Final Project Report

Protocol for Quality Testing of Sandalwood and Market Potential for Seed, Oil, Wood

Submitted To
Telangana State Forest Development Corporation

BY

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Project Title: Protocol for quality testing of sandalwood and market potential for seed, oil, wood.

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Aim: To establish the novel approach of determining the concentration of α- and β-santalol isomers in sandalwood oil for quality evaluation using gas chromatography and to assess the market potential for seed, oil, wood.

Objectives:

(i) To develop and optimize the methodology for extraction of sandalwood oil for enrichment of α- and β-santalol

(ii) To develop a gas chromatograph methodology for resolution and quantitation of α- and β-santalol from the sandalwood oil based on retention times of authentic standards

(iii) To present the market potential for seed, oil, wood based on the existing trends of production and demand

Introduction

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

US$ 2000 per kg. At present, due to dearth of sizable trees, Sandalwood trees are rarely utilized for fine wood-crafting as before.

Sandalwood is an evergreen tree, and it grows up to 9 m in height. The age of the tree could be about 100 years. The tree is adaptable in natural habitat, customarily straight to spreading, and may possibly interlock with other species. It parasitizes neighbouring plant species roots via a haustorium adaptation, i.e., a non-obligate association, however, causes no major damage to its hosts. This adaptation with other plants helps the tree to obtain macronutrients, nitrogen, phosphorus, and potassium, particularly during its initial stages of growth. During the early growth phases, it establishes small stands and may propagate itself via wood suckering. In younger trees, the bark is observed to be black in colour, but cracked with redness. The heartwood is very hard and yellow-brown in colour. The heartwood is fragrant in nature with an oily texture. The leaves appear to be thin and opposite with ovate to lanceolate shape. Leaves are bright green with a shiny glabrous surface. Fruits are formed after 36 months, however, viable seeds are produced only after 60 months. Seeds dispersal happens through birds.

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

The main reason for the economic and cultural value of Sandalwood is the oil contained in the Sandalwood timber, mainly in the heartwood. Noteworthy to mention that heartwood oil content differs widely within the species and between species of *Santalum*.

Sandalwood is renowned for its oil, which is extremely appraised for its sweet-smelling, persistent aroma, and the fixative property, which is highly demanded by the perfume industry.

Sandalwood oil has a wide range of ethnomedicinal uses, especially for treating common colds, skin diseases, bronchitis, heart illnesses, common faintness, fever, the urinary tract infections, inflammations, liver diseases, and other illnesses [1]. The antioxidant and antihyperglycemic potentials of Sandalwood oil and its major phytoconstituents, α-santalol have been proven in animal models [2]. Further, different parts of the tree have been shown to have antimicrobial, anti-proliferative, and antioxidant properties, probably credited to phytoconstituents, such as α-santalol, sesquiterpenoids, shikimic acid, etc [2-5]. Earlier reports indicated that heartwood of Sandalwood was priced at INR 12 lakhs per tonne and oil was priced at INR 22,000 per kg [6]. However, the rates are highly determined by the quality of oil. Due to the high value of oil and timber, Sandalwood has been central among all Sandalwood species in the aspect of research [7].

Currently, most of the world demand of Sandalwood is supplied from Australia using *S. spicatum* known as Australian Sandalwood. Due to the high value and the demand, there is a growing attention at present in establishing Sandalwood, especially Sandalwood plantations in the tropical regions over the most demanding other forest plantation species, i.e., teak, mahogany, etc. by the private sector plantation companies, due to the large domestic demand and the existing high demand. In accordance with that, there is a trend in Sandalwood plantation establishment in Australia, India, Sri Lanka, China, and Fiji since recently. However, the plantation sector lacks the information on establishing Sandalwood plantations, which is identified as a great risk when considering their profit maximizing goal. Without the knowledge of nursery techniques, host suitability, plantation establishment, growth rates, and

oil characteristics, managers of Sandalwood plantations might therefore face difficulties in achieving the expected revenue outcomes [7].

Over the years, there has been a decline in Sandalwood production, resulting in the declined production of the essential oil. With stocks of South India's most valuable forest commodity getting depleted, it is necessary to intensify research towards evolving improved varieties. The species is experiencing population decline from illegal harvesting and over-exploitation. There is a diminishing availability of wood, suggesting the species has a high rate of decline. In parts of India economically viable trees (above 30 cm dbh) are commercially extinct. Commercially utilizable trees are few in number in the species range. There is also decline due to the poor recruitment caused by fire and overgrazing in the habitat and also due to infection by spike diseases in India. As the species is widespread and pressure is variable across this range, over three generations it is considered that population decline has been at least 30% [8] and IUCN in 2017 listed it as a vulnerable plant species. In an effort to boost its production, farmers are encouraged by governmental agencies to cultivate Sandalwood trees. However, its commercial cultivation is a great challenge to the agroforestry sector, because trees do not get established properly. Other challenges include the supply of elite samplings to farmers, and understanding the agronomy of the tree, diseases and pests, etc. Though, chemical synthesis of Sandalwood oil has been attempted, it is un-economical at the industrial scale. Various biotechnological applications have been attempted with little success, especially identifying key biosynthetic pathways and genes responsible for the biosynthesis of Sandalwood oil components, mainly sesquiterpenes. The information available on this plant is quite scattered and fragmentary.

In India, sandalwood tree is native to Karnataka (South India) flourishing well from sea level up to 1800 m altitude, as a small evergreen or often deciduous tree. It is an achlamydosporous flowering plant, i.e., in which the seeds are devoid of integuments like

many species of the family[9]. The south Indian states of Tamil Nadu and Karnataka together account for more than 90% of the natural population of Sandalwood in India [10-12]. Sandalwood is found naturally in the dry-deciduous forests of south India and other parts of the country, and the wood of which is of superior quality compared to wet tropical homestead grown trees in south India. Incidentally, the last remaining largest natural tract of sandal is found in the natural forests of Marayoor forest division of Idukki district, Kerala. Traditionally high-quality Sandalwood is used for extraction of the precious Sandalwood oil which is often called 'liquid gold'. Other uses include costly carvings for handicrafts, medicinal, cosmetics and even as 'fuel wood' for funerals and for making sandal paste in Hindu temples across the state. The demand for this high-quality Sandalwood far exceeds supply and hence each auction held at Marayoor Forest division fetches record prices.

The production of Sandalwood in India dropped from 4000 tonnes heartwood per year in the 1950s to a mere 500 tonnes in 2007, despite global annual demands of 5000–6000 tonnes for its wood and 100–120 tonnes for its oil, respectively [13]. Illicit felling and smuggling are very rampant, and are the major problems in the sandal tree-growing states. High economic value of Sandal wood provides sufficient incentives to farmers for growing this tree on a commercial scale. However, the area under sandal tree is decreasing fast, because of illicit felling coupled with the difficulty in field establishment of sandal trees in new areas. India had been the leader in Sandalwood oil production for perfumes and pharmaceuticals from time immemorial [14]. The wood was imported to ancient Egypt for the purpose of preparation of medicines, for embalming the dead, in ritual burning to venerate the gods, etc. [15]. The studies on wood properties (such as anatomical, physical, and biochemical, etc.) in sandal are of great relevance, because of the wide genetic diversity base that it possesses. This will facilitate initiation of massive tree improvement programs of the species [16], which are few and far between in the country.

Review of Literature

Sandalwood, in its usual zone of distribution needs a critical attention, mainly the need for conservation of its natural habitats, preventing the loss of genetic diversity loss, because of meticulous exploitation, bio resource development problems, and other pertinent challenges. The importance and value of Sandalwood is predominantly dependent on the volume of its heartwood, the oil concentration and superiority [17, 18]. In turn, the superiority of Sandalwood oil is governed by, mainly two chief sesquiterpene alcohols, namely α-santalol and β-santalol) that are responsible for the pleasant characteristic aromatic odour. As recorded in the standard documents [19, 20], the blend of these two chemical compounds accounts up to 90% of the total volatile compounds from the wood. Heartwood contains the maximum oil concentration and the highest quantity of santalols [21, 22]. With ageing, Sandalwood oil content rises as more and more heartwood is developed over a period. A group of enzymes known as sesquiterpene synthase decides biosynthesis of the sandalwood sesquiterpenes. Though the enzymes are genetically controlled, sesquiterpenes biosynthesis may also be controlled by many factors, including environmental regulatory or genetic v/s environmental factors [23].

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

Production of Sandalwood in India

In its natural zone of occurrence in southern states and other states large tracts of plantations have been raised. The price trend in the international market has increased drastically. In 1999 the rate of Sandalwood (heartwood) in International market was Rs. 650.00/kg, whereas this rate has gone up to Rs. 3700/kg in 2007 and Rs. 4100/kg in 2010–11 and Rs. 9000/kg in 2019–2020. The average sale value for the wild Indian Sandalwood's heartwood increased from US$ 9400 per tonne in 1990 [24] to around US$ 150,000 per tonne in July 2014 (on small volumes based on an auction held in Tamil Nadu, India), indicating a momentous yearly compounded growth rate [25]. It is projected that the world demand for Sandalwood is about 5000 to 6000 tonnes per year, and for its oil, it is about 100 to 120 tonnes per year [13]. The country's production during 1930s through 1950s was around 4000 tonnes of heartwood per year which has now decreased to a meager 500 tonnes of heartwood per year.

