Sandalwood: history, uses, present status and the future

A. N. Arun Kumar, Geeta Joshi and H. Y. Mohan Ram*

Sandalwood (Santalum album L.) is a valuable tree associated with Indian culture. It is the second most expensive wood in the world. The heartwood of the tree is treasured for its aroma and is one of the finest natural materials for carving. Sandalwood oil is used in perfumes, cosmetics, aromatherapy and pharmaceuticals. The monopoly of sandalwood trade by the Governments of Karnataka, Tamil Nadu and Kerala and its consequences have resulted in severe exploitation, pushing S. album into the vulnerable category of the IUCN Red List. Extensive research has shown that sandalwood exhibits considerable genetic diversity for different traits. However, information pertaining to heartwood and oil content is meagre mainly because of non-availability of sandalwood plantations. Carrying out further research on these two important traits is difficult as natural populations have dwindled rapidly. We strongly urge that it is essential to encourage the establishment of community/corporate sandalwood plantations in different parts of India with appropriate incentives and adequate protective measures. These plantations can form the base population sources to regain the leadership of India in the sandalwood industry for perfumery and the precious art of carving.

Keywords: Heartwood and oil content, phytoplasma, restoration strategies, *Santalum album*, traditional value.

History and tradition

SANDALWOOD (*Santalum album* L.) is a prized gift of the plant kingdom woven into the culture and heritage of India. It is one of the most valuable trees in the world[1] (Figure 1 *a*). The natural distribution of sandalwood extends from 30°N to 40°S from Indonesia in the east to Juan Fernandez Islands (Chile) in the west and from Hawaiian Archipelago in the north to New Zealand in the south[2]. It is a small to medium-sized hemiparasitic tree, distributed rather widely in India. The populations are more concentrated in the southern region, especially Karnataka, Tamil Nadu and Kerala. For more than 5000 years, India has been the traditional leader of sandalwood oil production for perfumery and pharmaceuticals[3]. The aroma of the oil and the wood is esteemed by people belonging to three major religions of the world – Hinduism, Buddhism and Islam. According to *Vamana Purana*, the wood is recommended for worshipping God Shiva. Goddess Lakshmi is believed to reside in the sandalwood tree (*Brahma Vaivarta Purana*)[4]. The ancient Egyptians imported the wood and used it in medicine, for embalming the dead and in ritual burning to venerate the gods[5]. Rabindranath Tagore wrote 'as if to prove that love would conquer hate, the sandalwood perfumes the very axe that lays it low'. Long before the reorganization of states in India, B. M. Srikantaiah (former professor of English and Kannada in Mysore University/Maharaja's College, Mysore), the champion of the 'navodaya movement' (renaissance) in Kannada composed a poem on the Princely State of Mysore entitled *Children of Mysore*. He wrote: 'Chinnada nadadu mysuru, Gandhada gudiyadu mysuru, Veeneya bedagadu mysuru, Nalumadi Krishanana mysuru' (the English rendering would be broadly: A land of gold that's Mysore, A sandalwood shrine that's Mysore, The elegance of Veena music that's Mysore, Nalmadi Krishna's Mysore). It is customary in certain communities among the Hindus to put a piece of sandalwood in the funeral pyre. The beige-coloured paste of sandalwood is applied on the forehead and other body parts, especially by devotees of God Krishna (Vaishnavites) and for ritual bathing of Hindu gods.

Properties and uses

Sandalwood is commercially known as the East Indian sandalwood and its oil the East Indian sandalwood oil. The heartwood that constitutes the central part of the tree

A. N. Arun Kumar and Geeta Joshi are in the Institute of Wood Science and Technology, 18th Cross, Malleswaram, Bengaluru 560 003, India; H. Y. Mohan Ram is in Shriram Institute for Industrial Research, 19 University Road, Delhi 110 007, India.
*For correspondence. (e-mail: anarunkumar@gmail.com)

