Australian Government
Australian Centre for
International Agricultural Research

Pacific sandalwood

Growers' guide for sandalwood production in the Pacific region

ACIAR MONOGRAPH 218

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Editors
Tony Page
David Bush
Bronwyn Clarke
Lex Thomson

2022

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Page T, Bush D, Clarke B and Thomson L (eds) (2022) *Pacific sandalwood – Growers' guide for sandalwood production in the Pacific region.* ACIAR Monograph No. 218. Australian Centre for International Agricultural Research, Canberra.

ACIAR Monograph Series No. 218 (MN218)

ISSN 1031-8194 (print)

ISSN 1447-090X (pdf)

ISBN 978-1-922787-06-4 (print)

ISBN 978-1-922787-07-1 (pdf)

Technical editing by Dr Joely Taylor

Design by Griffin Graphics

Printing by CanPrint Communications

Foreword

Sandalwood trees (*Santalum* spp.) are highly valued for their fragrant heartwood oils, which have been used for centuries for religious and customary purposes. Now sandalwood oil is in demand internationally for cosmetics, aromatherapy, scenting of soaps, perfumery and medicines. The oil-bearing heartwood is also used for ornamental or ceremonial carvings, and powdered for the manufacture of incense joss sticks.

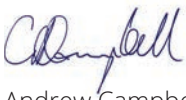
There has been trade in sandalwood in the Pacific region since the 1400s, when Chinese merchants and Arab traders started visiting Timor and surrounding islands. Trade then expanded throughout the region to Hawaii, Fiji, French Polynesia, New Caledonia, Vanuatu and Tonga. The sandalwood trade remains an important source of income for many smallholders in the Pacific region, and farmers and industry alike seek to transition from wild harvest to plantation sandalwood.

The Australian Centre for International Agricultural Research (ACIAR) was mandated, as set out in the ACIAR Act (1982), to work with partners across the Indo-Pacific region to generate the knowledge and technologies that underpin improvements in agricultural productivity, sustainability and food systems resilience. We do this by funding, brokering and managing research partnerships for the benefit of partner countries and Australia. We also support the dissemination of the knowledge and experience gained from research by publishing books, guides and manuals for a range of audiences.

For the past 30 years, ACIAR invested in considerable research and development of best practices for the cultivation of sandalwood by smallholder farmers, coincident with rapidly expanding areas of smallholder plantings. Drawing from this investment and its outcomes, in 2012, ACIAR published *Vanuatu sandalwood – Growers' guide for sandalwood production in Vanuatu*. The original guide provided very practical guidelines, informed by research, for establishing productive sandalwood woodlots and was well used not only in Vanuatu, but in Fiji and Tonga as well.

Continued and growing interest in sandalwood production beyond these countries has led to a review and update of the original guide, for smallholders and their advisors in Indonesia, Timor-Leste, Papua New Guinea and Australia, as well as in Vanuatu, Fiji and Tonga.

The investment of ACIAR and its brokering of collaborative research and development, as well as further investment to extend the outcomes of the research, will increase the sustainable supply of sandalwood and improve the incomes of smallholder growers throughout the Pacific region.



Andrew Campbell

Chief Executive Officer, ACIAR

Contents

Photo: (facing page) Luis Almeida

Contributors

Editors

Tony Page
University of the Sunshine Coast, Maroochydore, Australia

David Bush
CSIRO Australian Tree Seed Centre, Canberra, Australia

Bronwyn Clarke
CSIRO Australian Tree Seed Centre, Canberra, Australia

Lex Thomson
University of the Sunshine Coast, Maroochydore, Australia

Authors

Luis Almeida
Agricultural Innovations for Communities (AI-Com), Dili, Timor-Leste

Antonia Alves
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

João Boavida
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Waisea Bolatolu
Ministry of Forestry, Suva, Fiji

Tony Burridge
Horticulture and Forest Science, Department of Agriculture and Fisheries, Australia

David Bush
CSIRO Australian Tree Seed Centre, Canberra, Australia

Bronwyn Clarke
CSIRO Australian Tree Seed Centre, Canberra, Australia

Luis da Costa Patrocinio
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Sonu Dutt
Ministry of Forestry, Suva, Fiji

Sitiveni Hamani
Ministry of Agriculture and Food, Forests and Fisheries, Nuku'alofa, Tonga

Liliek Haryianto
Centre for Forest Biotechnology and Tree Improvement, Yogyakarta, Indonesia

Maloni Havea
Ministry of Agriculture and Food, Forests and Fisheries, Nuku'alofa, Tonga

Jeremias Jose Cristovao
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Phyllis Kamasteia
Department of Forests, Port Vila, Vanuatu

David Lee
University of the Sunshine Coast, Maroochydore, Australia

Heimuli Likifau
Ministry of Agriculture and Food, Forests and Fisheries, Nuku'alofa, Tonga

Jalesi Mateboto
Land Resources Division, The Pacific Community, Suva, Fiji

Pasimati Motuliki
Ministry of Agriculture and Food, Forests and Fisheries, Nuku'alofa, Tonga

Yeni Nurchayani
Universitas Gadjah Mada, Yogyakarta, Indonesia

Linden Oa
Papua New Guinea Forest Authority, Port Moresby, Papua New Guinea

Tony Page
University of the Sunshine Coast, Maroochydore, Australia

Ida Pereira
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Anto Rimbawanto
Centre for Forest Biotechnology and Tree Improvement, Yogyakarta, Indonesia

Guduru Rome
Papua New Guinea Forest Authority, Port Moresby, Papua New Guinea

Mario Sacaio
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Michael Tabi
Department of Forests, Port Vila, Vanuatu

Hannington Tate
Food and Agriculture Organization of the United Nations, Port Vila, Vanuatu

Jale Tauraga
Ministry of Forestry, Suva, Fiji

Nick Thompson
Apudthama Land Trust, Ipima Ikaya Aboriginal Corporation RNTBC, Injinoo, Australia

Lex Thomson
University of the Sunshine Coast, Maroochydore, Australia

Joseph Tungon
Department of Forests, Port Vila, Vanuatu

Maria Vilar Moreira
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Victor Ximenes
Ministry of Agriculture and Fisheries, Dili, Timor-Leste

Robert Williams
Agricultural Innovations for Communities (AI-Com), Dili, Timor-Leste

Acknowledgements

The editors and authors would like to acknowledge the following people whose work has contributed to the knowledge compiled in this document:

Vanuatu

Keith Amos, Judy Kalotap, Toufau Kalsakau, Godfrey Bome, Mailing Muru, Ian Serel, Leslie Simeon, James Willie Kalton, Craig Mowatt, David Jake, Jimmy Thomson, David Tadnel, Kalen Abbie, Tom Kalpokas, Jonathan Naupa, Jimmy Mau, Josen Boe, Joe Junior Nakou, Andrew Yawak, Sam Yakar, Remi Kali, David Kalanga, Steven Nilwo, Lee Peterson, John Rungu, Tony Keith, Edmond Julun

Timor-Leste

Adalfredo do Rosario Ferreira, Oscar Fernandes, Agosto Fernandes, Cosme, Domingos Da Costa, Antonia Madadeira, Salvador Soares, Constantinho Hornai, Antonio Gomes, Tito Bernadino, Gaspar da Costa, Abel Barreto, Jose Soares, Salvador P Nunes, Vriciumu de Deus, Mr Domingos Gusmão, Mr Costantinho N Hornai, Casimiro dos S Mendes, Orlando Berek, Julião da Silva, Juvensio Magno, Joanico Faria, Mr Mario da Costa, Mr Ubanu Ferreira, Agostinho Belo, Modesto Sarmento

Papua New Guinea

Ruth Turia, Claude Saliau, Wake Yelu, Gedisa Jeffrey, Anton Lata, Sonia Intu, John Popo, Masu Eka, John Hasu, Mark Hasu, Henry Havosa, Alois Fauma, Robert Aburu, Bernard Iburo, Sebara Baina, Lava Mnama, Aire Bulina, Josephine Waine, Javen Evera

Fiji

Sanjana Lal, Sairusi Bulai, Ponijesi Bulai (deceased), Maika Daveta, Lice Lili, Elina Young, Maika Lesubula, Josefa Matagasau, Ulita Naikemu, Kururita Siva, Salaseini Toma, Noa Vakacegu

Tonga

Leody Vainikolo, Sunia Napa'a, Tevita Faka'osi, Sione Fifita

Australia

John Doran, Grant Pronk, Paul Macdonell, Tim Coakley, Ken Robson, Ben Boxshall

Images published in this guide are by the editors except where otherwise stated.

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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1 Introduction

1.1 Sandalwood products

Sandalwood trees (*Santalum* spp.) are highly valued for their fragrant heartwood oils (Figure 1.1) and are recognised as one of the most precious non-timber forest products. The oils have been used for centuries for religious and customary purposes, and are now used internationally for cosmetics, aromatherapy, scenting of soaps, perfumery and medicines.

The oil-bearing heartwood is also used for ornamental or ceremonial carvings, or powdered for the manufacture of incense joss sticks (Figure 1.2), which are valued in the international agarbatti (incense) market.

Figure 1.1 Sandalwood heartwood oil

Photo: Tony Page

1.2 Sandalwood markets

Since the 1400s, when Chinese merchants and Arab traders started visiting Timor and surrounding islands, there has been trade in sandalwood in the Pacific region. As new trade routes opened, this trade spread to other Pacific islands including Hawai'i, Fiji, French Polynesia, New Caledonia, Vanuatu and Tonga. Trade has risen and fallen with the availability of sandalwood. Tree populations recover to some extent, during times when trade has dropped off. Interest in planting and growing sandalwood for both cultural and commercial reasons has increased in the Pacific islands in recent times. In Vanuatu a modest commercial industry has been operating consistently since the 1970s, with an annual quota of about 80 t. In recent decades, the total amount of heartwood exported from Fiji and Tonga has been <100 t/year. In Timor-Leste, sandalwood exports have been prohibited since 2012 in an effort to enable wild populations to recover; however, there is still some black-market trade. Sandalwood exports from Papua New Guinea spiked between 1997 and 2002, when an average of ~36 t was exported annually. More recently (2013–2018), annual harvests ranged from <1 to 5 t, except in 2019 where 20 t was exported.

Sandalwood is used mainly in India, China, Taiwan, Hong Kong and the Middle East, with substantial markets in Europe, Japan, South Korea, North America and elsewhere. The high demand for sandalwood products and the low level of commercial production of these trees has resulted in a sharp decline in the natural supplies of many sandalwood species. International prices for sandalwood have therefore consistently risen over the past few decades. However, the price that this product attracts is dependent on its quality. Until recently, the price paid to villagers in Vanuatu for 1 kg of heartwood had risen at an annual rate of 10% since 1990. Sandalwood prices in Vanuatu are currently being affected by the lower quality of the available product. Now that recent plantings are maturing and developing substantial heartwood, the price may be expected to rise again.

Figure 1.2 Large ornamental carving from sandalwood (left page) and incense burners in a temple (above)
Photos: Tony Page


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2 Sandalwood species

2.1 Distribution and size

Sandalwood trees vary in size depending upon, among other factors, the species of sandalwood and the location where it is grown.

Santalum album

Indian sandalwood is a small tree, between 4 and 10 m tall. It occurs in the seasonally dry tropics of southern India; Sri Lanka; Indonesia (Aceh in north-west Sumatra, West Timor and Lesser Sunda Islands); Timor-Leste; and the northern coastline of the Northern Territory, Australia.

Santalum austrocaledonicum

Vanuatu and New Caledonia sandalwood is a small tree (5–10 m tall) that occurs naturally in west-coast Santo, western Malekula, north-western Efate, Erromango, Tanna, Aniwa, Futuna and Aneityum, Vanuatu; and Grande-Terre, Isle of Pines and the Loyalty Islands, New Caledonia.

Santalum lanceolatum

Northern sandalwood is a shrub or small tree growing up to 8 m high. It is a tropical species that occurs in the northern parts of Australia (latitudes north of 20°), in Queensland, the Northern Territory and Western Australia.

Santalum macgregorii

Papua New Guinea sandalwood is a medium-sized tree that is usually less than 8 m tall but which may grow up to 20 m tall and 25 cm in diameter. It occurs naturally in Papua New Guinea, occurring in the Central and Gulf provinces from near sea level to 750 mASL. Recent research has indicated that some sandalwood populations in Western Province, Papua New Guinea, thought to be *S. macgregorii* may actually be *S. lanceolatum*, or more closely related to *S. lanceolatum*.

Santalum yasi

Fiji, Tonga and Niue sandalwood is a shrub or small tree to 9 m tall with a light, spreading crown. It occurs from Niue through ‘Eua, Tongatapu, Ha’apai, Vava’u and Niuas (Tonga) and the Fiji Islands (Lau Islands, to Bua and Macuata provinces (Vanua Levu), Udu Peninsula (north-east Vanua Levu), Nausori Highlands (western Viti Levu) and Kadavu).

2.2 Biology

Sandalwood is an obligate hemiparasite, which means that although the trees can photosynthesise, they must grow with other species to survive. Their roots have specialised outgrowths (haustoria) that penetrate the roots of nearby trees and shrubs and absorb water and nutrients from them (Figure 2.1).

Figure 2.1 Haustorial connection of sandalwood root (left) and cross-section of haustoria penetrating the host root (right)

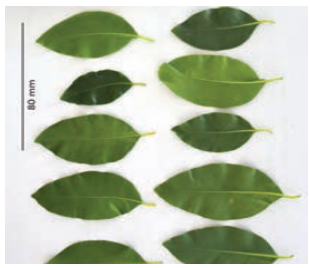
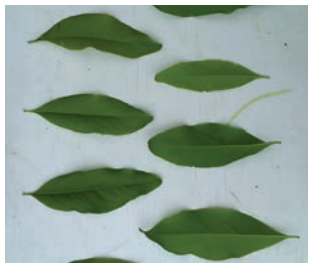
Photos: Tony Page

When growing sandalwood seedlings, a host plant needs to be planted with the sandalwood (a 'pot host'). Host plants also need to be planted among sandalwood trees in the field to promote vigorous sandalwood growth.

