees flower twice a year from March to May, and September to December. Some times the two flushes of flower production may overlap each other so that the same tree may show all stages of development of flower initiation to mature fruits at one time. Fruit a globose, fleshy drupe; red, purple to black when ripe, about 1 cm in diameter, with hard ribbed endocarp and crowned with a scar, almost stalk less, smooth, single seeded. Seeds are naked, lack testa and are dried and stored in polybags or gunny bags [25] .The species is spread rapidly through seed dispersal by birds, which feed on the outer fleshy pericarp. Viable seed production occurs when the tree is 5 years old.

Figure – 1:*Santalum album L.*tree

Figure – 2 Inflorescence

Figure – 3 Flower

Figure – 4 fruit

Historical Background

The sandal wood is one of the most oldest known perfumery and has 2000 Years of Uninterupped history. The tree most probably indigenous to peninsular India. There are many references of sandal wood in Indian mythology. It is mentioned in Indian literature as old as MilindaPanha (200 B.C.), Patanjali Mahabhashyaya[26] . Dhamma pada, VinyaPitaka. Sandalwood is also mentioned in epics Ramayana and Mahabharta[26,27].*S. Album* has been grown from last 23 centuries and india has been the major source for exporting 85% of the sandalwood worldwide.The aroma of the oil and the wood is esteemed by people belonging to three major religions of the world - Hinduism, Buddhism and Islam. The people of Greek came to know about the medicinal and religious importance of sandalwood during the period of Alexender the great and a Europian*Hakeem* (physician) of MadarsaSalarno for the first time used it as an ayurvedic medicine. Egyptians imported the wood and used it in medicine, for embalming the dead and in ritual burning to venerate the gods[28] .

Scientific classification[29,30]

Phylum: Spermatophyta

Sub Phylum: Angiospermae

Class : Magnoliopsida

Order : Santalales

Family : Santalaceae

Genus :*Santalum*

Species: *album*

Botanical name:*Santalum album Linn.*

Figure - 5

Vernacular name

English : White Sandal Wood [31,32]

Tamil :Sandanam[30],Chandanam[31,32]

Telugu : Sriganda[37],Chandanamu[33,34]

Urdu : Safed Sandal [34,35]

Hindi : Chandan [35],Chandal[36],Ujla Chandan [37]

Sanskrit : Srigandha[38], Chandana [36]

Gujarati : Sukhada[31],Suket[36]

Bengali : Chandan [36, 38, 39], Sadachandan[39]

Sindhi : Sukhad[36]

Kashmiri : Safedchandan[36, 39]

Marathi : Gandhachakoda[33, 36]

Punjabi : Chandal[39] , Sufed Sandal [39].Chandan [39]

Kannada : Shrigandha[40]

Habitat and Distribution

The sandal family is distributed between 30ºN and 40ºS from Indonesia in the West to JuanFernandez Island in the north to New Zealand in the South. . There is still debate as to whether S. album is endemic to Australia or was introduced by fishermen or birds from eastern Indonesia centuries ago.In India *Santalum album* is found all over the country, with over 90% of the area in Karnataka and Tamil Nadu covering 8300 sq. kms. In Karnataka, it grows naturally in the southern as well as western parts over an area of 5000 sq. kms. In Tamil Nadu, it is distributed over an area of 3000 sq. kms. and

dense population exists in North Arcot (Javadis and Yelagri hills) and Chitteri hills. The other states where sandal trees are found are Andhra Pradesh, Kerala, Maharashtra, Madhya Pradesh, Orissa, Rajasthan, Uttar Pradesh, Bihar and Manipur. 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 to 1600 mm. It grows well in early stages under partial shade but at the middle and later stages shows intolerance to heavy overhead shade[41] . It also grows on low lateritic cliffs above the beach. The vegetation type is a typical monsoon vine thicket growing on pure sand. It has been recorded on coastal sand dunes immediately above the normal high water mark and close to the mangroves.It is a partial parasite that attaches to the roots of other trees, it needs 'nurse' species in the area of planting out. Host plants that fix nitrogen and provide light shade are preferred. Senna siamea is good for this, and a most probable natural host is *Drypeteslasiogyna*, observed to be the most prolific species in the vicinity of *S. album.* It does not tolerate frost or waterlogging, but is drought-hardy and is a light demander in sapling and later stages. Prolonged drought and fire kill trees[42] .It is now also planted in China, Sri Lanka, Nepal, Malaysia, the Philippines and Northern Australia.

DOCUMENTED SPECIES DISTRIBUTION

Native: Australia, India, Indonesia

Exotic: Kenya

Species origin (Source :***Orwa et al.2009*)** **Figure - 6**

Different species (Var) of Santalum occurring in the world

There are more than 56 species and varieties of *'Santalum'* mentioned in the literature, based on the morphological characters[46] .

1. *Santalum acuminata*
2. *Santalum album*
3. *Santalum austrocaledonicum*
4. *Santalum cognatum*
5. *Santalum cunninghamii*
6. *Santalum cygnorum*
7. *Santalum diversifolium*
8. *Santalum freycinetianum*
9. *Santalum homei*
10. *Santalum involutum*
11. *Santalum latifolium*
12. *Santalum longifolium*
13. *Santalum marchionense*
14. *Santalum mida*
15. *Santalum murrayanum*
16. *Santalum obtusifolium*
17. *Santalum papuanum*
18. *Santalum preissii*
19. *Santalum raiateense*
20. *Santalum venosum*
21. *Santalum cuneatum*
22. *Santalum fernandezianum*
23. *Santalum insulare*
24. *Santalum littorale*
25. *Santalum megacarpum*
26. *Santalum oblongatum*
27. *Santalum pelgeri*
28. *Santalum spicatum*
29. *Santalum acuminatum*
30. *Santalum angustifolium*
31. *Santalum boninense*
32. *Santalum crassifolium*
33. *Santalum ellipticum*
34. *Santalum haleakalae*
35. *Santalum hornei*
36. *Santalum lanaiense*
37. *Santalum leptocladum*
38. *Santalum macgregorii*
39. *Santalum margaretae*
40. *Santalum mitchellii*
41. *Santalum myrtifolium*
42. *Santalum ovatum*
43. *Santalum persicarium*
44. *Santalum preissianum*
45. *Santalum salicifolium*
46. *Santalum yasi*
47. *Santalum affine*
48. *Santalum capense*
49. *Santalum densiflorum*
50. *Santalum hendersonense*
51. *Santalum lanceolatum*
52. *Santalum majus*
53. *Santalum multiflorum*
54. *Santalum paniculatum*
55. *Santalum pyrularium*
56. *Santalum obstfolium*

However, currently only 16 recognised species have been identified in *'Santalum'* and their geographical occurrences in the world are as follows [43]

Species and varieties	Geographical occurrence
• *S.album L*	• Australia, Indonesia, India
• *S.austrocaledonicum*Viell	• New Caledonia, Vanuatu
• *S.boninense* (Nakai) Tuyama	• Bonin Islands
• *S.lanceolatum* R.Br.	• Australia
• *S.macgregorii*F.Muell	• Papua New Guinea
• *S. obtusifolium* R.Br.	• Australia
• *S.yasi*. Seem	• Fiji, Tonga
• *S.freycinetianum*Gaudich	• Hawaii Islands (O'ahu.Moloka'l)
• *S.haleakale*. Hillebr	• Hawaiian Islands (Maul)
• *S.ellipticum*Gaudich.	• Hawaiian Island
• *S.paniculatum*Hook&AM.	• Hawaii Islands
• *S. fernaandezianum*F.Phil.	• Jaun Fernandez Island
• *S.insulare*Bertero	• Society Islands (Tahiti)
• *S.acuminatum* (R.Br. A.D.C.)	• Australia
• *S.murrayanum* (T.Mitch) C.A.Gardner	• Australia
• *S.spicatum* (R.Br.) A.D.C.	• Australia

Cultivation and Harvesting

The sandalwood trees are cultivated mainly by showing the seeds. When sandalwood tree plants are 15 to 20 years old then in august to march the seeds are collected from the sandalwood. The collected seeds are then well treated and dried in sunlight before seminate on nursery beds. Two types of seed beds i.e. sunken and raised beds are available in the nursery for the showing of sandalwood seeds. After 7 to 8 months, a seedling grows up to 30 to 35 cm on nursery beds and they are ready for the transfer in the main field. The pit size is digged 45×45×45 cm for planting the sandalwood seedlings and is kept 10 feet plant to plant distance.

Sandalood tree grows well and matures after 30 years from planting so, it will be ready for harvesting. In the latest technology there are many tree cutting instruments available in the market so farmers can use any instrument for harvesting sandalwood trees. The heartwood of sandalwood trees are

transferred tnto the mill and soft woods are removed. By using some machine this hard sandalwood is transferred into powder. This sandalwood powder is soaked in water for 2 days after it is used for making oil and other cosmetic products.

YIELD

Sandal is considered to be a slow growing tree. It grows at the rate of 5 cm. of girth or more per year under favourable soil and moisture conditions. The heartwood formation starts around ten years of age. The following table gives an idea of growth and development[41] .

Table – 1: Average heartwood formation per tree

Age (year)	Girth at breast height cm.	Yield of heartwood in kg.
10	10	1
20	22	4
30	33	10
40	44	20
50	55	30

PRODUCTS[42]

Food*:* Fruits are edible.

Fodder*:* Trees are sometimes lopped for fodder; the foliage of *S. album* is palatable to grazing animals such as rabbits, sheep, goats, cattle, pigs, horses and camels.

Fuel*:* The wood has been used as a fuel but is generally considered too valuable for this purpose.

Timber*:S. album* is mainly grown for its timber, which weighs 870 kg/cubic m, is durable and strong. Its close grained heartwood is used for ornamental and carving work.

Tannin or dyestuff*:* The bark contains about 12-14% tannin and has good potential in the tanning industry.

Seeds yield an oil that can be used in the manufacture of paint.

Essential oil*:* A valuable oil, 'the sandal oil', is distilled from the heartwood (yield varies from 4-10%) and is used in perfumery, soap making and medicines. The roots contain maximum quantity of oil and hence are more valuable.

Other products*:* Powder from the heartwood is used to make incense sticks, burnt as perfumes in houses and temples, or is ground into a paste and used as a cosmetic.

TRADITIONAL USES

In the Indian traditional medicine system Ayurveda, white sandalwood (=*Chandana*) has largely been used as a demulcent, diuretic, and mild stimulant[44]. Sandalwood oil has been traditionally used for treatment of common colds, burns, headaches, bronchitis, fever, infection of the urinary tract, inflammation of the mouth and pharynx, liver and gallbladder complaints and other maladies. The oil finds use in Ayurveda as antiseptic, cooling, diaphoretic, antipyretic, antiscabietic, diuretic, expectorant, stimulant, expectorant, carminative, cicatrisant, antiphlogistic, antiseptic, antispasmodic, aphrodisiac, astringent and in the treatment of bronchitis, psoriasis, palpitations, sunstroke, urethritis, vaginitis, acute dermatitis, herpes zoster, dysuria, urinary infection, gastric mucin augmenting activity, and gonorrheal recovery as it contains antibacterial and antifungal principles [45-51]. Sandalwood oil along with other plant mixtures has been used to cure stomach illnesses, in treatment of elephantiasis and lymphatic filariasis[52]. The hydrolyzed exhausted sandalwood powder (HESP) on pharmacological screening demonstrated antiremorogenic, antiinflammatory, anti-mitotic, antiviral, anticancerous, hypotensive, antipyretic, sedative, ganglionic 89 blocking, and 90 insecticide properties[53-55.]

Venous and lymphatic stasis such as varicose veins and swollen lymph nodes of the lymphatic system were traditionally treated with sandalwood oil, where the therapeutic potential was attributed to santalols that have antiinflammatory effect[56.] In the traditional Chinese medicine (TCM), sandalwood (=*Tan Xiang*) was used by herbalists to treat skin diseases, acne, dysentery, gonorrhea, anxiety, cystitis, fatigue, frigidity, impotence, nervous tension, immune-booster, eczema, stomachache, vomiting and stress. According to Chinese medicine, sandalwood acts in case of any type of chest pains, originating either from lungs or hearts. The regulating and dispersing action of the oil is curative of the angina pain. Sandalwood also earns a mention in Discorides' De Materia Medica. Furthermore, the German Commission E monograph suggests 1/4 teaspoon (1–1.5 g) of the sandalwood oil for the supportive treatment of urinary tract infections[57] as well as forpains, fevers and strengthening the heart.The sandalwood oil is used as a flavouring substance in food products such as frozen dairy desserts, candy, pan masala, baked food, gelatine, puddings and also in alcoholic and non-alcoholic beverages. US Food and Drug Administration, Flavour and Extract Manufacturers Association Council of Europe and Joint

FAO/WHO Expert Committee has approved sandalwood oil for use as food additives. Besides, its uses in medicine and beverages it is also used in making idols and inlay ivory work. Such work is done on cottage industry scale. Many more items prepared from sandalwood such as rosary from seeds, garland from chips, soaps, perfumes, inscense sticks, powder etc. is long back industry of the people of ancient time. The wood used to make cabinets, caskets, jewel boxes and deed cases. The rich Hindus place pieces of sandalwood in funeral pile[58] . In Karnataka, the Government has taken lot of interest for the improvement of handicraft industries. They are supplying wood to the carvers at about 25% of the original price and the rest is borne by the Industries department so as to encourage and keep alive the skill and craft and also to earn foreign exchange for the country [41].