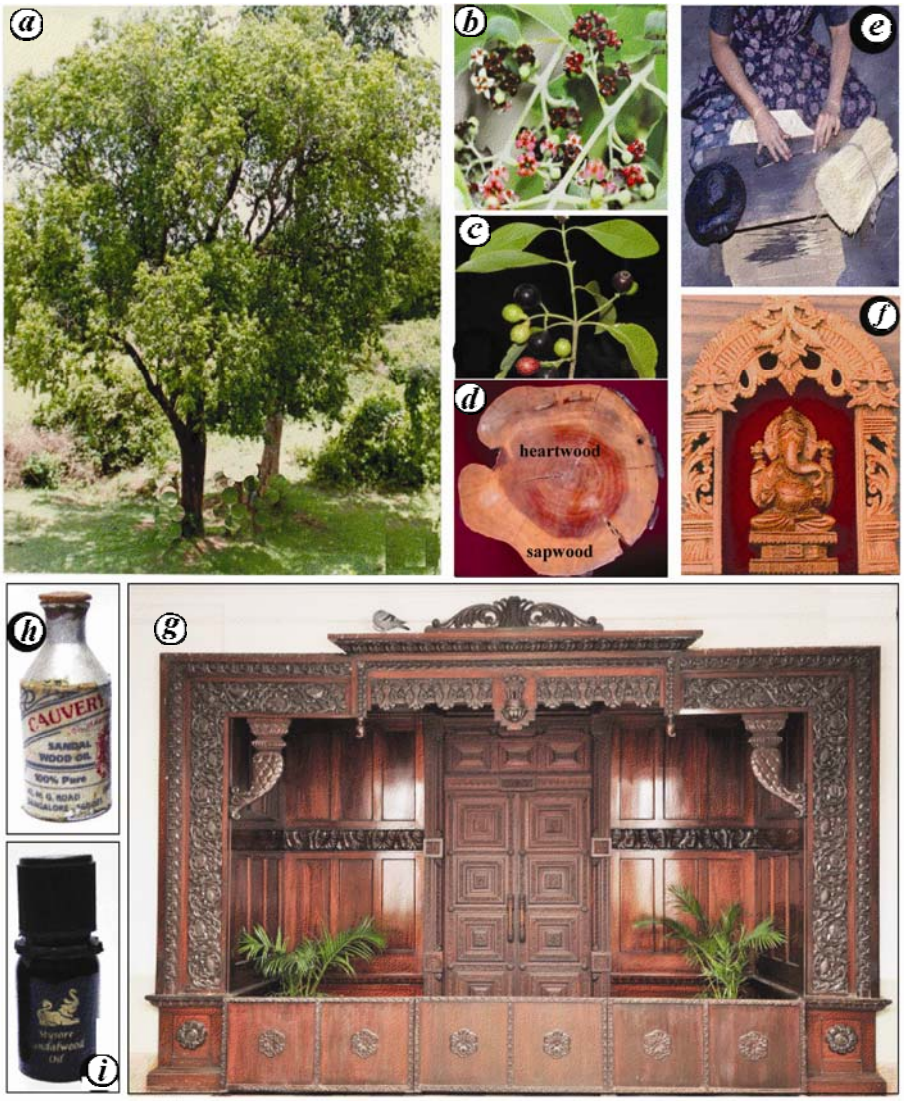

Figure 1. ***a***, An unusually large sandalwood tree showing optimum growth it can attain. Such trees are nowhere to be seen in India today. ***b***, A portion of inflorescence with buds and flowers of different ages. ***c***, A portion of the flowering shoot displaying young and mature fruits. ***d***, Sandalwood disc showing darker heartwood and paler sapwood in the periphery. ***e***, Rolling of agarbattis (see text for details). ***f***, Idol of Ganesha, the elephant-headed Hindu God of wisdom and success with an ornate frame. ***g***, The exquisitely carved sandalwood door leading to the cabinet room is a spectacular feature of the imposing building at Vidhana Soudha in Bengaluru. ***h***, An aluminium bottle containing sandalwood oil which used to be sold at the Crafts Emporium in Bengaluru before 1960s. ***i***, A plastic bottle (with 5 g of sandalwood oil) presently sold.

is valued for its fragrance (Figure 1 *d*). The outer wood (sapwood) or any other part of the tree has no scent. The heartwood is described as astringent, bitter, moderately hard, heavy, durable, yellow or brown in appearance, with an oily texture and is an exquisite material for carving intricate designs[2]. The carved images of gods and mythological figures have a high demand in the market (Figure 1 *f*). It is no wonder that sandalwood is the second most expensive wood in the world, next to the African Blackwood (*Dalbergia melanoxylon*). A wide variety of articles such as boxes, cabinet panels, jewel cases, combs, picture frames, hand fans, pen holders, card cases, letter openers and bookmarks are made from sandalwood. The Vidhana Soudha which houses legislative chambers of state of Karnataka in Bengaluru has an intricately carved, imposing sandalwood door leading to the Cabinet Room[6] (Figure 1 *g*). Sandalwood is sacred and is used in religious ceremonies and is an important ingredient in 'homa' (havana), a Sanskrit word which refers to any ritual in which making offerings into a consecrated fire is the primary action. Among the Buddhists, sandalwood is burnt during prayers and meditation. The sapwood is white or yellow and not scented, and is used in preparing turnery item and agarbattis (Figure 1 *e*). Sandalwood oil

is obtained by steam distillation of heartwood powder. It is expensive and sold by weight. The current (2012) cost of 5 g of oil sold at the Karnataka Government outlet is Rs 1500 (Figure 1 *h* and *i*), which works out to be Rs 300,000/kg. Sandalwood oil is a pale yellow to yellow viscous liquid, with a sweet, fragrant, persistent, spicy, warm, woody, animalic, milky and nutty notes[2]. It is extensively used in perfumery, cosmetics, aromatherapy and pharmaceutical industry. The attributes are due to two forms of a sesquiterpene alcohol – α-santalol (7–60%) and β-santalol (7–33%). Being good fixatives these are highly valued in perfumery and toiletry industry, especially for certain delicate scents that are extremely rare and fragile. No composition of the heavy or oriental type of perfume is complete without an ample dose of sandalwood oil. Most Indian attars (*atar*, in Persian means a fragrant essential oil or aroma) use sandal oil as the base because of its inherent capacity to absorb most of the ethereal notes of other whole herbs or flowers, as it can enhance their perfumery status and stability. Perhaps one of the most precious perfumery materials from antiquity down to modern times, the popularity of sandalwood oil has shown no signs of waning. The oil is used as a flavouring substance in food products such as frozen dairy desserts, candy, pan masala, baked food, gelatin, puddings and also in alcoholic and non-alcoholic beverages. The oil is approved for use by the US Food and Drug Administration, Flavour and Extract Manufacturers Association, Council of Europe and Joint FAO/WHO Expert Committee on Food Additives[5].

On account of acute scarcity of sandalwood oil, search for novel synthetic raw materials imitating the characteristic odour profile of sandalwood oil has become a challenging task. Extensive studies are being carried out to investigate the structure–odour relationship[7]. The oil is used for its therapeutic effects in Ayurveda, Chinese and Tibetan medicinal systems[3]. It is used in the treatment of common colds, bronchitis, fever, dysentery, piles, scabies and infection of the urinary tract, inflammation of the mouth and pharynx, liver and gall-bladder complaints and as an expectorant, stimulant, carminative, digestive and as a muscle relaxant[5]. A recently conducted *in vitro* study has shown that sandalwood oil is effective on methicillin-resistant *Staphylococcus aureus* (MRSA) and antimycotic-resistant *Candida* species[8]. In another study, a crude extract as well as isolated compounds of sandalwood oil (primarily α- and β-santalol) showed antibacterial activity against *Helicobacter pylori*, a Gram-negative bacterium which is strongly linked to the development of duodenal, gastric and stomach ulcers[9]. Sandalwood oil exhibited virulence against isolates of drug-resistant herpes simplex virus type I (ref. 10). The oil also showed anti-carcinogenic activity[5]. A recent study[11] reports that β-santalol exhibited anti-influenza A/HK (H3N2) virus activity of 86% with no cytotoxicity at the concentration of 100 μg/ml. Sandalwood oil elevates pulse rate, skin conductance level and systolic blood pressure and brings about higher ratings of attentiveness and mood in humans[12].