Sandalwood exhibits different growth habits and features across the spread of its geographic range (Table 2.1):

- **Habit** – Sandalwood growth habit is influenced by the environment in which it grows. Trees growing in open positions tend to have a short, crooked and forked trunk with a spreading crown. Trees growing in forest and sheltered positions will typically develop a longer, straighter trunk with a narrower crown and fewer heavy branches.
- **Bark** – The bark varies from smooth to rough and fissured, grey to reddish brown to almost black in some *S. album*, often with lichen on older trees.
- **Leaves** – Leaves range from near-linear in some *S. yasi* through to ovate or broadly lanceolate in *S. album*. Leaves are typically narrower in seedlings, becoming somewhat broader with age. Pacific sandalwood species leaves are mostly discolourous with a dark shiny green upper and a matte light green lower surface. *S. lanceolatum* leaves are either the same colour on either side or slightly discolorous and often slightly glaucous (greyish blue or green, or covered with a greyish waxy bloom). Planting position, soil type and amount of shade can strongly affect leaf colour. Sandalwood (especially *S. yasi*) grown in open, sunny sites with inadequate hosts, have lighter yellower leaves.
- **Flowers** – Sandalwood has small, greenish white to cream-coloured flower parts (tepals) that turn light pink through to dark red at maturity (except for *S. austrocaledonicum* and *S. lanceolatum*, whose flowers remain greenish white to cream until maturity). These flowers are borne on branched inflorescences twice each year. In *S. austrocaledonicum*, *S. lanceolatum* and *S. macgregorii*, individual flowers typically open in the morning of one day and close by the afternoon of the next. In *S. album* and *S. yasi*, flowers can stay open for several days and do not close before forming fruit or falling off.
- **Fruit** – Fruit is firm and green when young, red when ripening, and purplish black when mature. Each fruit contains a single seed covered with a juicy flesh and has a scar on the top from the tepals.
- **Seed** – Seed is covered by a hard (woody) testa and contains a white-coloured kernel that can be sticky to the touch. Seeds range from about 9 to 15 mm in diameter. The outer surface is smooth or slightly textured, and light brown.
  The seed shape of the different species is variable. While. *S. album* has a near-spherical seed, *S. yasi* has an ovate seed with a sharp point at one end. Seeds of *S. austrocaledonicum* from the southern islands are generally spherical; seeds from the northern islands are slightly elongated.
- **Wood** – The inner heartwood colour varies from yellow to red or reddish brown, and the outer sapwood is pale yellow to white. Heartwood is rich in oils that are highly aromatic and commercially valuable.

Table 2.1 Comparison of different growth habits and features of *Santalum* species

	Santalum album	*Santalum austro-caledonicum*	*Santalum lanceolatum*	*Santalum macgregorii*	*Santalum yasi*
Habit					
Bark					
Leaves					

	Santalum album	*Santalum austro-caledonicum*	*Santalum lanceolatum*	*Santalum macgregorii*	*Santalum yasi*
Flowers					
Fruit					
Seeds					

3 Nursery

3.1 Seedling production

There are various ways that growers can produce plants for establishing plantations:

1. growing seedlings in a nursery
2. transplanting seedlings from one location to another (wildings)
3. planting seeds in the ground (direct seeding)
4. taking cuttings.

Of these, growing seedlings in a nursery is probably the most common and it is our main focus in this guide. In future, this method may become preferable to transplanting wildings because programs to produce genetically improved sandalwood are underway for the main sandalwood species discussed here. Wildings may not perform as well as seedlings grown from improved seed. You should ask your local sandalwood extension officer or government agriculture / forestry staff whether improved seed or seedlings are available. Growing cuttings is challenging, particularly for inexperienced growers with a basic nursery set-up. Direct seeding can work well but has issues with achieving good germination, browsing by pests (e.g. rats), satisfying the need for intensive weeding, and achieving consistent spacing.

A very common method for establishing new sandalwood plants is to sow seeds in a germination medium and then transplant and raise seedlings in soil-filled polybags. The seedlings are typically grown with a pot host in a plant nursery (Figure 3.1) and then transplanted to the field during the wet season (preferably the early wet season).

Figure 3.1 (photo on facing page) Production nursery, Timor-Leste

Photo: Luis Almeida

3.2 Seed collection and storage

Collecting and preparing seeds

1. Pick

Pick ripe fruit from the tree and collect fruit that has recently fallen to the ground. Ripe fruit are soft, shiny and purple to black. Immature fruit are hard, dull and green. Do not collect seeds from green fruit because they will not be viable. Any fruits that show some reddish colouration are fine to collect, but are harder to process if slightly immature.

2. Soak

Soak the ripe fruit in a bucket of water overnight (about 12 hours) to loosen the flesh.

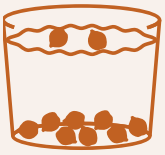
3. Clean

Rub the soaked fruit between your palms to remove the flesh from the seed. Rinse the seed in clean water to remove any impurities.

Flesh

Seed

4. Float



Place the seeds in a bucket of water. Discard seeds that float, since most of these will not be viable. Non-viable seeds break easily when pressed between the thumb and forefinger and have a small kernel that is shrunken away from the shell. Viable seeds have a kernel that fills the shell and sinks in water.

Collect the seeds that sink, because these are viable.

5. Dry

Dry the cleaned seeds on a flat surface in a warm, dry area, but not in full sun because this can overheat and kill the seeds.

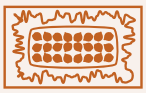
6. Store

Store dried seeds in a clean calico or paper bag, in a cool, dry place away from rats. Seeds stored like this can remain viable for up to 6 months, but should be sold or used as soon as possible.

Dried seeds stored in a sealed container in a refrigerator (2–4 °C) remain viable for more than 1 year.

Seeds stored in plastic bags will sweat and rot if not dried properly prior to storage. In Timor-Leste, growers market and store their dry seed in a plastic bottle, perforated with many holes for ventilation, for up to 3 months.

7. Transport



Keep seeds cool and dry during transport. If sending seeds as a parcel, place the calico bag in a box and pack it with scrunched paper so that the seeds do not become too hot during transit.

Figure 3.2 Method of collecting and preparing seeds for storage and transport

It is important to use good-quality seeds because they produce strong, healthy seedlings. Use the basic methods of seed preparation outlined in Figure 3.2.

Seed cleaning is an important exercise, particularly if the seeds are going to be stored for any length of time (Figure 3.3). Storage life of seed is shortened if it retains some of the flesh, because the flesh and its contained sugar provides an energy source for microorganisms such as mould and other fungi. Particular attention must also be paid to properly drying the seeds, which is also important for storage. When moisture builds up during storage this can promote unwanted germination and/or the growth of mould and fungi, which severely reduces seed viability (Figure 3.4). In Timor-Leste, dry seed is sometimes sold and stored for short periods, up to 3 months, in a plastic bottle with many holes for ventilation (Figure 3.5).

Figure 3.3 Increasingly cleaner seed from left to right

Figure 3.4 (above) Poorly stored seed creates the conditions for fungal growth, which will result in rapid loss of seed viability

Figure 3.5 (right) Dry seed stored in a plastic bottle with holes for ventilation

Photo: Luis Almeida

3.3 Germination

Seeds germinate best when they are sown in a free-draining medium such as a 2:1 mix of river sand and soil (Figure 3.6). Composted sawdust is also a very good germination medium.

Figure 3.6 Germinating seeds (top) and seedlings ready for transplanting to polybags (bottom)

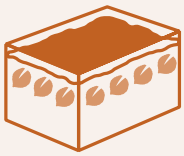
Viable sandalwood seed can typically take several months for complete germination of all the seed in a seedlot. This is caused by variable levels of seed dormancy between individual seeds. This can be an advantage where there is only one person to manage operations because there will only be small numbers of seedlings to be handled, at one time, for each task (e.g. potting, sorting, hardening). However, there are disadvantages such as the substantial variation in seedling size in the nursery, the need for close attention to seedling sorting (based on size), and variable shade management and hardening between groups of seedlings.

Germinating seeds

1. Nick

'Nick' the seed shell to expose the kernel. Nicked seed begins to germinate after 2 weeks, whereas seeds that are not nicked may take 6 weeks to germinate.

2. Sow

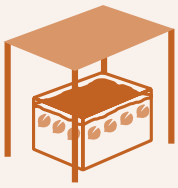


Sow seeds in a seedling tray or pot, just (5–10 mm) below the surface of the medium so that the seeds do not touch each other.

3. Water

Keep the medium moist but not wet. During the wet season, trays may need to be brought out of the rain.

4. Protect



Protect germinating seedlings from full sun and predation by rats and birds.

Figure 3.7 Method of germinating seeds

There are two main methods used to promote simultaneous germination:

1. The use of nicking the seed coat (as described in Figure 3.7) for low numbers of seed.
2. Treatment with gibberellic acid for high numbers of seed. Sandalwood seed can be soaked overnight in a solution of gibberellic acid at a rate of 0.1 to 0.25 g/L active ingredient (100 to 250 ppm). In some trials, longer periods of soaking, up to 48 hours, in a stronger solution (500 ppm) have produced better results, but longer soak times require the seed to be agitated/stirred regularly to oxygenate the solution and avoid seed damage. If available, you can also use a fish tank aerator instead of manually agitating the solution.

Variation in the capacity for seed storage has been noted in sandalwood (e.g. *S. austrocaledonicum* from the Loyalty Islands has been found to store poorly whereas other *S. austrocaledonicum* provenances can be stored as described in Figure 3.2). As a rule, *Santalum* seed is best sown fresh, as medium-term storage is risky and can result in loss of viability.

3.4 Preparing a medium

The quality of sandalwood seedlings is heavily influenced by the quality of the growing medium and the method of transferring seedlings from the germination tray to a polybag (potting up). The importance of these steps should not be underestimated and diligence in following good practice in the nursery will be evident by vigorous growth in the field for many years to come.

3.4.1 Components of a growing medium

A good potting medium needs to contain all the necessary properties for growth in a small volume. Consequently, a potting medium needs to be slightly different from a garden soil (Figure 3.8). The three main components necessary for seedling growth are:

1. good-quality loamy topsoil
   - supplies essential nutrients for seedling growth
   - influences water-holding capacity
2. drainage particles
   - comes from larger aggregates (grains), typically sand
   - allows the medium to drain after rain and watering
   - increases the air in the medium, allowing roots to breathe and not be waterlogged
3. organic matter
   - comes from **well-composted** plant material – coconut husks, rice hulls, garden refuse, cocoa pods, coffee parchment, sawdust, woodchips, etc.
   - improves water-holding capacity
   - contains healthy microorganisms (to prevent soil-borne diseases)
   - improves nutrient retention.

Soils for potting media

Heavy clay soil should be avoided for potting media.

Light clay can be used for potting media if sand and organic matter are added.

Loamy soil can be used without adding sand but with added organic matter.

Figure 3.8 Use of different soils for potting media

Sandalwood seedlings perform well in a free-draining mix composed of:

- 2 parts loamy topsoil (nutrient)
- 1 part sand (drainage particles)
- 1 part coconut husk (organic matter).

3.4.2 Sand

Sand can be sourced from clean, freshwater streams. Sand is an important component to promote drainage of the potting medium.

Sand can be classed by its grain size:

- fine (small grains)
- medium (moderate grains)
- coarse (large grains).

Sand from coastal beaches (i.e. salt water) should be avoided. If it is your only source of sand, then it can be used provided it is thoroughly 'washed' in fresh water before use.

3.4.3 Sterilising soil and sand

Topsoil and sand can contain pests and diseases, particularly when the medium is not free draining. If possible, collect from sources known to be free of disease. If unsure, the topsoil and sand need to be heat sterilised to kill pests and disease (and weed seeds). Sterilisation can take place in half steel drums over a low-intensity fire (Figure 3.9). The soil and sand need to be turned regularly for even heat distribution for a period of 1 hour. Soil can also be sandwiched in black plastic and left in the sun (solarised) to achieve sterilisation (see Section 3.8.1).

Figure 3.9 Sterilisation of soil and sand in half steel drums

Photo: David Spencer

3.4.4 Organic matter

All organic matter needs to be composted before use. Composting breaks down fresh organic matter to release its nutrients and improve its structure. Composting involves piling and turning organic material and waiting (weeks to months) for it to break down. Suitable organics include sawdust, cocoa pods, coconut husks, rice hulls, coffee parchment, peanut shells, grass clippings, plant leaves, vegetable waste, animal manure, etc. Old coconut husks can be grated and used immediately, and don't need to be composted first (Figure 3.10).

Figure 3.10 Old coconut husks can be grated and used immediately

3.4.5 Mixing and ratio

The different components of the soil medium must be well mixed prior to use. Ratios of soil, sand and organic matter should be varied to ensure a good-quality, free-draining mix, according to the properties of the soil and sand (Figure 3.11).

Mixing and ratio adjustment

Soil, sand and organic matter must be mixed well prior to use. Mixing ratios can be adjusted according to the properties of the soil and sand.

- If heavier soil is used, then add more sand.
- If the sand is coarse, then less of it may be added.
- If the soil is already sandy, then there is no need to add sand, but increase organic matter additions.

Figure 3.11 Mixing ratios of soil, sand and organic matter

In Timor-Leste, where good-quality topsoil is available, they use this rather than make a mix. When using topsoil, it is critical that it is 'good quality', has the properties described above and is sterilised.

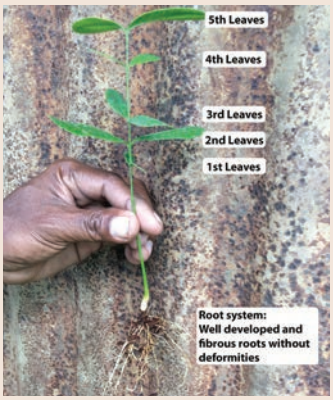
3.5 Growing seedlings

Seedlings are ready to be transplanted to polybags once they develop two true leaves (Figure 3.12).

Growing seedlings

Sandalwood seedlings are ready to transplant from germination trays into pots when they have reached the stage with 2–5 sets of leaves. In shallow germination trays (50 mm), the seedlings will need to be transplanted to polybags at or before the third leaf stage, because later than this the roots will have deformed at the bottom of the tray. In deeper germination trays (>50 mm), seedlings up to the fifth leaf stage can be readily transplanted without damage to the roots.

In some nursery operations, all seedlings within a germination tray are potted when most seedlings meet the above criteria. This means that some seedlings may have only 1–2 leaves. It is important that seedlings are sorted according to size after potting. Smaller seedlings will need a longer time under 50% shade (as described below).



Seedlings that are left in the germination tray too long will have deformed root systems (red circles) and low nutrients/vigour. These seedlings will not typically develop into strong plants and are best culled prior to potting up. For sandalwood, these seedlings will almost never produce a commercial tree and will not make the farmer any money.

Some seedlings in the germination tray will be of low vigour and these should be culled prior to potting up. The red circles in the image highlight those low-vigour seedlings that should have been discarded at the time of potting up. For sandalwood, these seedlings will almost never produce a commercial tree and will not make the farmer any money.

Lift seedlings from underneath the roots using a small stick until the roots are free from the sowing medium. Care should be taken not to break or damage the root system.

Fill polybag with growing medium until about two-thirds to three-quarters full. The remaining space at the top of the polybag will allow the seedling to be planted. Make a small indentation in the potting medium with a finger to accommodate any longer roots on the seedling.

