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Pacific sandalwood

Growers' guide for sandalwood production in the Pacific region

ACIAR MONOGRAPH 218

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Contents

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Acronyms and abbreviations

Term	Description
2CC	second cutting chips
DBH	diameter at breast height
DBHOB	diameter at breast height over bark

Units

Unit	Definition
cm	centimetre
cm AGL	centimetres above ground level
g	gram
ha	hectare
kg	kilogram
L	litre
m	metre
m^2	square metre
m AGL	metres above ground level
m ASL	metres above sea level
mm	millimetre
ppm	parts per million
t	tonne, metric tonne (1,000 kg)
°C	degree Celsius

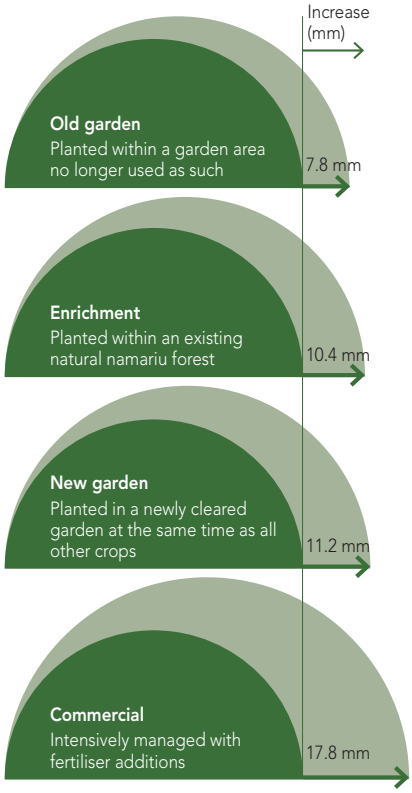
9 Tree and heartwood growth, and heartwood properties

9.1 Tree growth rates

Most data that have been collected on sandalwood growth rates indicate that an average growth rate of about 1 cm/year (at 20–30 cm above ground level) is typical on suitable sites. If you are not achieving this, on average, across several years, it may indicate issues with your site and/or management, for example a lack of suitable hosts. We recommend following the guidelines in this guide to give the best chance of achieving high growth rates and good heartwood development.

It is interesting that data collected so far from a wide variety of sandalwood species and sites indicates average growth rates of about 1 cm/year are normal, though significant variation around this average is also quite usual. For example, an inventory and re-measure of *S. yasi* and *S. album* of various ages and growing under various conditions in both Fiji and Tonga indicated growth of around 1 cm/year. *S. yasi* may therefore attain harvestable size (20–25 cm diameter at 20–30 cm above ground level with substantial heartwood development) within 25 years.

Similarly, in a comparison of sandalwood growth rates under four management regimes in Vanuatu (Figure 9.1), stem diameter was measured at 10 cm above ground level in 1,685 *S. austrocaledonicum* sandalwood trees planted under four management regimes across five islands (Santo, Malekula, Efate, Erromango and Tanna). Sandalwood grown under commercial conditions had significantly higher growth rates than sandalwood under all other management regimes, largely due to the attention to host tree planting and addition of fertiliser. However, there were no statistical differences between new garden and enrichment regimes in the mean growth rate in basal diameter, which was 10.8 mm/year under both regimes. Trees planted in old garden areas had significantly lower growth rates than trees grown under other management regimes. Although 93% of the data were collected from trees aged 10 years and under, these differences in early growth rates are likely to persist in later years.



Average annual increase in basal trunk diameter (at 10 cm above ground level) under various management regimes

Figure 9.1 Rates of sandalwood growth under four different management regimes used in Vanuatu

In Papua New Guinea, the growth rates for the local species *S. macgregorii* are highly variable between plantings, depending on site selection and maintenance, with current growth rates of around 1 cm/year in diameter (at 20–30 cm above ground level) for well-maintained plantings. However, the inclusion of mechanical ploughing of the site, good weed control, adequate spacing (4 m × 5 m) and use of hosts to promote excellent early growth could result in growth rates of up to 2 cm/year.

From measurements of planted *S. album* in Timor-Leste, stem diameter (20 cm above ground level) growth rates for a well-managed planting was between 0.9 and 1.1 cm/year. For plantings without sufficient hosts or planted in high competition situations, stem growth rates ranged from 0.45 to 0.75 cm/year.

The growth rate for 2-year-old *S. lanceolatum* under plantation conditions in Cape York, Queensland, averaged from 1.2 cm/year diameter at breast height over bark (DBHOB) for irrigated and 0.45 cm/year for non-irrigated plots.