Karnataka and Tamil Nadu together accounting for nearly 90% of total Sandalwood production in India while Andhra Pradesh, Kerala, Orissa, Madhya Pradesh, and Maharashtra contribute the rest. All India Sandalwood production figures show substantial decline over the years. Mortality due to spike disease and other factors, extensive smuggling from restricted zone to free zone, dwindling forest cover and existence of non-uniform legislative provisions on movement of Sandalwood from one state to another, are some of the causes for decline in the production of Sandalwood. As a result the present production of sandalwood is very low. Annual production of Sandalwood in Karnataka from 1958–1959 to 2010–2011 and the annual production of Sandalwood in Tamil Nadu from 1980–1981 to 2011–2012 was given by [16] along with its sky rocketed price for the same period.

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

The age of sandalwood tree and color of heartwood influences the content and quality of sandalwood oil. Heartwood from young trees (around 10 years of age, height <10 m, girth <0.5 m, heartwood diameter 0.5–2 cm) contains 0.2–2% oil and that from the mature trees (30–50 years of age, height 20 m, girth 1 m, heartwood diameter 10–20 cm) contains 2.8–5.6% oil [26].

Further, sandalwood oil from young trees contains 85% of santalol and level of santalones is higher compared to oil from mature trees. Sandalwood oil content markedly decreases along the length of the tree (from root to tip) and across the diameter of heartwood (from core to periphery) in various proportions. In general, it has been reported that nearly 45% reduction in oil content from root to tip, and approximately 20% reduction from core to periphery is observed [27]. The root contains 3.5–6.3%, stem 3–5%, and branches 1–3% oil. The quantity of oil within the heartwood of a matured Sandalwood tree varies amongst trees, ranging between 0.5 and 5% in S. album [28], 0.05–8% in *S. austrocaledonicum* [29], and 0.1–8.2% in *S. lanceolatum* [30].

The price of Sandalwood oil in 1975–1976 was Rs. 899.25/kg whereas in 2005–2006 it has gone up to Rs. 15,992.99/kg. Current rate of Sandalwood oil is Rs. 70,000 to 1,00,000 per kg. As per the Tropical Forestry Services, heartwood is used for extracting essential oil via hydro-distillation. The price for Sandalwood oil was about US$ 5000 per kg in the global market, which further raised to US$ 8000 per kg in 2014–2015 [31]. The cost of Indian Sandalwood is ten times higher than that of Australian Sandalwood. The heartwood of Indian Sandalwood produces higher oil, constituting increased levels of α- and β-santalols, the important aromatic compounds of Sandalwood oil compared to any other Sandalwood species [22, 31].

Sandalwood (Santalum album L.; family: Santalaceae), one of the highly valued commercial tree species, is harvested largely for its aromatic heartwood and essential oil. Sandalwood, called as “Chandana” in Sanskrit, is commercially known as “East Indian Sandalwood.” The oil extracted from the Sandalwood trees is considered to be unique and is preferred over other options for the preparations of perfumes, flavors, formulations, cosmetics, toiletries, beauty utilities, and medicines. The species is habitually spread across from the north Pacific Ocean (Hawaiian Archipelago) to south (New Zealand) and from east (Indonesia) to west (Juan Fernandez Island, Chile). It is believed that Sandalwood was introduced into India from Timor, Indonesia [32]. More than 90% of the Sandalwood is distributed in the states of Karnataka and Tamil Nadu, covering around 9000 km^2 [33], of which more than 70% occurs in Karnataka. The species is mostly found in dry deciduous and scrub forests. In Karnataka, *Santalum album* is estimated to be spread over an area of 5245 km^2 [34]. The fragrant oil is extracted from the heartwood only from the matured trees. Sandalwood finds its applications in various fields, including religious purposes, medicinal purposes, incense sticks (agarbattis), perfumes, handicraft, carvings, etc. The value of a Sandalwood tree is largely determined by the weight of its heartwood and the concentration

and composition of the oil contained within it [17]. About 500–1000 MT was traded during 2014–15 @ Rs. 10,000/kg as per reports [35].

Sandal Tree and Part Traded

The traded part in sandal tree is its wood. The Sandalwood is harvested as either green logwood or deadwood. Wood is cleaned using jet of water or mechanical chain and classified into different groups before selling. It is reported that commercialization of Sandalwood starts from extraction of mature trees from field, hammer marked and transportation to the nearest 'Final Cleaning Depot' under proper permit [36]. Sandalwood trees are cleaned and stored in the depots and the particular regarding the weight of the 'final cleaned wood' is recorded. The quality of final cleaned wood including sapwood and sawn dust is classified based on government rules and regulations. According to the Karnataka Forest Manual Rule No. 95, Sandalwood is classified into 21 classes, namely Vilayat Budh, China Budh, Panjam, Ghotla, Ghathadla, Bagardad, Roots—Class I, Roots—Class II, Roots— Class III, Jaipokal—I, Jaipokal—II, Ain Bagar, China Sali or Large Chilta, Ain Chilta, Milwa Chlta, Hattari Chilta, Basola Bukni, Saw dust, White chips, Barkt (Table1, Figure 1).

Table.1 Kumar ANA, Joshi G, Mohan Ram Hy (2012) Sandalwood: history, uses, present status and the future. Curr sci 103(12):1408-141

Classification of sandalwood sorted before being passed for sale (according to the Karnataka Forest Manual Rule No. 95)			
S No.	**Class**	**Description**	**Fixed price (in rupees in lakhs) per metric tonne of wood for the year 2010-2011**
1	Vilayet Budh (class 1 billets)	Sound billet weighing not less than 9kg and not exceeding 112 pieces per tons .	41.00
2	China budh (class 2 billets)	Slightly inferior billet weighing less than 4.50kg and not exceeding 224 pieces per tons .	41.00
3	Panjam (class 3billets)	Billets having small knots, cracks and hollows weighing not less than 2.2kg and not exceeding 448 pieces per tons .	37.00
4	Ghotla (billets of short length)	Includes short and sound pieces. There are no limit of weights and number per tons .	41.00
5	Ghatbadla	Billets with knots, cracks, small hollows, weighing not less than 4.5kg and not exceeding 250 pieces per tons .	41.00
6	Bagardad	Consists of solid pieces without limit as regards dimensions, weight or number.	39.50
7	Roots (class 1)	Pieces weighing not less than6.75kg and not exceeding 150 pieces per tons .	36.25
8	Roots (class 2)	Consists of pieces weighing not less than 2.25kg and not exceeding 448 pieces oertons .	37.40
9	Roots (class 3)	Consists of small and side roots below 2.25kg in weight	33.70
10	Jajpokal or badla (class1)	Consist of hollow pieces weighing not less than 3.10kg and not exceeding 320 pieces per tons .	40.75
11	Jalpokal (class2)	Hollow pieces weighing not less than 1.3kg per tons .	37.10
12	Anibagar	Consists of solid, cracked and hollow pieces weighing not less than 450g.	40.10
13	China Sali or large chilta	Consists of pieces and chips of heartwood weighing not less than 2.25g.	32.20
14	Ain Chilta	Consists of small pieces of heartwood	28.20
15	Hatrichilta	Consists of heartwood and chips obtained by plaining billets with Hatri or Randha (plane).	19.00
16	Milvachilta	Consists of pieces and chips having fair proportions of heartwood and sapwood.	15.50
17	Basolabukni	Consists of small heartwood and sapwood chips.	11.50
18	Saw dust	Sawn powder obtained while sawing the sandalwood.	7.50

Figure.1 Sorted sandalwood billets of various classes (numbers from 1 to 18 are the trade names of each class described in Table 1).

Uses of Sandalwood

Sandalwood is one of the finest woods for carving and tuning to intricate workmanship. Wood and powder is used in the manufacture of incense sticks, which are burned during religious ceremonies [37]. It is said sandalwood and oil finds its use in various forms, from “cradle to cremation”.

Uses of Sandalwood Oil

Powdered sandalwood upon distillation yields “East Indian Sandalwood Oil”, which is highly priced raw material in perfumery industry. In perfumery it is valued for its non-varying composition and fixative properties and for its persistent heavy sweet, woody fragrance.

The good fixative property and tenacious aroma of sandalwood oil are principally due to its major odoriferous, sesquiterpenic alcohols αand β santalols and esters (which are having high boiling range) forming more than 90 percent of the oil. The oil is used extensively in the cosmetics industry in the manufacture of soaps, face creams, toilet powders and air fresheners. The wood powder after removal of oil is called the exhausted powder is available product for incense (Agarbathi) stick industry[44].