Place the sandalwood seedling into the top part of the polybag. It is critical that the root system is not deformed in any way. The most common problem is the bending of the primary roots upward or around the stem, resulting in a seedling that becomes 'j-rooted' or 'girdled' respectively. Seedlings with these deformities will not perform well (or make money) in the nursery or after outplanting in the field.	
Fill the remaining space in the polybag with the potting medium until the sandalwood seedling roots are covered, and the surface of the medium aligns with the root collar (junction between roots and shoots).	
Centre the sandalwood seedling in the polybag and lightly press the potting medium down with the finger. Alternatively, the polybag may be picked up and its base 'tapped lightly' on the palm of the other hand to settle the potting medium. This will ensure that there are not too many air gaps in the potting medium.	
Any remaining space should be filled with the potting medium. Note this seedling only has two leaf pairs and will therefore need to be grouped with other small seedlings and allowed to grow under 50% shade for 3–5 weeks (see Section 3.5.2 on hardening seedlings).	
The potting medium is lightly pressed again with your fingers to firm in around the sandalwood seedling and eliminate any large airspaces.	
The sandalwood seedling should be well watered and set out in the nursery bed under shade (ideally under cover in humid zones). The polybags should be supported so they don't fall over. Ideally the nursery bed should have provision for drainage (such as gravel or fine rock) to allow water to move through the polybag and drain away rather than filling the polybag.	

Figure 3.12 Growing and potting seedlings

3.5.1 Planting the pot host

The pot host *Alternanthera* (see Section 6.4) should be planted as stem cuttings after the sandalwood is at the 4–6 leaf stage. Figure 3.13 shows the beneficial effect of timely planting of the pot host. If the pot host is planted too early, it will grow quickly and overtop the young seedling, leading to stunted growth and death of the sandalwood. If the pot host is planted too late, the sandalwood may grow slowly.

Figure 3.13 Sandalwood seedlings showing the effect of planting a pot host on growth rate. On the left are seedlings with no pot host, while on the right a pot host has been used

3.5.2 Hardening seedlings

Once the seedlings reach the 10–12 leaf stage, they need to be progressively moved to areas of higher light levels to 'harden' or acclimatise them to conditions in the field. They should have 50% shade in the first month, then 25% shade for another month, and then one to several months in full sun before they are planted in the field. Seedlings transplanted directly from the shade to a full-sun position in the field typically have poor survival.

A seedling is ready to plant in the field when it shows at least two of the following signs (Figure 3.14):

- The seedling is actively growing, with new shoots, and has deep green leaves.
- The bottom of the stem is slightly woody (i.e. changes from green to brown).
- The seedling is about 20–30 cm high.
- The seedling has small branches developing at the junction of the leaf and main stem.
- Some small roots are visible through the holes in the bottom of the polybag.

Figure 3.14 Seedling ready for planting in the field

3.6 Raising wildings

Seedlings germinated naturally under an existing sandalwood tree can be collected and transplanted to the nursery or another location (such seedlings are called wildings) (Figure 3.15). This is a simple method of establishing new stands of sandalwood:

- Select sandalwood trees that are fruiting or are otherwise known to fruit heavily.
- Clean all undergrowth from beneath the canopy of the selected sandalwood trees.
- Loosen the soil in the cleared area by shallow digging or cultivating only the top 5 cm of soil prior to fruit fall. Wildings begin to germinate in the cultivated area about 1–2 months after fruits have fallen to the ground.
- Water the cultivated area during dry periods, if possible, or after the first seedlings break through the soil.
- Keep the cultivated area free from weed regrowth.
- Remove seedlings when they are approximately 10 cm high by gently digging the seedling from underneath, trying not to disturb or break too many roots.
- Transplant seedlings immediately to polybags or another location, such as the sandalwood plantation.
- Water seedlings well after transplanting.

Figure 3.15 Wilding being carefully lifted from the ground (left) and wilding seedling ready for transplanting (right)

3.7 Nursery construction

A plant nursery is any place that grows seedlings for planting at another site. Nurseries can take many different forms, but good-quality sandalwood seedlings can be produced in basic nurseries, provided that it is in a sheltered position with ample natural light and accessible fresh water, and if plants are grown in a free-draining, nutrient-rich medium (Figure 3.16).

Figure 3.16 Production sandalwood nursery in Timor-Leste (left) and smallholder sandalwood nursery in Papua New Guinea (right)

The images in Figure 3.17 show examples of different sandalwood nurseries:

1. a greenhouse constructed from timber and plastic film, which is useful in cooler regions to keep the seedlings warm
2. a seedling bed with coconut leaves on a timber frame for shade
3. a seedling bed with managed *Gliricidia* trees for shade
4. a raised, sawn timber seedling bench with 50% shade cloth
5. a seedling bed with no shade, used for hardening seedlings before planting
6. a seedling bed with 20% shade cloth on a timber frame
7. seedlings in 1 kg rice bags on a raised timber bench with natural shade.


1


2


3


4


5


6


7

Figure 3.17 Examples of different sandalwood nurseries

3.8 Nursery management

In addition to appropriately managing the pot host and progressively hardening the seedlings, attention to hygiene, preparation of growing medium, drainage, and appropriate watering and fertilisation regimes will provide good results.

3.8.1 Hygiene

Good hygiene in the nursery can ensure the development of healthy seedlings. The key is to keep the nursery free from plant debris (e.g. prunings, fallen leaves, dead seedlings), which will limit the potential for disease to develop. Many unexplained problems in the nursery can be attributed to diseases caused by unseen fungi and bacteria. Sterilising the growing medium can help to prevent diseases being brought in by the soil (see Section 3.4.3). The medium can be sterilised by heating it over a fire in a steel drum or sandwiching it in black plastic and leaving it in the sun for a day (Figure 3.18).

Figure 3.18 Media sterilisation using black plastic and the heat of the sun (left) and by heating over a fire in a steel drum (right)

Photo: (left) Ken Robson

3.8.2 Drainage

A poorly draining medium can lead to waterlogging, particularly during the wet season. Waterlogging is the main cause of poor seedling growth and death in the nursery. It is therefore important that the potting medium is free draining and polybags are sited on a well-drained site or in raised beds.

3.8.3 Watering

The most critical factor for the health and vitality of nursery seedlings is the quality and availability of water in the polybag (potting media).

Seedlings will require watering on a regular basis.

The frequency of watering will be influenced by:

- prevailing weather conditions (heat and rainfall)
- level of sunlight (shade provision)
- size of the seedling.

Seedlings in full sun during the dry season are best watered once or twice per day, but during the wet season shelter from the rain may be necessary.

3.8.4 Fertiliser

Improved growth can be achieved by using fertile soil. A friable, rich topsoil high in organic matter will have more available nutrients than a sandy or heavy clay soil with low organic matter. Additional nutrients can be added to the soil by applying dilute solutions of worm castings, composted organic matter, or commercial liquid and/or slow-release fertiliser.

4 Establishing a plantation

4.1 Site selection

Suitable sites for establishing new sandalwood plantations, appropriate for rapid heartwood development:

- have a slight slope
- have volcanic soil overlying coral limestone
- receive good sunlight (not rainforest)
- have free-draining soil (i.e. that does not hold water for extended periods)
- are free from the fungus *Phellinus noxius* (see Section 8.1)
- have a distinct annual dry season, particularly in the cooler months.

Excellent growth can often be achieved on well-lit edges of existing forest (Figure 4.1) with the above attributes because the roots of diverse host species extend into the surrounding soil. As sandalwood is a high-value species, planting trees around villages or even within urban yards is feasible, though it is important to plant only as many as the surrounding hosts can support (Figure 4.2).

Figure 4.1 *S. yasi* planting in 'Eua, Tonga (left) and *S. yasi* plantation in Tutu, Taveuni, Fiji (right)

Photos: Lex Thomson

Figure 4.2 Sandalwood established in a cropping garden area in Papua New Guinea (left) and mixed kava garden in Vanuatu (right)

4.2 Site preparation

The best sandalwood growth rates occur when sandalwood is established at the same time as a new garden area. A site can be selectively cleared, leaving trees that serve as good hosts (see Chapter 6). It is important to kill stumps completely by burning to ensure that they are not a source of infection with *Phellinus* (see Section 8.1).

Sandalwood seedlings generally establish well when they are planted during the gardening season. The timing of the gardening season varies throughout the Pacific islands, but typically occurs at the start of the rainy season. This timing allows the sandalwood to establish its root system in the soil before the onset of the first dry season. Sandalwood will grow slowly during the first dry season, and in some very dry years may require supplemental watering. Rapid tree growth will occur from the second wet season.

Poor weed control in the first few years of the plantation is the main cause of tree death and plantation failure. Selecting a site with fewer weeds can help to reduce the labour inputs for controlling weeds. Sites that have many vigorous weeds need to be manually weeded every week.

Establishing sandalwood in a new garden area makes controlling the weeds less difficult because the weeds in the garden and sandalwood planting can be controlled at the same time. Better early growth of sandalwood occurs in newly established gardens than in older gardens where soil nutrients have been depleted. Sandalwood also benefits from fertiliser that is applied during the establishment years. As a guide, Nitrophoska® Special (or an equivalent organic fertiliser) may be applied at 25–50 g at 6 months; 50–100 g at 12 months; and 200 g at 24, 36 and 48 months. This fertiliser needs to be evenly distributed around the base of the tree, but **not** touching the stem.

4.3 Planting layout and tree spacing

Correct tree spacing, host ratio and management will help to maximise the growth of the sandalwood trees over their entire rotation (Figure 4.3). The plantation design will be influenced by the host species being used and their growth habits. The choice of host species (see Chapter 6) will be influenced by local availability and adaptability to the intended planting site. Different site-specific species configurations could be used in this style of grid planting, depending on local conditions (i.e. soils, climate, aspect, growing space), host species availability and grower objectives.

A 3 m × 6 m or 4 m × 5 m grid layout should provide sufficient space for all the plants (Figure 4.4). Sandalwood growth can be reduced when it is planted at high densities (i.e. spacing less than 3 m × 4 m). Although good early growth can be achieved at such densities, growth can stagnate after 3–4 years as a result of intense competition between the sandalwood trees for soil moisture, nutrients and light.

Figure 4.3 *S. album* plantation South Coast of Timor-Leste (left) and *S. lanceolatum* Quintis plantation, Queensland, Australia (right)

Photos: (left) Luis Almeida; (right) David Lee

Figure 4.4 Wide spacing in a large-scale commercial planting

At a spacing of 4 m × 5 m, the sandalwood trees are spaced at 4-m intervals along each row with a long-term host every 16 m, and a spacing of 5 m between each row (inter-row). A 5-m inter-row spacing will provide enough space for vehicle access to manage and harvest both the sandalwood trees and commercial host trees. A 5-m inter-row spacing permits the growing of crops between the rows for approximately 3–4 years (Figure 4.5). If crops need to be grown for a longer period, then a wider inter-row spacing of 6–8 m could be considered.

Figure 4.5 Garden plantings of sandalwood with a range of hosts

The 4-m spacing between each sandalwood tree provides space for the planting of intermediate host species between the sandalwood. This guide describes two distinct layouts: (1) **mixed species rows**, and (2) **alternate species rows**. The sandalwood to host ratios can vary depending upon site conditions and the hosts species used. Typically, the ratio of sandalwood to intermediate host (*Sesbania*) is 1:1. For sandalwood to long-term host, the ratio can vary between 1:1 and 2:1. A 1:1 sandalwood to long-term host ratio is recommended where the trees are growing on a site with one or more of the following: (1) infertile and shallow soil, (2) steep slope, and/or (3) long dry season. On more fertile sites with good annual rainfall and a short dry season, an up to 2:1 sandalwood to long-term host ratio may be considered.

4.3.1 Mixed species row plantings

A 'mixed species row' layout can be used to maximise the number of sandalwood trees, while still maintaining good access to host trees planted on site. This layout gives a 13% greater sandalwood stocking (375 trees) compared with an 'alternate species row' layout (333 trees) for a 4 m × 5 m grid. Long-term hosts should be planted every fourth space or 16 m, and rows should be offset so that each sandalwood tree is only 5 or 6 m from a long-term host (Figure 4.6).

4.3.2 Alternate species row plantings

The 'alternate species row' layout is a simpler arrangement, which should make management of both sandalwood and hosts more efficient. In this layout the sandalwood trees and long-term hosts are planted in individual rows, which alternate at a ratio of 2:1 sandalwood to hosts (Figure 4.7). Intermediate hosts species can be planted in every row (between the sandalwood and long-term host trees) depending on the planting objectives. A reduction in the stocking of intermediate hosts may be considered when agricultural crop production needs to be maximised. This can be achieved by either reducing the frequency of intermediate hosts within the rows or confining intermediate hosts to the sandalwood rows only.

The number of intermediate host trees will also depend on the size of the host tree. Pigeon pea (*Cajanus cajan*) has been included in every interspace between the sandalwood trees. Larger intermediate hosts such as coral tree (*Erythrina poeppigiana*), sesbania (*Sesbania grandiflora*) and cassis (*Leucaena leucocephala*) may be spaced more widely – say, every second or third sandalwood tree. In contrast, pinto peanut (*Arachis pintoi*) can be planted across the whole site and, when managed correctly, can fill the entire ground level and support all the sandalwood trees, as well as suppressing weeds.