9.2 Heartwood development

The value of sandalwood lies in its fragrant heartwood, and therefore the development of heartwood is critical. The rate at which heartwood develops is highly variable between species, but also between individual trees within a species. The rate of heartwood development is influenced by the age at which the tree begins to initiate the process. Typically, the earlier the heartwood starts to develop (i.e. in a young tree), the greater the volume of heartwood available at harvest (Figure 9.2 and 9.3).

Figure 9.2 Examining a core taken from an *S. yasi* tree in Tonga for heartwood development

Many experienced sandalwood farmers consider that the rate of heartwood development is strongly associated with soil type, rainfall and the level of sun exposure on the canopy of the sandalwood tree. The most experienced farmers say that sandalwood develops heartwood rapidly when it is grown in a shallow soil or soil with a high level of stone inclusions, together with a distinct annual dry period and exposure to full sun. The expected period for harvest under these conditions was 15–20 years but may be as much as 30–40 years for trees growing in areas of deep fertile soil, high and evenly distributed rainfall throughout the year, and a shaded canopy. More work is needed to determine the specific causes of heartwood development and how it varies between species and locations.

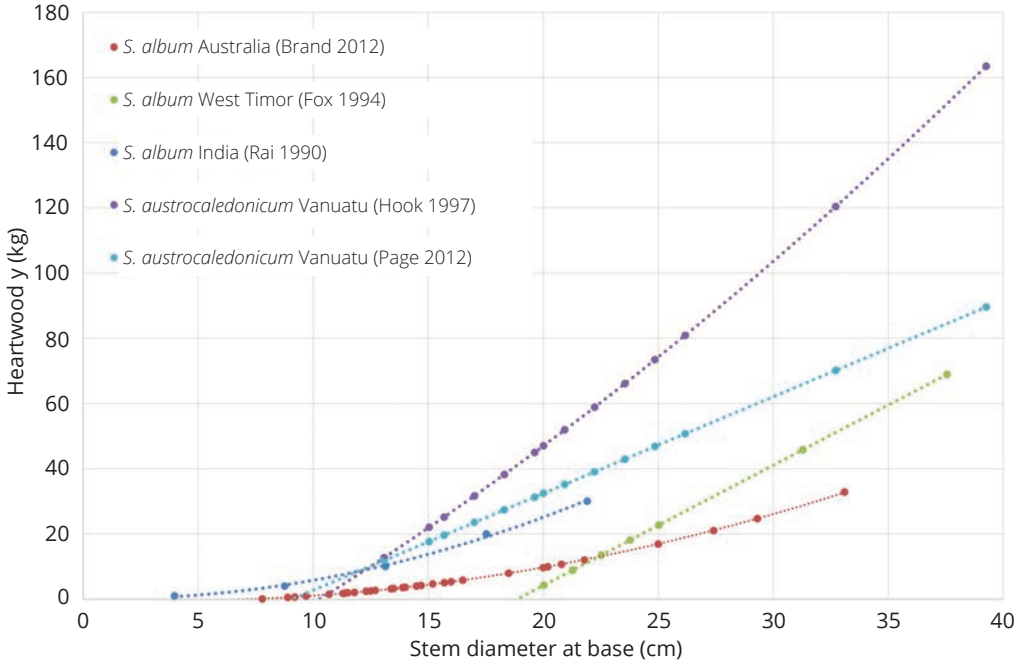


Figure 9.3 Heartwood development by five authors for *S. album* and *S. austrocaledonicum* for stem diameter standardised at the base (0.2 to 0.3 m from ground level). Data for Rai (1990), Fox (1994) and Hook (1990) were originally based on DBH and a conversion factor of 1.25 (*S. austrocaledonicum*) to 1.3 (*S. album*) to calculate basal diameter

9.3 Heartwood properties

The value of a sandalwood tree is largely determined by the weight of its heartwood and the concentration and composition of its oil.

Determining the rate of heartwood development in a sandalwood tree is important because it will affect the length of its commercial rotation. The weight of the heartwood is invariably limited by, or dependent on, the size of the tree. Larger trees typically have greater volumes of heartwood.

Tree age also has a positive influence on heartwood oil concentration and quality, with older trees (20+ years) mainly containing good quantities of heartwood.

The value of wood products from sandalwood is dependent upon the concentration (amount) and quality (fragrance) of the oil contained within.

