



Sandalwood (*Santalum spicatum* (R.Br.) A. DC.) excavation study

Jonathan E Brand^a, Syd R Shea^a and Ted Spadek^b

^a Department of Conservation and Land Management, Locked Bag 104, Bentley Delivery Centre, Western Australia, 6983

^b Chemistry Centre, 125 Hay Street, East Perth, Western Australia, 6004

Abstract

A mature *Santalum spicatum*, growing near Kalgoorlie, Western Australia, was excavated to determine its total biomass and the oil concentration in certain sections of the tree. A high proportion (38%) of the total tree weight was found in the root system, which consisted mainly of shallow lateral roots. The concentration of extractable oil in the heartwood varied between different sections of the tree and was highest in the butt, then large stems and large roots. Extractable oil from the butt, large stems and large root sections had the greatest proportion of β -santalol.

Introduction

Santalum spicatum (R.Br.) A. DC. (Western Australian sandalwood) is exported to Southeast Asia, mainly for use in incense manufacture (Richmond, 1977). *S. spicatum*, a root hemi-parasite, occurs naturally throughout a large proportion of Western Australia (Loneragan, 1990). The tree is harvested mainly from pastoral leases and vacant crown land in semi-arid regions. Western Australian sandalwood is normally

pulled from the ground to retrieve the heartwood from the tree's root (Shea *et al.*, 1997). This method of harvesting may result in large roots breaking close to the main stem and thus remaining in the soil. The amount of root material not harvested may be high due to the extensive lateral root system of the tree (Herbert, 1925).

Excavation of mature plants of *S. spicatum* will help determine the proportional weight of commercial wood contained in the root system. If a high proportion of wood is contained in the roots then new harvesting techniques may be warranted.

The fragrance of sandalwood oil is derived from sesquiterpenes, especially α -santalol and β -santalol (Adams *et al.*, 1975). Piggott *et al.* (1997) examined the composition of *S. spicatum* oil in different sections of a tree and identified five sesquiterpene alcohols: epi- α -bisabolol; α -santalol; farnesol; β -santalol; and nuciferol.

The aims of this study were to: (i) excavate and examine the root system of a mature *S. spicatum* tree; (ii) determine the biomass contained

within different sections of the tree; and (iii) determine the oil percentage and composition from different sections.

Methods

Excavation

The root system of a mature *S. spicatum* tree was excavated at Lakeside reserve (30° 50' S, 121° 36' E) near Kalgoorlie, in May 1997. The tree was growing near a creek, on a plain with *Acacia* and *Eucalypt* woodlands. The tree was 380 cm tall and had a stem diameter of 155 mm, at 150 mm above the ground. Pressurised water from was used to wash away the soil and expose the entire root system (Figure 1). The length and depth of the roots were measured and haustorial connections to host plants recorded.

The tree was divided into nine different groups: butt; large stems (> 40 mm diameter); large roots (> 40 mm diam.); medium stems (20-40 mm diam.); medium roots (20-40 mm diam.); fine stems (5-20 mm diam.); fine roots (5-20 mm diam.); dead branches; and leaves and twigs. The butt consisted of the main stem to a height of 15 cm above the ground, and roots to a length of 20 cm from the centre of the base. Stem and root diameter measurements included bark. Twigs with a diameter less than 5 mm were grouped with leaves. Each group was dried in an oven at 80°C for 48 hours, and then the dry weight was measured using a Mettler balance.

Oil extraction

Fresh wood samples from each group, except twigs and leaves, were

inside...

Sandalwood (*Santalum spicatum* (R.Br.) A. DC.) excavation study
Somatic embryogenesis in *Santalum album* L.
Santalum macgregorii F. v. Muller in Papua New Guinea

page 1
page 4
page 5



Exposed root system of a *S. spicatum* tree near Kalgoorlie, Western Australia

analysed for oil content at the Chemistry Centre, Western Australia. Seven cross-sectional wood pieces of 20-50 g were cut from each of the eight groups and ground through a crossbeater mill. Total oil from three of the ground samples was extracted using steam-distillation in a Dean and Stark apparatus for 24 hours. The mixed oil and water phases were extracted with dichloromethane, which was removed at 40°C by rotary evaporation under reduced pressure. Residual solvent was removed from the extracted oil using a high vacuum for 60 minutes. The weight of the total extractable distilled oil from each sample was expressed as a percentage of the wood dry weight.