Monopoly of sandalwood trade and its consequences

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 century[13]. 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 (ref. 14). 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 (ref. 15) (Table 1; Figure 2).

Nalwadi Krishnaraja Wodeyar (1884–1940) (aka Krishnaraja Wodeyar IV), whose period of sovereignty is often described as the Golden Age of Mysore, was instrumental in conceiving the idea of starting a sandalwood oil factory. Outbreak of the World War I had a severe impact on the forest economy of Mysore due to 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), Bengaluru[16]. 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.

Over 70 years ago, nearly 90% of the natural sandalwood populations occurred in the southern part of Karnataka and northern part of Tamil Nadu[17]. Excessive harvesting without replenishment of this invaluable resource has substantially reduced the sandalwood industry, resulting in global shortage and soaring of market prices. Importantly, *S. album* has been categorized as 'vulnerable' by the International Union for Conservation of

Table 1. Classification of sandalwood sorted before being passed for sale (according to the Karnataka Forest Manual Rule No. 95)

Sl. no.	Class	Description	Fixed price (rupees in lakhs) per metric tonne of wood for 2010–11
1	Vilayat Budh (Class I billets)	Sound billet weighing not less than 9 kg and not exceeding 112 pieces per tonne.	41.00
2	China Budh (Class II billets)	Slightly inferior billet weighing less than 4.50 kg and not exceeding 224 pieces per tonne.	41.00
3	Panjam (Class III billets)	Billets having small knots, cracks and hollows weighing not less than 2.2 kg and not exceeding 448 pieces per tonne.	37.00
4	Ghotla (billets of short length)	Includes short and sound pieces. There are no limits of weights and numbers per tonne.	41.00
5	Ghatbadla	Billets with knots, cracks, small hollows, weighing not less than 4.5 kg and not exceeding 250 pieces per tonne.	41.00
6	Bagardad	Consists of solid pieces without limit as regards dimensions, weight or number.	39.50
7	Roots (Class I)	Pieces weighing not less than 6.75 kg and not exceeding 150 pieces per tonne.	36.25
8	Roots (Class II)	Consists of pieces weighing not less than 2.25 kg and not exceeding 448 pieces per tonne.	37.40
9	Roots (Class III)	Consists of small and side roots below 2.25 kg in weight	33.70
10	Jajpokal or Badla (Class I)	Consists of hollow pieces weighing not less than 3.10 kg and not exceeding 320 pieces per tonne.	40.75
11	Jajpokal (Class II)	Hollow pieces weighing not less than 1.3 kg per tonne.	37.10
12	Ainbagar	Consists of solid, cracked and hollow pieces weighing not less than 450 g.	40.10
13	China Sali or Large Chilta	Consists of pieces and chips of heartwood weighing not less than 2.25 g.	32.20
14	Ain Chilta	Consists of small pieces of heartwood.	28.20
15	Hatri Chilta	Consists of heartwood and chips obtained by plaining billets with Hatri or Randha (plane).	19.00
16	Milva Chilta	Consists of pieces and chips having fair proportions of heartwood and sapwood.	15.50
17	Basola Bukni	Consists of small heartwood and sapwood chips.	11.50
18	Saw dust	Sawn powder obtained while sawing the sandalwood.	7.50

Nature (IUCN) in 1997. In Karnataka, sandalwood populations are sparse and devoid of larger girth classes; mature trees have been nearly vandalized[18]. The major cause of the decline of sandalwood has been smuggling.

A serious affliction from which sandalwood suffers is the spike disease and the economic losses caused by it are heavy. As a measure to control the spread of spike disease, 700,000 sandalwood trees in the State of Mysore and 350,000 in the erstwhile Coorg State during the period 1903–1916 were killed by the application of arsenical solution[19]. The other reasons of paucity of sandalwood include forest fires, absence of adequate number of seed-bearing trees, lack of established plantations and heavy demand by the Sandalwood Oil Factory. Sandalwood production (referring to the quantity of sandalwood auctioned) in Karnataka and Tamil Nadu has dwindled considerably (Figures 3 and 4). Apart from Karnataka and Tamil Nadu, sandalwood is found in Kerala. Marayoor (40 km from Munnar in Idukki district) is the only place in Kerala where sandal trees grow naturally. In 2011–12, 45.15 tonnes of sandalwood was extracted from this region. It is encouraging to note that the quantity of illegal sandalwood seized in Karnataka has dropped from 76.75 tonnes in 1999–2000 to 3.52 tonnes in 2010–11 (Figure 5). Although increased vigilance cannot be denied, there is also a sharp decline in the availability of trees of optimal girth for felling in sandalwood habitats. The decline in sandalwood availability has also affected traditional artisans (gudigars), from Sirsi, Soraba, Sagar, Honnavar and Kumta (in Karnataka), whose means of livelihood was sandalwood carving for generations. Even though the annual requirement of Karnataka State Handicrafts Development Corporation has been fixed at 100 tonnes, the gudigars received a paltry quantity of 0.74 tonnes.

The monopolistic rule on sandalwood had prevented anyone excepting the personnel of Forest Department to harvest and sell it. Unlike the situation with major commercial timber tree species such as teak, sal, pine, deodar, oak, acacia, eucalyptus, casuarina, willow and poplar in India, sandalwood stands out as one species for which no organized plantations have been established. Realizing the disadvantages of this rule and taking cognizance of the grim situation, the Governments of Karnataka and

Figure 2. Sorted sandalwood billets of various classes (numbers from 1 to 18 are the trade names of each class described in Table 1).

