ISSN: 2394-7543

- Volume 2 Number 4
- A Quarterly Issue
- January - March 2016

ENVIS Newsletter
Forest Genetic Resources & Tree Improvement

VAN VIGYAN

INSTITUTE OF FOREST GENETICS AND TREE BREEDING

(Indian Council of Forestry Research and Education)

From the
Director's Desk

The present issue of Van Vigyan, the Newsletter of the ENVIS Centre on Forest Genetic Resources and Tree Improvement gives a detailed account about the Indian Sandalwood, one of the most expensive woods available today. The aim of introducing "Know your trees" is to keep the readers better informed about different tree species available in the country. This write-up provides an insight into all aspects of the species. The newsletter also provides details of the latest publications brought out in the areas of forest genetics and tree improvement worldwide.

The ENVIS team sincerely looks forward to your suggestions and feedback and seeks your support and co-operation.

In this issue

Know Your Trees - *Santalum album* (Indian Sandalwood)

Botanical classification

Taxonomic position of *Santalum album* – Kingdom – Plantae; Division – Magnoliophyta; Sub division – Magnoliophytina; Class – Magnoliopside; Subclass – Rosidae; Superorder – Santalanae ; Order – Santalales; Suborder – Santalineae ; Family – Santalaceae; Subfamily – Santaloideae; Tribe- Santalaceae; Subtribe – Santalinae; Genus – *Santalum*; Species – *Santalum album.*

Common names

Indian Sandalwood, White Sandalwood (English); Chandana, Hari-chandana (Sanskrit); Chandan (Hindi); Chandan (Bengali, Punjabi); Srigandha, Chandana (Kannada); Chandanam (Malayalam); Santhanam, Srigandhara (Tamil); Chandanamu, Hari-chandanam (Telugu); Boga chandon (Assamese); Cha-chandan (Manipuri); Chandono, Gondassaro (Oriya); Sukhad, Suket (Gujarati); Sukhad (Sindhi).

Bois de santal (French); Sandelholz (German); Sandalo (Spanish); Sandalo (Italy); Sandalo branco (Portugese); behman surkh, sandal-abiyaz, sandale-abiaz (Arabic); Sandal suped, Sandale-suped (Persian); Sandal safaid (Urdu); vitt sandelträd (Swedish); Cendana (Indonesia), Ai nitu (Sumba), Hau meni (Timor), Chendana (Malaysia).

Introduction

The most common and widely accepted fragrant tree referred to as Sandalwood tree is from the family Santalaceae and belongs to genus *Santalum*. Santalaceae consists of 29 genera with ~400 species, out of which 19 species are specific to *Santalum* genus (Fox 2000; Harbaugh 2007; Harbaugh and Baldwin 2007; Nageswara Rao *et al.*, 2010; Harbaugh *et al.*, 2010; Butaud 2015, Teixeira da Silva *et al.,* 2016). Though various authors differ in reports regarding the genera or number of species, Teixeira da Silva *et al.* (2016) report that considering the Plant List (2015), only 12 species names are accepted while 41 remain unresolved. Out of the 18 species listed by them, one of the species *Santalum fernandezianum* has been reported to be extinct. Therefore, there is a stress on diverting attention particularly in the area of taxonomy of the genera.

Among various *Santalum* species, Indian Sandalwood (*Santalum album*) also sometimes referred as East Indian Sandalwood stands out for its highly valued oil and wood. Sandalwood and oil have earned some popular sobriquets like Dollar earning parasite, Queen of Essential oil and such others. Indian Sandalwood is naturally distributed 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 (Srinivasan, 1992). The first Sandalwood survey was carried out in India during 1977-78. It revealed that Sandalwood has been found to be distributed all over the country with Southern part of Karnataka and Northern part of Tamil Nadu being the natural areas. It was estimated that ~90% of the population was found in these two states covering an approximate area of 8300 sq.kms. Other peninsular states in which Sandalwood is found include Kerala and Andhra Pradesh. Isolated populations have been reported in various states such as Bihar, Gujarat, Haryana, Maharashtra, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamilnadu, Uttar Pradesh and West Bengal. Recently some of the other states in which Sandalwood is reported are Himachal Pradesh and Assam.

Sandalwood is a moderate sized evergreen tree that can attain a girth of 1 to 2.4 metres and height of 12 to 15 metres (Sen Sarma, 1982). The branches are erect as well as slenderly drooped. Sandalwood grows well in early

stages under partial shade but being a light demander, at the middle and late stages shows intolerance to heavy overhead shade. Sandalwood is not an exacting species and the tree grows well under varied set of conditions such as from sea level up to 1800 m altitude, moderate rainfall of 600 to 1600mm, in cool climate with long periods of dry weather (Troup, 1921). It also adapts well in different types of soils like sand, clay, red soils, laterite loam and even in black cotton soils, but has a preference for red ferruginous loam with varying fertility (Singh, 1995). However, it does not come up well in water logged or very cold areas. Trees growing on stony or gravelly soils are known to have higher scented wood.

Bark is reddish brown or dark brown in colour. The inner part of the bark is red. It is smooth in young trees, and becomes rough with deep vertical cracks as tree matures. Leaves are opposite, sometimes alternate, occasionally ovate or ovate-lancelolate, 1.5 to 3 inch long, sometimes larger in fertile localities, glabrous and shining above and glaucous beneath (Kulkarni, 1995). Young leaf is lush green or pinkish green and is truly evergreen (in very dry places it sheds its leaf). The colour of matured leaves varies from bluish to greenish yellow (Srimathi *et al.*, 1983). The crown has varied shapes like conical, round, obovate, elliptic or irregular. Prediction of seed production based on dimensions reveals that crown size especially length, has positive correlation to fruit production (Susila *et al.,* 1995).