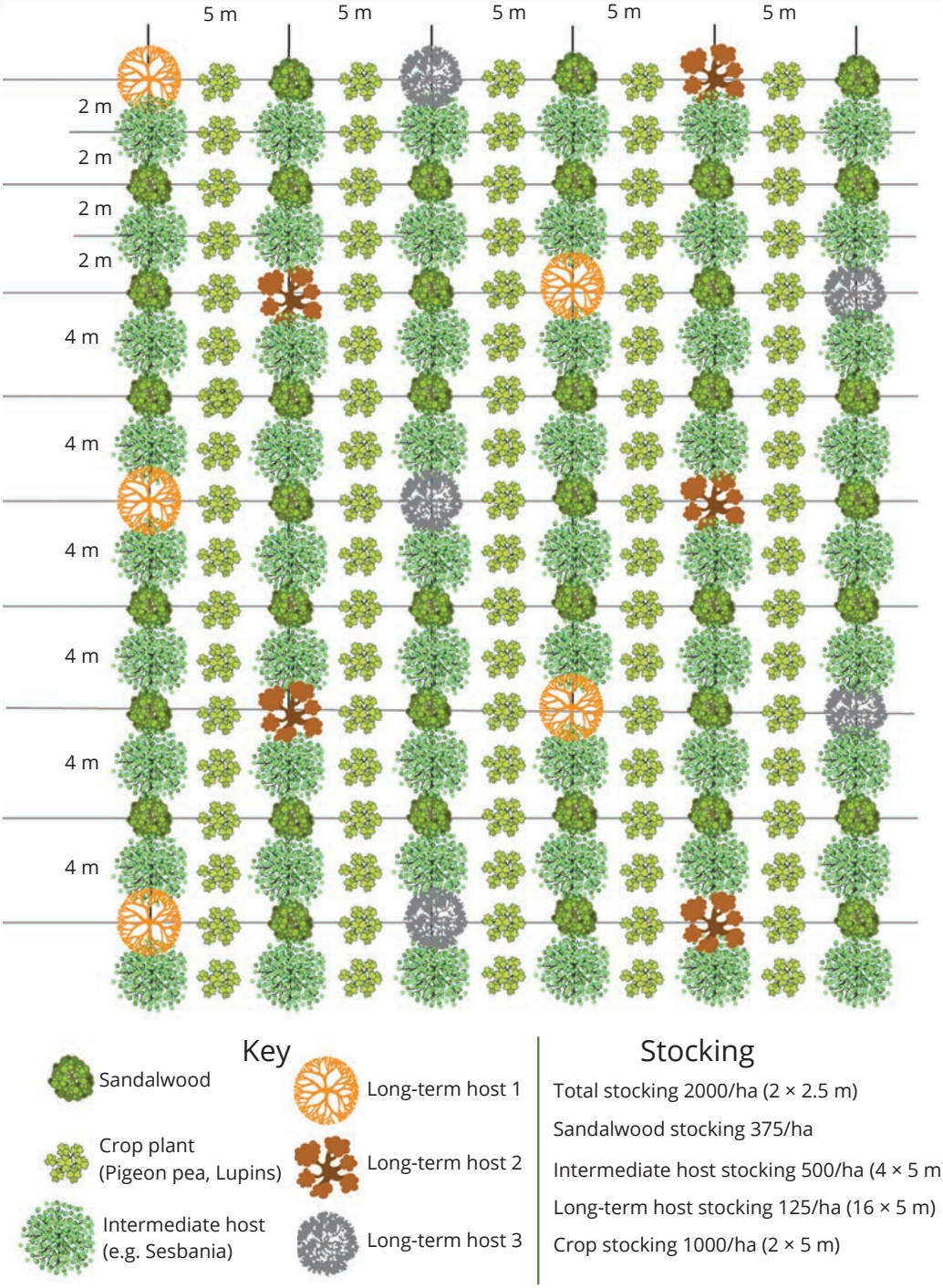
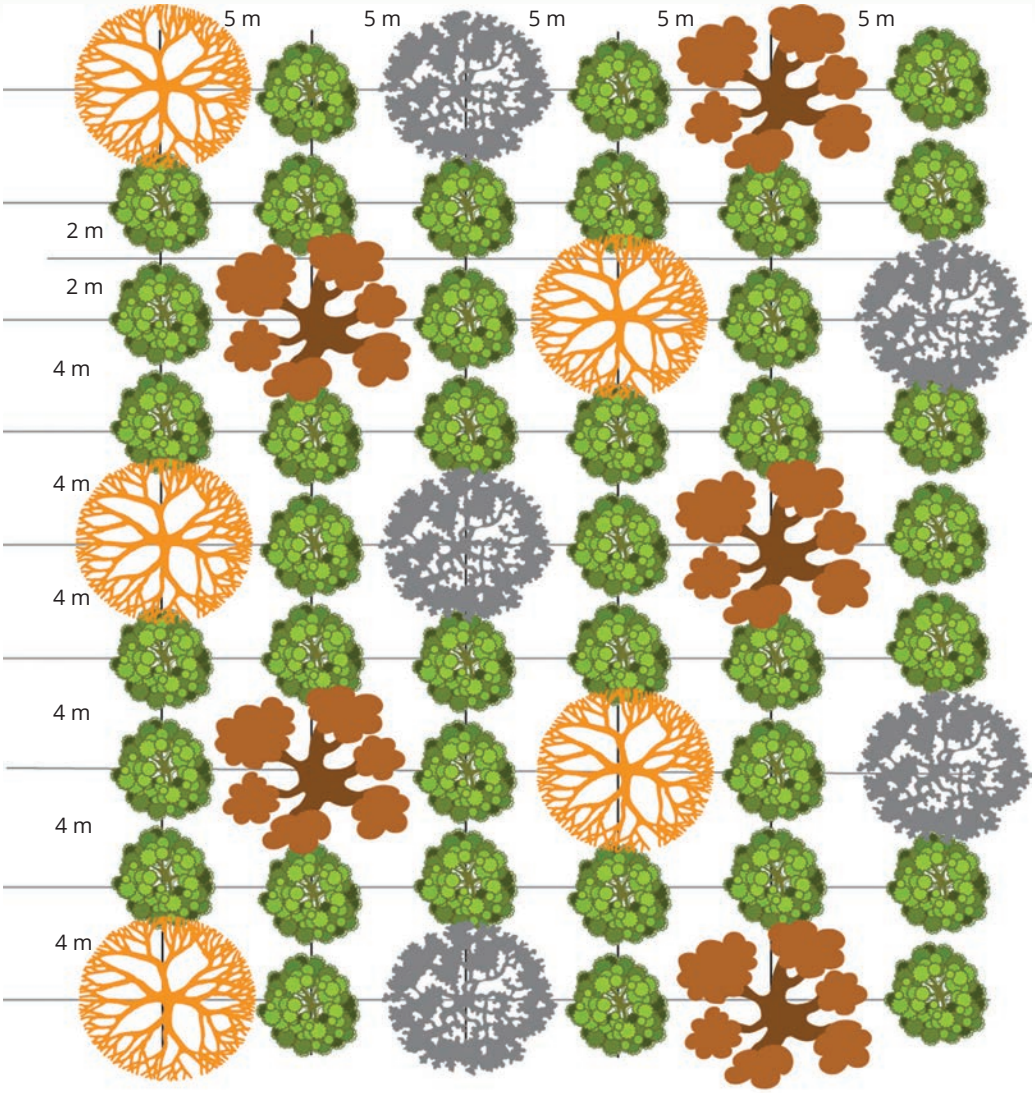


Figure 4.6 An example of a grid layout for a 'mixed species row' sandalwood planting. Representation of the first 5–10 years (left) and 10+ years (right). Persistence of crop plants is 3–4 years and intermediate hosts 5–10 years



Key

Sandalwood

Long-term host 1

Long-term host 2

Long-term host 3

Stocking

Total stocking 2000/ha (2 × 2.5 m)

Sandalwood stocking 375/ha

Long-term host stocking 125/ha (16 × 5 m)

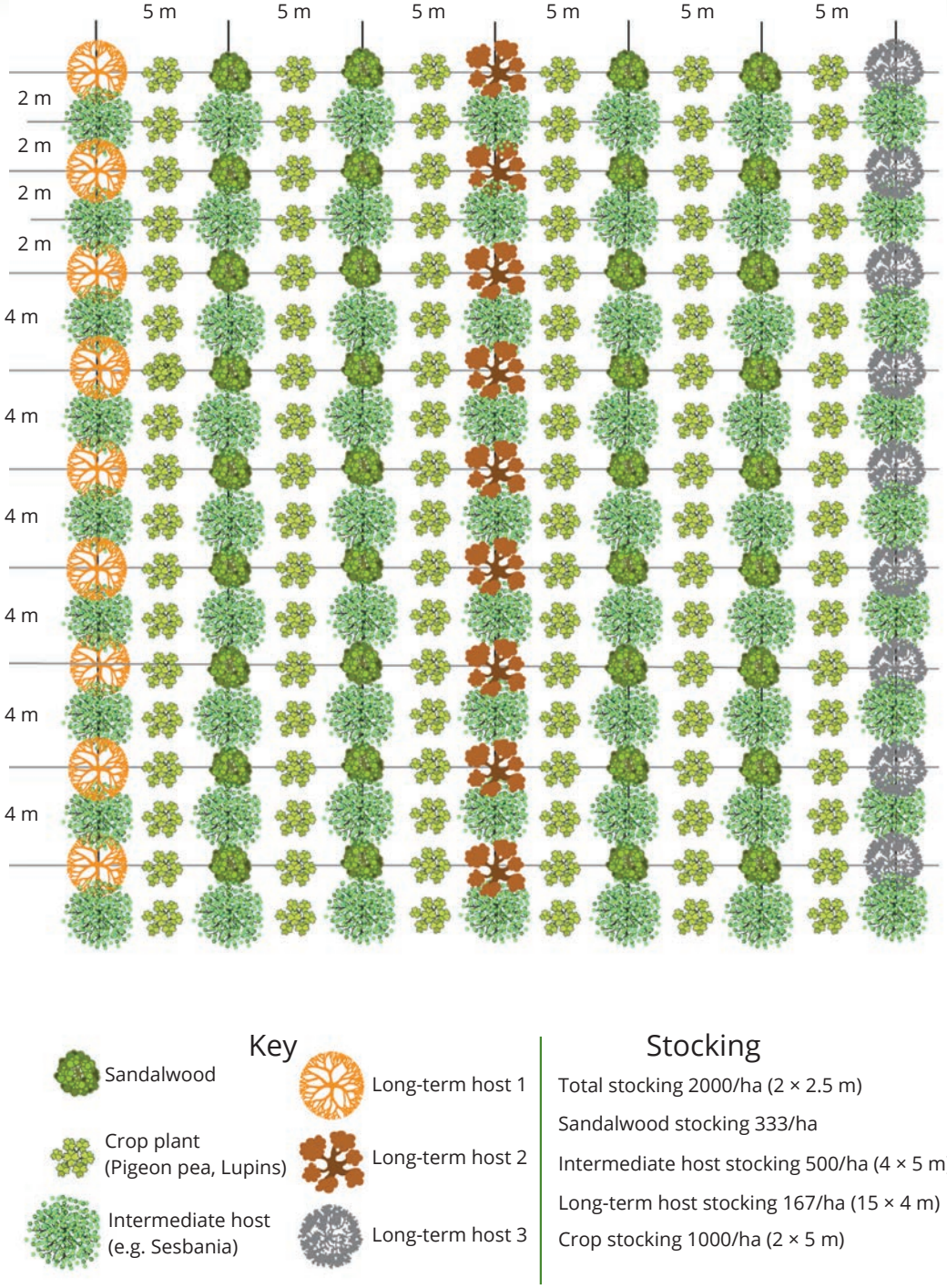
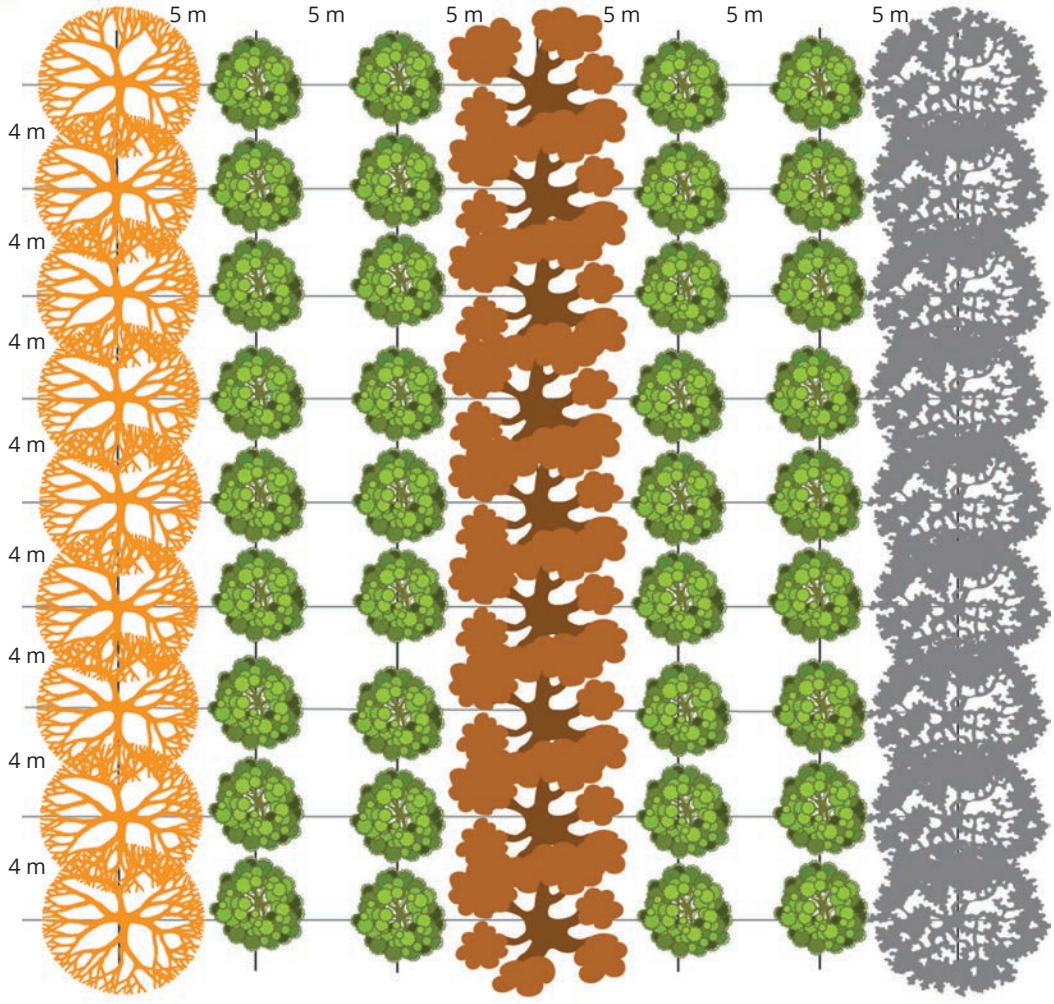


Figure 4.7 An example of a grid layout for an 'alternate species row' sandalwood planting. Representation of the first 5–10 years (left) and 10+ years (right). Persistence of crop plants is 3–4 years and intermediate hosts 5–10 years



Key

Sandalwood

Long-term host 1

Long-term host 2

Long-term host 3

Stocking

Total stocking 500/ha (4 × 5 m)

Sandalwood stocking 333/ha

Long-term host stocking 167/ha (15 × 4 m)

4.4 Direct seeding

Good results can be achieved by sowing sandalwood seeds directly in the soil at the planting site. Although a direct-seeded site requires high maintenance, seedlings managed appropriately can have greater early vigour than those transplanted from the nursery.

To achieve good survival, the area needs to be managed as intensively as a nursery:

- Keep the cultivated area free from weeds.
- Water seedlings frequently during hot, dry conditions (daily watering may be required).
- Provide the seedlings with shade, if necessary (e.g. an adjacent tree or a frame with coconut leaves).
- It may be a good idea to sow several seeds per planting location to make sure one germinates. If more than one germinates, don't be tempted to overstock the site. Dig these seedlings up and use them for another planting or raise them in polybags with growing medium, as described earlier, and sell them.

4.5 Planting seedlings

The planting technique that is used can mean the difference between vigorous early growth and seedling death. It is much better to take the time to plant seedlings properly than to rush this important step (Figure 4.8 and 4.9). Young seedlings enter a period of stress immediately after transplanting, and this stress should be minimised by good planting practices so that seedlings quickly restart leaf and root growth.

Planting seedlings to ensure the best chance of survival

Plant only in soil that has good soil moisture and when the weather is not too hot.

1. Dig hole

Dig a hole that is wider but only slightly deeper than the polybag.

2. Cut polybag

Cut the polybag carefully to minimise disturbance and breakage of the roots. *

3. Remove bag

Pick up the seedling and carefully remove the cut polybag.

4. Plant

Place the seedling in the hole without disturbing the roots.

5. Fill hole

Fill the hole and press the soil in only very slightly with hands. Never stamp the seedling in with feet, as this will break the roots of the seedling.