RELIGIOUS USES

Hinduism

Indian Sandalwood is very sacred in the Hindu Ayurveda and is known in Sanskrit as *Chandana*. The wood is used for worshipping the God Shiva, and it is believed that Goddess Lakshmi lives in the sandalwood tree. The wood of the tree is made into a paste using sandalwood powder and this paste is integral to rituals and ceremonies, to make religious utensils, to decorate the icons of the deities, and to calm the mind during meditation and prayer. 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[59] .

Buddhism

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 most popular scents used when offering incense to the Buddha and the guru[59].

Sufism

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[59] .

Jainism

Sandalwood use is integral part of daily practices of Jainism. Sandalwood paste mixed with saffron is 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. Sandalwood garlands are used to dress the body during Jain cremation ceremonies. During the festival of Mahamastakabhisheka that is held once in every 12 years, the statue of Gommateshwara is then bathed and anointed with libations such as milk, sugarcane juice, and saffron paste, and sprinkled with powders of sandalwood, turmeric, and vermilion[59] .

Chinese, Korean, 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, some sects of Taoists, following the Ming Dynasty Taoist Manual, do not use sandalwood (as well as benzoin resin, frankincense, foreign produced) incense and instead either use agarwood, or better still *Acronychia pedunculata*, in worship. In Korean Shamanism, sandalwood is considered the Tree of Life[59]

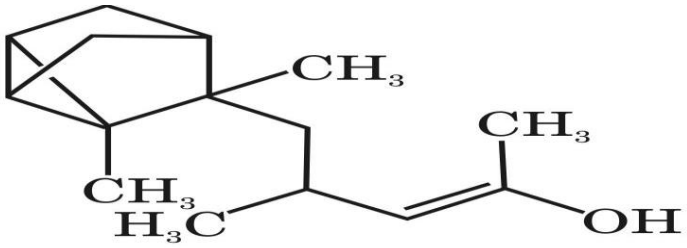
REPORTED PHYTOCHEMICALS IN SANDALWOOD

Sandalwood oil has been extensively studied for the chemical constituents and their isolation, synthesis and quantitative estimation.The volatile oil extracted from *Santalum album* L. derived from the roots and heartwood is colorless to yellowish, viscous (ref. index-1.499– 1.506, specific gravity 0.962–0.985 optical rotation -19–20º) liquid with peculiar heavy sweet odor, the chief constituents of the oil is santalol (90% or more) a mixture of two primary sesquiterpene alcohols, C15H24O like, α-santalol (b.p. 166–167ºC) and β-santalol (b.p. 177–178ºC) α-santalol is major components[60] . More than hundred constituents of sandalwood oil[61-63]in categories of tannins, terpenes, resins and waxes have been reported which include such as hydrocarbons- santene(C_9H_{14}), nor-tricyclo-ekasantalene ($C_{11}H_{18}$), α and β- santalenes ($C_{15}H_{24}$), alcohols-santenol (C9H16O), teresantalol$C_{10}H_{16}O$), aldehydes- nor-tricyclo-kasantalal ($C_{11}H_{16}O$) and the acids α-and β- santalic acids ($C_{15}H_{22}O_2$) and teresantalic acids ($C_{10}H_{14}O_2$)[64]
.

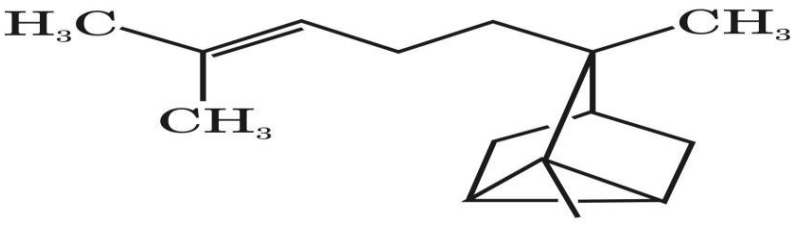
The fragrant parts of sandalwood oil α- and β-santalols were separated in pure form and a 0.5–0.8% higher yield in sandalwood oil was obtained by extracting wood powder with benzene[65]. Two minor components namely cyclosantalol (0.21–2.26%) and isocyclo-santalal (0.11–1.47%) new

sesquiterpenealdehyde were reported. Also a new acid – ketosantalic (as methylester) and gamma – L – glutamyl-S-(trans-1-propenyl)-L-cysteinesulfoxide, an interesting natural sulfoxide diastereoisomers, have beenisolatedfrom sandal. Some authors also report the presence ofTricyclosantalal, α-santalene, trans-β-bergamotene, β-santalene (S &E), α-curcumine, α- santalol, beta-santalol (S&E), nuciferol, α-santalaland β-santalal in *Santalum album*[66, 67].

Sandalwood oil was also applied to Nardenisation- a technique to separate terpenic components by shaking with two immiscible solvents, the polar solvent dissolving oxygenated and non-polar holding the non-oxygenated one without santalenes[68] . The hydrolysis of non-steam volatile matter of the spent sandalwood powder with methanolic hydrochloric acid provides anew essential oil of Hydrolysed Exhausted Sandalwood Powder (HESP)[69] , which is demonstrated to have anti-inflammatory, anti-pyretic, mildly sedative, ganglionic blocker/hypotensive agent or blood pressure depressant and insecticide in controlling forest pest[70] .

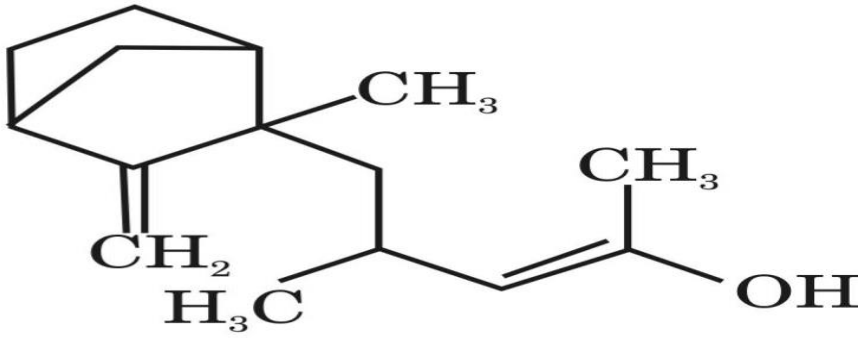


α-Santolol

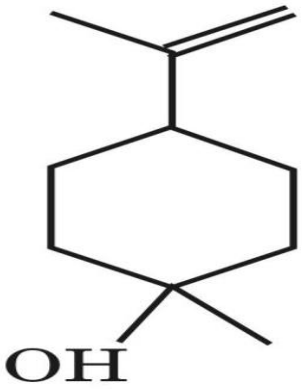


α-Santalene

Figure -7



β-Santolol



Cis β- terpinol

Figure -8

GC chromatogram of East Indian *Santalum album* L. oil

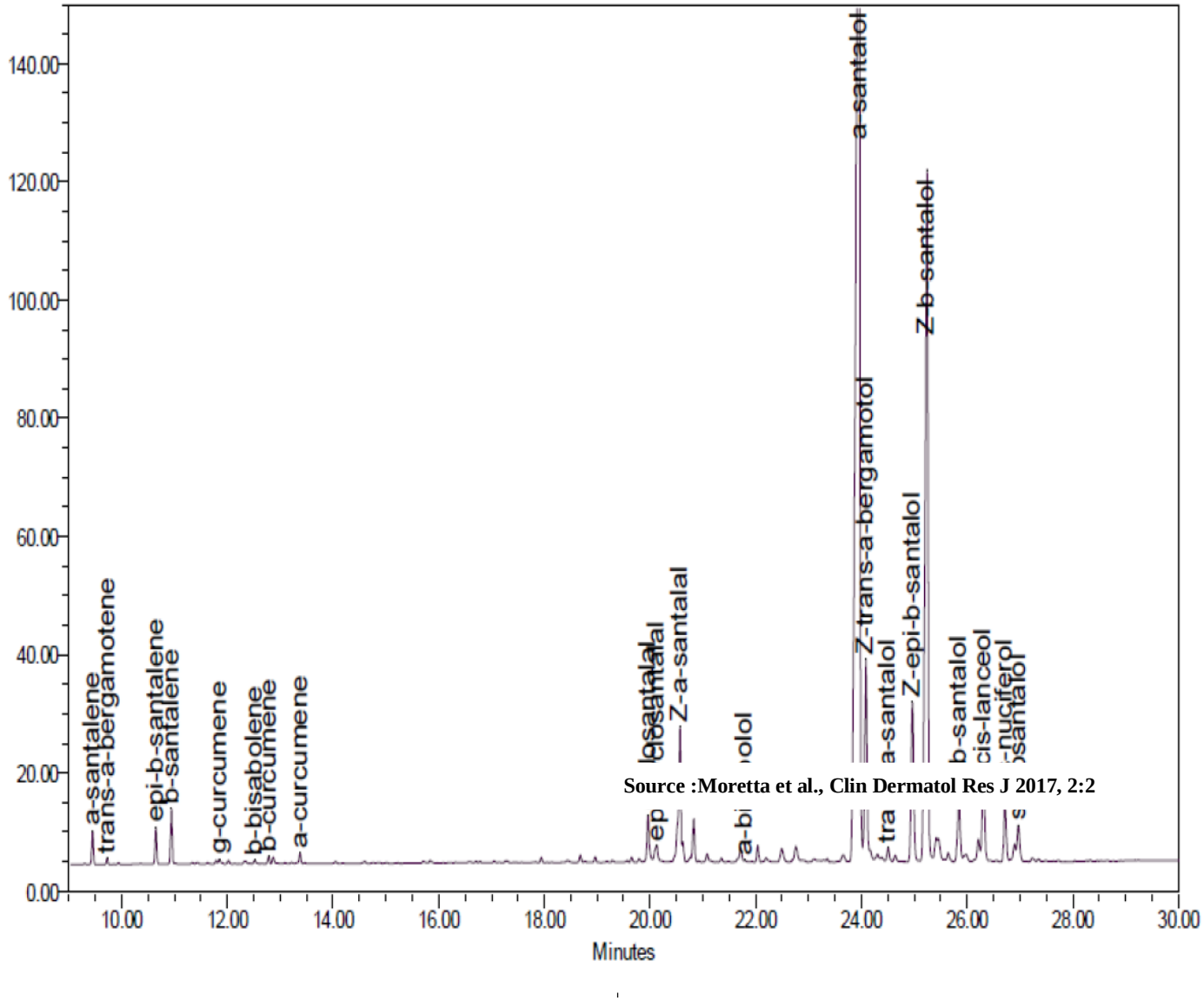


Figure -9: Typical GC chromatogram of East Indian *Santalum album* L. essential oil.

Typical composition of essential oils after the standardized extraction of sandalwood[72].