Phenology, Reproductive Biology and Breeding System

Initially, the flowers are straw yellow coloured and gradually turn to deep purplish brown on maturation. The flowers occur in axillary or terminal cymose panicles that are shorter than leaves and the floral organs develop in acropetal succession. It takes 30 to 35 days from initiation of bud stage to the anthesis and 85 to 95 days from initial stage to ripening of the fruit (Srinivasan *et al.* 1992). Generally the tree starts flowering at an early age of 2 to 3 years and flowering and fruiting seasons vary. Flowering time differs accross altitudes. Trees growing in lower altitudes flower about a month earlier than those growing in higher altitudes (Susila *et al.*, 1995). According to Brandis (1906) the flowering season is from February to July. Based on the flowering calendar, Ananthapadmanabha *et al.* (1991) classified sandalwood trees into three distinct groups i) Trees flowering twice a year (once during March – May and second time during September – December) ii)

Trees flowering once in a year (September – December) and iii) Trees which do not flower even after 15 years of age.

It has been described that the breeding system of *Santalum* species in general is facultatively allogamous with variation found between families and individuals at the level of self incompatability and having no ability for apomixis or parthenocarpy (Ma *et al.*, 2006; Muir *et al.*, 2007; Tamla *et al.*, 2012, Page *et al.,* 2012). This nature of outcrossing and the ability to self fertilize has provided an advantage for *Santalum* species to grow and survive in new areas (Teixeira da Silva *et al.,* 2016). Chromosome number of *S. album* was reported as 2n = 20 and with basic chromosome number x = 10 (Rao, 1942; Goldblatt and Johnson, 2000; Harbaugh, 2008). In a recent karyotype

analysis conducted by Zhang *et al.* (2010), for the first time a mixoploid was found (2n = 2x = 20 and 2n = 4x = 40). They also found predominance of chromosomes with centromeres in a median position and a few submedian centromeres. The authors also mention that considering the karyotypic analysis, *S. album* is a more primitive taxon. However, they stress that the occurrence of polyploidy and mixoploidy needs further investigation giving due importance to the geographical distribution. Even though there is definite geographical isolation and considerable morphological variation between *Santalum* species, reports indicate that viable hybrid progeny has been developed for crosses between *S. album* with each of *S. austrocaledonicum* (Tamla *et al*., 2011), *S. lanceolatum* (Tamla *et al*., 2011), and *S. yasi* (Bulai and Nataniela 2005; Doran *et al*., 2005).

Seed Collection, Processing and Nursery Techniques

The fruits are succulent drupes, 0.3 to 0.5 inch in diameter and purplish black when fully mature. The colour of the fruit changes from green to purplish black at maturity. The fruit has a single seed with brown endocarp which is moderately hard. The fruit shape varies from globose, ovate to elongate and sometimes show tapering ends. Some plants have large fruits, while others persistently bear smaller ones. The base of the fruits may be round or smooth or elongated and swollen. The green fruits are considered matured when they are purplish black in colour. It is suggested to clean the floor beneath the tree so that the fruits fallen on the ground may be collected. As the fruit pulp is susceptible to fungal infection, the fruits are soaked in water and pulp is rubbed on a rough surface so that seeds are obtained. The depulped seeds are dried in shade to remove the excess of moisture. Direct sun drying should be avoided as it causes a significant reduction in seed viability (Setiadi and Komar, 2001).The seeds are spherical with a diameter of 0.5 - 1cm and the weight ranges from 0.1 to 0.2g. The seeds may be grouped based on the size and weight as small, medium and big. Nagaveni and Ananthapadmanabha (1986), found that in a seed lot, 82 to 87% were medium sized seeds (0.1 to 0.2 gram seed weight and 7 to 8 mm size). The weight of seed is inversely proportional to the rate of germination and directly proportional to the seedling vigour.

The seeds have inherent morphophysiological dormancy (Baskin and Baskin 1998) which is non deep simple (Dileepa *et al.,* 2015) and seeds can be treated with Gibberellic acid solution (500ppm w/v) for 16 to 24 hours

prior to sowing in the germination beds for better and uniform germination. It has been observed that November-December is the ideal time to start raising sandalwood seedling in nursery as seedlings can be made available by July *i.e.* just before monsoon for field planting (Sivaramakrishnan *et al*., 1984). For germination, sand has been found to be the best medium. A germination tray or germination bed of one square meter can be used for germination of seeds. Srinivasan *et al*. (1992) recommended nursery bed of sand and soil in the ratio 1:3 for seed germination and sowing of 500 g of seed / sq.m. bed, from which about 1500 seedlings can be expected.

Sandalwood seed has epigeal form of germination in which the radicle emerges out breaking the seed coat. The hypocotyl elongates with a pronounced arching, the loop

appearing above ground while cotyledons remain underground. The lower portion of the hypocotyl becomes swollen and fleshy. The nutrients from the albumen are translocated to this swollen hypocotyl which is also referred to as 'carrot' of the seedling. The germination starts from 20th day onwards and continues upto 45 days. The seedlings can be transplanted to polybag when they are at two to three leaf stage. It has been observed that root trainers are better compared to polybags as they avoid root coiling and are easy for handling and transportation. Annapurna *et al.*(2004; 2005) have recommended the use of 270cc root trainer with potting media containing sand, soil, compost, cocopeat, burnt rice husk and charcoal, in 25:15:50:5:5 ratio, sieved with 6X6 holes/sq. inch to obtain plantable seedlings in 6 months. As Sandalwood is a partial root parasite, they need a host for better survival and growth than those without hosts (Nagarajaiah and Rao, 1993; Shinde *et al.,* 1993). Using leguminous host has distinct advantage over non leguminous hosts (Radomiljac and McComb, 1998). Fox and Doronila (1993) described that a suitable host should have, fine root growth, an even distribution of root growth within the pot, ability to withstand top pruning, low level of competition, low allelopathic influences, low growth structure, hemi parasitic compatibility.

Tree Improvement

Tree improvement work in Sandalwood begun in 1977 when Sandal Research Centre was established by Government of India, which was located in the present campus of Institute of Wood Science and Technology (IWST), Bangalore. The first Sandalwood survey was carried out to document the extent of distribution of Sandalwood in India in terms of population density, tree size and extent of heartwood. During the process of survey, successful efforts were made in identifying superior genotypes by using various criteria such as growth rate, heartwood per cent, oil content, resistance to spike disease, heartwood rot and borer infestation (Srimathi, 1995).

A total of 79 plus trees were identified from different sandalwood growing states of South India, namely, Karnataka, Tamil Nadu, Andhra Pradesh and Kerala,. Tree improvement related activities in sandalwood gained momentum during 1980 to 1984 as evident in the Table 1.