Production of Sandalwood

It may be difficult to estimate exact annual production of sandalwood in India since the proportion of wood harvested officially is small in proportion to that of illegally harvested. It is estimated that the annual harvest of sandalwood is currently approximately over 4,000 tonnes per annum. The official annual harvest in India during the year 2003-2004 was about 1400 tonnes. The quantity of sandalwood auctioned for thepublic is usually taken as the annual official production[37].

Production of Sandalwood Oil

India is maintaining the international quality of oil to “Agmark” standards (Ag representing agriculture, Mark representing the standard.) and has monopoly on the world trade. The production of oil is on the decline due to shortage of wood. During 1958 to 1970 nearly 180 to 200 tonnes of oil was produced to meet the worlds demand. The official production oil showed a drastic decrease in trend over the years and during 2004 the official Indian production is around 70 tonnes. It is estimated that the actual production of oil is above 150 tonnes, which is approximately two times the official government production. Apart from India, East Indian sandalwood oil is also produced in Indonesia, New Caledonia, Fuji Islands and Philippine Islands, however India’s contribution to the production is over 95 percent and accepted for its quality[37].

Sandalwood cultivation

Soil:

Sandalwood can grow in all types of well drained soils, but preferably in red laterite, sandy loam, gneiss, quartz and sand mixed black soils. The soils should be moderately deep with good drainage. The pH of the soil should be 5.5-8.5.

Climate:

Sandalwood grows well in hot climate between 15 degrees °C and 24 degrees °C, with 600-1500 mm rainfall per annum. The best growth is achieved in the range of 20 degrees °C-38 degrees °C temperature.

Seed Collection:

The seed can be collected from known superior populations of mature (more than 10 years old) tress. Ripened, purple colored fruits should be collected and soaked in water for 24 hours before rubbing to remove the pulp before drying under shade.

Telangana:

The heartwood of the the tree and oil is in great demand globally for its high economic value. In recent time, the biotic interference has been the main reason for the deletion of the sandalwood growth in our country, the Sandalwood Society of Telangana has been formed with objectives of providing an opportunity and a platform for the farmers to interact with the professional and industry.

Karnataka:

In Karnataka, *S. album* is spread over 5245 km^2 of area and is abundant in Shimoga, Chikkamagalur, Coorg, Hassan, Mysore, Dharwad, Bangalore, Kolar, Belgaum, Uttar Kannada, Dakshina Kannada, Bellary and Tumkur districts. In Sirsi, Dharwad, Sagar,Shimoga, Mysore and Bangalore divisions, the extent of Sandalwood plantations has increased substantially. During 2002-03 to 2005 -06, the Karnataka forest department has raised around 8937 Ha. of plantations of Sandalwood in the state. During 2004-07 and 2007-10 the department has raised around 1079 Ha and 18 Ha of sandalwood plantations only to a limited extent in the state. As per the forest department, annual report the forest department has raised sandalwood plantation later during 2010-11; 78 ha; 2011-12; 25 ha; 2012-13; 282 ha; 2013- 14; 35 ha; 2014-15; 115 ha.

Tamilnadu:

In Tamilnadu, Sandalwood occurs naturally in the plateau and hill tracks of Salem, Dharmapuri, Erode, Tiruvannamalai, Vellore, The Nilgiris, Villupuram and to certain extent in Madurai, Virudhunagar and Tirunelveli Districts and is spread in an area of around 3040 km^2 [38]. The natural regeneration of Sandalwood tracts is very good in these areas. Sathyamangalm forest division has been raised the sandalwood plantation during 1962-1994 around 205 Ha.

Kerala:

In Kerala, the Sandalwood bearing forests are mainly located in the Anjanad valley which is on the eastern side of Western Ghats falling in Marayoor forest range and to a limited extend in Arienkavu range of Tenmala forest division in an area of around 15 km^2 [39]. A total number of around 58,414 trees (Tree Density 39.988 trees / Ha) of above 30 cm GBH is found in Marayoor forest division in about 8100 Ha. of area thus proving the good natural regeneration in that forest division. In addition, it is estimated that around 1000 trees are also found in private and reserve forests in Kerala.

Methods

The following representative samples were procured from different southern states of India for standardization of the methodology of oil extraction and determination of santalols.

Figure.2 Different Sources Of Sandalwood

Tamil Nadu sandalwood

Karnataka sandalwood

Kerala sandalwood

Figure.3 Gerhardt Soxtheram-Automatic Rapid Extarction Procedure

Chipped smaller pieces of sandalwood (5" thick and 6" long

Shimadzu-AUW-DUAL DUAL SEMI MICRO BALANCE

Transferred into cellulose thimbland covered with cotton plug

Initial weight of the empty beaker

150ml solvent added into the extraction beaker and transferred into extraction beaker

Automated Soxtheram was run following conditions and operating parameters

Sandalwood oil after extraction collected

Sandalwood Oil

Extraction of oil usimg Soxtherm

To standardise the oil extraction process, sandalwood (Heartwood) of Gotla quality was purchased from the Government Sandal Depot in Mysore, Tamil Nadu, Kerala, and the Forest College Research Institute. The heartwood was chipped to smaller pieces of 2 cm length and 0.5-1.0 cm thickness[21]. These wood chips (10 g) were packed into a cellulose thimble, which inturn was placed into a glass beaker and extracted with 100 mL of methanol or *n*-hexane or petroleum (Figure 3.) ether using automatic soxtherm with the following settings:

T-Classification: 200°C

Hot Extraction: 140°C (Near the boiling point of santalol)

Temperature reduction interval: 4 min 5 Sec

Reduction pulse: 2 Sec

Hot Extraction: 20 min

Evaporation A: 4*interval

Extraction time: 20 min

Evaporation B: 4*interval

Evaporation C: 5 min

Total length of the programme: 1 Hr 18 Min

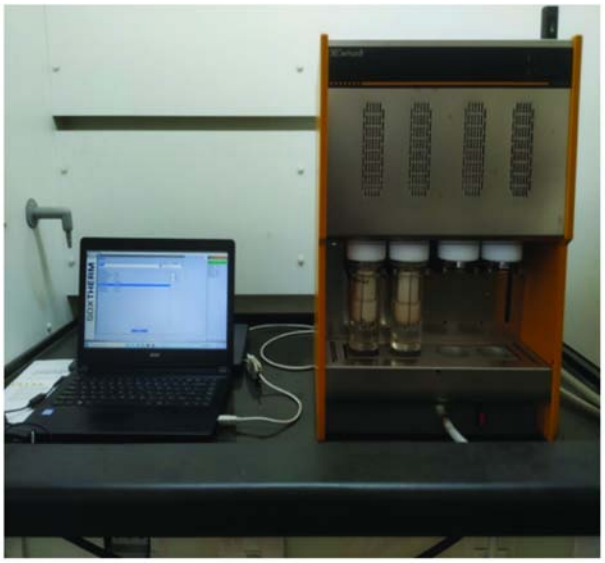


Figure. 4 Gerhardt Soxtherm Rapid automatic extraction

Calculation of oil yield

Oil yield from Ghotla grade sandalwood from the first extract was found to be 3.283% based on the formula given below:

$$\%\ oil\ yield = \frac{(final\ weight of\ the\ beaker - Initital\ weight\ of\ the\ beaker)}{sample\ weight} * 100$$

The residual chips in the thimble were further extracted with 100 ml of the corresponding solvent for the second time using the same settings on the automatic Soxtherm to determine if the oil recovery from the chips was complete. Oil yield in the second extract was found to be 1.86%.

Gas chromatography

GC analyses shall be carried out on Shimadzu Nexis GC-2030 instrument equipped with a AOC-20 series autosampler injection and using Carbowax 20M fused silica capillary Column information (SH-Rtx-5MS) (Length 30.0m x Inner diameter 0.25mm x Film

Thickness 0.25 µm) and a Flame Ionization Detector (figure 4) . Analytical conditions were set as follows: detector temperature, 200°C; injection port temperature,180°C; temperature programme, 80°C to 180°C with a gradient of 2°C/min; sample size, 1 µl; dilution, 1: 140 in acetone; split 1 :30; carrier gas, 30 ml N_2/min[21]. The identity of α- and β-santalol were verified by comparison of retention times with authentic standard compounds.

Figure .5 Gas Chromatography Flame Ionization Detector 2030

Sandalwood oil recovery after each extraction from the heartwood chips of *S. album* is presented in Table 2.

The important sesquiterpene alcohols recognized by Australian Standard (AS2112-2003), International Organization for Standardization ISO 3518:2002 (E) and European Union (E. U.)37,47 for sandalwood oil are well resolved to the base line with a program as described in the Experimental section (Fig. 6-12). The peaks were identified by comparing their retention times and co-injecting the characterized sesquiterpene alcohols with sandalwood oil.