Total extractable oil in the remaining four ground pieces in each group were extracted with ethyl acetate in a soxhlett apparatus, for 12 hours. After extraction, the extract was made up to 200 mL with ethyl acetate and a 100 mL aliquot was taken to determine the weight of extractable oil. Solvent was removed at 40°C by rotary evaporation under reduced pressure and residual solvent was removed from the extracted oil using a high vacuum for 60 minutes. Total weight of extractable oil was expressed as a percentage of the wood dry weight.

The mean oil percentage from each tree section was multiplied by wood dry weight to estimate total oil content in the tree.

A 10 mL aliquot was also taken from each solvent extracted sample to determine the percentage of β -santalol and farnesol in sandalwood oil. Internal standard (octanol) was added to the solution and then analysed by Gas-Liquid Chromatography with a Flame Ionisation detector. The concentrations of β -santalol

and farnesol were determined using peak area mode by comparison to authentic standards.

Results

Total dry weight of the tree was 74.4 kg, which included 45.4 kg of de-barked wood (Table 1). The proportion of wood was highest in the stems (46%), followed by the roots (38%), butt (9%) and dead wood (7%).

The root system consisted of one main lateral root, with a diameter of 7 cm at 100 cm from the stem base, and numerous smaller lateral roots. These extended up to 12 m from the stem base, but no deeper than 40 cm. The root system also contained a small tap-root to a depth of 90 cm. Fine feeder roots extended from the lateral roots and had haustoria attached to three different species: *Acacia burkittii* F.Muell. ex Benth., *Senna artemisioides* (DC.) Randell subsp. *filifolia* and *A. hemiteles* Benth. A total of 123 haustoria of 5-20 mm in length were recorded attached to the three host species. Two haustoria were also attached to the sandalwood's own root system.

The amount of oil obtained from solvent extraction was greater than steam distillation for each tree section (Table 2). Distillation recovered only

Tree Section	Wood		Bark		Total	
	(kg)	(%)	(kg)	(%)	(kg)	(%)
1. Butt	4.1	9.0	1.0	6.3	5.1	6.9
2. Large stems	12.1	26.7	3.5	22.1	15.6	21.0
3. Large roots	8.5	18.7	2.8	17.7	11.3	15.2
4. Medium stems	3.9	8.6	1.4	8.9	5.3	7.1
5. Medium roots	6.1	13.4	3.3	20.9	9.4	12.6
6. Fine stems	4.7	10.4	1.8	11.4	6.5	8.7
7. Fine roots	2.7	5.9	2.0	12.7	4.7	6.3
8. Dead wood	3.3	7.3	-	-	3.3	4.4
9. Leaves and twigs	-	-	-	-	13.2	17.7
Total	45.4	100	15.8	100	74.4	100

Table 1: Total dry weight of wood (heartwood and sapwood) and bark for each tree segment and proportion of wood and bark for each segment of the total tree.

Tree Segment	% Total oil extracted		% Compounds	
	Solvent	Distilled	β -santalol	Farnesol
1. Butt	7.3 \pm 0.5	1.6 \pm 0.1	9.8 \pm 0.2	1.2 \pm 0.1
2. Large stems	4.7 \pm 0.2	0.9 \pm 0.1	11.6 \pm 0.7	2.3 \pm 0.1
3. Large roots	3.8 \pm 0.2	0.7 \pm 0.1	10.5 \pm 0.5	1.5 \pm 0.2
4. Medium stems	1.8 \pm 0.1	0.2 \pm 0.1	6.7 \pm 0.5	2.0 \pm 0.3
5. Medium roots	2.8 \pm 0.3	0.4 \pm 0.1	5.4 \pm 0.2	ND
6. Fine stems	2.0 \pm 0.1	0.2 \pm 0.2	ND	ND
7. Fine roots	1.9 \pm 0.2	0.1 \pm 0.1	1.5 \pm 0.3	ND
8. Dead wood	0.8 \pm 0.2	0.1 \pm 0.1	ND	ND