From tree improvement perspective, documenting variability in a tree species is a pre-requisite before initiating any tree improvement programme. Considering this fact, numerous researchers have reported variability

Table 1. Sandal tree improvement research plots established during 1980 to 1984

Activity	Location	Year	Area (ha.)
Seed Stands	Marayoor (Kerala)	1980	3.00
	Chitteris (Tamil Nadu)	1980	5.00
Provenance trials	Nallal at Hoskote (Karnataka)	1981	3.14
	Kuderu at Anantapur (Andhra Pradesh)	1982	0.24
Clonal germplasm banks	Gottipura at Hoskote (Karnataka)	1980-82	1.00
	Karvatnagar at Chittoor (Andhra Pradesh)	1983	0.10
	Kurmbapatty at Salem (Tamil Nadu)	1983	0.50
Biotype germplasm bank	Gottipura at Hoskote (Karnataka)	1982	0.75
Clonal seed orchards	Nallal at Hoskote (Karnataka)	1982	1.35
	Akkarampalli at Tirupati (Andhra Pradesh)	1983	1.00
	Jarakabande at Bangalore (Karnataka)	1984	1.50
Half sib progeny trials	Nallal at Hoskote (Karnataka)	1980	0.20
		1981	0.65
		1983	1.20

(Srimathi, 1995)

for different traits in Sandalwood. Variability in flowering and fruit size has already been mentioned. There is variation with reference to colour, texture and thickness in case of bark and it is found that Rust coloured bark is associated with fast growth in sandal. Six types of leaves - ovate, lanceolate, elliptic, linear, small and big have been identified (Kulkarni and Srimathi, 1982) and the most common being ovate leaves. Sandalwood trees generally flower twice a year (60% of trees) while 36% trees flower once in a year and 4% of trees flower throughout the year (Ananthapadmanabha *et al.,* 1991). Various researchers have reported variability in seed trait such as size, shape, germination and vigour (Nagaveni and Ananthapadmanabha, 1986; Veerendra and Sarma, 1990; Ramalakshmi and Rangaswamy 1997; Annapurna *et al*., 2005).Three phenotypes have been identified in Sandalwood namely - Thindlu, Chickballapur and Robust type by Srimathi *et al*. (1983). Thindlu sandal type was characterised by small diameter class trees around 4-8 cm diameter at breast height having dark brown bark that comes out in irregular flakes and the heartwood being dark brown in colour. Chickballapur type was found to have small bluish green leaves similar to spiked plant and with broad sapwood. Robust type had compact crown with lush green foliage, thick sapwood and fast growing as compared to all other types.

The two commercially important traits having significant interest among researchers is the heartwood and oil. Various researchers have suggested, described or debated on different aspects of heartwood and oil (Cameron, 1894; Rama Rao, 1904; Puran Singh 1911, 1915; Troup 1921 and Fischer, 1927) but none could give any satisfactory evidence as regards heartwood and oil. In 1941, 5th Silvicultural Conference held at Dehra Dun received only three papers pertaining to heartwood and oil (Mitchell, 1941; Laurie, 1941 and Venkata Rao, 1941). Rao (1959) while discussing the future of tree genetics in India, emphasized that heartwood formation and its progress have to be critically observed using core samples. The importance of studying heartwood and oil was stressed even in First All India Sandal Seminar held at Bangalore, Karnataka (Kaikini, 1977) and in the Second All India Sandal Seminar held later at Salem, Tamil Nadu (Shanmuganathan, 1981). Studies on heartwood have always been intriguing. Srimathi and Kulkarni (1980) carried out a study on variation in heartwood content among similar girth trees growing in a single locality. They found enormous variability in heartwood content among the trees as 13% of the trees did not have heartwood. They opined that heartwood formation can start as early as five to six years in some of the trees and can be as late as over 15 years in other trees. A similar study conducted on 14 year old Sandalwood trees in Australia by Brand *et al.* (2006) in dicated that heartwood had not been formed in 20% of the trees. Arun Kumar (2005) reported considerable variability for heartwood diameter and oil in a known aged clonal germplasm bank of Sandalwood. From the perspective of selecting superior genotypes, Arun Kumar *et al.* (2011) reported that there was strong positive relationship between tree diameter and heartwood diameter. However, the intriguing story of heartwood and oil still continues.

IWST identified nine sandalwood provenances across the country on the basis of population density, phenotypic character, latitude and longitude. The nine provenances were Bangalore, Tangali and Mandagadde from Karnataka, Chitteri and Javadi Hills from Tamil Nadu, Marayoor from Kerala, Koraput from Orissa, Seoni from Madhya Pradesh and Horsley Hills (Chittoor East) from Andhra Pradesh (Jain *et al.,* 1998). Jayappa *et al. (*1981) studied regional variation in yield and quality of sandal oil. Wood samples used for this study were roots, Jaj, and Milwa (which are different heartwood grades of Sandalwood). Samples were collected from various locations such as Shimoga, Hassan, Tarikere, Dharwad, Mysore, Salem and Satyamangalam (Table 2). Though

Table 2. Variation in sandal oil, α and β santalol content of wood samples collected from different locations

Wood sample	Oil content (%)		α and β Santalol (%)	
	Minimum	Maximum	Minimum	Maximum
Root	6.56 (Mysore)	8.43 (Hassan)	88.07 (Hassan)	95.16 (Dharwad)
Jaj	4.22 (Satyamangalam)	5.79 (Hassan)	89.09 (Hassan)	94.98 (Tarikere)
Milwa	2.42 (Tarikere)	3.52 (Hassan)	88.62 (Hassan)	94.12 (Mysore)

reasons for this variation have not been attributed, yet it is important to know that variability exists in oil content across locations.

As mentioned earlier, enormous variation in morphological traits have been reported in Sandalwood. Similarly, genetic variation of Sandalwood has also been studied extensively. Various researchers have used isozymes (Brand, 1994, Suma and Balasundarn, 2003, Angadi *et al.*, 2003, Nageswara Rao *et al.*, 2007), random ampliflication of polymorphic DNA, (Sashidhara *et al.*, 2003; Suma and Balasundaran, 2003, Azeez *et al.,* 2009) and restriction fragment length polymorphism (Jones 2008) and found considerable variability. Srikanta Dani *et al.* (2011) in their study on genetic variation on isolated populations of *S. album* found that there was clonality within the existing population and attribute habitat fragmentation, isolation and vegetative reproduction as the reasons for this.