Santalum album is a small to medium-sized tree and the yield of heartwood oil varies with the age and is higher in older trees.The yield of oil is highest in roots (~10%) and lowest in wood chips (1.5–2%).

Results & Discussion

The sesquiterpene alcohols (Z)-α-santalol 1 and (Z)-β-santalol 2 together constitute over 80% of heartwood oil obtained from the well matured tree while heartwood oil of 14year old Indian sandalwood tree contains 44.7–46.7% (Z)- α-santalol and 20.8–22.2% (Z)-β-santalol, which is in the range of current international standards for the Indian sandalwood oil. Table.1. Essential oil extractions efficiency using different organic solvents**.** Whereas the Date in the table represents Mean±SD of three samples, n-Hexane yielded better recovery of sandalwood oil (~5.46 %). Table.3.Santalol content of heartwood samples used in this studies. Karnataka sandalwood yielded better recovery of % α-santalol and % β-santalol is respectively, 59.6±0.96% and 27.5±3.12%.

Essential oil extraction efficiency using different organic solvents

Serial extraction	Methanol	*n*-Hexane	Petroleum ether
	% Oil yield	% Oil yield	% Oil yield
First extraction	1.75±0.325%	2.69±0.570%	2.13±0.570%
Second extraction	0.95±0.061%	1.58±0.332%	1.03±0.640%
Third extraction	0.08±0.032%	1.19±0.416%	0.99±0.540%
Total	2.78%	5.46%	4.15%

Table.2. Essential oil extractions efficiency using different organic solvents

Data are mean±SD of three samples.

The mean total extractable oil concentrations within the heartwood using different solvents after repeated extractions varied from 2.78-5.46%. Relatively high oil concentration was achieved using a non-polar solvent, *n*-hexane. Relatively low oil concentration was obtained using a polar solvent such as methanol. Due to the high oil concentrations observed using *n*-hexane as the extracting solvent, further experiments were continued using the non-

polar solvent, *n*-hexane. Among various solvents, *n*-Hexane yielded better recovery of sandalwood oil from three successively pooled extracts (~5.46 %)

Source of sandalwood	% Oil yield	Area % of α-santalol	Area % of β-santalol	Area % of α-santalol and Area % of β-santalol
Karnataka	3.28%	59.6±0.96%	27.5±3.12%	87.2±4.07%
Kerala	3.01%	56.03±0.37%	25.8±0.932%	82.2±1.30%
Tamilnadu	2.95%	50.9±0.45%	22.9±0.852%	73.9±1.30%
Forest College & Research Institute, Mulugu	2.28%	45.1±0.92%	22.3±287%	67.5±4.99%

Table.3.Santalol content of heartwood samples used in this studies.

The percentage oil yield from the representative sandalwood samples collected from different southern states is shown in the Table 3. Oil yield using n-hexane a solvent showed better yield with sample from Karnataka (3.28%), followed by the sample from Kerala showing 3.01%. Sample collected from Tamilnadu showed an oil yield of 2.95% and the sample collected from the plantation available at the Forest Research Centre, Mulugu of the Siddipet district showed an oil yield of 2.28%.

The relative concentrations of α- and β-santalols in the oil extract were determined by gas chromatographic analysis. The quality of the oil extracted from a Ghotla grade billet procured from Sandalwood Depot in Mysore was relatively good with 59.6 % of α-santalol and 27.5% β-santalol and exceeds the expectations of ISO standard. Similarly, the heartwood procured from Kerala also appeared superior with 56% of α-santalol content and 25.8% β-santalol content. The heartwood samples from both Karnataka and Kerala yielded > 80% total

santalol content in the oil extract. On the other hand, the heartwood sample obtained from Tamilnadu and Telangana (FCRI, Mulugu) showed relatively less content of α-santalol as well as β-santalol, but still meet the ISO standard specifications in terms of santalol content. Thus, the present study successfully developed a methodology for extraction of sandalwood oil from a minimal amount of heartwood (10 g) and further characterize the quality based on the content of santalol isomers as determined using the gas chromatography and % Oil yield of heartwood samples from both Karnataka and Kerala yielded > 3.0% total santalol content in the oil extract. On the other hand, the heartwood sample obtained from Tamilnadu and Telangana (FCRI, Mulugu) showed relatively less content of % Oil yield, but still meet the ISO standard specifications in terms of santalol content.

GAS CHROMATOGRAM ANALYSIS of α-and β-santalol in different sandal heartwood

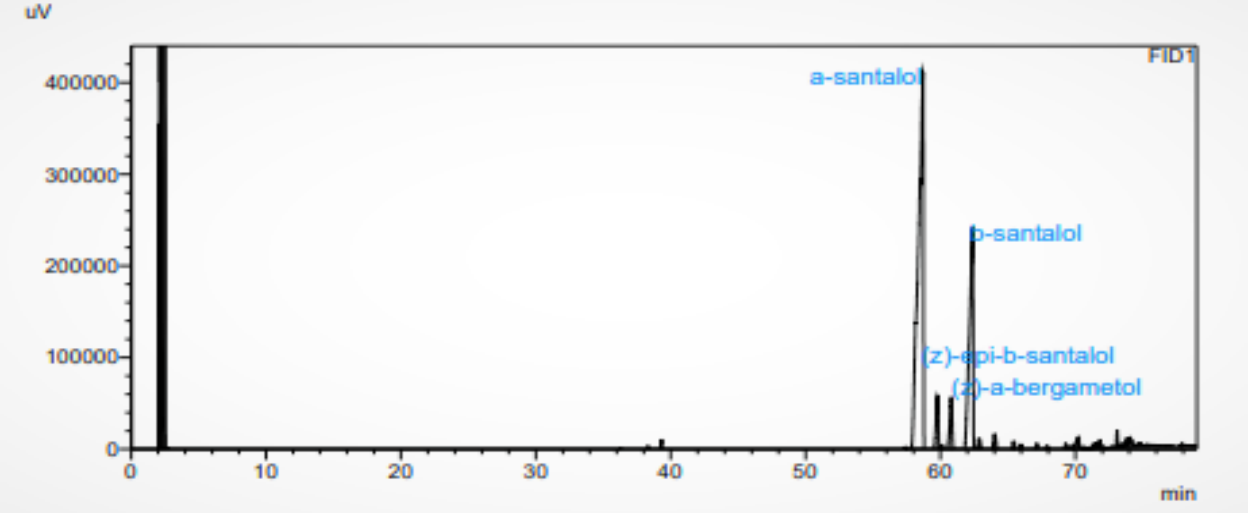
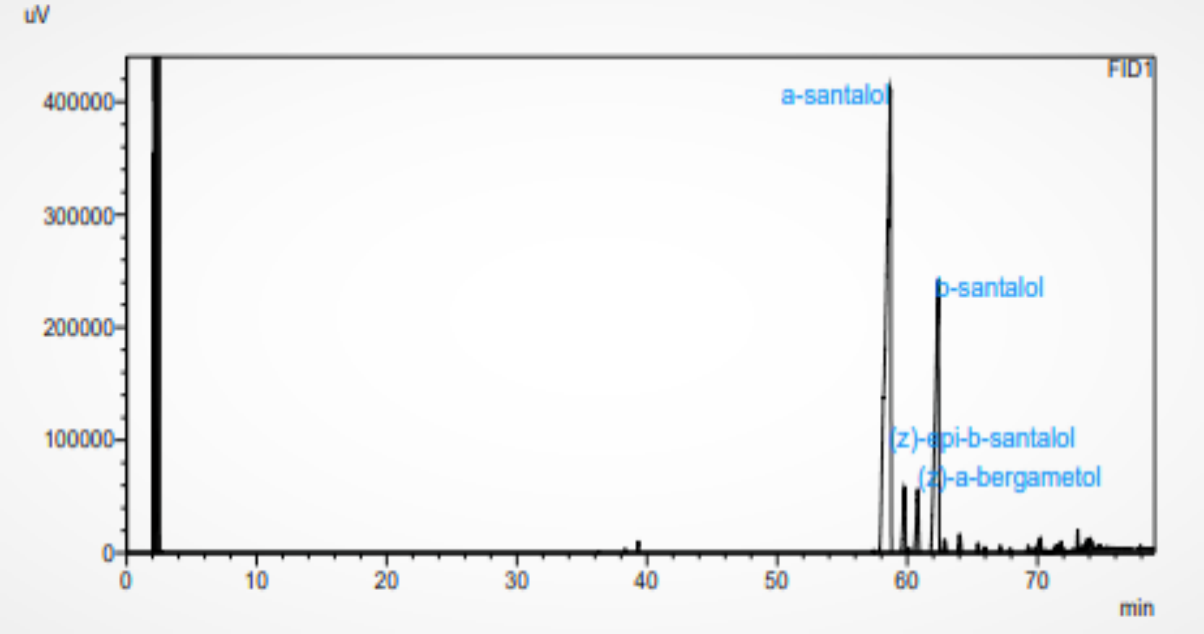
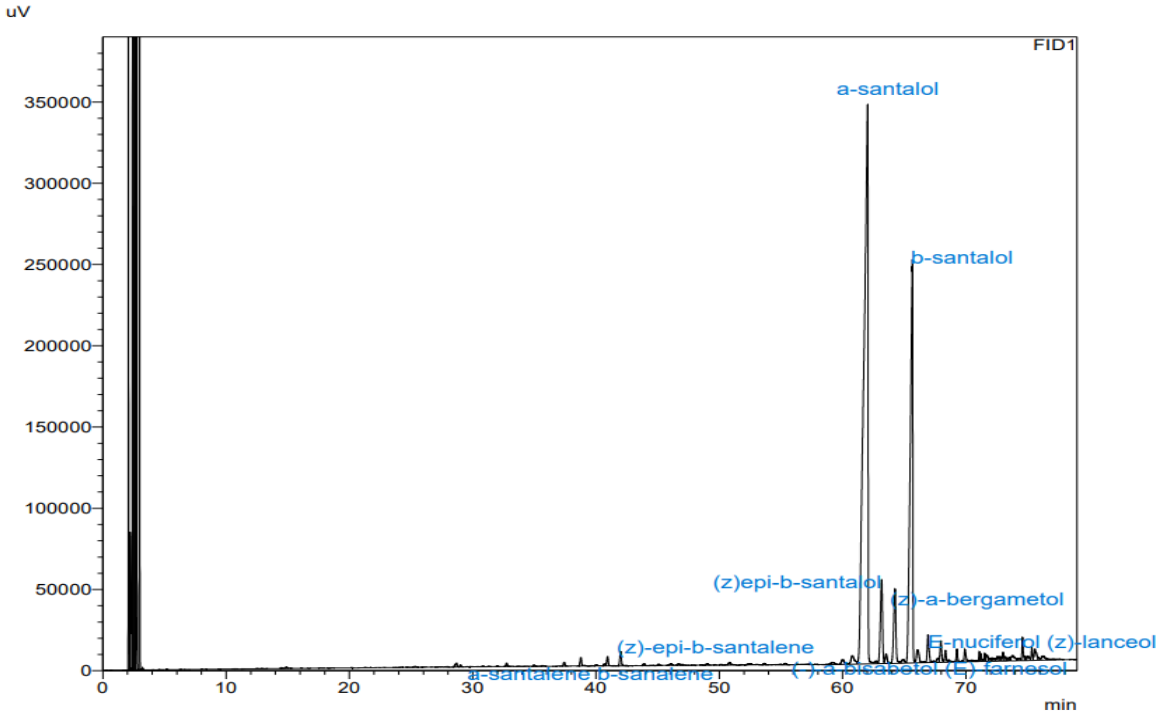