Name %

Z-α-santalol 46.35

Z-β-santalol 19.11

Z-trans-α-bergamotol 5.66

Z-epi-β-santalol 3.91

Z-α-santalal 3.86

cis-lanceol2.8

cis-nuciferol1.78

E-β-santalol 1.63

Spirosantalol 0.98

Cyclosantalal0.93

β-santalene0.84

epi-cyclosantalal0.58

epi-β-santalene0.54

α-santalene 0.51

trans-α-santalol0.33

α-bisabolol0.18

α-curcumene0.17

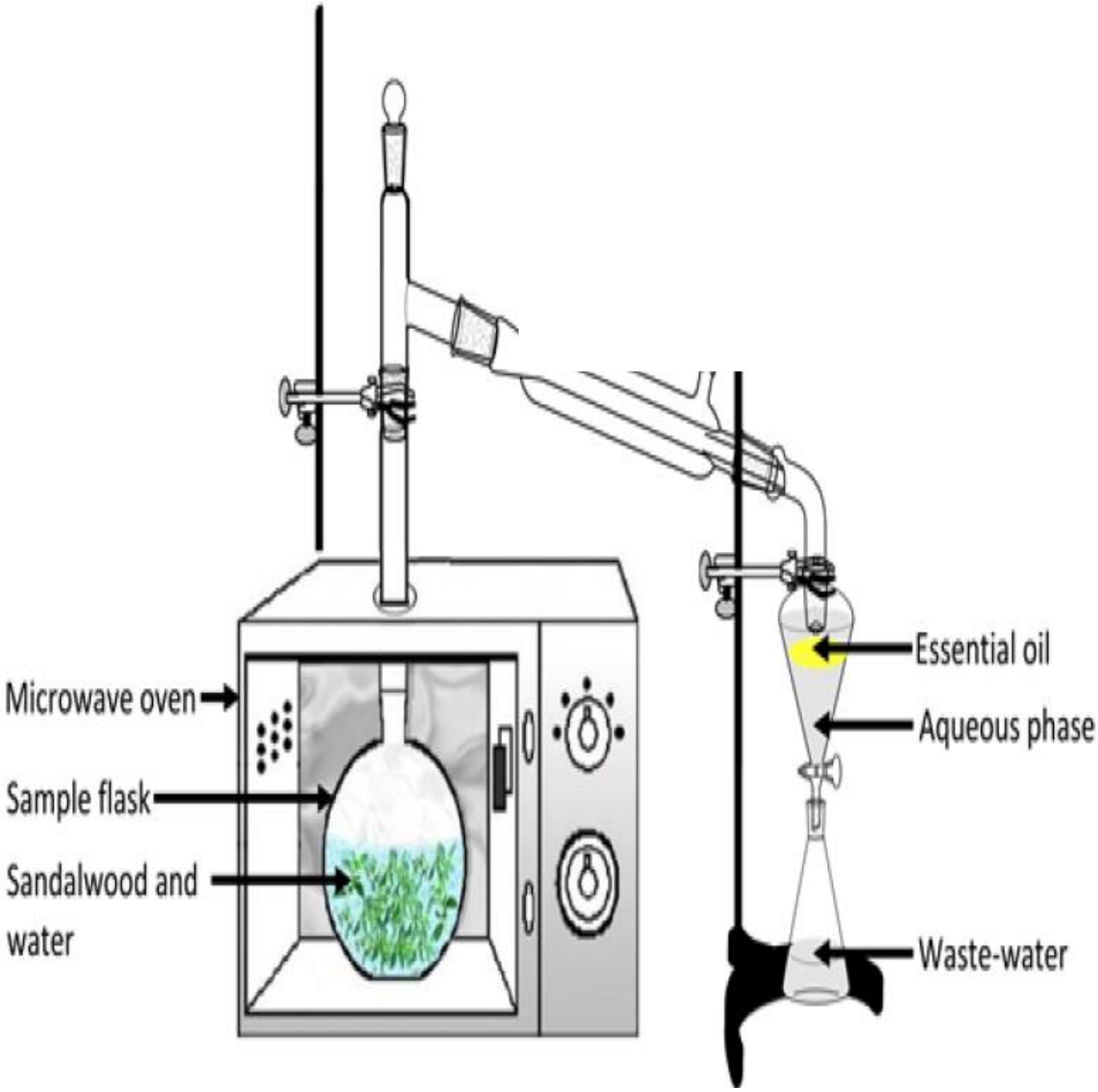
trans-α-bergamotene0.1

EXTRACTION AND BIOSYNTHESIS OF SANDALWOOD OIL

The main methods to obtain essential oils from the plant materials are hydrodistillation, steam distillation, solvent extraction, supercritical fluid extraction (SC-CO2) and liquid CO2 extraction have been used to obtain the volatile oil from sandalwood. Among these method, Steam distillation is the most common method used by sandalwood companies. It occurs in a four-step process, incorporating boiling, steaming, condensation, and separation. Water is heated to high temperatures (140-212 °F) and is then passed through the wood. The oil is very tightly bound within the cellular structure of the wood, so the high heat of the steam causes the oil to be released. The mixture of steam and oil is then cooled and separated so that the essential oil can be collected. This process is much longer than any other essential oil's distillation, taking 14 to 36 hours to complete, but generally produces much higher quality

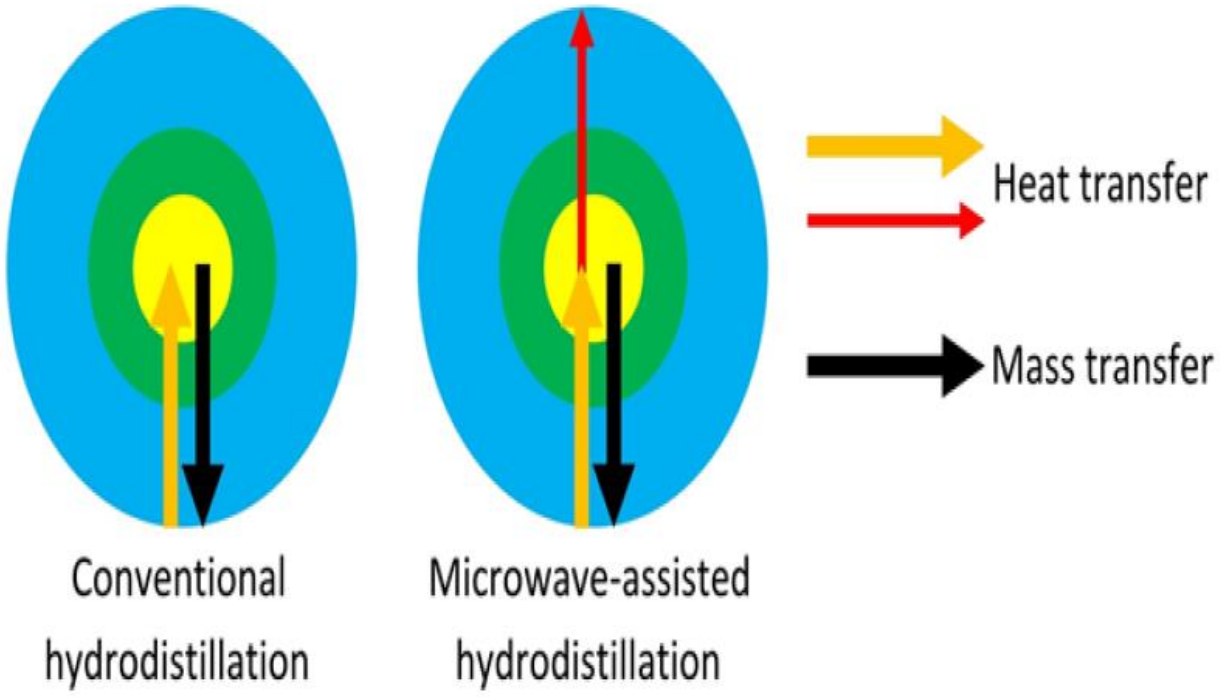
oil. Water, or hydro, distillation is the more traditional method of sandalwood extraction which involves soaking the wood in water and then boiling it until the oil is released. This method is not used as much anymore because of the high costs and time associated with heating large quantities of water. Alternative methods, employing microwaves, have been developed in order to shorten extraction time, improve the extraction yield, and reduce the operational costs. Microwave-assisted procedures for isolating essential oils have become attractive for use in laboratories and industry. The advantages of using microwave energy for oil extraction are more effective heating, fast energy transfer, faster response to process heating control, faster start-up, increased production, and elimination of some process steps.

However, to the best of authors' knowledge no work has been published on the extraction of essential oil from *Santalum* species using microwave ovens for heating. [138] carried out a study to investigate the potential of microwave-assisted hydro-distillation for the extraction of essential oils from sandalwood. From their study, it was found that the maximum yield oil extracted by microwave-assisted hydrodistillation is higher compared to conventional hydro-distillation. In the work of Hettiarachchi *et al.*, [73] it was observed that sandalwood oil yield extracted by conventional hydro-distillation for 9 hours is 0.43%. The fundamentals of the microwave-assisted hydro-distillation process are different from those of conventional methods because the extraction occurs as the result of changes in the cell structure caused by electromagnetic waves. In microwave-assisted hydro-distillation, the process acceleration and high extraction yield may be the result of a synergistic combination of two transport phenomena: heat and mass gradients working in the same direction[74]. On the other hand, in conventional extractions the mass transfer occurs from inside to the outside, although the heat transfer occurs from the outside to the inside of the substrate. In addition, although in conventional extraction the heat is transferred from the heating medium to the interior of the sample, in microwave-assisted hydro-distillation the heat is dissipated volumetrically inside the irradiated medium. Thus micro-wave distillation can be a new approach for extracting oil from sandalwood. Alpha- and Beta- santalol are the main components present sandalwood oil[75].



New approach for extracting *S.album* oil

Figure - 10: Microwave-assisted hydro-distillation



Source : Kusuma and Mahfud, 2016

Figure - 11: Heat and mass transfer mechanisms

QUALITY STANDARD

Aspect: limpid liquid, somewhat viscous

Colour: almost clear to yellow

Odour: heavy, sweet and very lasting odour

Physical Characteristics:

Density:0.968 to 0.983 @ 20^{o}C

Refractive index @ 20^{o}C: 1.503 to 1.508

Optical rotation@ 20^{o}C : -15 to -21^{o}

Solubility in 70% ethanol (v/v) @ 20^{o}C : less than 5 volumes of 70% ethanol for 1 volume of oil

Chemical Characteristics:

Ester number: max 10

Total alcohol content, calculated as santalol: 90% minimum

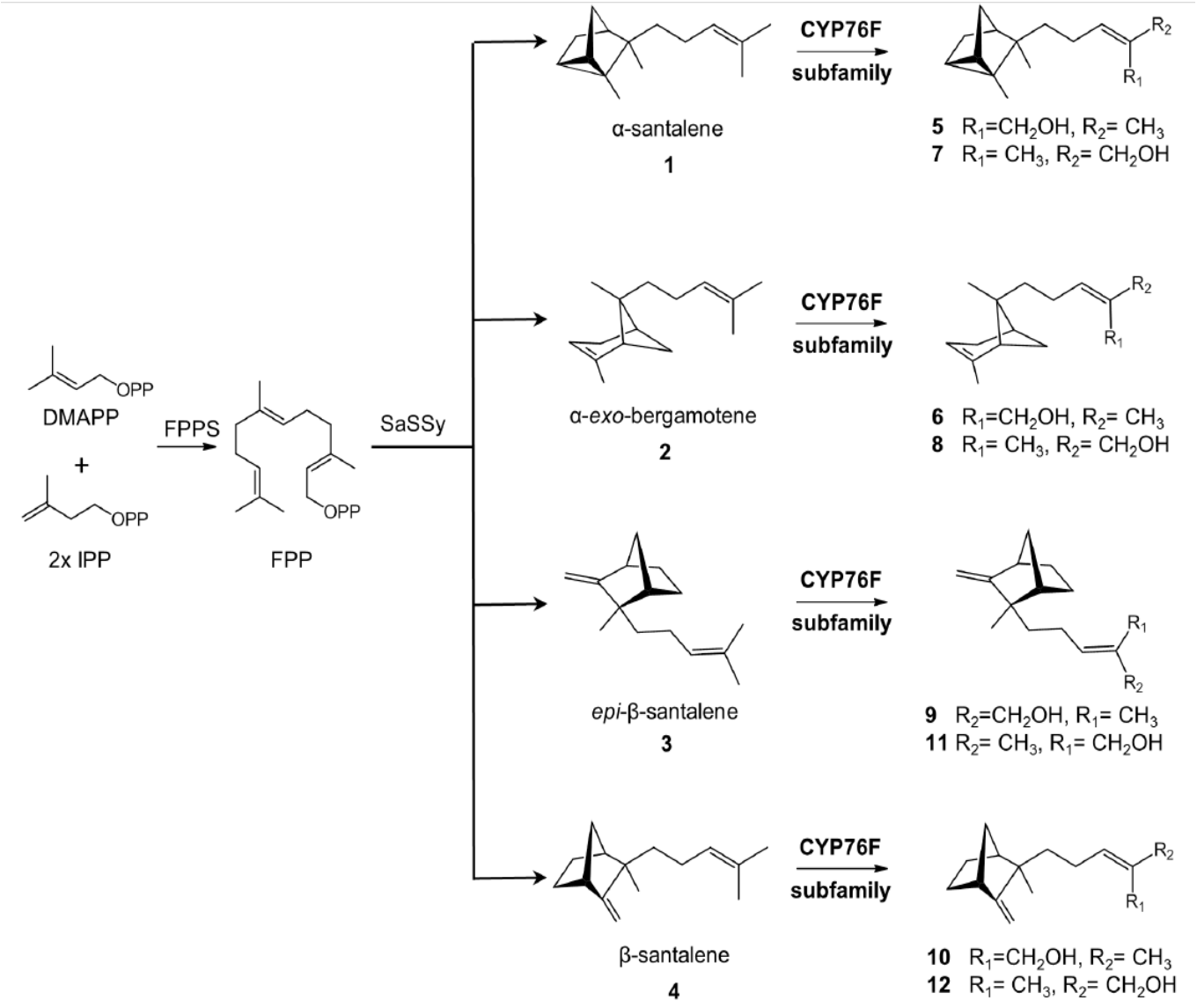


Figure - 12: Schematic biosynthetic pathway for santalols and bergamotol in sandalwood[76]

Compounds identified with numbers are: asantalene(1), a-exo-bergamotene (2), epi-b-santalene (3), b-santalene (4), (Z)-a-santalol (5), (E)-a-santalol (7), (Z)-a-exo-bergamotol (6), (E)-aexobergamotol(8), (Z)-epi-b-santalol (9), (E)-epi-b-santalol (11), (Z)-b-santalol (10), (E)-b-santalol (12). DMADP, dimethylallyl diphosphate; IPP, isopentenyl diphosphate; FPP, farnesyl diphosphate; FPPS, farnesyl diphosphate synthase; SaSSy, *S. album* santalene synthase.

PHARMACOLOGY

A number of pharmacological investigations on sandalwood and its oil have reported various biological effects ranging from aromatherapy, antibacterial to anticancer. The reported pharmacological activities of sandalwood as well as its oil are summarized here under:

AROMATHERAPY USES[77]

Body:

Sandalwood is recognized as having a pronounced effect on the genito-urinary tract and therefore is useful in urinary tract infections including cystitis (with bergamot and tea tree) and gonorrhea. Sandalwood is also a good pulmonary antiseptic and great for coughs, dry persistent ones in particular, as well as chronic bronchitis and sore throat. Good accompanying oils might include myrtle, frankincense, ravensara, thyme linalool or lemon. Sandalwood's relaxing properties mean that is particularly effective at night as it can help a cougher sleep better. Due to sandalwood's low toxicity level, this is an appropriate oil to use topically, in the bath, or as an inhalant. Sandalwood is also considered to be a digestive aid: blended with, for example, ginger, the spice oils or peppermint, it can help alleviate heartburn, nausea, diarrhea and vomiting. Lastly, but certainly not in importance, is sandalwood's role as a sexual tonic. Besides its relaxing, calming properties, sandalwood, along with jasmine, may possibly have a hormonal effect as well. It is an outstanding aphrodisiac, equally useful in cases of frigidity and impotence.