Agroforestry practices

During the last decade, considering the huge market value for heartwood and oil along with relaxed government policies, Sandalwood is being cultivated extensively in farmlands. Various non Sandalwood growing states of India have taken keen interest in its cultivation. Some of the preferable hosts are predominantly horticultural species such as Indian goose berry, Tamarind, Mango, pomegranate, *etc,* where intermediate revenue is obtained. Some of the preferable tree species as host that can be tried are teak and rosewood. Though protection issue is a concern, but considering the high value returns, it is a matter of time that various avenues would be found to deal with better protection. Institute of Wood Science and Technology, Bangalore, has been prominently suggesting

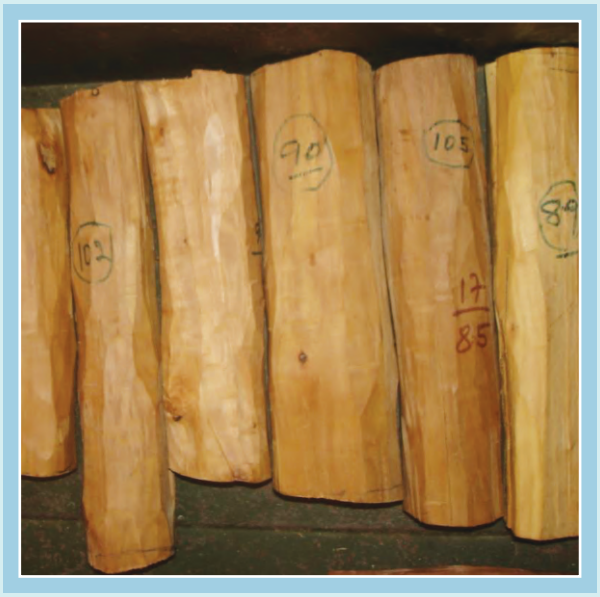
Table 3. Girth and yield of heartwood

Girth (cm)	Yield (Kg)
Upto 15	2.4
16 to 30	6.0
31 to 45	16.5
46 to 60	39.0
61 to 75	74.0
75 to 90	127.0

that if Sandalwood can be cultivated in every household, the protection issue can be conveniently taken care through 'social fencing' which is nothing but people's active participation in protecting each others trees.

Growth, Yield and Economics

Considering the huge demand and value for the Sandalwood, extensive plantations are being raised. Though growth data *per se* is not available in Sandalwood due to lack of plantations, Venkatesan (1980) proposed a table depicting the probable average heartwood yield that



can be expected under Tamil Nadu Forest conditions and suggested that each tree can yield at least one kilogram of heartwood per year after 20 years.

In an auction held at Marayoor by Kerala Forest Department in 2015, 52 tonnes of Sandalwood was sold at a record 40 crore rupees (Hindu, 2015). As per the Tropical

Forestry Services which has plantations in Western Australia, the cost of Indian Sandalwood oil that is extracted from the heartwood fetches ~US$ 5000 per kilogram in the international market.

Population status and conservation

Presently, sandalwood has been categorized as 'vulnerable' by International Union for Conservation of Nature and Natural Resources (IUCN, 2007). In Karnataka, sandalwood populations are not dense and are devoid of larger girth classes and mature trees were absent in the forest areas (Swaminath et *al.,* 1998) and in all likelihood it is no different in Tamil Nadu. Presently, Kerala has one of the largest concentrated patches of natural Sandalwood forest existing in the country and this patch is found in the Marayoor Sandal Division. Though, conservation of Sandalwood trees in its natural habitat is considerably difficult, yet, the solace is found in the form of extensive plantations that are being cultivated across the country. As all the plantations being raised are from seed origin, these plantations are the locations for source material specially when tree improvement in Sandalwood is considered.

Though Sandalwood cultivation is a profitable venture, cultivation practices are to be standardized. Information pertaining to heartwood formation and its development are not yet properly understood. Tree improvement studies in Sandalwood have to be given impetus, apart from the only survey that was carried out in late 70s, it is essential to carry out extensive resurvey of populations and assess their present status. To cater to the demands of extensive cultivation with quality planting material, mass multiplication through micro propagation has to be standardized. Use of biotechnological tools in understanding various aspects related to heartwood formation and oil biosynthesis are to be given due importance. All this would not only help in India being a leading country in Sandalwood production, but this would also generate huge foreign revenue.

References

Ananthapadmanabha, H.S., Nagaveni, H. C. and Rai, S. N. 1991. Endogenous gibberellin in relation to flower induction in sandal. Myforest **24**: 32-24.

Angadi, V.G., Jain, S.H. and Shankaranarayana, K.H. 2003. Genetic diversity between sandal populations of different provenances in India. Sandalwood Research Newsletter 17: 4–5.

Annapurna, D., Rathore, T.S. and Joshi, G. 2004. Effect of container type and size on the growth and quality of seedlings of Indian sandalwood (*Santalum album* L.). Australian Forestry, 67(2): 82-87.

Annapurna, D., Rathore, T.S. and Joshi, G. 2005. Studies on refinement of potting medium ingredients and their ratio for production of quality seedlings of sandalwood (*Santalum album* L.). Australian Forestry, 68(1): 43-48.

Arun Kumar, A.N. 2005. 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.

Arun Kumar, A.N., Srinivasa, Y.B., Joshi, G. and Seetharam, A. 2011. Variability in and relation between tree growth, heartwood and oil content in sandalwood (*Santalum album* L.). Current Science 100: 827–830.

Azeez, A.S., Nelson, R., Prasadbabu, A. and Rao, S.M. 2009. Genetic diversity of *Santalum album* using random amplified polymorphic DNAs. African Journal of Biotechnology, 8: 2943-2947.

Balasubramanian, P., Aruna, R., Anbarasu, C. and Santhoshkumar, E. 2011. Avian frugivory and seed dispersal of Indian Sandalwood *Santalum album* in Tamil Nadu, India. Journal of Threatened Taxa 3(5): 1775–1777.