- **Oil concentration** in heartwood can range from 1 to 8%, and typically those with higher concentrations will have a stronger fragrance. The strength of the fragrance is, however, a highly subjective olfactory assessment and therefore it can be misleading to use it as a reliable indicator of wood value.
- **Oil quality** is assessed by the type of aroma/scent that the sandalwood produces. While all sandalwood has a similar scent, there are subtle differences that discerning consumers can detect. The quality of the scent is directly related to the combination of different chemical compounds contained within the oil. The santalols (both α- and β-santalol) are the most important and are broadly described as having a 'soft and woody' aroma.

Oil yield and oil composition varies between wood type and tree parts (roots, butt, trunk and branches) (Figure 9.4), with highest oil and santalol concentrations found in the major roots and butts, which decrease vertically up the tree to the branches (Moretta 2001; Baldovini et al. 2011; Braun et al. 2014).

The age (maturity) of the tree also has a significant effect on heartwood quality, with older and larger trees typically producing greater volumes of heartwood with a higher oil concentration and santalol content than small young trees (Subasinghe et al. 2013). As a tree ages, the size (diameter) of the heartwood within the tree increases so that a greater volume of heartwood can be found in older trees (Page et al. 2010).

Branches (small logs)
Heartwood is found in the upper part of the trunk of younger trees and branches of trees older than 20 years. They typically have the least amount of heartwood and lowest concentration of oil of all plant parts.

Trunk (logs)
Most heartwood is found towards the base of the trunk and decreases with trunk height.

Stump (butt)
The most oil-rich heartwood is located in the stump.

Roots
The main roots can also contain heartwood but, like branches, heartwood in roots is mainly found in older trees.

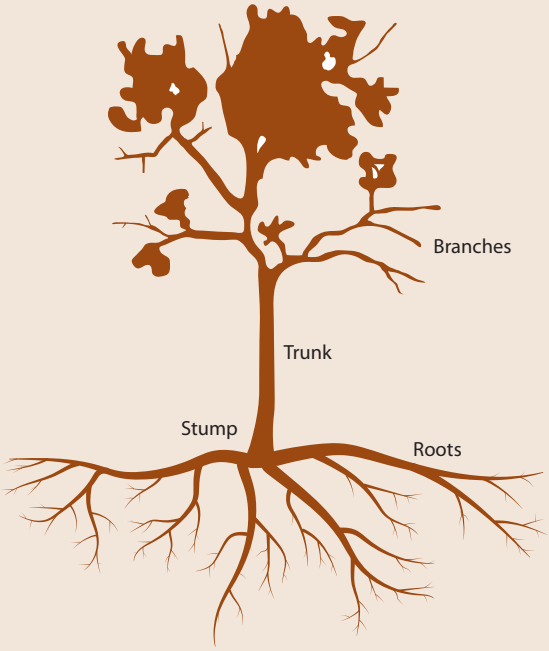


Figure 9.4 Heartwood oil is contained within the roots, stumps, trunks and main branches of a sandalwood tree

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10 Sandalwood harvesting and preliminary processing

10.1 Sandalwood harvesting

The time needed to develop enough heartwood for harvest will vary between trees and growing environments. Tree size is a good indication; the minimum harvestable size is 20 cm diameter at 0.2 m AGL, which represents a tree about 20–25 years old.

Oil is particularly concentrated in the roots and butt of the sandalwood tree; therefore, the stump and roots need to be dug out to gain maximum saleable value from the tree. Heartwood can be present in the branches of older trees but is unlikely to be in the branches of planted sandalwood with a rotation of 15–20 years.

Growers should also consider the cost and logistics of providing security and protection to trees as they reach harvestable size. Trees become vulnerable to theft from around 12–15 years of age, particularly the fast-growing individuals.

Knowing when a tree is ready for harvest may require an assessment of heartwood development. This may be done in one of three ways:

1. making small cuts in the branches
2. making small cuts in the roots
3. drilling into the trunk (20 cm AGL) using a small drill bit (6 mm) (Figure 10.1).

As an interim guideline (taken from Thomson et al. 2020), sandalwood may be harvested once they have reached 17–20 years of age, with a near-basal (at 20–30 cm above ground) diameter of 25 cm and once the sapwood band is 5 cm or less. While drilling has issues with insects and other gaining entry via the hole, in a vigorous tree the bark can quickly grow over the wound.