Mind And Spirit:

Sandalwood is calming and useful as an aid to meditation. It is excellent for the stresses of a hectic life as it helps reduce tension, confusion, fear and obsessions. It is also widely known to be anexcellent aphrodisiac and anti-depressant. Sandalwood helps us cut past ties, and move through and past grief, isolationist feelings, ego-centrism, and aggression. It opens us, allowing us to receive love, warmth and understanding. Sandalwood has the ability to bring us back to ourselves, to connect with the earth, to still the mind and allow creativity and our higher consciousness to flower. Sandalwood is one of the oldest and best known of all aromatics, having been in continuous use for over 4000 years. It runs like a common thread throughout many of the world's major religions: in Buddhism, Hinduism and Islam, sandalwood forms the heart of their aromatic aspects, helping to realize and bring the divine within. It has long been considered an important meditation aid. Sandalwood powder has also been used

throughout the medical systems of the world: Ayruvedic, Chinese and Tibetan. Sandalwood is also used in death rituals, especially in India. Ideally, one is immolated on a pyre of pure sandalwood and the ashes cast into the Holy Ganges, the Mother of India.

Skincare:

Sandalwood is good for all skin types, in particular dry and oily skin and acne. Even as it has moisturizing properties, it is a mild astringent and antiseptic. Sandalwood is also soothing for cracked, chapped and irritated skin. It is also recommended for mature and tired skin as well as stretch mark and scars.

Perfumery:

Sandalwood is extremely useful in high-class perfumery for its wonderful ability to blend almost any notes. It is a very popular fixative, deep and rich, yet unobtrusive, soft and sweet. Its long, lingering and subtle aroma makes it a perfect base note. Sandalwood is the utmost in complimentary notes.

Chinesemedicine:

Sandalwood is cooling, decongesting and astringent. It is indicated, therefore, for problems of a hot, inflammatory and catarrhal nature, most often for problems of the intestines, lungs or genito-urinary tract. Examples are diarrhoea, burning cystitis, and a harsh painful cough. Mentally, it will work best when a cooling action is needed against hot and agitated mental states. Commonly, Sandalwood is ground and used as a powder rather than an oil.

Ayruvedic Medicine:

Used for conditions of Pitta, heat, fire, as a cooling agent. Antifebrile, Anti-inflammatory and anti-infectious, here again Sandalwood is used ground to a paste.

Prolong Human Hair Growth

A team of researchers led by Ralf Paus of the University of Manchester**(19 September 2018, by Bob Yirka)** has found that applying sandalwood to the scalp can prolong human hair growth. In their paper published in the journal *Nature Communications*, the group describes experiments they conducted with the synthetic material and human skin samples. The research built on prior work by a team that had found that a receptor cell in skin called OR2AT4 was sensitive to chemicals in synthetic sandalwood—sandalwood application stimulated growth of keratinocytes. Because skin healing and hair growthare

closely related, the researchers wondered if applying synthetic sandalwood mightalso stimulate new hair growth. The researchers tested their idea by soaking skin samples in a synthetic sandalwood solution for six days and then observing the skinfor changes tohair follicles. They report that the treated hair follicles survived longer than those that wentuntreated, and also produced more growth factor. The researchers verified that it was the synthetic sandalwood interacting with the receptor OR2AT4 that caused the change by blocking the receptors, and noting that doing so inhibited the change from occurring[78].

Anti-inflammatory and Antioxidant activity sandalwood album Oil (SAO)

SAO is known to mediate its anti-inflammatory properties in vitro through multiple mechanisms. The oil inhibits the oxidative enzyme 5-lipoxygenase and has DPPH radical scavenging activity and in vivo, SAO was able to protect mouse livers from damage resulting from oxidative stress and the formation of reactive oxygen species[79]. Sandalwood oil when demonstrated in vivo showed increased glutathione S215transferase (GST) activity and acid soluble sulfhydryl (SH) levels in the liver of adult male Swiss albino mice in oral doses of 5 and 15 µL in 10 and 20 days, respectively[80]. Enhanced GST activity and acid-soluble SH levels were suggestive of a possible chemo-preventive action of sandalwood oil on carcinogenesis through a blocking mechanism. Similarly, methanolic extracts of sandalwood demonstrated acetyl cholinesterase inhibitory (180 µg mL-1) and DPPH and super oxide free radical scavenging activities (IC50 values of 160-191 µg mL-1) in albino mice, there by indicating potential to tackle dementia and memory loss, associated with Alzheimer's disease. Recently, we demonstrated the *in vivo* anti-hyperglycemic and antioxidant potential of sandalwood oil (1 g/kg BW) and its major constituent α-santalol (100 mg/kg BW) in alloxan- and D-galactose mediated oxidative stress induced diabetic male Swiss albino mice models, respectively[81]. Additionally, anti-inflammatory activity in skin was reported to rely on the activation of the enzyme 11b-HSD1, which plays a role in cortisol synthesis by keratinocytes[79] .

ANTI-MICROBIAL AND ANTI-VIRAL PROPERTY

The anti-microbial efficacy of *Santalum album* was demonstrated by 3 different methods like Microtitre well plate-based broth dilution assay, the disc diffusion assay and the agar spot assay. Microtitre well plate-based broth dilution assay results revealed that the Gram-negative bacterium *Pseudomonas* fluorescens and the Gram-positive bacterium Micrococcus flavus were resistant to sandalwood oil. The highest MIC_{70} was recorded against Alcaligenes faecalis at >40 µg ml^{-1}. The

lowest MIC_{50} values were observed against Salmonella typhimurium (0_078 µg ml $^{-1}$) and the highest MIC_{50} against Enterobacter cloacae (10 µg ml^{-1}). The lowest MIC_{90} value was observed against Staphylococcus aureus (0_0625 µg ml $^{-1}$) and the highest MIC_{90} was against Klebsiella aerogenes (10 µg ml $^{-1}$).

The disc diffusion assay results revealed the highest microbial susceptibility index (MSI) against Ent. Cloacae (100%) and Ps. fluorescens (100%). The lowest MSI was obtained for Arthrobacter nicotianae and Kl. aerogenes (both, 0%). The highest activity was recorded for sandalwood oil (93.75%) and the lowest for both callus and young tree leaves' extracts at 25%. The highest sensitivity to sandalwood oil was observed against A. nicotinae, while somatic embryo extracts displayed highest activity against Staph. aureus.

From the agar spot assay results, it was revealed that the lowest MSI was demonstrated by Acinetobacter calcoaceticus and Ps. fluorescens (both, 0%), both Gram-negative strains, thus rendering them the most resistant strains, whereas the highest MSI was observed against Pseudomonas aeruginosa (100%). Among the Gram-positive bacterium, the highest MSI was observed for A. nicotianae (80%) and the lowest for M. flavus (0%). The highest activity was observed for sandalwood oil (92.85%) and the lowest for old tree leaves' extract (14.28%), thus making them the most and the least bioactive extracts used in this investigation[82].

In an *in vitro* study sandalwood oil demonstrated antiviral activity against herpes simplex viruses (HSV)-1 and 2 in a dose-dependent manner through inhibition of viral replication. It was further assumed that sandalwood oil helped the cells protect themselves by modulating the liver's gluthatione S-transferase and levels of acid-soluble sulfhydryl[83] .Sandalwood oil has alsobeen shown to be used in prevention and treatment of warts, skin blemishes and other viral induced tumors on skin[84]. Additionally, sandalwood oil and santalol derivatives were claimed for use in treating cold sores and herpes[85] .

ANTIFUNGAL ACTIVITY

Sandalwood oil is reported to possess anti-fungal activity against *Microsporumcanis*, *Trichophyton mentagrophytes* and *T. rubrum*. Sandalwood oil was found to be effective against human pathogenic fungal strains *Microsporumcanis*, *Trichophyton mentagrophytes* and *T. rubrum* but was ineffective against *Candida albicans*, *Aspergillus niger*and *A. fumigates*[86] .

TETRANYCHUSURTICAE REPELLENT EFFECT OF SANTALOL FROM SANDALWOOD OIL

Thirty-four essential oils were screened for their repellent activities against the two spotted spider mite, *Tetranychusurticae*at 0.1% concentration level using choice and no-choice laboratory bioassays. Of these, 20 essential oils showed significant repellencies against *Tetranychusurticae*in the choice tests. In subsequent no-choice tests using these 20 essential oils, only sandalwood oil showed significant repellency against *Tetranychusurticae*[87] .

APOPTOTIC EFFECTS OF A-SANTALOL IN INHIBITING THE GROWTH OF HUMAN PROSTATE CANCER CELLS

The a-santalol-induced apoptotic cell death and activation of caspase-3 was significantly attenuated in the presence of pharmacological inhibitors of caspase-8 and caspase-9. α-Santalol, a derivative of sandalwood oil, induces apoptosis in human prostate cancer cells[88] .

INSECT GROWTH INHIBITOR FROM BARK OF *S. ALBUM*

Triterpenoid- urs-12-en 3 b-yl palmitate (m.p 115-116º, (a) D 24 +200, C46H80O2) has been isolatedfrom sandalwood. The tropical application of triterpenoiod on fresh pupae of forest insects viz: *Attevafabriciella, Eligma narcissus, Eupterote geminate* etc produced morphologically defective adults indicating growth inhibition activity of the compound. Also observed the chemosterilant activity on freshly emerged moths of *Attevafabricella* [89].

EFFECT ON NERVOUS SYSTEM

Santalols have been reported to have central nervous system (CNS) depressant effects such as sedation, and they affected sleep-wake cycle in sleep-disturbed rats, such as decreased walking time and increase in non-rapid eye movements. Results suggested action of santalols via circulatory system by adsorption into the blood through respiratory mucosa, hence demonstrating implication in patients having sleep related difficulty[90] . Alpha and Beta-santalols significantly increased the levels of homovanillic acid, 3, 4-dihydroxyphenylaceticacid and/or 5-hydroxyindoleacetic acid in the brain of mice upon intragastric and intracerebroventricular routes of administration[91] . Alpha-santalol was shown

to be a strong antagonist of dopamine D2 and serotonine 5-HT2A receptor binding. Furthermore, the effect of alpha-santalol, was the same as that of chlorpromazine as an antipsychotic agent[92] . Alpha-santalol caused significant physiological changes such as relaxing and sedative effects, whereas sandalwood oil provoked physiological deactivation but behavioral activation after transdermal absorption[93] . Furthermore, we have recently reported that TLC254 bioautographic assays indicated that alpha-santalol, the major constituent of the oil, is a strong inhibitor of both tyrosinase and cholinesterase *in vitro*, and hence there is a great potential of this essential oil for use in the treatment of Alzheimer's disease, as well as in skin-care[94] .

ANTINEOPLASTIC EFFECTS OF A-SANTALOL ON ESTROGEN RECEPTOR-POSITIVE AND NEGATIVE BREAST CANCER CELLS

Anticancer efficacy and the mechanism of action of α-santalol was investigated in human breast cancer cells by using p53 wild-type MCF-7 cells as a model for estrogen receptor (ER)-positive and p53 mutated MDA-MB-231 cells as a model for ER-negative breast cancer. α-santalol inhibited cell viability and proliferation in a concentration and time dependent manner in both cells regardless of their ER and-or p53 status. However, α-santalol produced relatively less toxic effect on normal breast epithelial cell line, MCF-10A. It induced G2/M cell cycle arrest and apoptosis in both MCF-7 and MDA-MB-231 cells. Cell cycle arrest induced by α-santalol was associated with changes in the protein levels of BRCA1, CHK1, G2/M regulatory cyclins, cyclin dependent kinases (CDKs), cell division cycle 25B (Cdc25B), Cdc25C and Ser-216 phosphorylation of Cdc25C. An up-regulated expression of CDK inhibitor p21 along with suppressed expression of mutated p53 was observed in MDA-MB-231 cells treated with α-santalol. On the contrary, α-santalol did not increase the expression of wild type p53and p21 in MCF-7 cells. In addition, α-santalol induced extrinsic and intrinsic pathways of apoptosis in both cells with activation of caspase-8 and caspase-9. It led to the activation of the executioner caspase-6 and caspase-7 in α-santalol treated MCF-7 cells and caspase-3 and caspase-6 in MDA-MB-231 cells along with strong cleavage of poly(ADP-ribose) polymerase (PARP) in both cells. Taken together, this study for the first time identified strong neoplastic effects against both ER-positive and ER-negative breast cancer cells [95] .