6. Watering

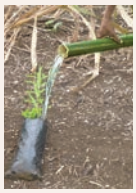
If the soil from the bag breaks apart and/or the roots are disturbed, it is important to water the seedling immediately to reduce the stress of transplanting.

* To reuse the polybag, follow the steps in Figure 4.9.

Figure 4.8 Recommended method for planting seedlings

Planting seedlings and saving the polybag for reuse

1. Wet



Wet the soil in the polybag.

2. Hold

Invert the seedling and hold the top of the soil in the palm of the hand.

3. Remove bag

Gradually remove the bag without disturbing the soil or roots.

Continue steps 4 to 6 in Figure 4.8

Figure 4.9 Method of planting seedlings to save the polybag for reuse

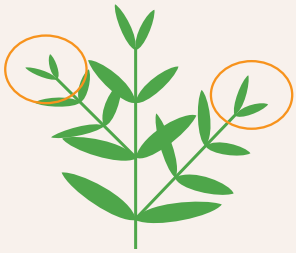
Formative pruning

1. Identify central leader

The central leader is the main, central growing point of the tree.

2. Identify competing leader

A side shoot that may compete with the central leader grows from below the central leader.



3. Remove side shoots

Break off the tips of side shoots by pinching them between fingers and thumb.

4. The pruned sapling

The growing tip of only the central leader remains.

5 Pruning saplings

The carving log, which is the most valuable sandalwood product, is formed in the heartwood of the lower trunk where there are no branches. Through formative pruning in the first 3–4 years of a tree's life, a farmer can promote a single-stemmed trunk and improve the chances of a tree forming a carving log. Heartwood development begins in the roots and butt of the tree and progresses up the main trunk. A fork in the trunk will typically slow the rate of vertical heartwood development up the main stems. Therefore, the volume of heartwood in two large branches is typically less than that in an equivalent-sized main stem.

However, it is important to note that pruning is no longer productive for poorly formed trees that are older than 3–4 years, and at this stage will do more damage than good. In these trees, pruning often stresses the trees and can severely reduce growth.

Without early pruning, growers will be unable to consider extending the rotation for some trees to meet carving log quality.

5.1 Formative pruning

Formative pruning of young saplings is the most effective pruning method because it removes only a very small amount of productive photosynthetic leaf material. This is achieved by 'pinching' off all growing tips that compete with the central leader (Figure 5.1).

Regular formative pruning means that there is little (or no) need for heavier pruning with secateurs, loppers or a bush knife (machete).

5.2 Form pruning

Often a tree is not pruned for a year or more and needs to be pruned to bring it back to being a tree with a single trunk (Figure 5.2). Form pruning is distinct from formative pruning in that it requires a sharp pruning saw or secateurs. It is important to make a clean pruning cut just above the 'shoulder/collar' of the side branch to leave the smallest possible wound and allow rapid healing of the pruning wound. Do not leave long branch stubs as they may lead to introduction of heartwood rot into the main stem. This method is effective for young saplings up to 4 years old, but less effective for older trees. Older trees should be left unpruned because pruning can introduce heartwood rot or disease.

Figure 5.1 (left) Guidelines for formative pruning

Form pruning

1. Identify forked sapling

Select saplings with a forked trunk.

2. Remove fork

Remove the fork by cutting the unwanted branch with a sharp knife or sacateurs.

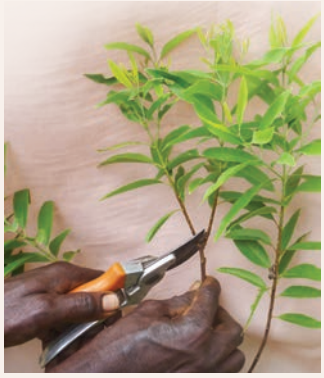
Figure 5.2 Guidelines for form pruning

3. Identify competing leader

A competing leader is a branch growing vertically towards the top of the tree.

4. Remove competing leader

Remove the competing leader with secateurs.



5. The pruned tree

5.3 Canopy reduction pruning

In areas of high intensity cyclones there can be a benefit in pruning large/heavy canopies to allow strong winds to pass through and reduce the chance of trees becoming windblown. The aim of this pruning intervention is to reduce the height and spread of the crown while also removing crossing/overlapping branches and any deadwood. This pruning is best achieved using a long-handled pole pruner and ladder, and attention must be given to safety when working at height.

Canopy reduction pruning is done at the start of cyclone season (late November), and if there is sufficient warning and a high likelihood that a high-intensity cyclone is to make a close pass, then some additional canopy reduction might be done (but this is only really possible for a smallholder with a limited number of sandalwood, i.e. fewer than 50–100 trees).

5.4 Remedial pruning

Pruning back to a single leader (singling) is often necessary when the central growing tip is damaged, possibly by wind, a bird or a falling branch. This can be done immediately after growth recommences.

Figure 5.3 demonstrates multiple competing leaders (yellow circles) growing mainly from a single branch after the original leader was damaged by a falling branch (orange circle). Competing leaders are removed by secateurs, leaving a clear leader (blue circle). Some stems may need additional pruning later if they begin to compete with the selected central leader.

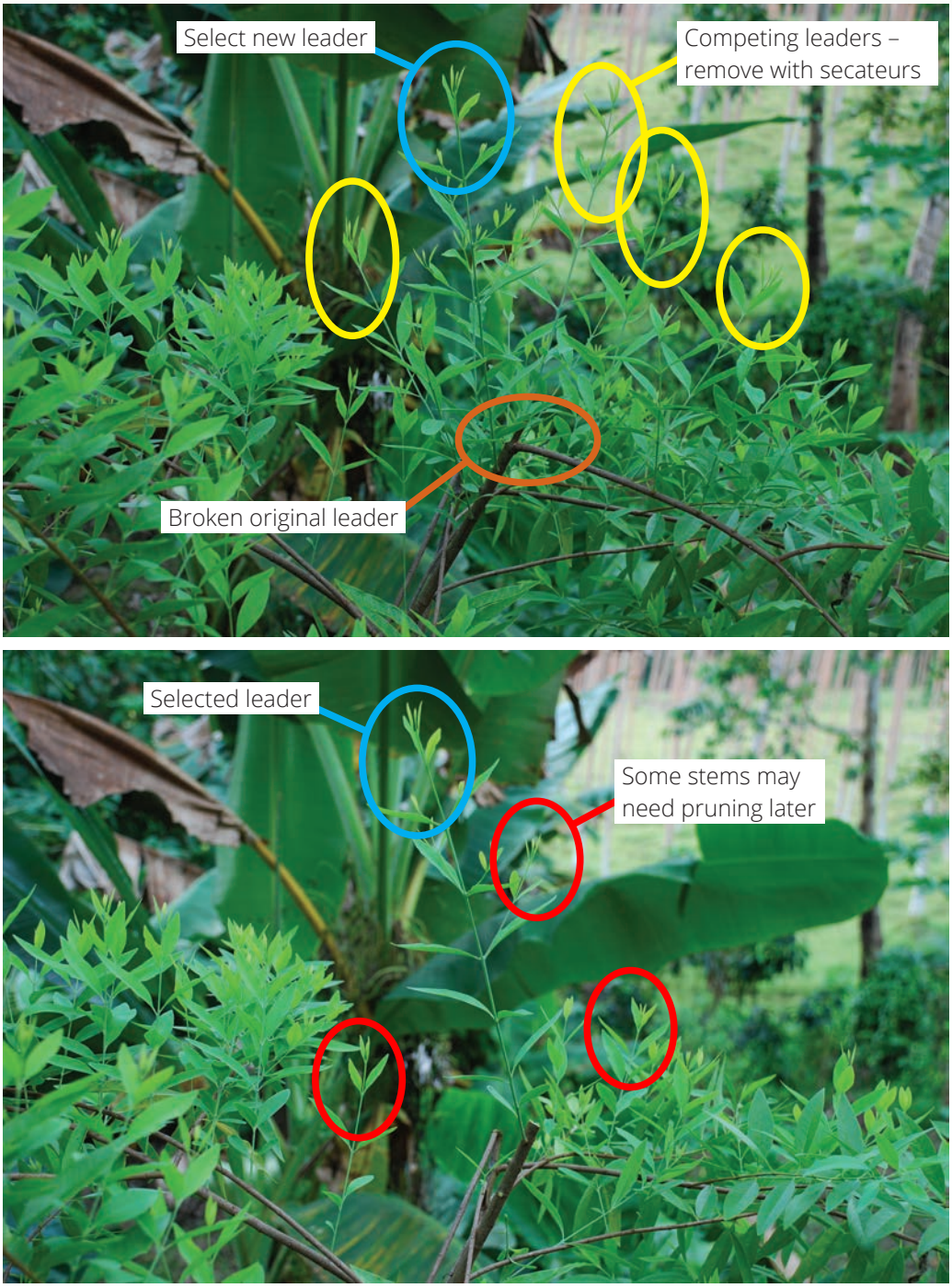


Figure 5.3 Guidelines for remedial pruning

5.5 Correctly pruned

A sandalwood tree that has been corre
pruned has (Figure 5.4 top):

- one trunk and a single leader at the t
- a canopy of leaves that extends approximately two-thirds of the height of the tree, providing a good area for photosynthesis, which will ensure a vigorous tree
- a canopy that tapers towards the top providing good balance (a low centre of gravity).

5.6 Incorrectly pruned

An example of a sandalwood tree that has been incorrectly pruned has (Figure 5.4 below):

- an inappropriate shape – in this case, a 'lollipop', because too many lower branches have been removed
- a reduced canopy – this reduces photosynthetic capacity and hence th vigour of the tree
- many branches at the top, which make the tree top heavy and unstable particularly in the wind.

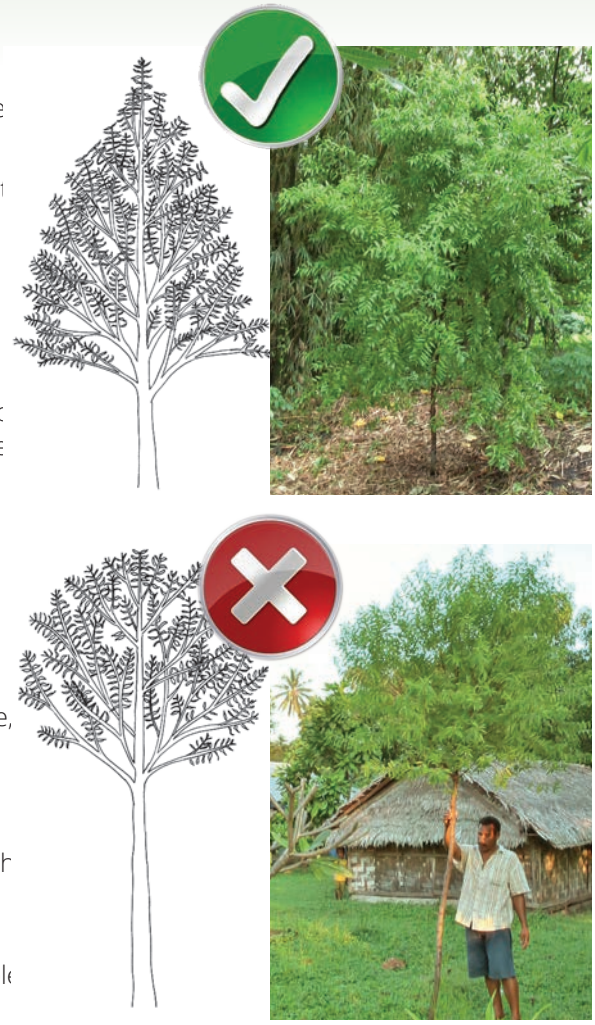


Figure 5.4 Examples of correct (top) and incorrect (below) pruning

6 Hosts

6.1 Host silviculture

Host species silviculture is a critical aspect to a successful sandalwood plantation. The growth and size characteristics of the host species will influence their optimal spacing (i.e. the distance between the sandalwood tree and the host species), arrangement and management.

The ratio, spacing and arrangement of hosts and sandalwood aims to:

- promote haustorial connections between hosts and all sandalwood
- maximise the number of different host species available to the sandalwood
- provide protection from exposure to sun/heat
- allow room for sandalwood to extract soil resources (water and nutrients)
- permit sandalwood to intercept direct sun for part of the day.

While hosts are essential for good sandalwood growth, some species can outcompete the sandalwood trees if they are planted at higher densities than described (Section 4.3) or if their growth is left unchecked. Ongoing plantation monitoring and adaptive management (i.e. silviculture) is therefore essential to balance the benefits of the host species with their potential to induce competitive stresses on the sandalwood trees.

Ensuring a good selection of hosts including short-term, medium-term and long-term hosts is critical to the good development of sandalwood (Figure 6.1). It is important that the development of the hosts matches that of the sandalwood. If the host is too slow to develop, then the sandalwood will be slow to develop, and may effectively 'overload' the host causing stress and even death of both the host and the sandalwood. Hosts that develop too quickly can overtop the sandalwood and cause it to develop poorly.

Host silviculture is an important but often overlooked aspect of sandalwood production. Hosts should be pruned back if they appear to be outgrowing the sandalwood. Removal of parts of the upper crown can help in this regard. If it appears that the existing hosts are struggling, it may be possible to introduce new hosts, though this is never as satisfactory as planting an adequate number of hosts at establishment (or in the 12 months before field planting of the sandalwood). The best hosts for later infill planting are pigeon pea through direct seeding, *Alternanthera dentata* and pinto peanut through stem cuttings, paper mulberry (*Broussonetia papyrifera*) through branch cuttings and some larger permanent hosts, especially those that are capable of root suckering such as *Acacia leptocarpa* and some *Casuarina* spp.

Figure 6.1 (photos on facing page) Well-spaced (5 m × 5 m) alternating rows of host (*Cassia fistula*) and sandalwood (*S. macgregorii*) in Papua New Guinea (above). Sandalwood (*S. austrocaledonicum*) planted with *Calliandra* alternated within each row in Vanuatu (below)

6.2 Host types

The plants with which sandalwood forms haustoria (see Section 2.2) are called hosts. Sandalwood forms haustoria with many different species, but some species (particularly legumes) support greater growth and vigour in the sandalwood. There are three main host types used for cultivating sandalwood:

1. **Pot host** – a herbaceous low-growing plant that is easy to propagate, which is planted in the polybag after the seedling reaches the 4–6 leaf stage. The size of the pot host needs to be maintained by pruning to avoid it outcompeting the sandalwood and typically persists in the field for the first few months after planting.
2. **Intermediate host** – a small tree or large shrub, typically a short-lived (about 5 years), nitrogen-fixing legume that is planted close (1–2 m) to the sandalwood. The intermediate host supports rapid early growth of the sandalwood. The size of the intermediate host will influence the distance it is planted from the sandalwood, and it may need to be pruned to ensure it does not outcompete the sandalwood.
3. **Long-term host** – a large tree that provides a host for the entire sandalwood rotation. It is planted at a lower density in the plantation and at least 3 m from the closest sandalwood tree (from 4 to 8 m to the closest sandalwood tree). Like the intermediate hosts, wider spacing is required for larger trees.