Figure 10.1 (photo on facing page) Taking a core to ascertain the level of heartwood development in an *S. yasi* tree in Fiji

Figure 10.2 Method of sandalwood harvesting

The images in Figure 10.2 show how sandalwood is harvested:

1. **Measure tree trunk** at 20 cm AGL to identify suitable trees.
2. **Examine the tree** for sufficient heartwood (see above) for harvesting.
3. **Reduce canopy** with a bush knife to collect branches and make felling less damaging to nearby trees.
4. The stripped tree is ready for felling and digging out.
5. **Fell trunk** and cut into logs using a chainsaw before **or** after digging out the roots.
6. **Dig out roots**, using shovels.
7. The exposed roots are ready for cutting and collecting.
8. Cut roots ready for weighing.

10.2 Preliminary processing

Sandalwood is sold by weight. Before selling it, the main requirement is to remove the sapwood from around the heartwood (Figure 10.3). This is usually done by gradually cutting the sapwood away with a bush knife (machete) (Figure 10.4). This process results in by-products: pure sapwood chips and second cutting chips (2CC) (Figure 10.5). While both by-products can be used in the manufacture of incense, it is generally the 2CC that has a market. The 2CC are chips that retain some heartwood and are more desirable for incense.

Figure 10.3 Cross-section of sandalwood logs (left) identifying bark, sapwood and heartwood; and (right) showing heartwood after bark and sapwood removed.

Figure 10.4 Removing bark and sapwood (left), and the sapwood chips as a by-product (right)

Figure 10.5 Secondary manual processing of sandalwood where all traces of sapwood are cut away from the heartwood

10.3 Productivity

For a hectare of planted sandalwood at 4 m × 5 m spacing, including hosts at a ratio of 2:1 (Figure 4.7), approximately 330 sandalwood trees may be available at harvest. If we assume an equal volume of sapwood and heartwood (18 kg each) and 1.5 kg of 2CC, then the volume of heartwood and 2CC would be approximately 6 and 0.5 t, respectively.

In general, the price of sapwood and 2CC is relatively low and much more sensitive to oversupply than sandalwood heartwood. Currently there is no reliable market for pure sapwood, therefore immature trees without heartwood and the sapwood chips by-product hold no commercial value.

10.4 Reference

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11 Product grading system

The sandalwood grading system is based on the tree structure and includes four primary categories, each with their own grades (depicted in Figure 11.1). Both oil concentration and total santalol content of heartwood oils have been consistently found to be elevated in the basal parts of the tree (major roots and butts) and decline with height above the ground. This is reflected in the sandalwood grading system described below. This system is for use with trees that are alive at harvest.

The four primary categories are (Figure 11.1):

- **Specialty** – Produced mainly in older trees greater than 20 years and are valued for their ornamental and decorative features. Carving logs are large logs without significant faults that are of sufficient size for an artist to carve into a decorative piece. Specialty grades also include naturally occurring features in the timber such as burls or wood forms that can be highlighted in natural showpieces. The pricing of specialty grades is often determined through negotiation between buyer and seller.
- **Typical** – Most commonly produced commercial grades across most tree age classes.
- **Faulty** – Diseased, insect affected, degraded, or improperly formed heartwood products. These faulty pieces are of low value and their faulty status annuls any grading based on tree origin.
- **By-products** – Derived through the process of de-sapping the sandalwood. Pure sapwood derived from de-sapping has limited commercial value.