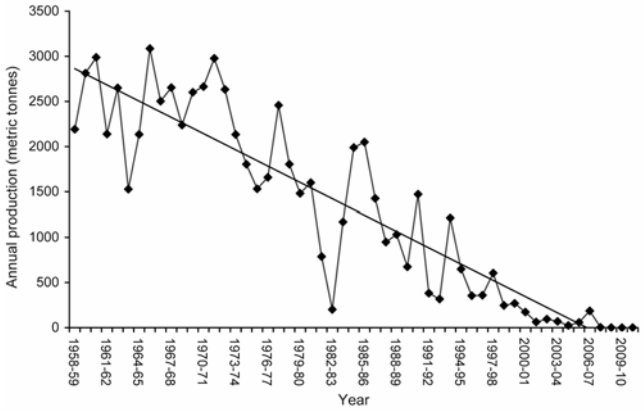

Figure 3. Annual production of sandalwood in Karnataka from 1958–59 to 2010–11.

Tamil Nadu promulgated The Karnataka Forest (Amendment) Act 2001 and The Tamil Nadu Forest (Amendment) Act 2002 respectively. The former Act clearly stated that 'every occupant or the holder of land shall be legally entitled to the sandalwood tree in his land'. At that point of time, the owners had no option but to sell sandalwood

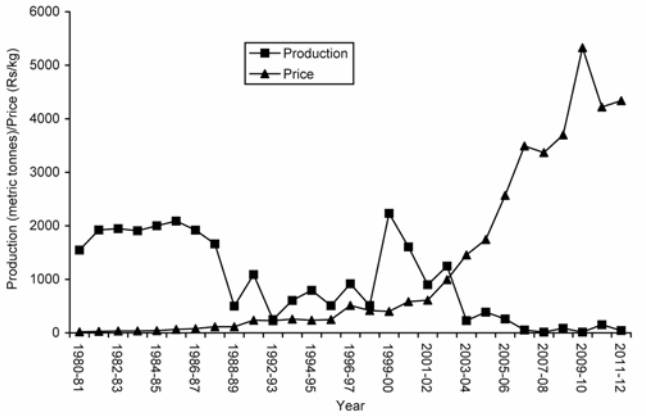

Figure 4. Annual production and price rise of auctioned sandalwood in Tamil Nadu from 1980–81 to 2011–12.

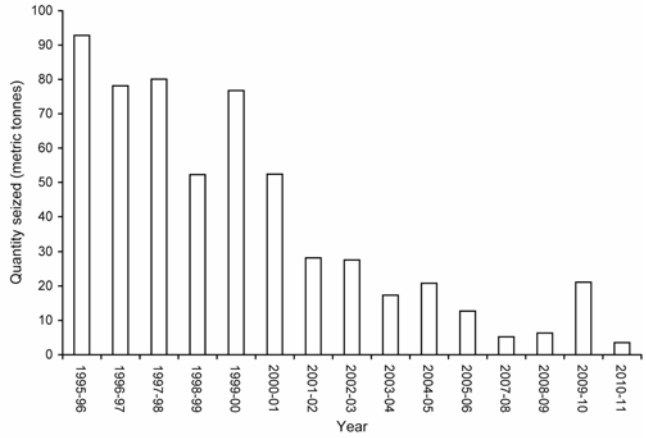

Figure 5. Quantity of smuggled sandalwood seized annually in Karnataka from 1995–96 to 2010–11.

exclusively to the Forest Department. Presently, the Government of Karnataka has authorized Karnataka Soaps and Detergents Limited and the Karnataka State Handicrafts Development Corporation to buy sandalwood directly from the landowners[20]. Although the debate on the consequences of this amendment is outside the purview of this article, it has paved the way for encouraging community and private entrepreneurs to cultivate sandalwood which is in great demand.

Research on sandalwood

Research findings on various aspects of sandalwood came to be recorded in the later part of the 19th century. One of the major findings was the parasitic nature of sandal reported in 1871 (ref. 21). In 1899, the spike disease of sandal was first noticed and reported from Coorg[22]. As sandal spike disease was the main disease that took a heavy toll on sandalwood, serious attention was paid to it. In 1903, the Government of Mysore offered a reward of

Rs 10,000 to anyone who finds an effective cure for the disease[23], which has not been claimed until now. Organized research on the spike disease was initiated at IISc in October 1927 and continued until 1933 (ref. 14). With the reorganization of Forest Research Laboratory in 1956 as the Regional Research Centre of Forest Research Institute and Colleges, an exclusive division named after sandal spike was started[2]. In the early part of the 20th century, the spike disease was believed to be caused by a virus. However, in 1969, a paper appeared in *Nature* claiming that the disease was induced by a mycoplasma-like organism (MLO)[24]. The current nomenclature of this causal agent has been accepted as phytoplasma. A clarification about the basic differences between mycoplasmas and phytoplasmas has been precisely outlined by Chen *et al.*[25]. Phytoplasmas are plant pathogenic bacteria of the class Mollicutes[26]. While presenting his overview on 'Phytoplasma: a century of pioneering research', Namba[27], has stated that phytoplasmas are responsible for causing devastating damage in over 700 plant species worldwide, transmitted by feeding insects. Whereas mycoplasmas can be cultured in the laboratory and are amenable to genetic manipulation, the phytoplasmas cannot be cultured outside host cells. This has become a challenging problem. Recently, a few researchers are concentrating on genome sequencing, comparative genome analysis and evolution of the phytoplasmas and mycoplasmas[25,28]. Steps towards molecular characterization of the phytoplasma associated with sandalwood spike disease have already been taken up by Khan *et al.*[28] who have classified the phytoplasma of the sandalwood spike disease as a subgroup of 16Srl-B, identical to those strains Ay1 and APh of the aster yellows.