Brand, J.E. 1994. Genotypic variation in Santalum album. Sandalwood Research Newsletter 2: 2-4.

Brand, J., Kimber, P. and Streatfield, J. 2006. Preliminary analysis of Indian sandalwood (*Santalum album* L.) oil from a 14-year-old plantation at Kununurra, Western Australia. Sandalwood Research Newsletter 21: 1–3.

Brandis, D. 1906. Indian Trees. Archibald Constable and Co. Ltd., London, 553p.

Bulai, P. and Nataniela, V. 2005. Research, Development, and Extension of Sandalwood in Fiji – A New Beginning. In 'Regional workshop on Sandalwood Research, Development and Extension in the Pacific Islands and Asia'. Noumea, New Caledonia, 7-11 October 2002. (Eds L. Thomson, S. Bulai and L. Sovea) pp. 83-91. Suva, Fiji: Secretariat of the Pacific Community.

Butaud, J.F. 2015. Reinstatement of the Loyalty Islands sandalwood, *Santalum austrocaledonicum* var. *glabrum* (Santalaceae), in New Caledonia. PhytoKeys 56:111–126.

Cameron, J. 1894. *Forest trees of Mysore and Coorg*. Mysore Government Central Press, Bangalore, 240-241.

Dileepa, M.M., Jayawardena, M., Jayasuriya, K.M.G. and Walck, J.L. 2015. Confirmation of morphophysiological dormancy in sandalwood (*Santalum album*, Santalaceae) seeds. Journal of National Science Foundation Sri Lanka 43 (3): 209-215.

Doran, J.C., Thomson, L., Brophy, J.J., Goldsack, B., Bulai, P., Faka'osi, T. and Mokoia, T. 2005. Variation in heartwood oil composition of young sandalwood trees in the south Pacific (*Santalum yasi*, *S. album* and F1 hybrids in Fiji, and *S. yasi* in Tonga and Niue). Sandalwood Research Newsletter 20: 3-7.

Fischer, C.E.C., 1927. *Santalum album in India*. Kew Bulletin No. 5: 200-202.

Fox, J.E.D., Doronila, A.I., Barrett, D.R. and Surata, K. 1996. *Desmanthus virgatus* (L.) Willd. An efficient intermediate host for the parasitic species *Santalum album* L. Timor, Indonesia. Journal of Sustainable Forestry 3(4): 13-23.

Harbaugh, D.T. 2007. A taxonomic revision of Australian northern sandalwood (*Santalum lanceolatum*, Santalaceae). Australian Systematic Botany 20: 409–416.

Harbaugh, D.T., Baldwin, B.G. 2007. Phylogeny and biogeography of the sandalwoods (Santalum, Santalaceae): repeated dispersals throughout the Pacific. American Journal of Botany 94:1028–1040.

Harbaugh, D.T., Oppenheimer, H.L., Wood, K.R., Wagner, W.L. 2010. Taxonomic revision of the endangered Hawaiian red-flowered sandalwoods (*Santalum*) and discovery of an ancient hybrid species. Systematic Botany 35:827–838.

Hindu. 2015. Marayoor sandalwood auction fetches record 40 crore. (http://www.thehindubusinessline.com/news/marayoor-sandalwood-auction-fetches-record-40-cr/article7777529.ece) dated 18th Oct. 2015.

Jain S.H., Angadi, V.G., Rajeevalochan, A.N., Shankarnarayana, K.H., Theagarajan, K.S. and Rangaswamy, C.R. 1998. Identification of provenances of sandal in India for genetic conservation. Sandal and its Products: ACIAR Proceedings 84: 117-120.

Jayappa, V. Nataraj, B.M., Shanbhag, P. K., Patil, K. B. and Srinivas, A. 1981. Regional variation in the yield and quality of sandal oil. A study by GLC. Proceedings of Second All India Sandal Seminar, Salem, Tamil Nadu Forest Department.

Jones, C.G., Plummer, J.A., Barbour, E.L. and Byrne, M. 2009. Genetic Diversity of an Australian *Santalum album* Collection – Implications For Tree Improvement Potential. Silvae genetica 58(5-6): 279-286.

Kaikini, N.S. 1977. A plan for reorienting the production of sandal in Karnataka state. Proceedings of All India Sandal Seminar, Karnataka Forest Department, pp. 215-224.

Kulkarni, H.D. 1995. Sandal (*Santalum album* L.) descriptor. In: Recent Advances in Research and Management of Sandal *(Santalum album* L.) in India. Eds:Srimathi, R. A., H. D. Kulkarni and K. R. Venkatesan, Associated Publishing Company, New Delhi, 249-259.

Kulkarni, H.D. and Srimathi, R.A. 1982. Variation in foliar charactersitcs in sandal – Biometric analysis in tree improvement of Forest Biomass. Eds. P.K. Khosla, International Book Distributors, Dehra Dun, 63-69.

Laurie, M.V., 1941. Sandalwood problems – statistical methods for the determination of heartwood increment in sandal. Proceedings of 5th Silviculture Conference, Dehra Dun, 492-495.

Ma, G.H., Bunn, E., Zhang, J.F. and Wu, G.J. 2006. Evidence of dichogamy in *Santalum album* L. Journal of Integrated Plant Biology 48: 300–306.

Mitchell, J. E. M., 1941. Sandalwood problems, factors affecting heartwood and oil content in sandalwood. Proceedings of 5th Silviculture Conference, Dehra Dun.

Muir, K., Byrne, M., Barbour, E., Cox, M.C., Fox, J.E.D. 2007. High levels of outcrossing in a family trial of Western Australian sandalwood (*Santalum spicatum*). Silvae Genetica 56: 222–230.

Nagarajaiah, C. and Rao, C.S. 1993. A successful method of establishing sandal tree seedlings. Current Research 22 (3-5): 51-52.

Nagaveni, H.C. and Ananthapadmanabha, H.S. 1986. Seed polymorphism and germination in *Santalum album* L. Van Vigyan 24: 25-28.

Nageswara Rao, M., Ganeshaiah, K.N. and Uma Shaanker, R. 2007. Assessing threats and mapping sandal (*Santalum album* L.) resources in peninsular India: identification of genetic hotspot for *in-situ* conservation. Conservation Genetics 8: 925–935.