Figure 6. A representative chromatogram of standard α- and β-santalol with retention times of 62 and 64 min, respectively.



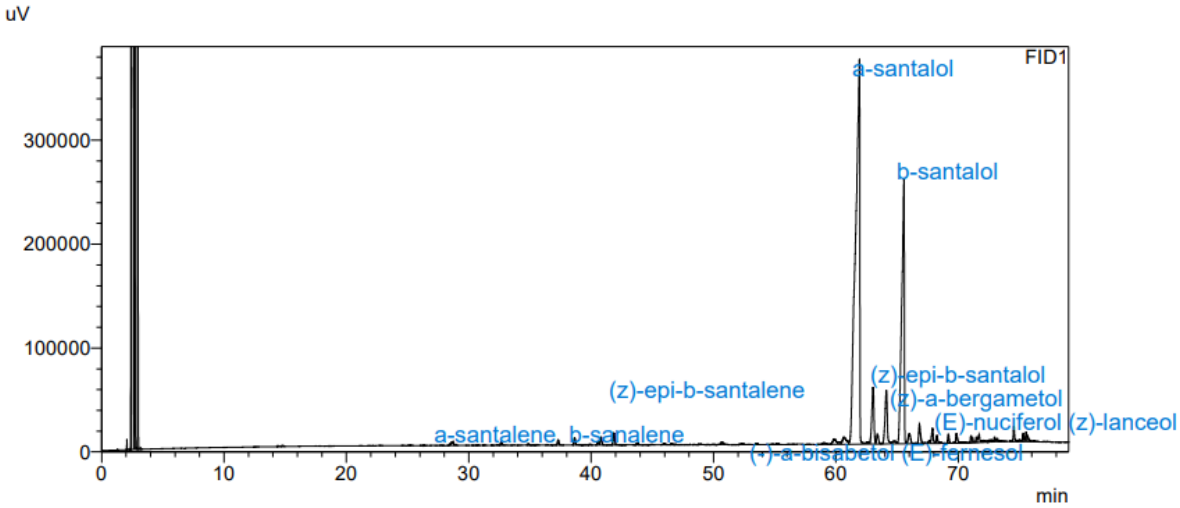
First Extraction of Karnataka sandalwood:

Figure:7. A representative chromatogram of Karnataka Ghotla (billets of short length) α- and β-santalol with retention times of 62 and 64 min, respectively



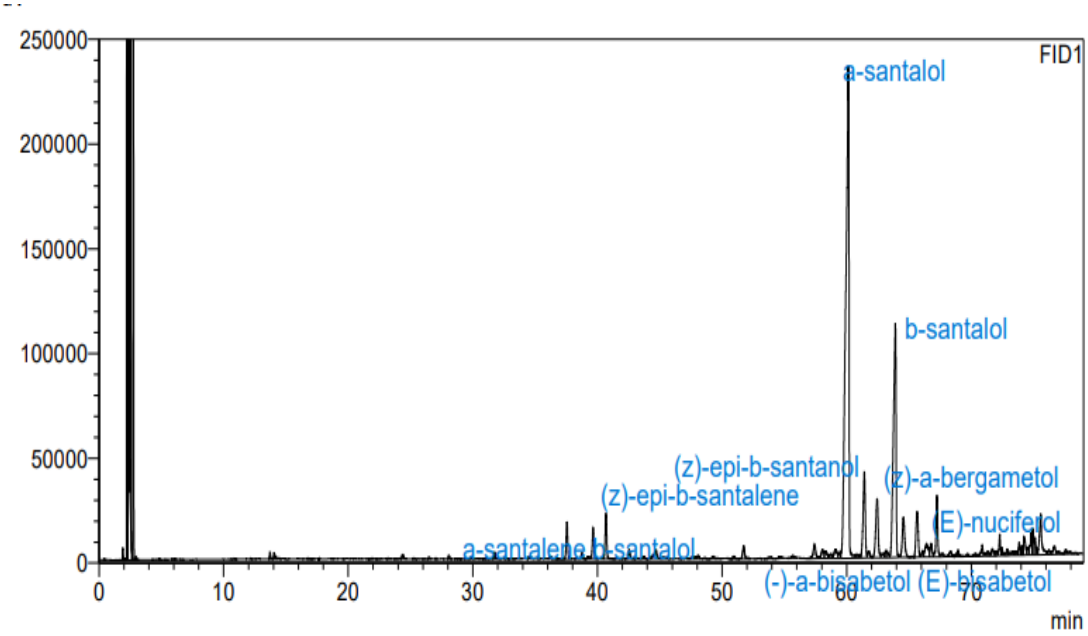
Second Extraction of Karnataka sandalwood:

Figure:8. A representative chromatogram of Karnataka Ghotla (billets of short length) α- and β-santalol with retention times of 62 and 64 min, respectively



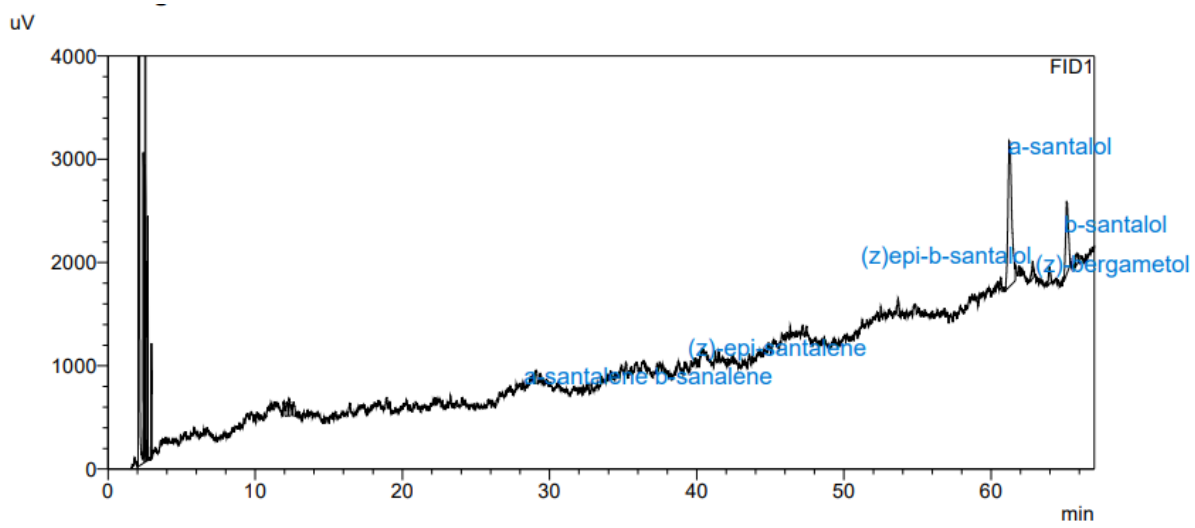
Third Extraction of Karnataka sandalwood:

Figure:9. A representative chromatogram of Karnataka Ghotla (billets of short length) α- and β-santalol with retention times of 62 and 64 min, respectively



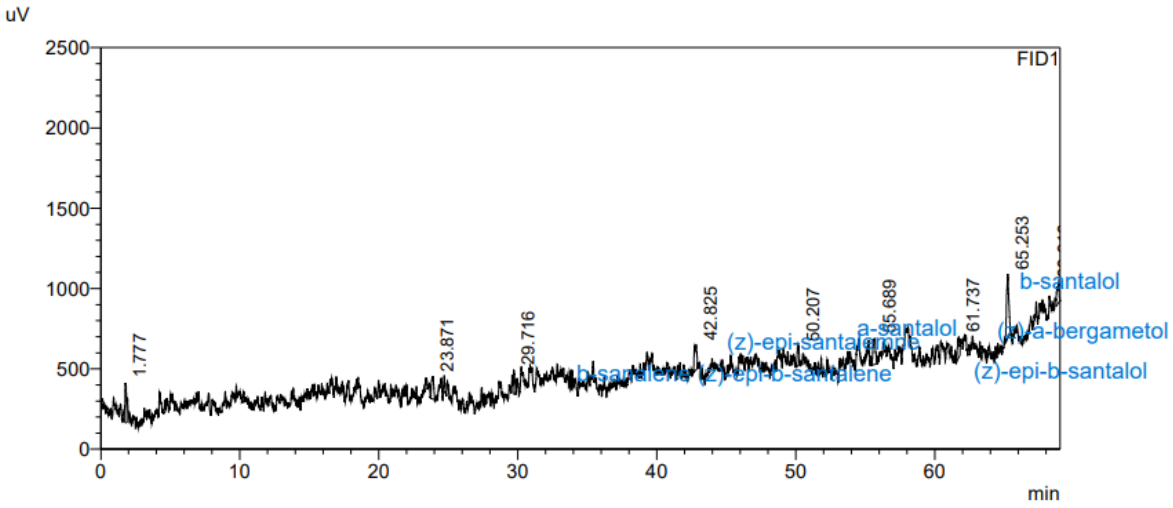
First Extraction:

Figure:10. A representative chromatogram of FCRI α- and β-santalol with retention times of 62 and 64 min, respectively



Second Extraction :

Figure:11. A representative chromatogram of FCRI α- and β-santalol with retention times of 62 and 64 min, respectively



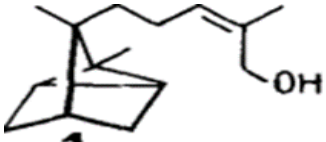
Third Extraction:

Figure:12. A representative chromatogram of FCRI α- and β-santalol with retention times of 62 and 64 min, respectively.

Classical research on Indian sandalwood oil obtained from *Santalum album L.* has shown its approximate composition to be 10 hydrocarbons (α- and β-*santalene*) and 90% *santalols* (55% to 60% α-*santalol* and 25% to 30% β-santalol [40]. Traditionally, the basic odour and the fixative properties of sandalwood oil are attributed to the sesquiterpene

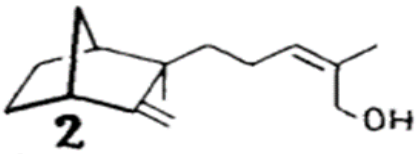
alcohols, dominated by α- and β-santalol [41, 42] coupled with the organoleptic excellence (in which minor and trace components also paly a role) [41-43]. Decisive to the appraisal of the oil is the percentage of total alcohols as santalol. The higher the alcohol level, the greater is the value of the oil; the best quality[42] oil has a santalol content of 94% or above, but high santalol contents in the oil have been viewed with mistrust. Such an evaluation lacks specificity and the errors involved there in have been commented upon [21, 44, 45]. Despite this, the importance given to the santalol content for checking the genuineness of the oil is enshrined in FCC [21], EOA, ISI, Agmark and other specifications of the oil. Strictly this must be coordinated with the acid prescribed limit. If the alcohol concentration is below this level, the oil faces rejection, even if the other physicochemical properties are in order.

To disqualify the oil solely on this basis sounds unconvincing; a more credible parameter is required. Packed column chromatography analysis is of little value in the evaluation *santalols* [21, 46-48]. In fact the sum of the percentages of α- and β-santalol found in the oil employing this procedure apparently approximates to that of the total alcohols declared by Agmark examination [21]. A new chapter opened up by the application of capillary gas chromatography to the analysis of sandalwood oil which allows us to decipher the sesquiterpene alcohol complex and offers an excellent method for estimating α- santalol and β-santalol [21, 46-48]. Provided the organoleptic profile is assured, it seems better to appraise the oils on the concentration of these isomers, instead of the total alcohol concentration. The establishment of this novel approach in judging sandalwood oil is the objective of the present investigation. In the present study, we have successfully developed and validated a method for extraction of sandalwood oil from the provided heartwood representative samples and further to determine the concentration of α- and β-santalols.



1

(+)-α- Santalol



2

(−)-β - Santalol(Z)

There are nearly 26 species of sandalwood distributed all over the world, out of which *Santalum album*, *S. yasi*, *S. spicatum* and *S. lanceolatum* yield fragrant oil of commercial importance. *S. album* produces the best fragrant material, and is one of the oldest perfumery materials. *S. album* is called the East Indian Sandalwood and powdered heartwood upon distillation yields East Indian sandalwood oil. The oil is highly rated for its fixative properties and for its persistent, heavy, sweet, woody odour. The word sandal has been derived from Chandana (Sanskrit), Chandan (Persian), Santal (French). *S. album* is found distributed in India, Indonesia, New Caledonia, Fiji Islands, Philippine Islands and Sri Lanka. India produces about 90 to 95 percent of the world production of sandalwood and oil, and the rest of world hardly 5 percent. In India, Karnataka and Tamil Nadu contribute to 90 percent of world production of sandalwood.

Sandalwood tree is a partial root parasite and needs a donor host for its good growth. Heartwood formation can occur at four years under plantation management, whereas under natural conditions it takes a longer time. The formation and development of heartwood is dependent on age, growth, soil and ground moisture; genetic factors also seem to play an important role. At the time of harvest the entire tree is removed and then heartwood is separated. The heart wood is hard, heavy, durable, pleasantly and strongly scented, yellow or brown in appearance. Roots, butt, stem (logs) and major branches yield sandalwood oil. Roots contain more oil compared to stem and the branches. Roots and logs of well-developed tree yield fragrant oil up to 6 percent. There will be gradual reduction in the oil content from roots to stem and branches. Though different methods of extraction of oil are available, like

solvent extraction and Super critical liquid carbon- di-oxide extraction; The conventional steam distilled oil is best for the superior quality due to its fragrance characteristics.

Sandalwood processing

The dead, dried and well-grown trees are removed by uprooting it. The wood should have very little moisture before processing. Processing is carried out in 2 stages; (i) rough cleaning and (ii) final cleaning. During rough cleaning the tress are cut near the butt (base) to separate roots and logs. Logs are cut to a maximum length of one meter depending on the available size. Bark and sapwood is removed. During final cleaning, small portions of sapwood adhering to heartwood are removed and the heartwood is given a smooth finish. Depending on the length, size and weight of wood, it is classified to different categories and sold [37].

The utility of these categories are different and fetches different price in the market. The skilled artisans prefer bigger size logs for carving to make curious items. Roots, small girth logs, branches and the shavings containing more heartwood portions obtained while dressing are used for distillation of oil. Sandalwood, sapwood is generally called “White Chips”, which also have a high demand in the incense stick industry.

Colour of heartwood and oil content

The superiority of wood is generally judged based on colour and from the portions of the tree from which it is taken. Weight of wood is also one of the criteria for selecting quality wood for higher yield of oil.