Realizing the importance of sandal and the necessity for research on varied aspects, apart from the spike disease, the Sandal Research Centre was established by the Government of India in Bengaluru in 1977. The aim of this Centre was to carry out research on diverse aspects of sandalwood tree – genetics, silviculture and management. The first sandalwood population survey of the country was carried out to study (i) population density, (ii) tree size and (iii) extent of heartwood[29]. During the survey, superior genotypes were also identified on the basis of rapid growth rate, quantity of heartwood and oil content, resistance to spike disease, heartwood borer and heartwood rot[30]. Thus, tree improvement activity in sandal gained momentum, in addition to sandal spike research. Several research groups in India (such as IISc, Bhabha Atomic Research Centre, National Chemical Laboratory and Institute of Wood Science and Technology) have carried out R&D work on micropropagation of sandalwood. Protoplasts, somatic embryos and synthetic seeds (both diploid and triploid) have been obtained *in vitro* for raising plantlets. The number of papers published is enormous and no attempt is made to go into the details here. However, there have been no reports of raising sandalwood plantations from culture-raised materials (Rao and Bapat[31], and reference cited therein).

Tree improvement

Sandalwood plants exhibit significant variability for many traits. Bark varies in colour, texture and thickness. Leaf types (ovate, lanceolate, elliptic and linear), small and large have been observed[32]. The plant shows self-incompatibility and the flowers are strictly adapted to cross-pollination by insects (flies such as *Phytomia argyrocephala*, *Eristalynus arvorum* and *Dolichomerus crassa*) and bees (*Apis florea*, *A. cerana*, *A. dorsata*)[33]. However, Sindhu Veerendra and Ananthapadmanabha[34] have reported that bees, butterflies and beetles are the pollinating agents. They have further noted that although *S. album* is a predominantly outbreeding species, it also exhibits seed set by selfing. Some extent of self-incompatibility and heterostyly in some genotypes has been observed by them[34]. The reward to the visiting insects is nectar, available in a cup-like disc. The freshly opened flowers are green and they turn pink the next day and secrete the nectar. These flowers are receptive to pollinators. Following pollination the flower colour changes to dark red (Figure 1 *b*). Young fruits are green, oval to spherical, variable in size, turning red to deep purple or black on maturity (Figure 1 *c*). Birds consume the pulp and disperse the fruits. Sixty per cent of the trees flower and bear fruits twice a year (during March–May and September–December), 36% once a year (September–December) and 4% throughout the year[35]. Seeds show polymorphic traits in size, shape, germination and vigour[36]. Three plant phenotypes have been recorded on the basis of the following features given in parentheses: (1) Thindlu (dark brown bark with irregular flakes and dark brown heartwood); (2) Chikkaballapur (small, bluish-green leaves similar to spiked plant with large sapwood) and (3) Robust (compact crown with lush green foliage, thick sapwood and fast growth compared to the other two types)[37]. Researchers have studied genetic diversity using isozyme, RAPD and RFLP analysis and have reported significant diversity among natural sandalwood populations[38–40]. Genetic diversity was higher among populations in Karnataka than in other states of South India[41]. As an *in situ* conservation strategy, eight sandalwood-bearing areas have been identified as potential provenances (a term used previously by foresters to indicate the place of origin) in India on the basis of latitude, longitude, population density and phenotypic characteristics[42].

Research pertaining to the two commercially important traits, i.e. heartwood and oil has not yielded critical data to address sandalwood improvement programmes. As early as 1894 it had been recognized that the tree attains a commercially profitable size between 27 and 30 years[43]. Subsequent studies showed interesting but contrasting

results. It was reported in 1921 that heartwood and oil formation in sandalwood are yet to be studied in detail. Recognizing the importance and need for research on sandalwood, in 1977, the First All India Sandal Seminar was held in Bengaluru. An important recommendation was that priority should be given to the rate of heartwood formation in trees growing under different conditions. In the Second All India Sandal Seminar that was convened in 1981, it was emphasized that superior genotypes with higher quantity of heartwood need to be identified and research on heartwood formation should be intensified. Tabulated data on heartwood yield for different girth size trees were published, but without supporting empirical evidence[15,44]. This aspect is essential because it is necessary to record data on the basis of plantations of different age groups. Not many plantations of different age classes were available then. Variations in sandalwood oil for α- and β-santalol content were available for wood samples collected from different locations[45]. Whether or not the variations could be attributed to tree age, genotype or locality effect could not be established with certainty. Research carried out during 1980s showed that variability existed in heartwood colour and its relation with oil content[46]. A study noted that variation existed in heartwood content for similar girth class in a given locality and in 13% of the population no heartwood had been formed[47]. In all these studies, the importance of age as a criterion was not taken into consideration. The probable effect of age was never understood, even though it was never denied that age played a considerable role in heartwood formation and oil content. A study conducted in a known aged clonal germplasm bank of sandal at Hoskote, Bengaluru, showed that considerable variability exists in heartwood diameter and oil content[48], suggesting an interaction of genotype and environment. Strong positive relationship between tree diameter and heartwood diameter has also been reported[49]. Similar observations were found in a study carried out in Australia and it was also reported that 20% of the trees failed to produce heartwood at the age of 14 years[50]. Thus variability observed in these two traits has generated a good deal of interest and should be crucial in any improvement programme of sandalwood. Yet, one needs to also accept all the complex, ecological factors that play a role in the growth of sandalwood, especially because sandal is a partial root parasite in the early stage of development. Sandalwood has been introduced in Rajasthan, Madhya Pradesh, Uttarakhand and Odisha. It has been reported that sandalwood trees grown in Rajasthan had produced heartwood and the oil percentage varied from 0.9 to 3.0 (ref. 51).

Considering the status of our knowledge, sandal tree improvement appears problematic. Much of the earlier research on sandal tree improvement was limited to identifying superior genotypes/candidate plus trees, which may not exist in the field today. Further, identification/enlisting of superior genotypes seems to be remote at this juncture as there are no trees available having economically viable girth in the natural habitat. This in turn would also hinder establishment of baseline data on the relationship between morphological traits with heartwood and oil content, variation across age and location. Relationship, if any, when obtained can become a dependable marker for identification of superior genotypes.