Nageswara Rao, M., Soneji, J.R., Sudarshana, P. 2011. *Santalum*. In: Kole, C., (ed) Wild crop relatives: genomic and breeding resources. Springer, Berlin, pp 131–144.

Puran Singh. 1911. Memorandum of the oil value of sandalwoods from Madras. Forest Bulletin Number 6, R.I. and Colleges, Dehradun.

Puran Singh. 1915. A further note on the oil value of some sandalwoods from Madras. Indian Forester 41:123-129.

Radomiljac, A.M. and McComb, J.A. 1998. *Alternanthera nana* R.Br. nursery sowing – time influences S*antalum album* L. growth following field planting. In: Sandal and its products. Proceedings of an International seminar, held on 18-19 Dec. 1997, Bangalore, India. Edited by Radomiljac, A.M., Ananthapadmanabha, H.S., Welbourn, R.M. and K. Satyanarayana Rao, ACIAR proceedings 84 : 188-191.

Rama Rao, M., 1904. Notes on sandal. Indian Forester 30: 248-267,357-362,394-403.

Ramalakshmi, S. and Rangaswamy, C.R. 1998. Physiological variation in seeds of provenances of sandal (*Santalum album*). In: *Sandal and its products,* Proceedings of an International seminar held on 18-19 Dec. 1997, Bangalore, India, Radomiljac A.M., Ananthapadmanabha H.S., Welbourn R.M. and K. Satyanarayana Rao. (eds), India, ACIAR Proceedings, 84: 121-125.

Rao, H.S. 1959. Problems in Indian forest plant breeding. Indian Forester 85: 515-527.

Sen Sarma, P.K. 1982. Sandalwood – Its cultivation and utilization. In: *Cultivation and Utilization of Aromatic Plants*. Eds: Atal, C.K. and B.M. Kapur. Regional Research Laboratory, CSIR, Jammu Tawi. 395-495. Setiadi D. and Komar, T. E. 2001. Current sandalwood seed source in Timor Island. Sandalwood research newsletter 13: 3-5.

Shashidhara, G., Hema, M.V., Koshy, B. and Farooqi, A.A. 2003. Assessment of genetic diversity and identification of core collection in sandalwood germplasm using RAPDs. Journal of Horticultural Science and Biotechnology 78: 528–536.

Shanmuganathan, K. 1981. Management of sandalwood - the future. Proceedings of Second All India Sandal Seminar, Salem, Tamil Nadu.

Shinde, S.R., Ghatge, R.D. and Mehetre, S.S. 1993. Comparative studies on the growth and development of sandalwood trees in association with different hosts. Indian Journal of Forestry 16(2): 165-166.

Singh, U.V. 1995. Sandalwood – scope for commercial propagation on community lands in India. Sandalwood Research Newsletter 4: 1-2.

Sivaramakrishnan, V.R., Ananthapadmanabha, H.S., Ramanujan, B., Subramani, M. and Nayar, R. 1984. Control of seedlings disease of sandal (*Santalum album* L.). Journal of Indian Academy of Wood Science 15 (2): 60-64.

Srikanta Dani, K.G., Ravikumar, P., Pravin Kumar, R and Kush, A. 2011. Genetic variation within and among small isolated populations of Santalum album. Biologia Plantarum 55 (2): 323-326.

Srimathi, R A. 1995. 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., H.D. Kulkarni and K.R. Venkatesan), Associated Publishing Company, New Delhi, pp. 327-353.

Srimathi, R.A. and H.D. Kulkarni, 1980. Preliminary findings of the heartwood formation in sandal (*Santalum album* L.). Proceedings of Second Forestry Conference, F.R.I. and Colleges, Dehra Dun. 1-13.

Srimathi, R.A., Kulkarni, H.D. and Venkatesan, K.R. 1983. Phenotypes of sandal. Journal of Bombay Natural History Society 80: 245-246.

Srinivasan, V.V., Sivaramakrishnan, V.R., Rangaswamy, C.R., Ananthapadmanabha, H.S. and Shanakaranarayana, K.H. 1992. Sandal. ICFRE, Dehra Dun. 233p.

Susila I.W.M. , dan M. Sinaga Effendi, (1995). *Studi fenologi dan kualitas benih cendana (Santalum album) di Nusa Tenggara Timur. Santalum* 19. 1-8. (Referred in Setiadi and Komar (2001).

Suma, T.B. and Balasundaran, M. 2003. Isozyme variation in five provenances of *Santalum album* in India. Australian Journal of Botany 51(3): 243-249.

Swaminath, M.H., Hosmath, B. J. and Mallesha, B. B. 1998. The status of sandalwood in India: Karnataka. Sandal and its Products: ACIAR Proceedings 84: 3-5.

Tamla, H.T., Cornelius, J. and Page, T. 2012. Reproductive biology of three commercially valuable *Santalum* species: development of flowers and inflorescences, breeding systems, and interspecific crossability. Euphytica 184(3): 323-333.

Teixeira da Silva, J.A., Mafatlal, K. M., Deepak, S., Tony, P., Xinhua, Z., Nataraj, M., Guohua, M. 2016. Sandalwood: basic biology, tissue culture, and genetic transformation. Planta 243(4): 847-887.

Tony, P., Tate, H. and Bled, C. 2012. Breeding behaviour of three sandalwood species *(Santalum album, S. austrocaledonicum* and *S. lanceolatum).* In: Sandalwood Resource Development, Research and Trade in the Pacific and Asian Region: proceedings of the regional workshop, pp. 102-108. From: Regional Workshop on Sandalwood Development, Research and Trade in the Pacific and Asian Region, 22-25 November 2010, Port Vila (Shefa), Vanuatu.

Troup, R.S. (1921). Silviculture of Indian Trees. Volume III, Clarendon Press, Oxford, pp. 799-819.

Veerendra, H.C.S. and Sarma, C.R. 1990. Variation studies in sandal (*Santalum album* L.): 1. Time of emergence and seedling vigour. Indian Forester 119(7): 568-571.

Venkata Rao, M.G. 1941. Sandalwood problems - Factors affecting heartwood and oil content in sandalwood. Proceedings of 5th Silviculture Conference, Dehra Dun, pp. 488-90.