HEPATOPROTECTIVE ACTIVITY

Hydro-alcoholic Extract of the leaves of *Santalum album* Linn.was carried out to determine the hepatoprotective activity in experimentally induced liver injury by carbon tetrachloride and paracetamol. The levels of serum marker enzymes, bilirubin, total protein and antioxidant status were determined by measuring lipid peroxidation, glutathione, superoxide dismutase and catalase activity. Total wet weight and histopathological study of isolated liver was also carried out. The oral pre-treatment with hydroalcoholic extract of the leaves of *S. album* (200 and 400 mg/kg) showed significant hepatoprotective activity against CCl4 and paracetamol induced hepatotoxicity by decreasing the activities of serum marker enzymes, bilirubin and lipid peroxidation, and significant increase in the levels of glutathione, superoxide dismutase, catalase and protein in a dose dependent manner, which was also confirmed by the decrease in the total weight of the liver and histopathological examinations[96] .

ANTI-TYROSINASE AND ANTI-CHOLINESTERASE POTENTIALS OF SANDALWOOD OIL

The anti-tyrosinase and anti-colinestrase potentials of sandalwood oil were probed by TLC-bioautographic and colometric methods. Results obtained from colorimetric assays indicated that sandalwood oil is a potent inhibitor of tyrosinase (IC50 = 171µg/ml) and cholinesterase (IC50 = 4.8-58µg/ml), in comparison with the positive controls used in the assays, kojic acid and physostigmine, respectively. The TLC-bioautographic assays indicated that α-santalol, the major constituent of the oil, is a strong inhibitor of both tyrosinase and cholinesterase. These in vitro results indicate that there is a great potential of this essential oil for use in the treatment of Alzheimer's disease, as well as in skin care[97] .

OLFACTORY RECEPTOR NEURON PROFILING

The mammalian olfactory system can discriminate between volatile molecules with subtle differences in their molecular structures. Efforts in synthetic chemistry have delivered a myriad of smelling compounds of different qualities as well as many molecules with very similar olfactive properties. One important class of molecules in the fragrance industry are sandalwood odorants. Sandalwood oil and four synthetic sandalwood molecules were selected to study the activation profile of

endogenous olfactory receptors when exposed to compounds from the same odorant family. Dissociated rat olfactory receptor neurons were exposed to the sandalwood molecules and the receptor activation studied by monitoring fluxes in the internal calcium concentration. Olfactory receptor neurons were identified that were specifically stimulated by sandalwood compounds. These neurons expressed olfactory receptors that can discriminate between sandalwood odorants with slight differences in their molecular structures. This is the first study in which an important class of perfume compounds was analyzed for its ability to activate endogenous olfactory receptors in olfactory receptor neurons[98] .

EFFECTS ON GENITOURINARY SYSTEM

Genitourinary tract infections such as cystitis and gonorrhea have been treated bysandalwood oil for years owing to the astringent properties of the oil and its effect on the mucus membranes of genitourinary tract; helps remove mucous congestion, restore mucous membrane and minimize the risk of infections such as herpes virus[99 – 101] . These traditional uses make sandalwood oil suitable for anti-ageing skin care, for toning effects and to prevent skin from ugly scars in modern cosmeceutical applications.

ANTI-HYPERGLYCEMIC AND ANTI-HYPER LIPIDEMIC ACTIVITY

Treatment of *S.album*in streptozotocin induced diabetic rats for 60 days demonstrated reduction in blood glucose level. Metformin treated group also showed a decrease in blood glucose as against an increase in diabetic control group. Total cholesterol (TC), low density lipoprotein (LDL) and triglyceride (TG) levels were also decreased in treated diabetic rats whereas, cardioprotective, high density lipoprotein (HDL) were increased. In case of metformin, the values were 11, 29 and 15% respectively, while HDL increased. Significant improvement in atherogenic index was observed in treated rats that led to the conclusion that *S.album* is effective in curing antihyperglycemic and hyperlipidemic activity[102] .

ANTI-ULCER ACTIVITY

Anti-ulcer activity has been reported in Hydro-alcoholic extract of *S. album* stem (SASE) at a dose of 5000 mg/kg. Two test doses of SASE (250 and 500 mg/kg) were subjected to screening of anti-ulcer activity by three *in-vivo* models namely – water immersion - restrain stress, ethanol and indomethacin induced gastric ulceration models in albino wistar rats. A proton-pump inhibitor,

Omeprazole 10 mg/kg and H2 receptor antagonist, Ranitidine 50 mg/kg were employed as standard drugs. The results revealed an increase in gastric protection as a significant decrease ($p < 0.001$) in average number of ulcers, severity of ulcers and cumulative ulcer index test groups. Histopathological evidences supported the above findings. The observed anti-ulcer effect of SASE at 500 mg/kg was comparable to that of standard drugs used in the experiments indicating significant anti-ulcerpotential especially at higher concentration[103].

ANTIPYRETIC EFFECT

The anti-inflammatory effect of sandalwood oil as well as HESP oil was investigated against yeast induced pyrexia in albino rat in dose of 200 mg/kg using 0.2% of tween 80 as control and 100 mg/kg paracetamol as standard. A significantly high antipyretic effect observed in case of sandalwood oil and HESP[104,105].

HAEMOLYTIC ACTIVITY

In a study conducted with the leaf extract of *Santalum album* L, it was found that minimum concentration of 475 µg/ml of the extract produced the lyses of the RBC. However, this haemolytic activity only takes place with parenteral administration. The results of this study have also revealed that the leaves of the plant *Santalum album* Linn contained saponins, which were responsible for haemolytic activities against blood[106].

CARDIOPROTECTIVE ACTIVITY

In a study, Sayeed et al evaluated the protective effect of S. album on doxorubicin induced cardiotoxicity in rat model. They reported that the aqueous extract of S. album significantly inhibits the cardiac tissue damage by reducing lipid peroxidation [39]. The fine powder of the *Sandal safed*was investigated for cardioprotective effect in isoproterenol (ISO) induced myocardial infarction (MI) in albino Wistar rats at two different doses. The results showed significant protective effect against ISO induced MI in dose dependentmanner[107].

ANTIANGINAL EFFECT OF *SANTALUM ALBUM*

A clinical trial was conducted to see the antianginal activity of Kuan- Xiong aerosol, acompound formulation, which contains sandalwood oil along with oils of *Piper longum*, *Dryobalanopsaromatica*, *Asarumseiboldi*, *Alpineaofficinarum*. An immediate and quick relief in anginal pain was proved in 69 cases of angina pectoris with the compound drug in comparison with nitroglycerine[108] .

SANDALWOOD AGAINST COMMON WARTS

Haque M and Coury DL in 2018 carried out the experiment in an open label trial of topical SWO in common warts, during which 10 subjects were asked to apply a drop of SWO onto the wart area twice a day and rub gently after the application with repeat applications every 2 to 3 weeks until 12 weeks. At the end of the study, 8 of 10 (80%) had complete resolution of all treated warts, while remaining 2 had moderate improvement (25% to >90%). None of the subjects complained of skin irritation, erythema, itching, peeling of skin or scarring, pain or discomfort or other adverse events[109] .

EFFECT OF SANDALWOOD OIL AND A-SANTALOL ON HUMANS AFTER TRANSDERMAL ABSORPTION

This study was conducted to investigate the effects of East Indian Sandalwood Oil (EISO) and α-santalol on physiological parameters as well as on mental and emotional conditions in healthy human subjects after transdermal absorption by recording eight physiological parameters, i.e., blood oxygen saturation, blood pressure, breathing rate, eye-blink rate, pulse rate, skin conductance, skin temperature, and surface electromyogram. Subjective mental and emotional condition was assessed by means of rating scales. While α-santalol caused significant physiological changes which are interpreted in terms of a relaxing/sedative effect, sandalwood oil provoked physiological deactivation but behavioral activation. These findings are likely to represent an uncoupling of physiological and behavioral arousal processes by sandalwood oil[110] .

A-SANTALOL AND B-SANTALOL AGAINST ORAL CANCER CELLS

Head and neck squamous cell carcinoma (HNSCC) is the sixth most common cancer worldwide, with no major advancements in treatment over the past 40 years. In a study, carried out with east indian sandalwood oil (EISO) and its two major constituents, α- and β-santalol against a variety of HNSCC

lines exhibited cytotoxic effects and caused accumulation of cells in the G2/M phases of the cell cycle. Additionally, treatment with these agents caused formation of multipolar mitotic spindles similar to those observed upon treatment of cells with compounds that effect microtubule polymerization. Indeed, the santalols, as well as EISO, inhibited the polymerization of purified tubulin, indicating for the first time that these compounds have the ability to directly bind to tubulin and affect microtubule formation. Modeling studies suggest that the santalols can weakly bind to the colchicine site on tubulin, and tropical administration of EISO to a HNSCC xenograft inhibited tumor growth with no observed toxicities[111] .

ANTI-HELMINTIC ACTIVITY

The anthelmintic activity was tested with Aqueous leaf and bark extracts of *Santalum album Linn* on Indian adult earthworms, *Pheretimaposthuma* (annelid) at various concentrations (25, 50 & 100mg/ml) by the determination of the time of paralysis and time of death of worms. These activity was compared with standard Albendazole. The aqueous extract showed significant activity when compared to the standard Albendazole. The paralysis and death time was 64, 60, 55 and 78, 75, 70 minutes respectively at concentrations 25, 50 and 100mg/ml for the bark extract and 80, 74, 69 and 85, 82, 75 minutes respectively at concentrations 20, 50 and 100mg/ml for the leaf extract. Whereas these are 46, 40, 34 min and 62, 58, 50 minutes for Albendazole. The results of this study have also revealed that Flavonoids, Phenols and Tannins in the leaf and bark extracts of *Santalum album* were responsible for its anthelmintic activity[112] .

The soothing and demulcent effects of sandalwood oil have been used to treat respiratory tract infections, specifically chronic bronchitis involving chronic dry cough[113-116] . However clinical trials data are not available for these activities, thus providing opportunities for further clinical 306 and *in vivo* studies.

NITRIC OXIDE SCAVENGING ACTIVITY

The extracts of Indian medicinal plants including *S. album* were examined for their possible regulatory effect on nitric oxide (NO) levels using sodium nitroprusside as an NO donor *in vitro*. Most of the plant extracts demonstrated direct dose dependant scavenging on NO and exhibited significant activity[117] .

ANTI SPASMODIC:

Being a relaxant and sedative in nature, this oil works great against spasm too. It relaxes nerves, muscles and blood vessels and hence ends spasm or contraction. Thus it is helpful in treating problems associated with spasm, such as cramps, aches, coughs etc[118] .

ASTRINGENT:

Although very mild, still sandalwood oil has some astringent properties which induce contraction in gums, muscles and skin. This proves beneficial in terms of strengthening hold of gums on teeth, strengthening of muscles, tightening of skin etc[118] .

ANTI SEPTIC:

Essential Oil of Sandal Wood is very good as an anti septic. It is safe for both internal and external applications. It ingested, it helps protect internal wounds and ulcers from infections. Similarly, when applied on skin, it protects wounds, sores, boils, pimples etc. from infections and from getting septic[118] .

CARMINATIVE AND DIURETIC ACTIVITY:

The Essential Oil of Sandal Wood, being relaxant in nature, induces relaxation in the intestines and abdominal muscles, thereby facilitating removal of gases. It does not also let gases form. Due to its relaxing and anti inflammatory nature, it also soothes inflammations in the urinary system and induces relaxation in it, thereby promoting easy passage of urine. It also increases frequency and quantity of urination. This helps a lot treating the infections and inflammations in the urinary system[118] .

MICROSCOPIC FEATURES

Wood 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 pen oration 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, a few of them contain prismatic crystals of calcium oxalate; xylem rays numerous, run straight, uni to tri-seriate, mostly bi-seriate, thick walled, radially

elongated having golden yellow to brownish contents and contain a few prismatic crystals of calcium oxalate[119].

SANDALWOOD ESSENTIAL OIL MICROCAPSULES IN DETERGENTS

In this latest study, β-cyclodextrin as the wall material and SEO as the core material, the molecular inclusion-n complex method was applied to obtain the SEO / β-cyclodextrin microcapsules under certain preparation conditions, and their morphology was characterized by SEM. When the stirring temperature is 55 °C, the coreto- wall ratio is 1:16 (mass ratio), the stirring speed is 250 r/min, and the stirring time is 4hr, the micro-sized spherical SEO microcapsules can be prepared, with the encapsulation rate of 10.02 %. Then, through the analysis of the experimental results, it's found that the ratio of SEO to β-cyclodextrin is a key factor in the formation of spherical microcapsules, which may be related to the structure of wall-wood sandalwood oil and β-cyclodextrin. Finally, the SEO / β-cyclodextrin microcapsules were analysed in terms of sustained release property and thermogravimetry. The test results showed that the SEO capsule has excellent sustained release performance and thermal stability, which is presumably due to the wall material β-cyclodextrin acting as a barrier to encapsulate the core material and improve the sustained release property. With good sustained release property and thermal stability, SEO microcapsule can be used to increase the flavor of detergents and cleansers[120].

COSMETIC THERAPY OF*SANTALUM ALBUM L.*

Apart from its pharmacological activity, *S.album* has also gained huge attention towards cosmetic and beauty therapy. In recent days peoples are becoming very concerned about their skin and beauty like dark spots, rashes, pimples, acne scars etc. Thus, sandalwood which is one of the precious gift of the nature, can be used as a home remedy to tackle such problems. Few home remedies of *S.album* are listed below:

SANDALWOOD REMEDY FOR INSECT BITE AND PRICKLY HEAT

Sandalwood paste help to get rid of prickly heat, and heal insect bites. The soothing and cooling effects of sandalwood paste, makes it an ideal remedy for prickly heat. Similarly, due to its antiseptic and anti-inflammatory properties, it can be used for treating minor burn, cut and insect bites. Just add turmeric powder (another herbal antiseptic) and milk to sandalwood powder and make a paste to apply on the affected area[118].