There is considerable genetic variability in sandalwood, which gives some hope to initiate improvement programmes. The first report of *Agrobacterium tumefaeciens*-mediated genetic transformation and regeneration in *S. album* using *in vitro* seedling axes and somatic embryos was published in 1998 (ref. 52). It is highly desirable to have a transgenic sandalwood plant having higher heartwood and oil content and also resistant to spike disease. However Jones and Plummer[53] have stated that 'with the present status of technologies, market and industry, transgenic sandalwood is unlikely to attract much commercial attention in the near future'. In the meantime what is essential is that we need to generate baseline field data on heartwood and oil content using traditional breeding methods and carrying out extensive field trials to authenticate the results.

Sandalwood cannot be equated with other commercial short-rotation or timber-yielding species in which improvement work has been considerably successful. The sandalwood tree has to be viewed from a different perspective. Some of the inherent advantages of sandalwood would certainly help not only in its survival, but also in redeeming its past glory. Traits unique to *S. album* are: (a) being predominantly outcrossing, (b) its ability to grow under diverse conditions such as very low rainfall and wide variety of soil types, (c) its innate survival capacity, (d) short juvenile phase and flowering by the end of 3–4 years, (e) endowment of over 60% of plants flowering and bearing fruits twice a year, (f) dispersal of fruits by birds and other animals, (g) easy seed establishment and (h) profuse coppicing ability.

The policy of the Governments of Karnataka and Tamil Nadu to abolish their monopoly on sandalwood has generated interest in public and private sectors to raise sandalwood plantations. There is a perpetual demand for genuine natural sandalwood oil for the world perfume industry and for traditional purposes. Even though Australia has been raising large sandalwood plantations, and may be able to meet the global demands, the Indian sandalwood fetches a premium price for its unique aroma. Australian sandalwood (*Santalum spicatum*) is sold at ~A$10,000 a tonne, which is far lower compared to the cost of the premium East Indian sandalwood[3] (equivalent of A$73,000/tonne). Whereas there is no plantation of any substantial size in India, the world's largest plantation of *S. album* has been established in the Kimberley, Western Australia. It is learnt that most mature trees in this plantation were reported to be harvested in 2012. There is a ban on export of sandalwood or sandalwood oil

from India. There are reports that some companies in India are even importing sandalwood from Australia to meet the high demand for domestic use.

As the present manuscript was in the final stage of preparation, our attention was drawn to an article by Kulkarni[54]. According to him, the Delhi-based Surya Vinayak Industries, which manufactures sandalwood oil and perfumery compounds and Dharampal Satyapal Group, makers of Rajnigandha pan masala have taken up commercial plantation of sandalwood in Madhya Pradesh. The Bangalore-based Namdhari Seeds has started plantations of sandalwood at Pavagada in Tumkur district of Karnataka. A large number of farmers and individuals with large land holdings have joined in the commercial cultivation in Karnataka, Maharashtra, Andhra Pradesh and Rajasthan. Whereas the news is heartening, it is our hope that in this endeavour experts are consulted and R&D practices unique to sandalwood are utilized. We are conscious that in the past certain corporate bodies that promised rich dividends for fast-growing teak plants to their shareholders could not achieve their targets and incurred huge losses.

The present need is mass distribution of seedlings, raising of sandalwood plantations and expanding their distribution range across the country. Unlike the situation with plantations of other commercial tree species, those of sandalwood would be the core centres for reinitiating sandalwood tree improvement programmes. This requires investments, vigilance and dependable plant protection methods. It is to be reckoned that tree improvement in sandalwood has crossed the exclusive domain of forestry researchers and is to be targeted with a basic science plan of approach, supported by active participation of entrepreneurs, end-users and scientific institutions and local bodies. There is a need to protect and enhance the abundance of this culturally valuable sandalwood plant material which has both genuine demand in India and abundant export potential.