6.3 Preferred hosts for each species

Different sandalwood hosts are used in different geographic areas, with the various species of sandalwood, to promote optimum growth and vigour of sandalwood plantings (Table 6.1).

Table 6.1 Sandalwood species and their preferred hosts in different countries

	Santalum album	*Santalum austro-caledonicum*	*Santalum lanceolatum*	*Santalum macgregorii*	*Santalum yasi*	Weed risk
Alternanthera nana	Timor-Leste	Vanuatu	Aust	PNG	Fiji & Tonga	
Alternanthera dentata					Fiji	
Sims' wattle *Acacia simsii*			Aust	PNG		
Pinto peanut *Arachis pintoi*		Vanuatu	Aust		Fiji & Tonga	
Paper mulberry/hiapo *Broussonetia papyrifera*					Tonga	
Pigeon pea *Cajanus cajan*	Timor-Leste	Vanuatu		PNG	Fiji & Tonga	
Calliandra calothyrsus & C. suranamensis	Timor-Leste		Aust	PNG	Fiji & Tonga	
Coral tree *Erythrina poeppigiana*		Vanuatu (intermediate to long-term host)				
Sesbania grandiflora	Timor-Leste	Vanuatu		PNG		
Egyptian pea *Sesbania sesban*			Aust	PNG		
Acacia auriculiformis			Aust	PNG		
Acacia crassicarpa			Aust	PNG		
Acacia leptocarpa				PNG	Fiji	
Acacia leucophloea	Timor-Leste					
Qumu *Acacia richii*					Fiji	
Namariu *Acacia spirorbis*		Vanuatu				
White siris *Albizia procera*	Timor-Leste			PNG	Fiji	Weed risk
Pink shower *Cassia javanica*	Timor-Leste			PNG		
Golden rain tree *Cassia fistula*	Timor-Leste			PNG		Weed risk
Beach she-oak/ nokonoko *Casuarina equisetifolia*	Timor-Leste	Vanuatu		PNG	Fiji & Tonga	
Citrus species, esp. *C. maxima, C. reticulata, C. x taitensis*		Vanuatu		PNG	Fiji & Tonga	
Poumuli/namamau *Flueggea flexuosa*	Samoa	Vanuatu			Fiji	
Leucaena leucocephala	Timor-Leste					High weed risk. Used for cattle fodder
Pterocarpus indicus	Timor-Leste	Vanuatu				
Tamarind *Tamarindus indica*	Timor-Leste					

6.4 Pot host

6.4.1 Alternanthera (*Alternanthera nana* and *Alternanthera dentata*)

Figure 6.2 Examples of alternanthera variation (top row) and alternanthera as a pot/initial sandalwood seedling plant host (bottom row)

Alternanthera is routinely used as the first host for sandalwood in the nursery. It is a highly variable ornamental plant (Figure 6.2). Sandalwood growth is more vigorous when alternanthera is planted in the polybag than when seedlings are planted without it. However, the pot host has to be regularly pruned; otherwise, the alternanthera can smother the sandalwood, eventually killing it. In wet conditions, the stem of alternanthera can fasten onto the stem of the sandalwood, causing it to rot and die.

6.5 Intermediate hosts

6.5.1 Sims' wattle (*Acacia simsii*)

Figure 6.3 *A. simsii* habit (left), flowers (top right) and fruit (bottom right)

This acacia, which is native to Australia and Papua New Guinea, is a small-sized (2–4 m) and relatively short-lived leguminous host shrub (Figure 6.3). It is propagated by seed and the very hard seed coat needs to be scarified or softened by pouring hot (70–80 °C) water over the seeds and soaking them for 24 hours. It should be spaced a minimum of 1.5 m from each sandalwood tree. Form pruning or thinning can be implemented as required.

6.5.2 Pinto peanut (*Arachis pintoi*)

Figure 6.4 *A. pintoi* flowers and foliage (left) and growing as a host for *S. album* (right)

Pinto peanut is a prostrate perennial shrub that is native to Brazil (Figure 6.4). It can reach 20–50 cm in height and forms a dense groundcover. It is a very suitable intermediate host because it is a nitrogen-fixing legume, does not compete with sandalwood for light and effectively suppresses weed growth. The plant propagates naturally by creeping stems (stolons), which can be easily removed to establish new plants. While it can take time and patience to establish on site, it is adapted to a wide range of soils, from sands to clays, preferably well drained.

6.5.3 Paper mulberry (*Broussonetia papyrifera*)

Figure 6.5 *B. papyrifera*: female flowers (left), male flowering catkins (centre) and fruit (right)

Photos: (left) Daderot, CC0 1.0; (centre) Didier Descouens, Fronton, France. 19 April 2014, CC BY-SA 4.0; (right) Didier Descouens, Clermont-le-Fort, France. 7 August 2019, CC BY-SA 4.0.

Figure 6.6 Paper mulberry (foreground) planted as host for *S. yasi* (tall tree in back) on ʻEua, Tonga

Photo: Lex Thomson

Paper mulberry is a small tree native to Asia and a Lapita/Polynesian introduction into the Pacific islands. It is fast growing, typically reaching 6–10 m with similar spread. In Polynesia it does not produce seed as all trees were originally female clones, so propagation is vegetative, from root or stem cuttings. This contributes to its lower weed potential in Polynesia, compared with some Pacific island nations (Hawai'i, Solomon Islands and Fiji) where both female and male plants have been introduced (Figure 6.5). If the paper mulberry is also being planted for the production of bark, then it can be planted at close spacing (e.g. 1.5–2 m × 1.5–2 m), but if it is planted purely as a host and will be allowed to grow into larger, permanent hosts then it should be planted at a wide spacing (e.g. 6–8 m apart and no closer than 2 m to planted sandalwood) (Figure 6.6).

6.5.4 Pigeon pea (*Cajanus cajan*)

Figure 6.7 *C. cajan* flowers (left), fruit (centre) and foliage (right)

Figure 6.8 Pigeon pea as host plants (to the front and back right of photo)

Pigeon pea is a short-lived (3–5 years) leguminous shrub that can be planted by direct seeding (Figure 6.7). The seeds take 10–15 days to germinate. Because of its relatively small size (1–2 m), it can be planted close (1–2 m) to a young sandalwood seedling, while not being so big that it reduces sandalwood growth through competition. It is possible to plant one pigeon pea for every sandalwood tree (even at close sandalwood spacing) (Figure 6.8). The pods, leaves and flowers make an excellent animal fodder and the seeds are a well-known human food.

6.5.5 Sesbania (*Sesbania grandiflora* and *Sesbania formosa*)

Figure 6.9 *S. grandiflora* flowers (left) and growth habit (right)

Figure 6.10 Sesbania is an excellent intermediate host for any sandalwood species

Native to Australia, South-East Asia and India, sesbania is another short-lived perennial legume that is highly suitable as an intermediate host. It grows slightly bigger than pigeon pea. It is a fast-growing, open-branching tree that grows up to 8–15 m tall with a stem of up to 25–30 cm diameter (Figure 6.9 and 6.10). It is easily propagated by seed and usually germinates well without scarification. It can also be propagated vegetatively by stem and branch cuttings. It is recommended that this species be planted no closer than 2 m from any sandalwood tree, with one sesbania plant for every 2–3 sandalwood trees. Form pruning may be required to produce a clear bole for timber production.

6.5.6 Egyptian pea (*Sesbania sesban*)

Native to north-east Africa but naturalised in many countries where it is cultivated, this is a fast-growing, short-lived single or multistemmed shrub or small tree from 1 to 8 m tall that becomes more spreading when widely spaced. It is propagated by seed, which requires a pretreatment such as scarification (abrasion or acid) or soaking in water at 80 °C for 8 minutes (hot water pre-treatment can result in significant seed death if not carefully monitored). It is recommended that this moderate-sized long-term host be spaced a minimum of 3 m from any sandalwood tree. Branches can be regularly pruned, or the tree may be coppiced or pollarded to facilitate fodder production. It seeds prolifically and will readily establish on moist bare soils so active regeneration control may be needed in some settings to maintain the desired density.

6.6 Intermediate to long-term hosts

6.6.1 Coral tree (*Erythrina poeppigiana*)

The coral tree may be used as an intermediate host planted 1–2 m from sandalwood, if it is regularly pruned. Alternatively, it may be used as a long-term host planted at least 3–4 m from the sandalwood. The coral tree is a fast-growing legume from South America that can add significant amounts of nitrogen to the soil (Figure 6.11). It does, however, require regular pruning to maintain a manageable size and ensure that it does not outcompete sandalwood during the establishment years. The prunings are very useful as green manure. The spacing of these hosts should be one for every 2–3 sandalwood trees.

Figure 6.11 *E. poeppigiana* planted as a host for *S. austrocaledonicum*

6.6.2 Calliandra (*Calliandra calothyrsus* and *Calliandra surinamensis*)

Native to Mexico, Central America and Colombia, calliandra is a fast-growing perennial, multistemmed shrub or small tree of 5–6 m with a stem diameter up to 20 cm (Figure 6.12 and 6.13). It is propagated by seed, which requires a pretreatment of soaking in hot or cold water for 24–48 hours. It is recommended that this moderate-sized host be spaced a minimum of 3 m from any sandalwood tree. Branches can be regularly pruned, or the tree may be coppiced to facilitate fodder and firewood production. It will readily establish on moist, bare soils, so active regeneration control may be needed to maintain the desired density. Sandalwood appears to feed very heavily on, and derive considerable growth benefits, from *C. calothyrsus* but there is a risk that sandalwood can kill calliandra (same applies to citrus), which then become infected with brown butt rot (*Phellinus noxius*), which can then spread into and kill the sandalwood. The remedy is to plant a variety of hosts, not just calliandra, and have an appropriately high host–sandalwood ratio. Sandalwood seems to derive less growth benefit from *C. surinamensis*, but the latter is a stronger host, and its semi-horizontal branching habit is desirable to prevent overtopping of sandalwood.

Figure 6.12 *C. calothyrsus*: habit (left), flowers (centre) and fruit (right)

Photos: (left) Forest & Kim Starr, CC BY 4.0; (centre) Forest & Kim Starr, CC BY 3.0; (right) Roger Culos CC BY-SA 4.0.

Figure 6.13 *C. surinamensis*: habit (left), flowers (centre) and fruit (right)

Photos: (left) Katherine Wagner-Reiss, CC BY-SA 4.0; (centre) Scott Zona, CC BY 2.0; (right) Philipp Weigell, CC BY 3.0.

6.7 Long-term hosts

6.7.1 Papuan wattle (*Acacia auriculiformis*)

Figure 6.14 *A. auriculiformis* habit in natural stand (left), open seed pod and seed (top right), and collected seed pods with leaves (bottom right)

Northern or Papuan wattle (*A. auriculiformis*) is a medium-sized tree that grows to 30 m and adapts well to a range of soil types (Figure 6.14). It has a large spreading canopy and a spreading, densely matted root system. This tree is a very good host for sandalwood, although given its size and vigorous growth, attention needs to be given to appropriate wide spacing and canopy management. It is very useful for fuelwood and as a shade tree since it retains its canopy during the dry season. Plant at a minimum of 4–5 m from any sandalwood tree and plant midway between each third or fourth sandalwood tree (i.e. 16–20 m apart).

6.7.2 Salwood (*Acacia crassicarpa*)

Figure 6.15 *A. crassicarpa* in the wild, Keru, Papua New Guinea (left), flowers (top right) and seed pods (bottom right)

Salwood (*A. crassicarpa*) is a medium-sized tree that grows to a maximum of 30 m tall (Figure 6.15). The bole is often straight and branchless for about 13–18 m, and grows up to 50–60 cm in diameter. Salwood bark is dark or grey-brown, hard with deep vertical furrows; the inner bark is red and fibrous. It can grow on a wide range of soils from well to imperfectly drained acid soils. The crown is usually heavily branched and spreading in open environments and the canopy needs to be managed so it doesn't overtop the sandalwood. Plant at a minimum of 4–5 m from any sandalwood tree, midway between each third or fourth sandalwood tree (i.e. 16–20 m apart)

6.7.3 Coast wattle (*Acacia leptocarpa*)

Figure 6.16 *A. leptocarpa* habit (left) and flowering (right)

Native to Australia and Papua New Guinea, *A. leptocarpa* is a shrub (3–5 m) or small tree up to 15 m, with a diameter of up to 25 cm (Figure 6.16). It has a light to moderately dense crown and produces a single stem. It occurs on sandy or rocky soils. The hard-coated seed requires a regular dormancy breaking treatment such as pouring hot water (70–80 °C) over the seeds and soaking them for 24 hours. Discard floating infertile seeds, plant swollen seeds and re-treat any remaining seed. Form pruning may be required to limit the lateral spread of the crown, with prunings potentially used for firewood. The timber is decorative and useful in cabinet work but limited by the small dimensions of the tree. Plant a minimum of 2 m from any sandalwood tree, midway between each second sandalwood tree (i.e. 12 m apart).

6.7.4 Ai-maro (Kemak name), white-bark acacia (*Acacia leucophloea*)

Figure 6.17 *A. leucophloea* habit (top left), pollarded (top right), bark (bottom left) and foliage (bottom right)

A large spreading tree native to East Asia and the Indian subcontinent, *A. leucophloea* can grow up to 35 m in height and up to a diameter at breast height (DBH) of 100 cm (Figure 6.17). Seed viability can be low. Hot water pretreatment improves germination, but it can still take 1–3 months. This species is slow to establish compared with *Leucaena* but it is much longer lived. The crown can be pollarded for fodder and to restrict canopy spread, the leaves should not, however, be used as a sole feed due to hydrocyanic acid toxicity. It also produces an attractive and durable timber.

6.7.5 Qumu (*Acacia richii*)

Figure 6.18 *A. richii* pods

A. richii is endemic to Fiji and is a small to medium-sized tree (6–25 m) with a rather light or sparse canopy. As with most other acacias, the hard-coated seed (Figure 6.18) requires a pretreatment such as pouring hot water (70–80 °C) over the seeds and soaking them for 24 hours. Discard floating infertile seeds, sow only swollen seeds and re-treat any remaining seed. Form pruning may be required to limit the lateral spread of the crown given its freely branching habit. The wood is a valued timber. Plant a minimum of 2 m from any sandalwood tree, midway between each second sandalwood tree (i.e. 12 m apart).

6.7.6 Namariu (*Acacia spirorbis*)

Figure 6.19 *A. spirorbis* habit, Tanna, Vanuatu (left) and leaves and flowers (right)

Namariu is an excellent host species for sandalwood, especially in Vanuatu, and occurs in the wild on all islands with natural populations of sandalwood. Naturally occurring areas of namariu are an indicator of good sites for growing sandalwood. Namariu is a large (15–20 m tall, 40–60 cm in diameter), long-lived tree and may be used as a host for more than one sandalwood rotation (Figure 6.19). If pruned and maintained to produce a clean, straight bole, its timber can be used for local construction and fencing. The subspecies *spirorbis* is endemic to Vanuatu and New Caledonia, while subspecies *solandri* is endemic to Papua New Guinea and Australia.