SANDALWOOD REMEDY FOR SKIN CARE

For skin care Sandalwood powder and rose water can be mixed to make a thick paste to apply on skin. It can be effective in removing acne and acne scar. Just apply the paste on the affected are of the skin and leave for about half an hour. Then use lukewarm water to wash it off.

Turmeric and sandalwood paste is effective for removing Pimples, just to do is to mix equal quantity of sandalwood powder and turmeric and then add some water to it. Now mix them properly to make a fine and thick paste. Apply this paste on the pimples and leave overnight. On the next morning, you can wash it off with lukewarm water. This paste will not only help you to get rid of pimples, but also from acne scars[118] .

SANDALWOOD REMEDY FOR FAIR AND SMOOTH COMPLEXION

Sandalwood powder or paste is widely used to lighten skin complexion and treat sunburnt skin. To get a radiant complexion, mix sandalwood powder with coconut oil. You can also add a small amount of almond oil to it. Mix all these ingredients to make a paste and apply it on your face. Leave for about half an hour and then wash with lukewarm water. It will remove sun tan and make your complexion even[118] .

SANDALWOOD REMEDY FOR ANTI-AGING

Progressing age and continuous cellular damage caused by free radicals lead to the appearance of wrinkles, fine lines and furrows. But it can be prevented and controlled with regular consumption of anti aging fruits and juices and use of sandalwood remedies. Mix 2 teaspoon of sandalwood powder with 1 egg yolk and 1 teaspoon of honey. Apply the pack evenly on face and neck. Wait for 1 hour and wash with water it helps in increasing the elasticity of sagging and drooping skin[121].

SANDALWOOD REMEDY FOR ANTI-TANNING

A day out in the beach or a picnic in the park can be fun and full of enjoyment, but it takes a harsh toll on the exposed skin causing severe skin tanning. But, sandalwood is the ultimate solution to the question of how to protect our face from the sun. Mix one teaspoon of sandalwood powder with 1 teaspoon of sour curd and ½ teaspoon of honey. Blend it well and apply on face, hands and other tanned

areas of the body. Leave it on for 1 hour and wash off with water. It not only add natural glow to skin but alsoremoves skin tan [121].

GENETICS AND KARYOTYPE ANALYSISOF *SANTALUM ALBUM L.*

A karyomorphological study on *Santalum album* was conducted for the first time. This study carried out by Jaime A. Teixeira da Silva, et.alon 13 June 2015 confirmed previous ones in which the somatic chromosome number of *S. album* was noted as 2n=20 and with basic chromosome number x =10[122-124] . A mixoploid (2n=2x=20 and 2n=4x=40) was found for the first time for *S. album* in their study. The karyotype of *S. album*, reported for the first time in the present study for this hardwood species, showed a predominance of chromosomes with centromeres in a median position and a few sub-median centromeres. Moreover, the arm ratios of only a few chromosome pairs exceeded 2.0, while most others ranged from 1.13 to 1.49. This indicated that the intrachromosomal symmetry in *S. album* was very high. Stebbins[125]pointed out that karyotype evolution is generally from symmetry to asymmetry in higher plants. In other words, primitive plants have symmetric karyotypes whereas asymmetric karyotypes occur in more evolutionary advanced taxa. Karyotypic analysis indicates that *S. album* was a more primitive taxon. In the tetraploid (2n=40) accessions analyzed, the chromosomes were relatively larger in size than those of the diploids (2n=20). This was consistent with a report by Srimathi and Sreenivasaya[126] in which there was a 2- to 5-fold increase in the size of the chromosomes of the haustoria. There were two groups of submetacentric chromosomes in the tetraploids; however, only one such pair was found in diploids. Satellites occurred in the tetraploids. Mixoploidy is induced by natural, artificial or chemical factors. To date, many mixoploids have been documented[127-128] . The majority were found in anther culture regenerants. This phenomenon was thought to be caused by the application of plant growth regulators such as kinetin, indole-3-acetic acid (IAA), 2,4-dichlorophenoxyacetic acid (2,4-D), TDZ and BAP[138] claimed that the occurrence of tetra-ploidy in *Rubusparvifolius*L. (Rosaceae) was related toab normal mitosis in some diploid cells[141] reported cytomixis in the anthers of *S. album*, i.e. two microspore mother cells lying near each other became connected through a narrow projection forming a sort of conjunction tube and this resulted in the mixing of cytoplasm andnuclear contents of the two cells. It occurred inthose cells showing the presence of restitutional nuclei or some other similar irregular division.He also frequently observed that only three cellswere organized in *S. album* and that one of the microspores was fairly large with two nuclei while the other two were of normal size and uninucleate. Polyspory was reported in pollen meiosis of *S. album*

L.[142-144] observed that many *S. album* haustorium cells had 40 chromosomes, possibly endopolyploidy, which might berelated to physiological traits of the haustoria, such as the presence of IAA and other related plant growth regulators. In the present study, we found a mixoploid (2x +4x) in shoot-tip meristems of sandalwood seedlings, but the ratio wassmall, accounting for about 5% of the accessions analyzed. This might have been caused by abnormal mitosis or meiosis induced by a doublingin chromosome number. The genus *Santalum* distributed through out India, Indonesia, and Australia is diploid[142] Hawaiian clades are tetraploid[159]. Bystudying data from flow cytometric analysis of Pacific island sandalwoods[146]reported that *Santalum* appeared to include tetraploidies, ranging from diploid (n=10) to octoploid (n =40). The majority were diploid andtetraploid, and *S. album* was diploid among allthe accessions investigated. Even the ploidy levels of taxa within the same section in the genus were not completely consistent. For example, *S. freycinetianum* was related to *S. album* and they were all clustered into the same section, eventhough *S. freycinetianum* is tetraploid. There is evidence that *Santalum* polyploids have already colonized the Pacific islands[146].In the present study, about 95% of shoot tipsof *S. album* accessions analyzed were diploid, with the exception of 5%, which were 2x+4xmixoploids. The specimens collected were from sandal wood distributed in South India. Thisindicates that the ploidy of *S. album* is slightly different depending on the geographical region. The occurrence of polyploidy and mixoploidy in *S. album* deserves further investigation in combination with the species' geographical distribution[147].

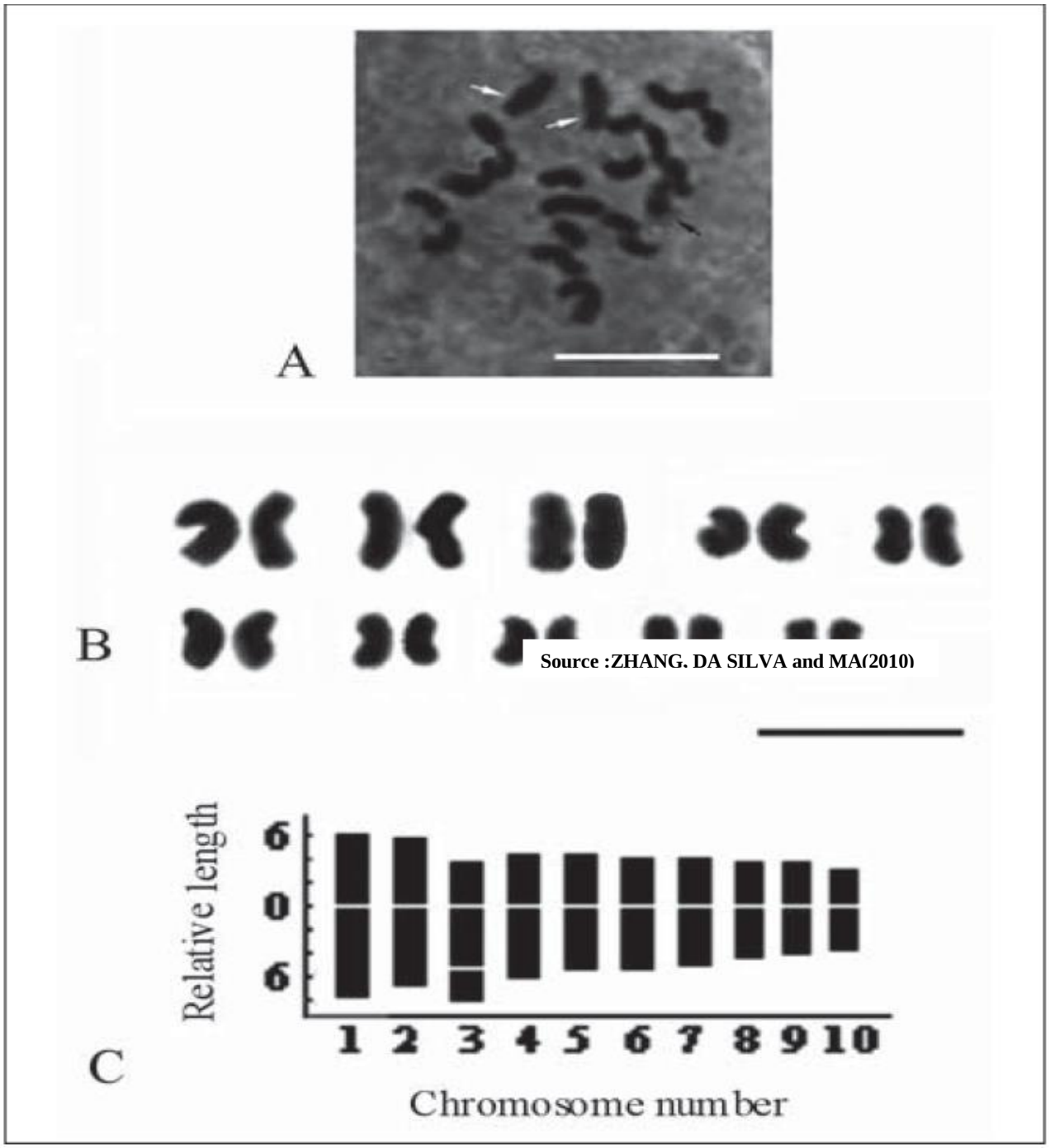


Figure - 12: Somatic metaphase chromosomes (A), karyogram (B), and idiogram (C) of the diploid *S. ablum*. White arrows and black arrows indicate secondary constrictions and supernumerary chromosome, respectively.

MONOPOLY OF SANDALWOOD TRADE AND ITS CURRENT STATUS IN INDIA

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 16th century13. 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. 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. The classification of the sorted sandalwood into 18 classes was introduced in 1898. 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 sandal wood oil factory. Outbreak of the World War I had a severe impact on the forest economy of Mysore due to 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, 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 professors J. J. Sudbourough and H. E. Watson, scientists working at the Indian Institute of Science (IISc), Bengaluru16. 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 sandal oil gained international popularity for its fine quality[148].

Over 70 years ago, nearly 90% of the natural sandalwood populations occurred in the southern part of Karnataka and northern part of Tamil Nadu. Excessive harvesting without replenishment of this invaluable resource has substantially reduced the sandalwood industry, resulting in global shortage and soaring of market prices[148]. At present sandalwood scarcity is looming in bothIndia and Indonesia, the main producers of S. *album.*In these countries, the decline in the sandalwood resource is due to heavy pressure for clearing forested land for food production, the destruction of sandal host trees for wood

products such as fuel wood, and illegal harvesting. For example, in India the volume in the official sales of sandalwood from the two main producing States, Kamataka and Tamil Nadu, has declined. Also, whereas 25 years ago only 10 trees were harvested to produce a tonne of sandalwood, about 100 trees are required now (Karnataka and Tarnil Nadu State Forest Department data), indicating that the average size of S. *album* trees being harvested has fallen significantly. This is strong evidence of serious resource decline. There is interest in *Santalum* species plantation establishment in response to the pressures on sandalwood supplies. In many developing countries, a major incentive to plantation establishment is the increasing pressure for conversion of natural forest land to agriculture. This means that increasing demands for timber supplies must be met, at least in part, by producing more timber from intensively managed plantations. For *Santalum*, plantations are the only way to redress increasing problems of resource availability of this important genus. It is important that the Indian supply of sandalwood be maintained: if it disappears, there are potentially serious downstream effects for Australia and South Pacific producers such as PNG, Vanuatu and Fiji. If the natural sandalwood market collapses due to supplies declining below a certain level, there could be three serious outcomes for those countries. First, there would be overwhelming pressure to overharvest to compensate for the loss of the Indian resource, thus destroying current management programs, and possibly leading to the loss of some species. Second, the opportunity to develop viable and sustainable industries based on S. *yasi*, S. *macgregori* and S. *austrocaledonicum*in the smaller South Pacific countries would be lost. Third, alternatives to sandalwood or sandalwood oil may be found, making it difficult to recapture the market when plantation sandalwood becomes available[149]. Realizing the sharp decline in the sandalwood population, the Karnataka and Tamil Nadu Forest Departments amended the Sandalwood Act in 2001 and 2002 respectively and made the grower himself a owner of the sandalwood as per the Amended Act. Further, Govt. of Karnataka already made amendments on the sale of Sandalwood through Forest Dept. & Govt. Departments to eliminate the clandestine trade and to encourage farmers to take cultivation of Sandalwood on commercial scale during the recent years.