1. Fox, J. E., Sandalwood: the royal tree. *Biologist* (*London*), 2000, **47**, 31–34.
2. Srinivasan, V. V., Sivaramakrishnan, V. R., Rangaswamy, C. R., Ananthapadmanabha, H. S. and Shankaranarayana, K. H., *Sandal* (*Santalum album* L.), ICFRE, Dehra Dun, 1992.
3. Hansda, R., The outlook for non wood forest products in Asia and the Pacific, Working Paper No. APFSOS II/WP/2009/18, Food and Agriculture Organisations Regional Office, Bangkok, 2009, p. 89.
4. Sensarma, P., *Plants in the Indian Puranas: An Ethnobotanical Investigation*, Naya Prokash, Calcutta, 1989.
5. Burdock, G. A. and Carabin, I. G., Safety assessment of sandalwood oil (*Santalum album* L.). *Food Chem. Toxicol.*, 2008, **46**, 421–432.
6. Raman, A, *Bangalore–Mysore*, A Disha Guide, Orient Longman Ltd, Delhi, 1994, p. 11.
7. Brocke, C., Eh, M. and Finke, A., Recent developments in the chemistry of sandalwood odorants. *Chem. Biodivers.*, 2008, **5**, 1000–1010.
8. Warnke, P. H. *et al*., The battle against multi-resistant strains: renaissance of antimicrobial essential oils as a promising force to fight hospital-acquired infections. *J. Carnio Maxillofacial Surg.*, 2009, **37**, 392–397.
9. Ochi, T., Shibata, T., Higuti, T., Kodama, K., Kusumi, T. and Takaishi, Y., Anti *Helicobacter pylori* compounds from *Santalum album*. *J. Nat. Prod.*, 2005, **68**, 819–824.
10. Schnitzler, P., Koch, C. and Reichling, J., Susceptibility of drug resistant clinical herpes simplex virus type 1 strains to essential oils of ginger, thyme, hyssop and sandalwood. *Antimicrob. Agents Chemother.*, 2007, **51**, 1859–1862.
11. Paulpandi, M., Kannan, S., Thangam, R., Kaveri, K., Gunasekaran, P. and Rejeeth, C., *In vitro* anti-viral effect of β-santalol against influenza viral replication. *Phytomedicine*, 2012, **19**, 231–235.
12. Heubeger, E., Hongratanaworakit, T. and Buchbauer, G., East Indian sandalwood and α-santalol odor increase physiological and self-rated arousal in humans. *Planta Med.*, 2006, **72**, 792–800.
13. Ganeshaiah, K. N., Uma Shaanker, R. and Vasudeva, R., Bioresources and empire building: What favoured the growth of Vijayanagara Empire? *Curr. Sci.*, 2007, **93**, 140–146.
14. Adkoli, N. S., Sandalwood in Karnataka. Retrospect and prospect. In Proceedings of the All India Sandal Seminar, Bangalore, 1977, pp. 86–94.
15. Venkatesan, K. R., A fresh look at the management of sandal. In Proceedings of Second Forestry Conference, FRI and Colleges, Dehradun, 1980, pp. 1101–1108.
16. Subbarayappa, B. V., *In Pursuit of Excellence – A History of The Indian Institute of Science*, Tata McGraw Hill Publishing Company Limited, New Delhi, 1992.
17. Rai, S. N., Status and cultivation of sandalwood in India. In Proceedings of the Symposium on Sandalwood in the Pacific (eds Hamilton, L. and Conrad, C. E.), 9–11 April 1990, Honolulu, Hawaii, US Forest Service General Technical Paper PSW–122, 1990, pp. 66–71.
18. Swaminath, M. H., Hosmath, B. J. and Mallesha, B. B., The status of sandalwood in India: Karnataka. In *Sandal and its Products*, ACIAR Proceedings (84) (eds Radomiljac, A. M. *et al.*), IWST & KSFD, Bangalore, 1998, pp. 3–5.
19. Rajan, B. K. C., *Ten Forest Products*, Jaya Publications, Bangalore, 1992.
20. Venkatesha Gowda, H. S., Natural sandalwood industry – present scenario and future prospects. In Proceedings of the National Seminar on Conservation, Improvement, Cultivation and Management of Sandal (*Santalum album* L.) (eds Gairola, S. *et al.*), Institute of Wood Science and Technology, Bangalore, 2007, pp. 196–203.
21. Scot, J., Notes on horticulture in Bengal, No. 2, Loranthaceae, the mistletoe order, their germination and mode of attachment. *J. R. Hortic. Soc. India*, 1871, **2**, 287.
22. McCarthy, C., Progress Report of Forest Administration in Coorg for 1898–99.
23. Muthanna, M. A., Spike disease of sandal. *Indian For.*, 1955, **81**, 500–508.
24. Hull, R., Horne, T. W. and Nayar, R. M., Mycoplasma-like bodies associated with sandal spike disease. *Nature*, 1969, **224**, 1121–1122.
25. Chen, L. L., Chung, W. C., Lin, C. P. and Kuo, C. H., Comparative analysis of gene content evolution in phytoplasmas and mycoplasmas. *PLoS ONE*, 2012, **7**, e34407.
26. Hogenhout, S. A., Oshima, K., Ammar, E. D., Kakizawa, S., Kingdom, H. N. and Namba, S., Phytoplasmas: bacteria that manipulate plants and insects. *Mol. Plant Pathol.*, 2008, **9**, 403–423.
27. Namba, S., Phytoplasmas: a century of pioneering research. *J. Gen. Plant Pathol.*, 2011, **77**, 345–349.
28. Khan, J. A., Singh, S. K. and Ahmad, J., Characterisation and phylogeny of a phytoplasma inducing sandal spike disease in sandal (*Santalum album*). *Ann. Appl. Biol.*, 2008, **153**, 365–372.