6.7.7 White siris (*Albizia procera*)

Figure 6.20 *A. procera* habit (main) and foliage (inset)

Native to Australia, South-East Asia and India, *A. procera* is a large, fast-growing, dry-season deciduous tree with an open canopy, up to 30 m tall, often with a straight bole of up to 9 m and reaching a diameter of 30–60 cm (Figure 6.20). It is an aggressive coloniser and potentially an invasive species. Fresh seed requires no pretreatment, stored seed responds well to soaking in hot (70–80 °C) water for 5 seconds, removing seed from direct heat and soaking in tap water overnight. Direct sowing into well-prepared soil is more successful than planting out from a nursery, as long as soil moisture is good and weeding is done regularly. Plant a minimum of 3 m from any sandalwood tree and plant midway between each second or third sandalwood tree (i.e. 12–18 m apart). Form pruning may be needed to produce a clear bole for timber production.

6.7.8 Golden shower (*Cassia fistula*) and pink shower or Java cassia (*Cassia javanica*)

Figure 6.21 *C. fistula* habit (left) and flowers (right)

Figure 6.22 *C. javanica* habit (left) and flowers (right)

Native to Asia, *C. fistula* and *C. javanica* are widely cultivated and are naturalised in many tropical countries. They are fast-growing, medium-sized, dry-season, deciduous/semi-deciduous trees. They commonly reach a height of 25 m (sometimes up to 40 m) and have a spreading crown (Figure 6.21 and 6.22). They are propagated by seed germinating from 7 to 30 days. It is recommended that these moderate to large-sized, long-term hosts be spaced a minimum of 3 m from any sandalwood tree and only be planted at the midpoint between each second or third sandalwood tree (i.e. 12–18 m apart) so they do not dominate the sandalwood trees later in the rotation. Form pruning may be required to produce a clear bole for timber production. They will coppice vigorously and produce many root suckers, which will need to be controlled, and are considered a weed in many areas.

6.7.9 Beach she-oak or nokonoko (*Casuarina equisetifolia*)

Figure 6.23 *C. equisetifolia* planted (left), female flowers (top right) and cones from a female tree (bottom right)

Native to the Pacific, South-East Asia and Australia, beach she-oak has been used widely as a sandalwood host (Figure 6.23). It provides good protection from winds without overtopping the sandalwood. Trees grow rapidly but can be easily controlled with minimal pruning. Spacing needs to be at least 15 m × 6 m to allow sufficient space for the growth and development of the sandalwood. Trimmings and thinnings may be used for firewood.

6.7.10 *Citrus* spp. (orange, pamplemousse, lime or lemon)

Figure 6.24 Mandarin host to *S. yasi*, Vavau, Tonga (left) and mandarin host to *S. yasi*, Taveuni, Fiji (right)

Citrus species are the main non-nitrogen–fixing species recommended as sandalwood hosts (Figure 6.24). However, if there are not enough citrus trees relative to the number of sandalwood trees, the citrus can be killed by the sandalwood. The use of citrus as a long-term host has the advantage of providing supplementary income during the maturation of the sandalwood trees, but the better (stronger) citrus hosts tend to be wilder forms of less commercial value, including rough lemon, pomelo and wild mandarin.

6.7.11 Poumuli or namamau (*Flueggea flexuosa*)

Figure 6.25 *F. flexuosa* plantation (left), flowers (top right) and fruit (bottom right)

Figure 6.26 Unpruned *F. flexuosa* (left), close up of flowers (top right) and fruit (bottom right)

Flueggea is native to Malesia from the Philippines through to the Solomon Islands and Vanuatu and has been introduced to several other Pacific islands. The species is adapted to the lowland, humid tropics and grows well on a wide range of soils. It is a small to medium-sized tree, typically reaching 10–15 m tall, with a DBH around 20–30 cm (Figure 6.25 and 6.26). Poumuli is propagated using fresh seed after the ripe fruits are de-pulped. Seed does not require any pretreatment prior to sowing. It is recommended that this host be spaced a minimum of 3 m from any sandalwood tree and only be planted at the midpoint between each second or third sandalwood tree (i.e. 12–18 m apart) so it does not dominate the sandalwood trees later in the rotation. This tree has a good bole form and produces a highly durable timber favoured for building construction uses (as a pole in ground contact).

6.7.12 Cassis (*Leucaena leucocephala*)

Figure 6.27 *L. leucocephala* stand (left), flower (top right) and seed pods (bottom right)

Cassis is a small tree 3–15 m tall and 10–35 cm in diameter (Figure 6.27). It is a potential sandalwood host, particularly if used as a fodder for feeding cattle in a cut-and-carry system. Although the species is exotic to the Pacific, it often occurs in wild sandalwood populations in Vanuatu. Cassis is, however, very competitive and invasive, and sandalwood growth will be severely reduced if cassis growth is not controlled by heavy pruning and weeding of naturally occurring seedlings. Cassis is a good indicator of suitable growing sites for sandalwood, but care must be taken to ensure that it does not become a weed.

6.7.13 Rosewood or bluwota (*Pterocarpus indicus*)

Figure 6.28 *P. indicus* habit (left), flowers (top right) and fruit (bottom right)

Sandalwood occurs naturally with rosewood, and early research indicates that rosewood is a good host for sandalwood. Rosewood is native to South-East Asia and the northern Pacific. Rosewood is a very large tree, 25–35 to 48 m tall and up to 2 m DBH, with a wide, spreading crown (Figure 6.28), and therefore spacing would need to be at least 15 m × 6 m to ensure that these trees do not dominate the sandalwood later in the rotation. No pretreatment is needed for seed germination, and it can also be propagated vegetatively. This tree produces valuable hardwood timber and, if managed by pruning, may produce a commercial product after two sandalwood rotations.

6.7.14 Tamarind (*Tamarindus indica*)

Figure 6.29 *T. indica* habit (left), flowers (top right) and fruit (bottom right)

Tamarind is an evergreen, slow-growing and long-lived leguminous tree growing up to 30 m under good conditions (Figure 6.29). Given its slow growth, tamarind could be established a year prior to planting the sandalwood. The species is highly adaptable, growing equally well in dry tropical savannah climates and also areas with high and regular rainfall. It has an irregular-shaped crown and short trunk and is resistant to strong winds and cyclones. Its bark is dark grey in colour and fissured in texture. The leaves are finely pinnate compound with 10–20 pairs of oblong leaflets. The long slightly curved bean pods are a feature of the species, which contain 1–12 seeds surrounded by a sweet to sour sticky orange-coloured pulp. The pulp is used widely as a flavouring component in chutneys, curries and other cooked dishes.

7 Weeds

7.1 Importance of weed control

Every newly planted seedling requires a weed-free area of at least 1 m^2 for at least 3 years. The most common cause of plantation failure is inadequate weed control during the years of establishment. This means that labour inputs for weed control need to be considered in any new sandalwood planting.

There are three forms of effective weed control:

1. Manual pulling is used during the wet season, when conservation of soil moisture is not an issue.
2. Mechanical cutting ('brushing') with a bush knife is used during the dry season, when conservation of soil moisture is important (Figure 7.1).
3. Chemical control with grass-selective or contact/knockdown herbicides can be used if spray drift is adequately controlled. These types of herbicides are generally too expensive and inaccessible for smallholders. Systemic broad-spectrum herbicides (such as glyphosate) should not be used for any reason once the sandalwood has been planted because a systemic herbicide can move through the vascular system of the weeds and into the sandalwood through its haustoria, which can retard growth and potentially kill the sandalwood. Systemic herbicides can be used pre-planting to rid the planting site of weeds, but this should occur several weeks before planting.

Figure 7.1 Mechanical cutting (brushing) of Guinea grass (*Megathyrsus maximus*) with a bush knife

Several vines, locally known as rope weeds, are the most problematic for establishing sandalwood in Vanuatu. These vines include *Neonotonia wightii* (glycine), *Merremia peltata* (merremia and big leaf) and *Mikania micrantha* (mile-a-minute or American rope). These vines can be controlled by manual cutting, but do regrow rapidly (Figure 7.2).

Mechanical cutting of weeds

Soybean

Sandalwood thrive with good, weekly weed control

Merremia

Poorly controlled weeds have swamped any sign of sandalwood saplings

Mile-a-minute overrunning sandalwood

Figure 7.2 Vine weeds are particularly problematic if not regularly controlled by mechanical brushing. Vine weeds such as glycine, merremia and mile-a-minute have rapid growth and are particularly problematic

Singapore daisy (*Sphagneticola trilobata*) is a significant problem for sandalwood plantings in Vanuatu (Figure 7.3). The only way to deal with this weed is to prevent its entry into the plantation by immediate removal when observed. This weed is problematic for the following reasons:

- It significantly depresses the growth of many trees, including sandalwood, since it has an aggressive root system, which is mildly phytotoxic to other plants.
- It promotes a water saturated area around the base of the sandalwood that promotes fungi such as *Phellinus* spp. and *Phytophthora* spp.
- There is no effective method of control in sandalwood plantings. Manual removal is not sufficient to remove the weed as it grows back from any stem or root fragment that remains. It is possible to control Singapore daisy using metsulfuron-methyl, but this herbicide will also result in the death or significant deformation of the sandalwood trees.

Figure 7.3 Singapore daisy (*S. trilobata*) is a low-growing weed that depresses sandalwood growth and promotes stem rot

In Fiji and Tonga, *Spathodea campanulata* (African tulip tree) and *Tecoma stans* (yellow trumpetbush) are major weeds for sandalwood plantings. These two exotic woody weeds, both in family Bignoniaceae, provide intense competition and shade out sandalwood as well as being environmentally invasive, ecosystem transforming species. In Timor-Leste, Siam weed (*Chromolaena odorata*) is an invasive plant that can rapidly smother young tree plantings. In Papua New Guinea, kunai grass (*Imperata cylindrica*) is very hostile to sandalwood trees, owing to its aggressive root system and susceptibility to fire during the dry season.

7.2 Weed control – pulling and cutting

If manual weed control is used it is best to clean around the base of each tree every 2–4 weeks for the first 6–12 months.

Vine weeds often need to be cut or pulled (depending on the season) on a fortnightly basis after seedlings have been planted. This weeding regime needs to be maintained for a number of years, until the trees begin to shade out the weeds. If the rope weeds are too big, they can only be cut. Only small rope plants can be pulled out easily in the wet season.

When vine weeds are a particular problem, the lower branches of the sandalwood may be pruned to 'lift' the crown of the tree away from the ground (Figure 7.4). This leaves only the trunk for the vine weeds to attach to. Although this might not reduce the frequency of weeding, it can help reduce the time spent weeding during a visit.

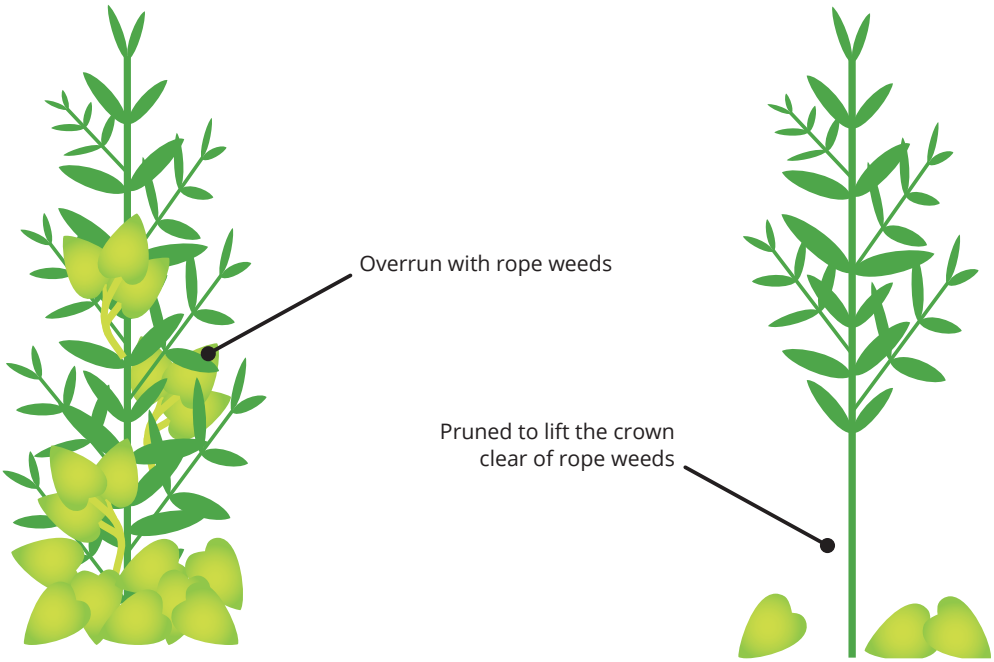


Figure 7.4 Method of trimming vine weeds and pruning lower branches of sandalwood to lift the crown of the tree away from the ground

7.3 Host competition

Sandalwood does not grow well under high competition for soil nutrients, water and light from other plants, including hosts.

Although hosts are necessary for good sandalwood growth, most can outcompete sandalwood if they are too dense or their growth is left unchecked.

Planting among weed thickets often leads to stunted sandalwood growth, with pronounced leaf yellowing (Figure 7.5).

Yellowing sandalwood in leucaena thicket

Crowded sandalwood surrounded by casuarina

Crowded sandalwood with too few hosts

Figure 7.5 Examples of crowded sandalwood and effect on plant health and growth

7.4 Sandalwood competition

Sandalwood growth is severely reduced when it is planted at a high density (spacings less than 3 m × 4 m). Although good early growth can be achieved at such densities, after 3–4 years growth will stagnate as a result of competition between sandalwood trees for soil nutrients, water and light. Figure 7.5 shows severe examples of the effects of high-density plantings. The trees in the top right image are limited by both the high planting density (1.5 m × 1.5 m) and the high number of host trees (*Casuarina* oak trees) planted around the sandalwood. The trees in the bottom image are 10 years of age; they are spindly because of a high planting density and lack of available long-term hosts.

8 Pests, diseases, and other problems for production

8.1 *Phellinus noxius*

Phellinus noxius is a fungal root infection (brown root rot) that has the potential to kill sandalwood seedlings and trees (Figure 8.1). The leaves of affected trees will rapidly turn from green to brown before dropping within a few weeks of showing the first symptoms. If the disease is present, a brown skin, which is the fruiting body of the fungus, can be seen at the base of the tree.

The disease is spread through the root systems of affected trees, and infection can therefore rapidly spread to other trees in a plantation.