Distillation and Extraction

Karnataka Soaps and Detergents Ltd are the pioneers in distilling quality sandalwood oil. Distillers follow different methods for obtaining oil from wood. However, steam distillation is a simple and efficient method and is widely accepted [37]. Sandalwood is powdered and sieved to get mesh size of 12 to 36 and then charged into copper or stainless

steel stills. Steam is bubbled up at the base under pressure 30 to 40 Psi (low pressure steam) for 100 to 120 hours. The crude oil floating on the surface of distillate is skimmed off and filtered. Moisture present in the oil is removed by vacuum process. On an average, wood yields about 5 to 6 percent of oil. The exhausted powder is used in incense stick manufacture and a resin is also extracted from it

Mature *S. album* heartwood typically contains 6-7% oil, a relatively high concentration compared with the net-best sandalwood species, *S. yasi* and *S. austrocaledonicum*, which have around 5% and 3-5% oil respectively [49]. Santalum album oil quality is also superior and is determined by the proportions within the oil of α- and β-santalol, which give the distinct aroma [50]. The total santalol concentration in *S. album* oil can be over 70% [51]. The current international standard for S. album oil requires that it contain 41-55% of α-santalol and 16-24% β-santalol (ISO 3518 2002E). A study on 14-y-old S. album trees grown in plantations at Kununurra found heartwood oil concentrations of 2-9-3.4%, and high santalol concentrations (45-47% α-santalol and 21-22% β-santalol) within the oil [52]. Although the oil concentration was relatively low in the 14-y-old trees, the results were still encouraging because the young plantations were shown to produce oil of international standards.

Besides oil concentration and quality, the amount of heartwood within a sandalwood tree is vitally important in determining its value. Santalum album trees in India re reported to initiate heartwood at around age 10 years [24], and to reach their prime at age 30-60 years [53].

Economy

Description and Uses

The entire sandalwood oil traded internationally is known to be East Indian sandalwood oil produced by solvent distillations from the heartwood and roots of *Santalum*

album. Figure 13 presents the average East Indian sandalwood oil prices from 2011 to 2014. Sandalwood oil from Australian *S. spicatum* and West Indian and African "sandalwood" oils are no longer processed.

Sandalwood oil with sweet, woody odour is widely used in the fragrance industries, but more specifically in the higher-priced perfumes. It is with excellent blending properties and containing the large proportion of high-boiling constituents in the oil (approx. 90% *santalols*) also price it valuable as a fixative for other fragrances. In India, it is produced, for the manufacture of traditional attars such as rose attar; the delicate floral oils are distilled directly into sandalwood oil.

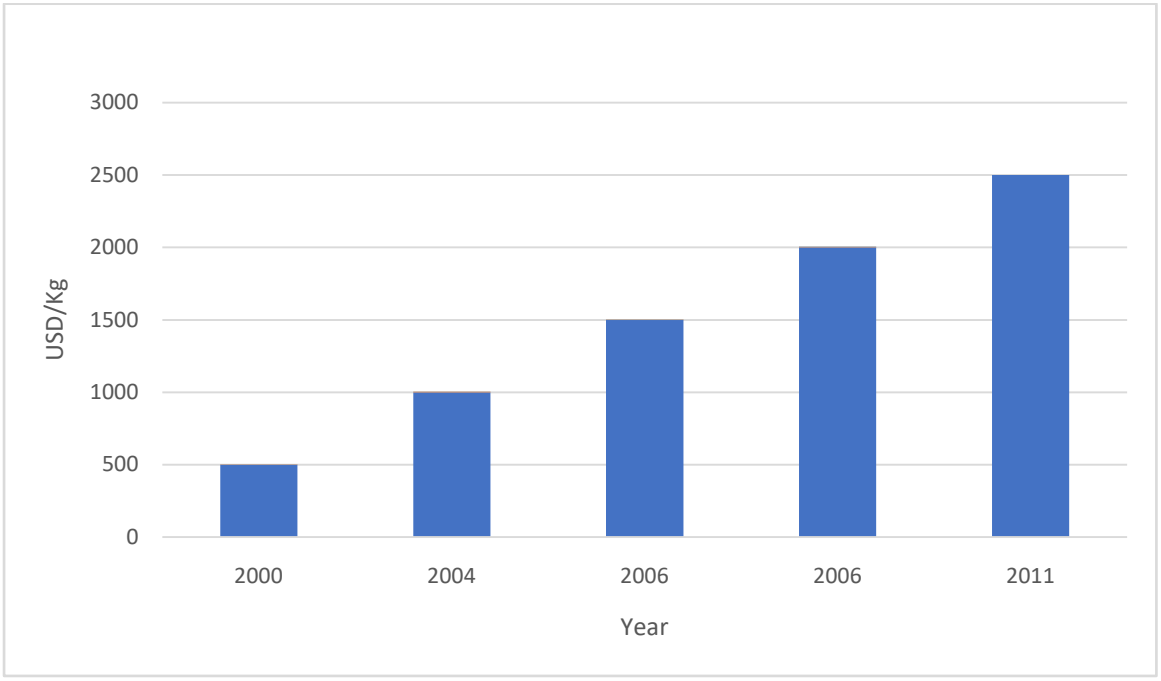


Figure 13. Average East Indian sandalwood oil prices. (Source: Public Ledger)

Major cosmetic segments and applications of sandalwood oil Segment Sub-segment Benefits of applying sandalwood oil Fragrances Perfumes Fixatives (when used in small amounts) fragrance Skin care Facial skin care, body care, moisturizer, anti-aging Skin condition properties, use on dry cracked and chapped skin Hair care Shampoo, conditioner Fragrance Toiletries Soap, body wash, bath salt Used in small amounts as fixatives fragrance.

Indian sandalwood oil and wood powder exhibited skin-conditioning properties. Sandalwood oil is also used as a fragrance in toiletries and hair care products [54]. Fairly traded sandalwood oil has a very good market. It is to be noted that fair trade certification is only available for cultivated products, not for wild-harvested sandalwood. Organically certified sandalwood oil has a market. However, it depends primarily on the prospective buyer. Sandalwood oil from India cannot be certified organic due to diversification of production sites. In other countries, it is possible, however, where monitoring of the production sites is more feasible.

Production of Sandalwood Oil

India is maintaining the international quality of oil to "Agmark" standards (Ag representing agriculture, Mark representing the standard.) and has monopoly on the world trade. The production of oil is on the decline due to shortage of wood. During 1958 to 1970 our organization was producing nearly 180 to 200 tons of oil meeting the worlds demand. The official production oil showed a drastic decrease in trend over the years and during 2004 the official Indian production is around 70 tons . It is estimated that the actual production of oil is above 150 tons , which is approximately two times the official government production. Apart from India, East Indian sandalwood oil is also produced in Indonesia, New Caledonia, Fuji Islands and Philippine Islands, [37].However India's contribution to the production is over 95 percent and accepted for its quality.

Consumption of Sandalwood Oil in India

India is one of the biggest consumers of sandalwood and oil, the essential oil required in perfume formulations, cosmetics, beauty aids and religious functions. The consumption of oil is mainly in the following industries: Perfumery, Attar preparations, Soaps and toiletries, Incense sticks, Medicines and Chewing tobacco. Domestic consumption is increasing regularly and annual requirement of oil is more than 80 tons. The official figures available

with regard to wood production and oil would not match the quantity in use by various industries because of the level of illicit dealing. Punitive action required to contain illegal activities by enacting uniform laws in entire country. Because of short supply of natural oil, some of the industries making incense stick and pan masala (scented chewing tobacco) have switched over to synthetics, unmindful of the harmful effects to human beings. At present oil obtained from *Osyris sp. Amyris sp.* and *S. spictum* are also used as alternates

Consumption of Sandalwood and Oil outside India

Sandalwood and oil is mainly used in the perfumery formulations, religious functions, handicrafts and medicines (Aromatherapy) Some of the most expensive perfumes are based with sandalwood oil in the world. The consumptions of wood and oil are mainly in the following industries; Perfumery, Attar formulations, Religious functions, Aromatherapy, Incense sticks

Market trend

From 1998 to 2004, the sale price of sandalwood in India has increased from Rs. 600/ to Rs.2000/ per kilogram, at an annual average increase of over 20 percent, whereas the average increase of oil from 1998 to 2004 was Rs. 15,500/ to Rs.32,000/ per kg. During 2003 there was a fall in the oil price to about 10 percent, may be due various problems in the export market. This is also due. The export regulation by the Indian Government [37].

The major export markets for Indian sandalwood and oil are France, Taiwan, Hong Kong, Japan, Malaysia, Singapore, Middle East, South Africa, UK and USA. UK and USA accounts for 75% of the export sales. It is anticipated with the increase in affluence of China, it might be one of the future major importer of sandalwood products. The gap between supply and demand is increasing; with the result there will be price increase both in the domestic as well international market.

Current demand

It is estimated that the annual requirement by the Indian essential oil industries is about 120 tons of oil. Out of which 60 to 70 tons of oil is used in tobacco chewing industries and Attar production industry. The demand in the export market is above 60 tons. The demand for the natural oil is increasing though number of synthetic products and adulterants are available in the market [37]. Synthetic products are mostly used in the low quality perfumes; prolong use of these synthetic stuff on the skin may be more harmful.