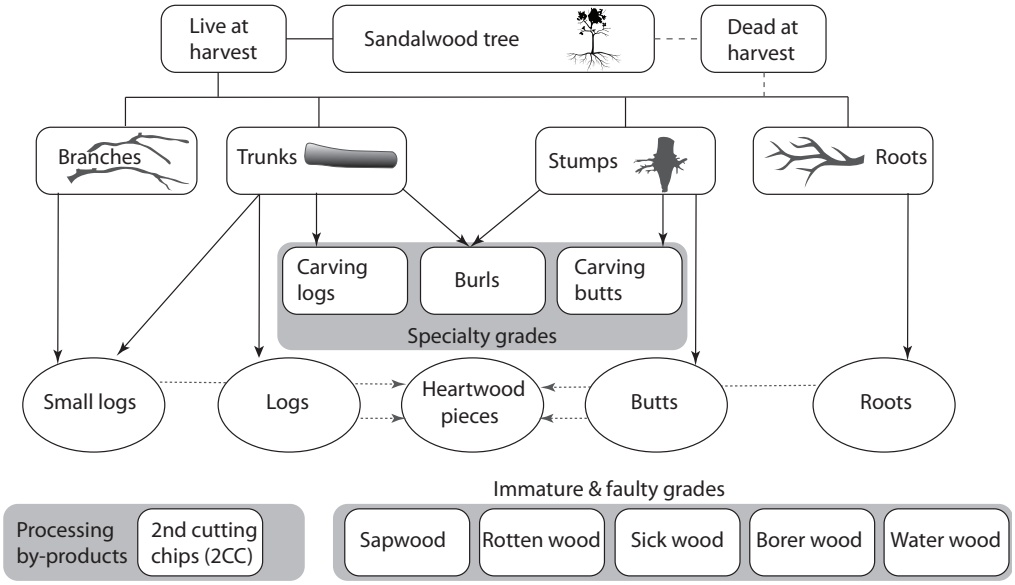

Figure 11.1 The sandalwood products are based on the tree structure and include four product categories: (1) specialty; (2) typical (within ovals); (3) faulty; and (4) by-products

Note: Dashed lines are connections that are not common in tropical sandalwood species. Dotted lines indicate that heartwood pieces can be derived from any source of the tree.

11.1 Typical sandalwood grades

A simplified five-grade system is proposed for the **typical sandalwood** category.

1. Butts

The stump section is separated from the roots and the trunk billet with all sapwood removed. The length of the trunk section is no more than 15 cm above ground level. They are further classed as small (<10 cm trunk section at ground level – Figure 11.2) and large (>10 cm trunk section at ground level – Figure 11.3). Small-sized sandalwood butts are often associated with immature trees and thus the oil concentration and commercial value is considerably less than large-sized butts.

Figure 11.2 Small sandalwood butts/stumps with trunk sections of less than 10 cm at ground level

Figure 11.3 Large sandalwood butts/stumps with trunk sections of greater than 10 cm at ground level

2. Roots

Solid roots with all sapwood removed (Figure 11.4).

Figure 11.4 Solid roots with all sapwood removed

3. Logs

De-sapped, large-diameter sections of branch (rarely) and trunk heartwood 30–100 cm long and >10 cm diameter at smallest end (Figure 11.5).

Figure 11.5 Logs – de-sapped, large-diameter sections of trunk heartwood 30–100 cm long and >10 cm diameter at smallest end

4. Small logs

De-sapped, small-diameter sections of branch and trunk heartwood 30–100 cm long and 3.5–10 cm diameter at smallest end (Figure 11.6).

Figure 11.6 Billets – de-sapped, small-diameter sections of branch and trunk heartwood 30–100 cm long and 3.5–10 cm diameter at smallest end

5. Heartwood pieces

A single grade for pure heartwood pieces, fragments, small branches and debris. Small pieces of heartwood that do not conform to any specialty, typical or faulty grades (Figure 11.7).

Figure 11.7 Heartwood pieces – a single grade for pure heartwood pieces, fragments, small branches and debris that do not conform to any specialty, typical or faulty grade

11.2 Processing by-product

1. Second cutting chips (2CC)

A **by-product** of the second stage of de-sapping, which is often undertaken by traders (Figure 11.8).

Figure 11.8 Second cutting chips – a by-product of final de-sapping after the bark has been removed; typically contains a 1:1 proportion of heartwood and sapwood

11.3 Immature and faulty sandalwood grades

An additional five grades describe **immature and faulty** heartwood products. These products have low commercial value.

1. Sapwood

The wood of immature trees that lacks any notable heartwood (Figure 11.9). Sapwood is the low-value, white-coloured outer layer of wood in mature trees that lacks oil and is also a by-product of the process of de-sapping. Sapwood is abundant in young trees and is also found in the branches of mature sandalwood trees.

Figure 11.9 Sapwood – the outer layers of a mature tree or wood of an immature tree that lacks any notable heartwood

2. Rotten wood

Heartwood with significant areas of degradation, usually associated with water entry into the wood and/or disease entry (Figure 11.10).

Figure 11.10 Rotten wood – heartwood with significant areas of degradation associated with water or disease entry into the wood

3. Sickwood

The heartwood of a tree that has been affected by disease, most notably soil-borne fungal diseases such as *Phytophthora* spp. and *Phellinus* spp. (Figure 11.11). Typically, the central core of the tree is infected and becomes degraded.

Figure 11.11 Sickwood – the heartwood of a tree that has been affected by disease, most notably soil-borne fungal diseases such as *Phytophthora* spp. and *Phellinus* spp.