Venkatesan, K.R. 1980. A fresh look at the namagement of sandal. Proceedings of Second Forestry Conference, F.R.I. and Colleges, Dehra Dun.

Venkatesan, K.R., Srimathi, R.A., and Kulkarni, H.D. 1995. 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.

Zhang, X.H., Teixeira da Silva, J.A., Ma, G.H. 2010. Karyotype analysis of *Santalum album* L. Caryologia 63:142–148.

Arun Kumar A. N., Geeta Joshi and Rekha R. Warrier*

Institute of Wood Science and Technology, Bengaluru

*Institute of Forest Genetics and Tree Breeding, Coimbatore

Recent literature on FGRs & TIP

1. Aitken, S.N. and Bemmels, J.B. 2016. Time to get moving: assisted gene flow of forest trees. Evolutionary Applications 9: 271-290.
2. Berglund, T., Lindström, A., Aghelpasand, H., Stattin, E. and Ohlsson, A.B. 2016. Protection of spruce seedlings against pine weevil attacks by treatments of seeds or seedlings with nicotinamide, nicotinic acid and jasmonic acid. Forestry 89: 127-135.
3. Chakraborti, U., Biswas, O., Das, A.K., Roy, S., Das P. and Mitra, B. 2016. Studies on sacred groves and sacred trees along the Eastern Bank of river Hoogly of North 24 Parganas, West Bengal. Indian Forester 142: 156-166.
4. Duncan, C.J., Worth, J.R.P., Jordan, G.J., Jones, R.C. and Vaillancourt, R.E. 2016. Genetic differentiation in spite of high gene flow in the dominant rainforest tree of southeastern Australia, *Nothofagus cunninghamii.* Heredity 116: 99-106.
5. Huang, Y., Mao, J., Chen, Z., Meng, J., Xu, Y., Duan, A. and Li, Y. 2016. Genetic structure of needle morphological and anatomical traits of *Pinus yunnanensis.* Journal of Forestry Research 27: 13 -25.
6. Ji, X., Nie, X., Liu, Y., Zheng, L., Zhao, H., Zhang, B., Huo, L. and Wang, Y. 2016. A bHLH gene from *Tamarix hispida* improves abiotic stress tolerance by enhancing osmotic potential and decreasing reactive oxygen species accumulation. Tree Physiology 36: 193-207.
7. Kamalakannan, R., Varghese, M., Suraj, P.G. and Arutselvan, T. Options for converting a clone trial of *Eucalyptus camaldulensis* into a clonal seed orchard considering gain, fertility and effective clone number. Journal of Forestry Research 27: 51-57.
8. Liepe, K.J., Hamann, A., Smets, P., Fitzpatrick, C.R. and Aitken, S.N. 2016. Adaptation of lodgepole pine and interior spruce to climate: implications for reforestation in a warming world. Evolutionary Applications 9: 409-419.
9. Liu, M., Yang, M., Song, D., Zhang, Z. and Ou, X. 2016. Invasive *Acacia mearnsii* De Wilde in Kunming, Yunnan Province, China: a new biogeographic distribution that threatens airport safety. NeoBiota 29: 53-62.
10. McLean, J.P., Moore, J.R., Gardiner, B.A., Lee, S.J., Mochan, S.J. and Jarvis, M.C. 2016. Variation of radial wood properties from genetically improved Sitka spruce growing in the UK. Forestry 89: 109-116.
11. Rai, S.N. 2016. Basal area and diameter increment in long term research sites in tropical forests in India. Indian Forester 142: 13-17.
12. Sing, T.P., Rawat, R.S., Rawat, V.R.S. and Gupta, M.K. 2016. Soil organic carbon stocks under different forest types in India. Indian Forester 142: 207-212.
13. Spoladore, J., Mansano, V.F., Dias de Freitas, L.C., Sebbenn, A.M. and Lemes, M.R. 2016. DNA Microsatellite Markers for *Swartzia glazioviana* (Fabaceae), a Threatened Species from the Brazilian Atlantic Forest. Applications in Plant Sciences 4: http://dx.doi.org/10.3732/apps.1500081
14. Sugai, K. and Setsuko, S. 2016. Isolation and characterization of *Ligustrum micranthum* (Oleaceae) microsatellite loci using paired-end Illumina reads. Plant Species Biology doi: 10.1111/1442-1984.12119
15. Tiwari, V.P. 2016. Volume and biomass functions for trees grown under arid conditions in India. Indian Forester 142: 23-30.
16. Tsubomura, M., Kurita, M. and Watanabe, A. 2016. Determination of male strobilus developmental stages by cytological and gene expression analyses in Japanese cedar (*Cryptomeria japonica*). Tree Physiology doi: 10.1093/treephys/tpw001
17. Ueno, S., Taguchi, Y. and Tsumura, Y. 2016. Development of chloroplast markers for Japanese and snow camellias. Plant Species Biology 31: 80-84.
18. Weed, A.S., Ayres, M.P., Liebhold, A.M. and Billings, R.F. 2016. Spatio-temporal dynamics of a tree-killing beetle and its predator. Ecography 39: doi: 10.1111/ecog.02046

Upcoming Events

Event	:	**53rd Annual Meeting of the Association for Tropical Biology & Conservation**
Venue	:	Le Corum, Montpellier - France
Date	:	19-23 June 2016 For details mail to: info@atbc2016.org
Event	:	**International Scientific Conference on Reforestation Challenges**
Venue	:	University of Agriculture, Cracow, Poland
Date	:	27-29 June 2016 For details mail to: wles@ur.krakow.pl
Event	:	**14th European Workshop on Lignocellulosics and Pulp (EWLP 2016)**
Venue	:	Autrans, France
Date	:	28-30 June 2016 For more details: http://www.ewlp2016.org/
Event	:	**IUFRO Workshop – Climate-induced Range Shifts in Boreal Forest Pests: Ecological, Economic and Social Consequences**
Venue	:	Sept-Îles and Baie Comeau, Québec, Canada
Date	:	11-15 July 2016 For more details: http://tinyurl.com/IUFROquebec2016
Event	:	**IUFRO Workshop on Biological Invasions in Forests**
Venue	:	Shepherdstown, West Virginia, USA
Date	:	18-21 July 2016 For details mail to: aliebhold@fs.fed.us
Event	:	**International Conference on Sustainable Forest Development in View of Climate Change**
Venue	:	Putrajaya, Malaysia
Date	:	08-11 August 2016 For more details: http://www.forr.upm.edu.my/sp/pages/4509/SFDCC2016
Event	:	**The 9th International Conference on Traditional Forest Knowledge (TFK)**
Venue	:	Bogor, Indonesia
Date	:	29-31 August 2016 For details mail to: eamzuhud@ipb.ac.id
Event	:	**IUFRO – The 9th International Symposium of Pine Wilt Disease**
Venue	:	Seoul Olympic Parktel, Seoul, South Korea
Date	:	29 August - 02 September 2016 For more details: http://www.pinewiltdisease2016.or.kr