Some of the reasons for the increase of demand for the natural sandalwood oil are:- Synthetic chemicals are molecularly different to natural sandalwood oil. Synthetic chemicals differ significantly in olfactory products [37]. Natural oils has high odour thresholds.

Therapeutic benefits- Synthetics has different resultant impact on the nervous system. India is depending on the natural forest for sandalwood production and harvest. There is no concerted effort to grow more trees and the natural propagation is also restricted due to low density of sandalwood population. Sandalwood tree has already been listed as an endangered species. Industries depending on mainly Indian sandalwood are already looking out for alternates like Australian native sandalwood, Tanzanian sandalwood (*Osyris sp*.) and West Indian sandalwood (*Amyris sp*), when once they get established to the new alternates, it may be difficult to revert back to Indian sandalwood derivatives. Due to persistent use of alternates and mixing them in the sandalwood industry, it is likely that spurious adulterants may reach the markets and the value of purity may be lost.

The growing demand of sandalwood and oil can be met only with short rotation sandalwood crop developed from plantations raised elsewhere with improved management techniques to produce scented heartwood as quickly as possible.

It is good to mention here that sandalwood has been notified as an aromatic and medicinal plant by **National Medicinal Plants Board,** it is likely at a later date that the

plants grown outside the forest limits may not attract all the forest laws. Prior to this Karnataka and Tami Nadu government have amended the **"Sandalwood Forest Act", 2001** and 2002, respectively declaring the landlords possessing the trees in their land are the absolute owners of sandalwood [37].

More farmers and corporate bodies have come forward to grow sandalwood to maintain its glory forever. Since the man has become the exploiter of nature, the KSDL Being a bulk user of sandalwood for captive consumption and ISO certified for EMS and QMS systems in the state sector, the Company has initiated environment friendly measures. In this direction, Company has drawn up "Grow More Sandalwood" programme to facilitate the growers to get quality seedlings at reasonable price in one of division at Shimoga along with details of the latest Technical & Marketing information on Sandalwood. In the mean while Karnataka Government has also notified KS&DL as Nodal Agency to procure sandalwood directly from the growers [37].

Global sandalwood market

It is difficult to quantify the size of the global market for sandalwood due to a lack of published and available trade data and also the scale of illegal trade (likely around 33% of the total market). The most reasonable estimate of the annual global sandalwood market in recent times is 6320 ADTH in 2011–2012 [55]. It is clear, however, that global demand for sandalwood remains strong and also that demand has considerably outstripped supply, especially for East Indian sandalwood, in the past two or three decades. Consequently, prices rose rapidly in the 2000s: the price of *S. album* sandalwood in India increased at a compounded rate of 15.1% between 1992 and 2014, and the wholesale price for high-quality.

East Indian sandalwood oil reached ≥USD 3000 kg−1 (for perfumes and new pharmaceutical uses in the United States) in 2016 and early-to-mid 2017 before dropping back to around USD 2000–2500 kg−1. The retail price for East Indian sandalwood oil

derived from Australian plantations is also strong— for example AUD 1416 per 100 ml (Sydney Essential Oil Company 2020). The global sandalwood oil market in 2020 is estimated at USD 97 million (approx. 50 tonnes) (Global Sandalwood Oil Markets Report 2020, http://www.360market updates.com).

Sandalwood market outlook

The market outlook and prices for sandalwood heartwood and oil of high quality (i.e. with high levels of santalols and attaining the East Indian sandalwood ISO standard) are expected to remain strong for at least the next ten years. The global sandalwood oil market is predicted to double in value over the next five years, to USD 197 million by the end of 2026 (Global Sandalwood Oil Markets Report 2020, http://www.360marketupdates.com).

The price elasticity for sandalwood products is rather high—that is, demand will increase substantially if the price of sandalwood falls due to latent high demand from uses such as in medicinal/body-care products. Counterbalancing this price elasticity is the low likelihood of a major, sudden and sustained drop in sandalwood price because the price is buffered and underpinned by product and regional market diversification—that is, diverse uses, including perfumes and attars, fragrant smoke, carving wood, medicinal and body-care products, in diverse regions with strong economies, such as hina, Europe, India, the Middle East and North America. There are growing middle classes with high disposable incomes in China and India, nations with traditional cultural associations with sandalwood, which will maintain upward pressure on price even as supply increases or if individual products or markets face a downturn. Nevertheless, sandalwood is a luxury item, the price of and demand for which would inevitably decline to some extent in a major global economic downturn. It is likely that a range of new uses will be developed and traditional uses will be re-established when more reliable and consistent supplies of high-quality sandalwood oil are generated through sustainably managed plantations.

There is a substantial unmet demand to include sandalwood oil in high- and mid-range perfumes, body-care products, aromatherapy, traditional eastern medicines, new pharmaceutical products, and top-of-the-range solid furniture. Such uses and associated increased demand in China, India and other Asian economies will help underpin the price of better grades of sandalwood oil for the foreseeable future.

There is potential for an oversupply of plantation Australian sandalwood, which may result in a drop in the price for *S. album*and *S. spicatum* wood and oil when peak production is reached, but prices for Pacific Island sandalwoods will likely be less affected [56]. In the future, species with inferior oil quality, such as *S. spicatum*, may struggle to maintain their market share, with lower grades of *S. album* products, including spent still charge, and possibly also lower grades of plantation *Aquilaria* agarwood, displacing *S. spicatum* in agarbatti. Synthetic santalols are expensive to produce and in lesser demand in the perfume sector, and they are unlikely to be a major replacement for natural santalols [56, 57]. Nevertheless, the biosynthesis of sandalwood oil [58] may become economic in the future. Other innovations may also affect sandalwood oil production, such as the production of larger amounts of higher-quality heartwood at a younger age through improved genetics and silviculture, including new heartwood stimulation technologies [59].

India

Production in 2040

The annual official harvest of sandalwood (*S. album*) was 300–370 ADTH in 2008–2012 [60], but the total production in 2011–2012 was estimated at 1250 ADTH, with 1000 ADTH associated with illegal harvesting [55]. By 2040, the production of sandalwood from wild sources will substantially have been overtaken by that derived from planted *S. album*. In 2012, there was more than 1500 ha of *S. album* plantations in India [60].

There has been considerable private-sector interest in developing sandalwood plantations, including in more northern locations, such as Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan, where the species does not naturally occur and which are free from sandalwood spike disease (a mycoplasma organism). The area currently planted to sandalwood in India is estimated to have grown dramatically in the last five years to an estimated 30 000 ha in 2019, in both agroforestry configurations and plantations, with the majority of the plantings in Gujarat and Karnataka states through an initiative of Karnataka Soaps and Detergents Ltd.

The Indian plantations of *S. album* are estimated to produce about 8 ADTH ha^{-1} on a 25–30-year rotation. It is considered that about 1000 ha of 25–30-year-old sandalwood plantation will be harvested per year in 2040, producing 8000 ADTH with an oil content of 2.5% oil, or 200 tonnes of oil. It is estimated that wild stands will produce 2000 ADTH with an oil content of 5% oil, or 100 tonnes of oil.

Demand in 2040

The local demand for sandalwood oil is estimated at a minimum of 250 tonnes in 2040. It is likely that local *S. album* plantation wood will mainly be used domestically or agarbatti,5 funeral pyres (rather than oil production) and some oil, especially for soaps/attars.

India will likely be a net importer of sandalwood heartwood and/or oil in 2040, but it is difficult to predict the quantity due to uncertainties in the production, quality and maturation times of its recent plantations. These new plantations are mainly in non-traditional sandalwood-growing areas, and the impacts of sandalwood spike and other pests and diseases are unknown and growth rates/heartwood development rates uncertain.

Sandalwood resource in India especially the wild populations is currently threatened mainly because of illicit felling, forest fire and grazing and to certain extent spike disease

coupled with heavy domestic and international demand and with inadequate uniform regulation in the Southern states especially in Tamil Nadu, Karnataka and Kerala. Smuggling of Sandalwood has created socio-economic and law and order problems in all Sandalwood producing states. A uniform law for the entire country on use and transport of Sandalwood may help in the improvement of overall status of Sandalwood wealth in the country. Raising large scale plantations in the natural Sandalwood bearing areas will also add up to the resource building of the valuable tree species. However, the lack of production or domestic consumption data make it impossible to judge the state of the supply base and whether this (and the level of exports) is likely to change in the future. Australian Sandalwood industry is all set to dominate World supply of Sandalwood oil. Highest priorities for *S. album* (East Indian Sandalwood) research has been evincing globally in the field of conservation, understanding plant physiology and genetics to maximize oil production and minimize maturation period, processing, markets mainly focusing to the industrial needs.

Requirements for submission of samples for sandalwood quality analysis at FCRI and cost of analysis

100-150g of heartwood sample (chipped or powdered from is required).

Cost of analysis of a single sample of sandalwood for quality assessment= Rs. 5,000.00

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