ND - Not detected

14% of oil when compared to solvent extraction, but was indicative of the solvent results ($r = 0.99$). Oil percentage varied between tree sections and was highest in the butt, large stems, large roots and medium roots. The estimated total volume of extractable oil in the tree was 1.6 L and most of this was contained in the stem (0.73 L), root (0.54 L) and the butt (0.30 L).

The percentage of β -santalol was highest in the extracted oil from the butt, large stem and large root, ranging from 9.8% to 11.6% (Table 2). A low percentage of farnesol was detected in the oil from the butt, large stem, large root and medium stem, ranging from 1.2% to 2.3%.

Discussion

The *S. spicatum* root system consisted almost entirely of lateral roots, except for one small tap-root which had penetrated to a depth of only 90 cm. The lateral roots extended over 12 m from the base of the tree stem, no deeper than 40 cm. The fine feeder roots had numerous haustoria, which were attached to a variety of host plants, including: *A. burkittii*, *S. artemisioides* subsp. *filifolia* and *A. hemiteles*.

The root system contained a high proportion (38%) of the total wood weight. Small roots (5-40 mm), which are not normally harvested, represented 51% of the root system weight. A reasonable amount of

extractable oil was present in this root material (1.9-2.8%), when compared to large root material (3.8%). The estimated total volume of extractable oil in the tree was 1.6 L and 34% of this was contained in the root system. However, the percentage of β -santalol contained in the oil from the small root material (1.5-5.4%) was much lower than in the butt, large root and large stem (9.8-11.6%). These findings are consistent with Piggott *et al.* (1997) found that the proportion of sesquiterpene alcohols in *S. spicatum* oil varied between different sections within the tree. Since the fragrance of sandalwood is partly derived from the amount of β -santalol (Adams *et al.*, 1975), the oil contained in the smaller root material may be less fragrant than in other sections of the tree. This study, albeit limited to a single tree, showed that a large amount of wood and oil is contained in the root system.

Acknowledgements

We would like to thank Peter Jones, Ben Sawyer, Kim Phillips-Jones, Tim Brett and Grant Pronk for assisting with the sandalwood excavation.

References

Adams, D.R., Bhatnagar, S.P. and Cookson, R.C. (1975). Sesquiterpenes of *Santalum album* and *Santalum spicatum*. *Phytochemistry*

Table 2:

Mean oil percentage of each *S. spicatum* tree segment as determined by solvent extraction and steam distillation and proportion of β -santalol and farnesol in solvent extracted oil within each *S. spicatum* tree segment.

14: 1459-1460.

Herbert, D.A. (1925). The Root Parasitism of Western Australian Santalaceae. *Journal and Proceedings of the Royal Society of W.A.*, 11: 127-149.

Loneragan, O.W. (1990). Historical Review of Sandalwood (*Santalum spicatum*) Research in Western Australia. Research Bulletin No. 4. Department of Conservation and Land Management, Western Australia.

Piggott, M.J., Ghisalberti, E.L. and Trengove, R.D. (1997). Western Australian sandalwood oil: extraction by different techniques and variations of the major components in different sections of a single tree. *Flavour and Fragrance Journal* 12: 43-46.

Richmond, P.C. (1977). The Sandalwood Trade. *Western Australian Forests Department*, Information Sheet 26.

Shea, S.R., Radomiljac, A.M., Brand, J. and Jones, P. (1997). An overview of sandalwood and the development of sandal in farm forestry in Western Australia. In: Radomiljac, A.M., Ananthapadmanabha, H.S., Welbourn, R.M. and Satyanarayana Rao, K. (Eds.), *Sandal and its Products*. Proceedings of an international seminar held on 18-19 December 1997, Bangalore, India. ACIAR Proceedings No. 84, pp. 9-15.