ENVIS ACTIVITIES

Awareness Poster on Red Tamarind hybrids

An awareness poster highlighting the significance of tamarind hybridization in southern India was prepared by the ENVIS Centre at IFGTB. The poster entitled 'Red Tamarind Hybrids - An FGR Then! A prospective Selection Now!' was released by the Director IFGTB, Shri. R.S. Prashanth on 1st January 2016 in the presence of Dr B. Gurudev Singh, Group Co-ordinator Research, Dr Kannan C.S. Warrier, Co-ordinator ENVIS and all the Heads of Divisions. The Director had an interactive session with the scientists on how to utilize and promote the identified prospective tamarind genetic resources among the tree growers.

IFGTB-ENVIS observed the International Day of Forests - 2016

The ENVIS Centre on Forest Genetic Resources and Tree Improvement observed the International Day of Forests on 21st March 2016 at IFGTB. Dr Kannan C.S.Warrier, Co-ordinator ENVIS welcomed the gathering. The Director IFGTB, Shri. R.S. Prashanth, released an awareness poster based on the theme of the year 2016, 'Forests and Water' in the presence of Dr B. Gurudev Singh, Group Co-ordinator Research and all Heads of Divisions. The Director emphasized the responsibility of every individual to protect the existing forest cover which is the major source of fresh water. The function concluded with the planting of tree saplings by the dignitaries.

SECAS exhibition at Palakkad Railway Station, Olavakkode

Science Express Climate Action Special (SECAS) train flagged off on 15 October 2015 from Delhi is an innovative mobile science exhibition mounted on 16 AC coaches custom-built for Department of Science & Technology (DST) by Indian Railway. It aims to create awareness among various sections of society, especially students, as to how Climate Change can be combated through mitigation and adaptation. The train is scheduled to travel across the country for about 7 months, halting at 64 locations in 20 States, covering 19,800 km.

The SECAS train was stationed at the Palakkad Railway Station in Olavakkode, Kerala on 22.03.2016 and 23.03.2016. During the two-day exhibition, IFGTB-ENVIS participated and associated with the event organizers as part of creating awareness to school, college students and public. Information boards were displayed in platform highlighting the activity of ENVIS, significance of Forest Genetic Resources and Tree Improvement and photo gallery of major activities by the Centre.

More than 4000 people visited our stall including school/college students, teachers, parents and general public. The ENVIS Co-ordinator, Dr Kannan C.S. Warrier explained about the concept of ENVIS, various ENVIS Centres under MoEF&CC focal point, and importance of conserving existing forest genetic resources to mitigate the fluctuating climatic conditions. The school children were supplied with various knowledge products such as environmental quiz booklets, name-slips with tree passport information and calendar cards with a note on important days of environmental significance.

ABOUT IFGTB

Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore is a National Research Institute under the Indian Council of Forestry Research and Education. IFGTB envisions a wood secure society. The Institute primarily aims to carry out research to improve productivity of forest tree species through conventional breeding programmes and biotechnological interventions. The major areas of research include tree improvement , breeding, planting stock improvement, marker assisted selection, genomics, clonal propagation, agroforestry systems, climate change research, integrated disease and pest management, seed handling and testing, eco restoration and conservation.

ABOUT ENVIS

ENVIS established by the Government of India, in 1982 has been on providing environmental information to decision makers, policy planners, scientists and engineers, research workers, etc. all over the country. It is a comprehensive decentralized information system on environment involving effective participation of institutions / organisations in the country actively engaged in work relating to different subject areas of environment. A large number of nodes, known as ENVIS Centres, have been established in the network to cover the broad subject areas of environment with a Focal Point in the Ministry of Environment, Forest & Climate Change.

INSTRUCTIONS TO CONTRIBUTORS

Dear Author/ Subscriber/ Contributor,

We invite contributions to the ENVIS Newsletter issues! The ENVIS Centre at IFGTB focuses on Forest Genetic Resources and Tree Improvement. It aims to act as a window for quality scientific publications and a forum for presenting your thinking on the challenges in the fields of FGRs and tree improvement. The ENVIS Newsletter, Van Vigyan, a quarterly publication, publishes original research articles, reviews, reports, research highlights, news-scan etc., related to the thematic area of the ENVIS Centre. Original research and review articles, notes, research and meeting reports are invited for the newsletter. Details of forthcoming conferences / seminars / symposia /trainings / workshops also will be considered for publication in the newsletter. Articles may be sent in Times New Roman (with font size 12) in double spacing with a maximum of 5-6 typed pages. Photographs/line drawings and graphs need to be of good quality with clarity for reproduction in the newsletter. Only electronic submission will be accepted.

Details may be sent to: ifgtb@envis.nic.in.

ENVIS Team

R.S. Prashanth, IFS
Director

Dr Kannan C.S. Warrier
Scientist E and Coordinator, ENVIS

Dr Rekha R. Warrier
Scientist E and Editor

Dr V.N. Mutharaian
Programme Officer

T. Vamadevan
Information Officer

V. Thangavel
IT Assistant

INSTITUTE OF FOREST GENETICS AND TREE BREEDING

Forest Campus, P.B. No. 1061, RS Puram HPO, Coimbatore - 641 002
Phone : 91 422 2484100; Fax : 91 422 2430549
Email: ifgtb@envis.nic.in, kannan@icfre.org; Web : http://envis.nic.in/ifgtb/index.html, ifgtb.icfre.gov.in