4. Waterwood

Sandalwood with incomplete, uneven or wounded heartwood development (transition wood) or heartwood that has been damaged (Figure 11.12). This product is suspected to be associated with cyclone damage. It is known as waterwood, as resource owners describe it having a high wood water content at the time of harvest.

Figure 11.12 Waterwood – sandalwood with incomplete, uneven or wounded heartwood development (transition wood) or heartwood that has been damaged

Note: This product is suspected to be associated with cyclone damage.

5. Borerwood

Heartwood with evidence of insect attack and/or borer damage.

11.4 Specialty heartwood

Three grades describe the **specialty heartwood** products.

1. Carving logs

De-sapped, totally clean heartwood logs with a smooth surface, with a minimum diameter at the smallest end of 10 cm. The minimum length is 20–30 cm and the maximum length is 120 cm. Must be near circular in cross-section and have no hollows, cracks or knots, and be entire (Figure 11.13). All sapwood and transition wood must be removed so there is only heartwood. Ends need to be sealed with clear end sealer (Coakley 2007).

Figure 11.13 Carving logs de-sapped (left), and totally clean heartwood logs (right)

2. Carving butts

Decorative art pieces of the buttwood. The value of a decorative carving butt is determined by agreement between producer and buyer.

3. Burls

Rare pieces of heartwood where the grain has grown in a deformed manner. The deformations result in decorative patterns that can be used for art and carving pieces. Burls can be formed by biological infections that don't cause wood rot (Figure 11.14). The price for burl pieces would be through agreement between producer and buyer.

Figure 11.14 Burls are outgrowths on the stem (left) and form rare decorative pieces of wood (right)

11.5 Reference

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12 Processing sandalwood

The carving log attracts the highest price in the marketplace, followed by oil and then heartwood powder. However, the profitability of each product also depends on the cost of production.

All products require the outer sapwood to be removed (de-sapped), which is typically done by the harvester or grower before sale. Traders will often undertake further de-sapping, to remove all traces of sapwood next to the heartwood. This final de-sapping process produces a by-product known as second cutting chips (2CC), which is a mix of sap and heartwood.

The cost of de-sapping is influenced by the regularity of the heartwood shape. Typically, the total cost of processing is lowest for carving logs, as they contain large amounts of regularly shaped heartwood, and is highest for young trees, branches and roots. For carving logs, the ends are then sealed (usually with wax) to prevent rapid drying and cracking.

Powdered wood requires additional milling and blending of different powders to achieve a final product that is acceptable for use in agarbatti.

Sandalwood oil is the most expensive product to produce because the heartwood needs to be milled to a consistent grade before the oil is extracted by an energy-intensive and complex process called distillation. The oil content (by weight) of milled heartwood is variable, but in good-quality heartwood it will be around 3–4%.

During distillation, steam is generated in a boiler, which is typically fuelled by diesel, coconut oil, wood or electricity, and passes through powdered heartwood, where it mixes with the heartwood oil. This mixture is then cooled and condensed, with the oil forming a layer on top of the water. Distillation can take several days to liberate all of the oil from the heartwood.

The production of high-quality oil requires a high level of experience and knowledge of the process. The price of oil therefore contains the cost of the heartwood and other inputs, such as fuel and labour – this is why oil has a much higher price than powdered heartwood. The high input costs for oil production may mean that profitability is marginal for some processors.

12.1 Processed product

1. Heartwood chips

Heartwood that is chipped into a consistent size specification (grade) that is used in distillation of oils (Figure 12.1).

Figure 12.1 Heartwood is milled to a consistent size specification (grade) of 3–5 mm chips, which are then used for extraction of oil

2. Heartwood powder

Heartwood that is ground into powder that is used in the manufacture of joss sticks and other incense products (Figure 12.2 and 12.3).

Figure 12.2 Heartwood is milled into a fine powder so that it can be used in the manufacture of joss sticks and other incense products

Figure 12.3 Processing agarbatti

3. Heartwood oils

Fragrant oil that is liberated from the heartwood by a range of means including solvent extraction, water or steam distillation, or supercritical fluid extraction (Figure 12.4 and 12.5).

Figure 12.4 Sandalwood oils are extracted from the heartwood and come in a range of colours (from light straw colour to dark honey brown)

Note: To attract a premium price, heartwood for oil extraction should have a high oil content (>3%) and a high combined α- and β-santalol content, preferably above 50%.

Figure 12.5 Sandalwood oil distillation units where chipped wood is treated with steam under pressure to release the oil from within

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