29. Venkatesan, K. R., Srimathi, R. A. and Kulkarni, H. D., Survey of sandal populations. In *Recent Advances in Research and Management of Sandal* (*Santalum album* L.) *in India* (eds Srimathi, R. A., Kulkarni, H. D. and Venkatesan, K. R.), Associated Publishing Company, New Delhi, 1995, pp. 3–52.
30. Srimathi, R. A., Breeding of sandal – a tropical hardwood tree – current status and future prospects. In *Recent Advances in Research and Management of Sandal* (*Santalum album* L.) *in India* (eds Srimathi, R. A., Kulkarni, H. D. and Venkatesan, K. R.), Associated Publishing Company, New Delhi, 1995, pp. 327–353.
31. Rao, P. S. and Bapat, V. A., Somatic embryogenesis in sandalwood (*Santalum album* L.). In *Somatic Embryogenesis in Woody Plants: Vol. 2. Angiosperms* (eds Mohan Jain, S., Gupta, P. K. and Newton, R. J.), Kluwer Academic Publishers, Dordrecht, The Netherlands, 1995, pp. 193–210.
32. Kulkarni, H. D. and Srimathi, R. A., Variation in foliar characteristics in sandal. In *Biometric Analysis in Tree Improvement of Forest Biomass* (ed. Khosla, P. K.), International Book Distributors, Dehra Dun, 1982, pp. 63–69.
33. Bhaskar, V., Pollination biology and fertilization in *Santalum album* L. (Santalaceae). *Flora*, 1992, **187**, 73–78.
34. Sindhu Veerendra, H. C. and Ananthapadmanabha, H. S., The Breeding system in sandal (*Santalum album* L.). *Silvae Genet.*, 1996, **45**, 188–190.
35. Ananthapadmanabha, H. S., Nagaveni, H. C. and Rai, S. N., Endogenous gibberellin in relation to flower induction in sandal. *Myforest*, 1991, **24**, 32–34.
36. Annapurna, D., Rathore, T. S. and Somashekhar, P. V., Impact of clones in a clonal seed orchard on the variation of seed traits, germination and seedling growth in *Santalum album* L. *Silvae Genet.*, 2005, **54**, 153–160.
37. Srimathi, R. A., Kulkarni, H. D. and Venkatesan, K. R., Phenotypes of sandal. *J. Bombay Nat. Hist. Soc.*, 1983, **80**, 245–246.
38. Shashidhara, G., Hema, M. V., Koshy, B. and Farooqi, A. A., Assessment of genetic diversity and identification of core collection in sandalwood germplasm using RAPDs. *J. Hortic. Sci. Biotechnol.*, 2003, **78**, 528–536.
39. Nageswara Rao, M., Ganeshaiah, K. N. and Uma Shaanker, R., Assessing threats and mapping sandal resources to identify genetic 'hot-spot' for *in-situ* conservation in peninsular India. *Conserv. Genet.*, 2007, **8**, 925–935.
40. Jones, C. G., The best of *Santalum album*: essential oil composition, biosynthesis and genetic diversity in the Australian tropical sandalwood collection. Ph D thesis, The University of Western Australia, 2008; http://www.plants.uwa.edu.au/studentnet/postgrad-rofiles?profile/1/id/379
41. Nageswara Rao, Padmini, S., Ganeshaiah, K. N., Uma Shaanker, R. and Jaya, R. S., Indian sandalwood crisis. *Perfumer Flavorist*, 2008, **33**, 38–43.
42. Jain, S. H., Angadi, V. G., Rajeevalochan, A. N., Shankaranarayana, K. H., Theagarajan, K. S. and Rangaswamy, C. R., Identification of provenances of sandal in India for genetic conservation. In *Sandal and its Products* (eds Radomiljac, A. M. *et al.*), Australian Centre for International Agricultural Research (ACIAR) Proceedings (84), Canberra, 1998, pp. 117–120.
43. Cameron, J., *Forest Trees of Mysore and Coorg*, Mysore Government Central Press, Bangalore, 1894, pp. 240–241.
44. Rai, S. N. and Kulkarni, H. D., Sandalwood plantations. In *Plantation Crops Opportunities* (eds Srivastava, H. C., Vatsya, B. and Menon, K. K. G.), Oxford & IBH Publishers Company Ltd, New Delhi, 1986, pp. 295–300.
45. Jayappa, V., Nataraj, B. M., Shanbhag, P. K., Patil, K. B. and Srinivas, A., Regional variation in the yield and quality of sandal oil. A study by GLC. In *Recent Advances in Research and Management of Sandal* (*Santalum album* L.) *in India* (eds Srimathi, R. A., Kulkarni, H. D. and Venkatesan, K. R.), Associated Publishing Company, New Delhi, 1995, pp. 166–170.
46. Shankaranarayana, K. H. and Venkatesan, K. R., Chemical aspects of sandalwood oil. In *Cultivation and Utilization of Aromatic Plants* (eds Atal, C. K. and Kapoor, B. M.), Regional Research Laboratory, Jammu, 1982, pp. 138–141.
47. Srimathi, R. A. and Kulkarni, H. D., Preliminary findings of the heartwood formation in sandal (*Santalum album* L.). In Proceedings of Second Forestry Conference, FRI and Colleges, Dehra Dun, 1980, pp. 1–13.
48. Arun Kumar, A. N., Evaluation and characterization of clonally propagated sandal (*Santalum album* L.) accessions of diverse origin with special reference to heartwood, oil content and other morphological characters. Ph D thesis, Forest Research Institute, Dehra Dun, 2005.
49. Arun Kumar, A. N., Srinivasa, Y. B., Joshi, G. and Seetharam, A., Variability in and relation between tree growth, heartwood and oil content in sandalwood (*Santalum album* L.). *Curr. Sci.*, 2011, **100**, 827–830.
50. Brand, J., Kimber, P. and Streatfield, J., Preliminary analysis of Indian sandalwood (*Santalum album* L.) oil from a 14-year-old plantation at Kununurra, Western Australia. *Sandalwood Res. Newsl.*, 2006, **21**, 1–3.
51. Jain, S. H., Arya, R. and Hemant, K., Distribution of sandal (*Santalum album* L.), current growth rates, predicted yield of heartwood and oil content and future potential in semi-arid and arid regions of Rajasthan, India. *For., Trees Livelihoods*, 2007, **17**, 261–266.
52. Veena Shiri and Sankara Rao, K., Introduction and expression of marker genes in sandalwood (*Santalum album* L.) following *Agrobacterium*-mediated transformation. *Plant Sci.*, 1998, **131**, 53–63.
53. Jones, C. G. and Plummer, A. J., Sandalwood. In *Compendium of Transgenic Crop Plants: Transgenic Forest Tree Species* (eds Kole, C. and Hall, T. C.), Blackwell Publishing Ltd, 2008, pp. 309–320.
54. Kulkarni M., Corporate sector enters sandalwood plantation. *Business Standard* (e-paper), 8 April 2011.

ACKNOWLEDGEMENTS. We thank the Director, Group Coordinator (Research) and Head of Tree Improvement and Propagation Division, Institute of Wood Science and Technology (IWST), Bengaluru for facilities and support. Mr K. M. Chandrashekar, ACF, Government Sandalwood Depot, Mysore, kindly provided the photographs of sandalwood billets. Mr G. Ravikumar, Research Officer (Grade II), IWST for photographs of sandalwood tree and flowers. Dr R. Murugan, Central University, Sikkim for the photographs of the fruits and Nilotpal Baruah, for the photographs of the sandalwood door at Vidhana Soudha, Bangalore. We acknowledge Dr M. Sanjappa, Ex-Director, BSI and Dr Ramakrishna, Ex-Director, ZSI for their suggestions. Mrs Vimala and Dr H. Y. Rajagopal have translated the Kannada poem cited in the text. H.Y.M. is beholden to the Indian National Science Academy, New Delhi for the award of Srinivasa Ramanujam Research Professorship and Dr R. K. Khandal, Director, Sriram Institute for Industrial Research, Delhi for various facilities provided. Dr Narendra Kumar's help in the preparation of the manuscript is deeply appreciated.

Received 8 June 2012; revised accepted 5 November 2012