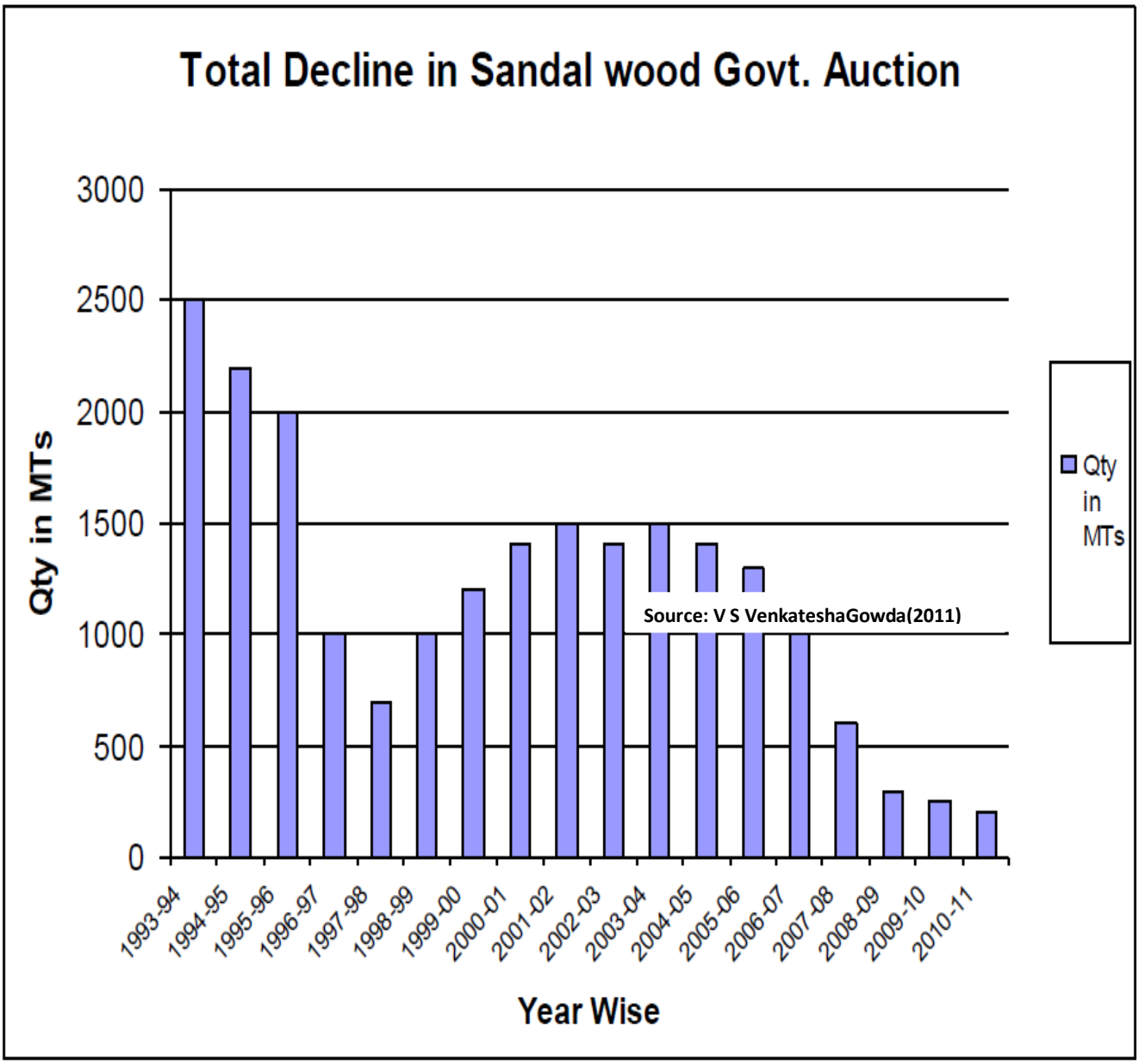


Figure - 13: Total Decline in sandalwood Govt.Auction

TRADE LIBERALISATION IN SANDALWOOD

Wherever the sandal tree is found in Kamataka, itis the property of the State Government No-one is allowed to buy, sell or trade except through the Forest Department. The major quantity of heartwood obtained from dead and dying trees has been harvested for Sandal Oil Factories at Mysore and Shimoga. Small quantities are being released on a retail sale basis and for temples and carving. Small consignments were also exported on a trial basis by the Kamataka State Forest Industries Corporation.

Restriction on Trade

Each state has its own rules and regulations on sandal trees. Indeed, the Sandalwood Advisory Committee formed by the Government of India could not make any positive suggestions to satisfy all the member states, This itself can be a problem. For example, in Kerala, even though sandal trees are not available in appreciable quantities, several small-scale sandalwood distilleries have been established along the border of Kamataka and Tamil Nadu and most of the

smuggled billets reach there. The reduced intake by the sandal oil factories of Mysore and Shimoga has caused a large accumulation of sandal heartwood stock in the kotis of the Forest Department of Kamataka. This has caused anxiety about fire protection during storage, leading to payment of huge insurance premiums annually[150].

Sandalwood is an exclusive property of the Karnataka State Government (s. 84), and under section 85, the landholders are responsible for the preservation of all sandal trees grown thereon. If they fail to report any theft of or injury to sandal trees, they are liable for a penalty and for compensation to the State Government. Conviction of an offence pertaining to sandal trees brings imprisonment up to seven years and fines up to Rs.25000. Such stringent rules have discouraged sandal trees in private landholdings. People uproot the sandal recruits and small seedlings to avoid responsibility and future penalty in the event of any offence. This has considerably reduced the population of sandal trees on private holdings. A licence to store, sell or disintegrate sandalwood or sandalwood oil is required under section 87. This has also discouraged entrepreneurs from taking up industries based on sandalwood as raw material such as soaps and perfumery products. The sandalwood definition under section 2(18) includes even bark and leaves which have no monetary value, yet the same restrictions and penalties are imposed, thereby further impeding the growing of sandal trees. Under Karnataka Forest Rules (KFR) 1969, section104, all owners are required to declare the presence of sandal trees on their land, and renew

that record every five years to include all new recruits. The owner will have right to bonus on harvesting only if he has declared the trees to the local Division Forest Officer.

This in fact binds him to protect the sandal trees, failing which he becomes liable for penalty and punishment as well as compensation. Therefore many people believe it is safer to remove and destroy sandal trees as they regenerate on their land[150].Normally dead and dying trees are harvestedby the Forest Department; but if one wants to remove a few living trees to make room for buildings, plantings, or other purposes, it may take many months before approval is granted. All these procedures, rules and delays have put a curse on the existence of sandal trees on private lands. Even if one or two mature sandal trees are available on any private lands, it is always under threat of illicit felling or smuggling, leading to harassment of owners by the Police or Forest Department.

Liberalised Trade

In this period of liberalisation in all sectors, it is necessary to review the various restrictions and amend the legislation to bring in free trade in sandalwood also. People should be able to possess and sell sandalwood to anyone who offers a good price. The Forest Department should make arrangements to protect their own forest produce without imposing any restrictions on others' material. This will encourage people to grow more and more sandal trees becauseof the value it fetches at present. Moreover, people must also grow other tree species as host plants, and this itself will encourage tree-growing. This would indirectly help in bringing more trees onto farm lands thus improving the ecology and environment of the locality. Sandal trees are not very specific to soil and climatic conditions and establish quickly and easily in many soil types and climates. Hence growing sandal trees will be attractive as a supplementary income. Once the population of sandal trees increases and the market rate stabilises, there will be no need to fear theft or smuggling because people themselves will protect their valuable property. Also, the price may ultimately come down making it less attractive for smugglers[150] .

SANDALWOOD RESEARCH AT GLOBAL PERSPECTIVE

Scientific research on sandalwood started in the period of 1940-50. It was commenced with the silvicultural trials because that was the time the sandalwood, especially *S. album* was started to introduce to countries like Australia from its native range of existence. From that era, research evolves from silvicultural studies, ecological studies to oil chemistry and genetics. Most of such researches were funded by the different research institutes and different governments due to the importance of having

new information on these species. However, according to the reputed sandalwood research devotees, still there are areas to be further explored in sandalwood research[151]. The following sections analyse the researches conducted on different areas of sandalwood in the past.

1.SILVICULTURE AND PROPAGATION [151]

Silviculture research of sandalwood perhaps has the longest history among all types of sandalwood research conducted in the past. *S. album* was frequently studied in this aspect mainly becausethis species was tried to introduce to many new locations or countries as its oil has the highest value among all sandalwood species. Seed germination was given a priority among the silvicutlure studies by many researchers around the world, e.g.,[152– 158] . The reason of this was due to the prolonging dormancy period and low germination rates of sandalwood seeds. Prof. J.E.D. Fox was one of the pioneers to study the silviculture and host species of *S. album* in the world[154-158] . Following his work, many researches were conducted in the recent past on the effect of different host species in different localities, e.g., Subasinghe and Hettiarachchi (Unpublished),[159] . Those studies conducted on *S. album* showed a variation of results. However, the most commonly identified suitable hosts by the above mentioned researches were *Pongaminapinnata*, *Casuarina equestifolia*and *Sesbenia grandiflora*. In 2004, Brand et al conducted a study on the effect of *Acacia* host species on *S. spicatum* growing in Australia and they found out *A. saligna*and *A. acuminate*as the best species. However, those studies should be further researched to find out the most suitable species for different climatic regions.

There was an interest among the researchers especially in the Pacific region from the past to formhybrids of sandalwood. These studies mainly focused on producing higher contents of sandalwood oils with a better survival rate. According to Ananthapathmanabha[160] ,*S. album* X *S. yasi*hybrid called F1 shows a more vigour and an average of 7% oil which is almost impossible to obtain from the parent trees. In 1998 McComb and Jones attempted to form a hybrid using *S. album* and *S. spicatum* using *in vitro*culture method. A trial established in Hawaiian Ethnobotanical Garden of Honolulu in 1959 in hybridisation of *S. frecinetianum*and *S. album* is still present. However, there is a debate on the quality of the oil produced by those hybrids and further, there is a fear among the top level sandalwood merchants in entering low quality sandalwood oils by the hybrid species to the market. Biotechnological approaches were also attempted to propagate *S. album* in mass scale by many scientists. Bapat and Rao and Sanjaya et al in 1998 conducted detailed studies on that aspect in India[159, 160] .

2. PESTS AND DISEASES OF SANDALWOOD[160]

Large scale plantation programs have necessitated a demand for planting stock, for which nurseries have been established in different states. Good quality seeds and grafts of superior clones are used for the production of plants. Sandalwood seedlings and grafted plants face problems from insects pets and diseases, which take a heavy troll and sometimes the whole stock is wiped off. More than 150 insects are known to occur on *S.album*, but only a few have been recorded as serious and bearing economic importance. These includes defoliators, sapsuckers, steam borers and termites.

Defoliators

Sandalwood seedlings in the nursery are subjected mainly to attack by defoliators and sapsuckers. *Crytotheleacramerii* Westwood cuts off the young seedlings, almost at ground level. A bag is constructed of small pieces, of the seedling stem, and these are placed side by side so as to form a cylindrical bag open at both ends. The sandalwood seedlings ultimately dry up. The weevil Sympiezomias cretaceous Faust (Curculionidae: Coleoptera), a polyphagous weevil feeds on the leaves from the edges towards the midrib. Sometimes the distal half of the leaves gets cut off as a result of circular holes made in a line by the adult weevils. The nymph and adults of the grasshopper, *Holochloraalbida* Kirby (Locustidae: Orthoptera) are green resembling a leaf. These hoppers usually gnaw on tender shoots of sandalwood seedlings.

The nymphs and adults of the grasshopper, *Letana inflate* Brunner are slender and resemble the stem of sandalwood seedlings. They feed voraciously on the foliage. The eggs are laid in longitudinal slits in succulent sandalwood seedlings stems and the slit swells and cracks laterally,damaging the seedlings.

The nymphs and adults of the grasshopper, Teratodesmonticollis Gray (Acrididae: Orthoptera) are dull green, brighter under the wings. The pronotum is produced into a sharp hood over the body, giving it a striking appearance. Its green color and appearance camouflages well with the sandalwood seedlings. They have been observed as a serious defoliator of sandalwood seedlings.

The bagworm, *Acanthopsychemoorei* Heyl (Psychidae: *Lepidoptera*) carries its bag upright at right angles to the stem or leaf of the seedlings, but in the later instars the bag is heavy and is carried in a

pendant position. The black caterpillar was seen defoliating the sandalwood seedlings giving a burnt appearance to the leaves.

The attack of bagworm, *Pteroma plagiophelps*Hampson (Psychidae: *Lepidoptera*) results in total defoliation and drying up of sandalwood seedlings. Defoliation by these bagworms also impart a burnt appearance to leaves.

Sapsuckers

About 50 species of sap sucking insects were recorded on *Santalum album* by Mathur and Singh[161]. Out of these, only a few are considered injurious to the sandalwood seedlings. Most of the coccids attack both sandalwood seedlings and trees. Use of sandalwood twigs for grafting purposes, when affected by coccids, has led to the failure of grafted plants. As the coccids produce honeydew, badly infested plants get completely covered by sooty molds, which reduce photosynthesis the vigor of sandalwood seedlings.

Two species of coccids, *Saissetiacoffeae* and *S. nigra*were first recorded in Coimbatore on Sandal[162]. The adult female of *S. coffee* Targioni- Tozzetti is elliptical in outline, convex, brown and shiny. *S. nigra* Nietner females are black and larger. The nymphs move and settle on the under part of the sandalwood plant. These scales feed on the sap of leaves and tender shoots of sandalwood seedlings, causing die back. The coccid, *Aspidiotus*sp. Is a minor pet causing witling and yellowing of the leaves of nursery plants.

The coccid, *Ceroplastesactiniformis* Green has a thick pale white or pink waxy spherical test and the marginal area is divided into eight portions, which enclose a central cone area. Being sapsuckers, they cause severe sap drainage and sooty mold formation on the leaves below. The sap drainage leads to die back and ultimate death of sandalwood seedlings in nurseries. Spraying with monocrotophos (0.02-0.05%) kills this coccid.

The coccid, *Pulvinariapsiddi*Mask is a common and destructive polyphagous insect in many sandalwood nurseries. The coccid, *P. maxima* Green is a new record on sandalwood seedlings and is found very common on Neem. Sometimes it is considered to cause considerable damage to young

sandalwood trees. The leathery pale brown adult females cover the tender shoots and stems in numbers and the white male scales are generally found conspicuously on the sandalwood leaves. The ovisacs are prominent and comparatively very long. The infestations leads to premature fall off the leaves.

Spike Disease

Spike disease is one of the important diseases of sandal. The disease was first noticed in Frazerpet (Coorg, Karnataka) by McCarthy as early as 1899. Disease is caused by mycoplasma-like organisms (MLO). 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 of disease the inter-nodal distance on twigs becomes small, haustorial connection between the host and sandal breaks and the plant dies in about 2 to 3 years. Spread of disease is sporadic and the disease is transmitted in nature by insect vectors. It has been found that other insect vectors in addition to *Nephotettixvirescens*may also be responsible for transmission of disease. So far no permanent remedial measures have been prescribed for control of spike disease. Stem borers *Zeuzeracoffease*Nietn (red borer) *Indarbelaquar denotata* Walker (bark-feeding caterpillar) and *Aristobiaoctofasiculata*Aurivillius (heartwood borer) are some of the pests causing considerable damage to living trees.

3.VARIABILITY IN COMPOSITION OF OIL FROM INDIAN SANDALWOOD[163]

Various studies have been carried out for documenting variation in oil content and its composition. The variation of oil content in 6 year old *S. album* was estimated from 0.64% to 1.78%. The studies carried out in Sri Lanka by Suba singh *et al.* (2013) on *S. album* showed a higher variation of oil content and they found high oil content, *i.e.* up to 6.36%. Further, the research was conducted on the estimation of alpha and beta santalol levels in *S. album, Santalum spicatum, S. yasi, Santalum austrocaledonicum* by some other researcher as well. Moreover, the content and composition of oil from the central and transition zones of the Sandalwood disc analysis of growth and oil composition[164-166] and solvent extractable volatile profiling[166] from heartwood of East Indian sandalwood tree are the few studies in this direction. It has been found that in most of these studies the growing conditions or environments were not similar. Moreover, the quantities of the heartwood for extracting oil were not sufficient, which also plays an important role in estimating oil yield and its composition. Variations in

the composition of oil from trees grown in homogenous condition may have an effect on the quality of SW oil, which could lead to inconsistency in medicinal and aromatherapy properties. In this connection, it is imperative to understand and estimate the yield and chemical composition of Sandalwood oil from mature Sandalwood tree grown in homogenous conditions.

When the heartwood samples of *S. album* having different girth size *i.e.*, 47.1, 53.4, 61.2, 69.1, 72.2, 74, 75.4, 81.6 and 82.4 cm were analysed for oil yield, the it was found that oil content from these samples varied from 1.6 to 3.6 %. Highest % yield of oil (3.6%) was observed in tree with girth 72.2 cm while the lowest % oil yield *i.e.* 1.7 and 1.6% in tree with girth size 69.1 cm and 72.2 respectively. The values of physical parameters such as relative density and specific gravity of the oils were observed within the limit of high-quality SW oil (ISO 2002). The colour were observed as colourless to pale yellow and refractive index (1.501–1.5025) of the oil were almost consistent with the all samples while specific gravity was varies from 0.9435-0.974.

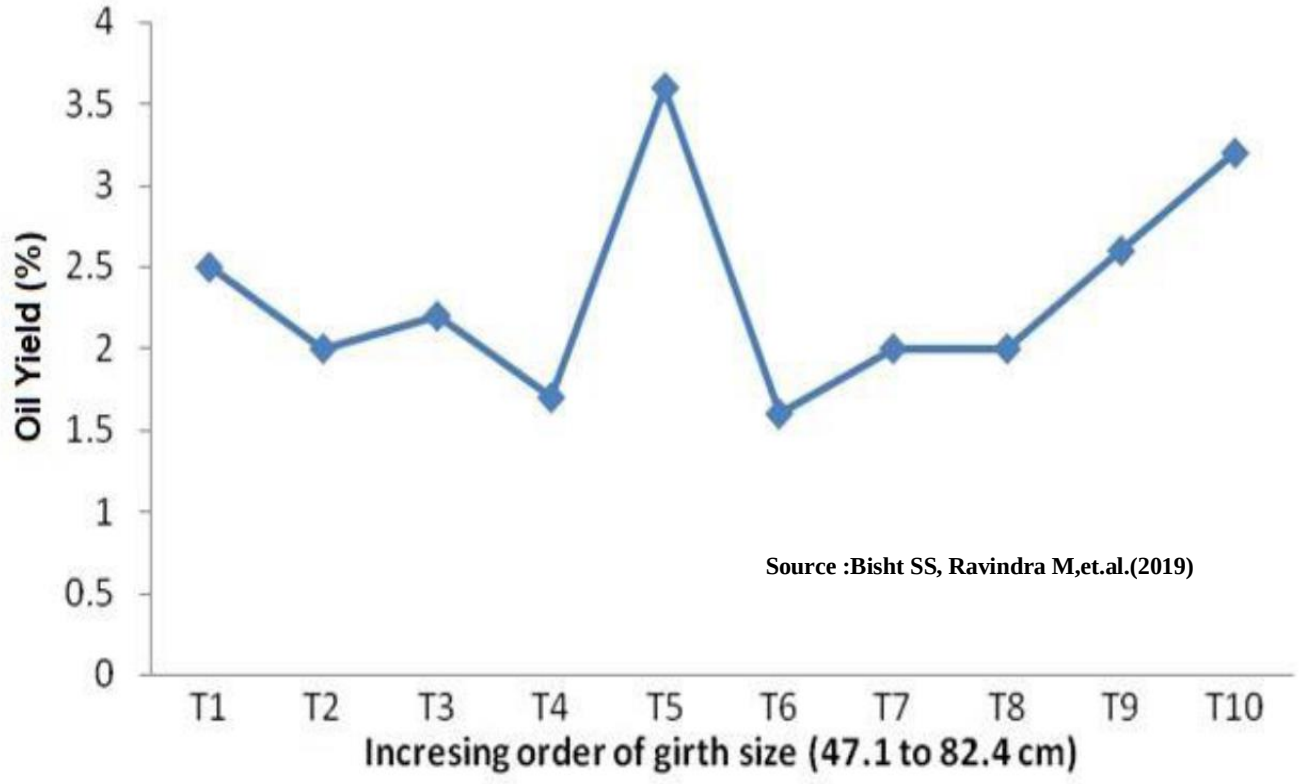


Figure14:Variation trend of % SW oil yield in different girth SW trees.

CHALLENGES OF SANDALWOOD FARMING IN INDIA

To counter challenges in physical protection of mature trees (from 10th year onwards) from theft, farmers have to invest in securing the plantation by investing in tamper proof boundary walls, engaging security staff for patrolling along with trained dogs especially in large scale plantation areas. Remote surveillance systems similar to home security systems are being implemented by companies like Hitachi India Pvt Ltd in recent times. However, these are still in the R&D phase and have not been fully commercialized as yet. Due to the long gestation period of sandalwood (15-20years) under farming situations, the main challenge is to generate a sustained income during the period to meet the cost of protection and maintenance. The opportunity in sandalwood agro-forestry is to introduce horticulture species as secondary host along with short term primary hosts and annual intercrops whenever and wherever possible. Horticulture crops like pomegranate, guava, citrus, *Syzigiumcumini*(Jamun), grafted mango, grafted Indian gooseberry (amla), custard apple (sitaphal) have been tried out by farmers across India with varying degrees of success. However, there is no standard package of practices available on horticulture crops depending on soil, climate and market. ICAR institutions engaged in agroforestry research in semiarid areas like CAFRI, Jhansi, CRIDA, and Hyderabad should set up sandalwood based agroforestry demonstration plots with horticulture species as secondary hosts for demonstration to farmers incorporating latest scientific technologies and R&D inputs. This will perhaps go a long way to promote sandalwood in combination with horticulture in the country[169] .

SANDALWOOD: THE SAVIOUR OF ECOLOGICAL BALANCE AND SUPER WEALTH CREATOR

Nearly 25 species of the genus Santalum L. commonly known as sandalwood are awaiting their turn to transform the ecological balance of nature after suffering serious setback and gross depletion due to indiscriminate hacking in the past. The wild existence of the leading species *Santalum album* L. has suffered to the highest level. Natural as well as artificial regeneration could conceivably rejuvenate their existence and thus provide an extremely valuable natural resource that could be harvested on a sustainable basis. Planned plantations of these species, individually or in various combinations, is capable of fulfilling almost all the luxuries of the futuristic progressive civilization, mainly through their fragrant and beautiful wood and its products. Considering their semi parasitic nature, additional advantages can also accrue through the intercropping of more than 300 host plants. The flow of food, fodder,fuel, fibre, fruits,flowers and ,fragrance is likely to provide additional sources of income.

Collectively they can form a basis for lucrative and exploitative trade in future. Although the initial establishment of plantations is challenging, once established, sandalwood trees withstand all the vagaries of nature due to their tough, hardy and tenacious nature. Moreover, they possess good regeneration potential and an ability to colonise new and suitable sites. The species can be planted practically anywhere with the help of available modern technologies. The existing research gaps need the immediate attention of the scientists as the production and utilization of woods of this type is perhaps the need of the day[170] .

CONCLUSION

Santalum album is a prized gift of the plant kingdom woven into the culture and heritage of India. With more than 200 constituents, the essential oil is emergent as an interesting and biologically valuable active source of phytochemicals. Therapeutic potentials associated with this plant and its active chemical ingredients promise future healthcare applications, as shown by abovementioned pharmacological investigations, such as the roles of santalols in combating cancer, tumor, viral diseases, microbes, oxidants, as well as anti-ulcer, skin nourishing agent and as its dietary factors, thus supporting its traditional uses. The aim of this review is comprehend and put forth, available information on biological activities of this plant from a pharmacological point of view for future directions in clinical applications. This review also deals with some cosmetics and beauty therapy as well the global oil production details. India is in the first position in the export of raw materials of *Santalum album* and it must be in the first position in future, therefore, we have to increase the area of healthy Sandalwood plantations, protect them and government should give priority for the Research and Development of the *Santalum album* to increase export of the quality raw material.

Here, the few suggestions are enlisted which can be implemented to increase the output of *Santalum album*:

- Only Quality planting material (QPM) stock where seed source is known should be procured by farmers for planting purposes.

- Sandalwood plants procured should be raised only by certified and accredited nurseries. The certification agency could be the various institutes of ICFRE/state Forest departments/public sector undertakings like KSDL Karnataka.

- Scientific management inputs should be adhered to in initial stages of raising sandalwood like spacing, host management, intercropping, pruning of sandalwood trees, fertilization, drip irrigation and pest management. There is 5 day training programme on sandalwood being conducted at Institute of Wood science and Technology (IWST), Bangalore twice a year which can be accessed in the website (http://iwst.icfre.gov.in/). Prospective farmers and nursery men can register for the training and get scientific and practical inputs on sandalwood cultivation.

- Currently there are innumerable half-baked nurserymen turned 'consultants' masquerading as sandalwood experts. Prospective sandalwood farmers should be able to sift the grains from the chaff and not fall prey to them. It is always better to enter into an MOU with Govt. agencies like IWST, KSDL etc for continued support in plantation programmes.

- Protection of growing sandalwood trees has become a major constraint for farmers. Protection of trees requires an investment cost equivalent to 30 % of the expected revenue. Rather than relying on physical protection of trees, farmers could explore the possibilities of installing remote surveillance and protection systems that is available and being offered by companies like Hitachi India Pvt Ltd.

- Rules and regulations regarding procurement of sandalwood from farmers by private entities need to be explored for enhancing profits to cultivator. Currently a monopsony situation exists where there is only a single buyer in the market which is the Forest Dept or Govt undertakings. Markets need to be liberalized further which will fall under the ambit of policy and governance.

- Currently there are no schemes by commercial financial institutions on sandalwood tree insurance. It is desirable that nationalized banks come forward with finance schemes for sandalwood cultivation. Insurance companies should also float schemes on tree insurance like in the case of horticulture crops. Currently some State Medical Plant Boards are encouraging sandalwood cultivation by offering subsidy schemes which is an added incentive[171].

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