Figure 8.1 Examples of *P. noxius* infection in sandalwood trees: (left page) brown root rot at the base of a sandalwood trunk, and (above) *Phellinus*-infected sandalwood losing its leaves

8.1.1 *Phellinus* prevention

The best way to control *Phellinus* is to prevent infection by:

- avoiding planting in areas where the disease is already established
- selecting a site that is free draining and on a slight slope; waterlogged soil promotes the growth of the fungus
- removing all living stumps when clearing a new site, because living stumps and roots are the most likely sites for *Phellinus* spores to establish a new colony; stumps should be burned to ensure that they are completely dead
- allowing a short period of fallow after clearing, or ensuring that the refuse and roots of old trees that may harbour *Phellinus* have decomposed
- planting herbaceous plants adjacent to each sandalwood tree (e.g. *Euphorbia tithymaloides* (vinil), and *Cordyline fruticosa* (cordyline or nangaria) are said to help prevent the spread of infection, although it is not known how)
- avoiding unnecessarily cutting into the sandalwood tree with a bush knife
- pruning during dry conditions to limit the chance of infection of cut stems and to help the rapid healing of the wound (because sandalwood grows rapidly during the dry season)
- avoiding movement of infected plants into the sandalwood plantation.

8.1.2 *Phellinus* control

Controlling *Phellinus* can be difficult. When a tree becomes infected by the fungus, it is important to reduce its spread to other trees in the plantation by:

- reducing the number of people walking around and touching the affected areas of the tree and then touching other (healthy) trees without washing their hands and feet with soap and water
- removing and burning any fallen branches from the plantation
- cutting a wide circle (5–10 m diameter) around the affected tree with a spade to cut the roots
- disinfecting any tools used on an infected tree by washing them with soap and water, and then placing them in a fire or boiling water before using them on a healthy tree.

At the first sign of symptoms, such as drying leaves, some growers believe that the following control methods help reduce the spread of infection:

- Plant herbaceous plants adjacent to each sandalwood tree (e.g. devil's backbone, cordyline).
- Excavate a hole around the trunk of the affected sandalwood tree and place plenty of cut bush lemons in the immediate root zone, as is done in coffee production in Tanna.

If a tree is killed by *Phellinus*, it remains a source of infection for other trees. The dead tree needs to be burned on site to kill any disease remaining in the wood and soil. It is also important to dig and break the roots to reduce movement of the fungus along the roots to other trees in the plantation. Mature trees may be salvaged for their heartwood, although often the disease reduces the quality (see Section 11.3).

8.2 Leaf blackspot

Blackspot is a fungal disease that affects the leaves of sandalwood, particularly in saplings (Figure 8.2). Although blackspot will not usually kill a tree, it is an indication that conditions are too humid for sandalwood. Blackspot can appear intermittently, and its presence will depend on seasonal environmental variation. If blackspot is persistent for most of the year, this is a good indication that the climate is not ideal for growing sandalwood. The effect of blackspot on growth rates and heartwood formation is not known.

Figure 8.2 Leaf blackspot on sandalwood

8.3 Seedling wilt, damping off and dieback

The mortality of young sandalwood seedlings under nursery conditions due to disease is widespread in Timor-Leste and may occur elsewhere in the Pacific. Symptoms include seedling wilt, leaf lesions, stem girdling and ultimately dieback. These diseases cause significant seedling mortality of up to 80–90% (Figure 8.3), particularly under wet and humid conditions.

The canopy of the seedlings displays three distinct symptoms:

1. girdling wound or lesions on the stem (Figure 8.4)
2. leaf wilt/lesions and damping off (Figure 8.5)
3. stem girdling and dieback.

Figure 8.3 Significant seedling losses associated with seedling wilt disease in Timor-Leste

Figure 8.4 Stem lesion symptoms causing girdling and leaf drop above the lesion area

Figure 8.5 Leaf wilt and lesions observed on young sandalwood seedlings

The following conditions are likely to promote onset and development of fungal disease:

- Persistent rain and associated leaf wetness. The number of consecutive rain days can be more important than the total level of precipitation.
- Heavy shade trees adjacent to the nursery area, and/or the combination of heavy cloud and shade cloth.
- Close spacing of the sandalwood seedlings reducing air flow, raising humidity and facilitating disease transfer.
- The growth and abundance of pot hosts growing and outcompeting the sandalwood. This has three effects:
  - raising humidity and reducing air flow among the seedlings
  - providing an alternative host for the disease
  - reducing the vigour of the sandalwood. It is important to note that despite being a root parasite, young sandalwood can be outcompeted by its host.

8.3.1 Cultural methods of control

The onset of fungal disease can be reduced by:

- using clean and disease-free potting media/topsoil
- using well-drained potting media to reduce waterlogging
- growing seedlings on raised benches or a free-draining substrate (rocks)
- surface sterilising seeds prior to sowing.

The incidence of the disease may be limited by the following cultural practices:

- Prune the pot hosts to reduce humidity and increase air flow.
- Remove all dead plants from the nursery.
- Isolate any sick plants in a dedicated and separate area in the nursery.
- Remove any dead or affected leaves in the nursery.
- Reduce plant density by spacing the seedlings more widely.
- Sort seedlings based on size and health.
- Increase available light in the nursery area to help improve sandalwood growth and reduce humidity.
- Increase air flow in the nursery to reduce humidity.
- Water seedlings on demand (according to seedling needs) rather than a regular schedule.
- If possible, limit leaf wetness by growing under clear polythene plastic.

8.4 Sap-sucking and defoliating insects

Various sap-sucking insects occur on sandalwood trees, including mealy bugs and aphids (order Hemiptera), and beetle borers (order Coleoptera) (Figure 8.6). These insects are abundant in some localised areas and at particular times of the year, but none is considered to be a serious pest of sandalwood. These insects are more common on weaker or stressed saplings, and rarely occur on vigorously growing trees.

The best method of controlling these pests is to ensure that the sandalwood trees are planted in an appropriate site, with good weed control. Such practices will help to promote tree vigour and ensure that these pests do not become a problem.

Mealy bugs and aphids have been controlled using white oil pesticide; however, the spray should be applied only to the pest (broadcast spraying should not be used), to avoid killing non-target beneficial insects.

Some insects, such as ladybirds (order Coleoptera, family Coccinellidae), can be effective predators of mealy bugs and aphids, and their presence in the plantation should be promoted.

Trees infested with mealy bugs or aphids are often covered in sticky honeydew, which is a sweet by-product of feeding. This honeydew can promote the growth of blackspot, and infestations of ants seeking the available sugars.

Young sandalwood seedlings can also be susceptible to defoliating insects such as locusts and caterpillars. While these pests are not necessarily a widespread problem, an isolated outbreak can potentially destroy a young planting of up to 2 years of age. These pests can be controlled through manual removal, particularly at the early stages of infestation. If the pest population begins to build up, then an application of chemical insecticides may be necessary to gain control.

Figure 8.6 Mealy bugs (left) and borer beetles (right) can cause harm to young sandalwood seedlings

8.5 Pot host field issues

Sandalwood performs best when the pot host (*Alternanthera*) persists in the field for 1–2 years. Under wet-season conditions it is important to monitor and cut / pull back the pot host growing around the stem of the young sandalwood trees. The two main reasons for this are: (1) the pot host can sometimes fasten/wrap around the stem of the sandalwood and cause rotting and partial or full ringbarking; and (2) in some areas of Timor-Leste the pot host can harbour a snail that can consume the outer bark of the sandalwood (Figure 8.7). Both these problems can cause seedling mortality and are promoted during high rainfall and dense growth of the pot host around the stem. This can be easily rectified by cutting or pulling back the *Alternanthera* from around the sandalwood stem.

Figure 8.7 Bark damage due to pot host wrapping and rotting around the stem (left) and snail (inset right) caused bark damage of young seedling (right). Both these sources of damage can cause seedling mortality in the field

Photos: Luis Almeida

8.6 Leaf galling

Leaf gall is a serious pest of sandalwood trees and can cause significant loss of health and vigour (Figure 8.8). Leaf galling is a particular problem in Timor-Leste and is found throughout the country. The galls are caused by the larvae of an (as yet) unidentified fly or wasp. The larvae consume the leaves causing severe deformation. Young shoots are the most affected by this problem, which can cause a complete loss of growth in that season. The scale of the problems is determined by the severity of infestation. Little is known about this pest and methods of control, but at this stage it appears that stressed trees are more susceptible to leaf gall. Leaf gall often facilitates secondary infection of white scale (Figure 8.9). Further research is required to identify the insect pest and determine methods for management and control.

Figure 8.8 Leaf galling insects affect the leaves (left) and new shoots (right) of sandalwood in Timor. The galling is often followed by infestation of white leaf scale (right)

Figure 8.9 Leaf scale insects can be prevalent in some areas

8.7 Web-forming, leaf-eating caterpillars

Sandalwood trees in Timor-Leste are susceptible to defoliation caused by a caterpillar that forms large colonies within a silken web nest (Figure 8.10). While these colonies can be found on large mature trees, they don't appear to cause significant damage. However, they can completely defoliate young (1–3 years) sandalwood trees in a plantation. This can reduce the health and vigour of the trees and repeated defoliation can result in tree death. Control of this pest is therefore recommended by targeting the colony through physical removal, pesticide treatment or flame treatment.

Figure 8.10 Web-forming, leaf-eating caterpillars form colonies on the bark of mature trees. They eat sandalwood leaves (left) and under some conditions defoliate young, planted trees (right)

Photos: Luis Almeida

8.8 Grazing and browsing animals

The leaves of all young sandalwood species are highly palatable to a range of grazing animals. Both feral and village animals can graze young saplings and severely reduce the chance of plant survival (Figure 8.11). Sandalwood trees may need to be at least 5 years old before they can tolerate animal grazing. This is particularly a problem in some areas of Timor-Leste and Indonesia where there is an abundance of grazing animals in the community including goats, cattle and horses. In Papua New Guinea and Vanuatu, pigs (both wild and domestic) can be particularly problematic when sandalwood is planted in association with root vegetables. When pigs dig to seek out the root crops they will uproot and/or disturb any young sandalwood seedlings and cause significant losses.

The only effective method of controlling cattle grazing is to exclude animals from the planting. This can be done by tethering, installing tree guards or fencing the plantation. Without such control, animal grazing can completely destroy a young sandalwood plantation. In areas where pigs are a concern, the exclusion of companion root crops can limit issues with pigs.

Figure 8.11 Grazing animals can cause significant damage to young sandalwood trees

8.9 Seed predation by birds

The sweet flesh of sandalwood fruit is a prized food for many types of birds. Fruit consumption by birds limits the amount of seed that can be collected for planting or sale. The problem is more pronounced where trees are isolated, because birds are left undisturbed for long periods and it is difficult for a farmer to collect seeds regularly.

Positioning new plantings close to village or garden areas will help the farmer maintain the trees and limit seed loss from consumption by birds.

A sandalwood tree that is a particularly valuable source of seeds may be protected by using a net over its canopy or branches. Another method, which has a limited effect, is hanging shiny objects in the branches of the tree to distract and frighten the birds. Scarecrows can also be effective. However, many birds are quick to see through these tricks, so it is important to place these objects in the plantation only as the seeds mature and quickly remove them after the farmer has finished harvesting the seeds.

8.10 Waterlogging and/or high watertable

All sandalwood species are intolerant of waterlogging and will become yellow and stunted under such conditions. Sandalwood growing on sites with a high water table will grow well in the first few years, but growth will gradually decline, leaves will become yellow, and the tree will become more susceptible to pests and disease. Sandalwood tends to grow best when there is a distinct dry period at some time during the year.

8.11 Fire

Sandalwood does not tolerate fire and will die even when exposed to a low-intensity fire (Figure 8.12). The most susceptible species include *S. album*, *S. yasi* and *S. austrocaledonicum*. *S. macgregorii* and *S. lanceolatum* have thicker bark and have a moderate tolerance to low-intensity fires. Fuel loads in sandalwood smallholdings should be kept to a minimum by removing grass and woody debris from the site. During dry periods, care should be taken to limit people lighting fires close to and upwind of the sandalwood plantation. In Papua New Guinea where sandalwood is planted into kunai grasslands, the risk of fire is very high. Kunai needs to be eliminated from the site prior to planting either through ploughing and/or herbicide. Firebreaks surrounding the sandalwood plantation need to be maintained throughout the dry season. Green firebreaks may also be considered by planting species such as noni (*Morinda citrifolia*) or mango (*Mangifera indica*) and maintaining a debris-free ground layer.

Figure 8.12 Sandalwood grows in areas that are susceptible to fire in the dry season (left). The trees have limited tolerance to fire and are killed from exposure (right)

8.12 Cyclones

Ideally, sandalwood plantings should be established in areas with good wind protection, to limit the damage caused by cyclones (Figure 8.13). The use of windbreak trees known to be tolerant to high winds, such as *Casuarina equisetifolia*, can reduce the wind speed in sandalwood plantations. Sandalwood trees tend to break under cyclonic winds but can recover through new growth from the damaged stem. Trees with broken trunks should be pruned with a saw to give a good clean cut to prevent water entry and rotting of the main stem. There is evidence that the native Pacific species (*S. yasi*, *S. austrocaledonicum* and *S. lanceolatum*) may be more cyclone resistant than species such as *S. album* and *S. macgregorii*. Sandalwood trees tend to be windblown in deep fertile soils with high rainfall and a high water table. In such locations, sandalwood trees don't generally establish deep enough root systems to anchor themselves. Windblown sandalwood can recover through a process of gradual lifting and propping over several months. A tree managed in this way will re-establish its canopy and root system. Cyclones can cause the formation of 'waterwood' (see Section 11.3) at the expense of high-value heartwood. More research is required to determine if waterwood can further develop into true heartwood over time.

Figure 8.13 Cyclone damaged sandalwood trees: *S. yasi* (left) and *S. austrocaledonicum* (centre and right)

8.13 Sun scorch

Sun scorch is a problem in environments where there is not adequate shading and the trees and their main stems are exposed to the full sun (Figure 8.14). It can be promoted when the sun's heat is reflected on dark and bare soil where there is also a lack of ground vegetation or mulch. Sun scorch exposes the inner heartwood, making it more susceptible to other diseases (see Section 8.16).

Figure 8.14 Sun scorch is often found on the sides of trees exposed to hot sun

8.14 Bark slash

Bark slash wounds (Figure 8.15) are typically made using a bush knife, either indiscriminately (vandalism) or systematically (marking ownership). Bark slash is more commonly encountered in areas of high foot traffic (vandalism) or where people seek to mark ownership of the tree to limit theft. The effect of bark slashing on tree health and vigour depends upon severity, and in some villages this practice has been banned.

Figure 8.15 Systematic slashing of the bark as a way to mark ownership of or vandalise other trees. The effect of this damage to the bark on tree health and vigour depends upon the severity of application

8.15 Heartwood check damage

Heartwood checking is damage caused by people cutting into the main stem to check for heartwood development (Figure 8.16). This technique causes significant damage to the tree through the following:

- reduces growth by severing the vascular tissues that connect the roots and the leaves
- creates a wound for entry of pathogens and wood rotting fungi
- introduces a weakness to the trunk, making it more susceptible to being broken in strong winds.

If it is necessary to check the tree for heartwood development, this should be done by making small cuts in the branches and/or roots. While these methods have similar issues to heartwood checking in the main stem, it is less invasive. Alternatively, a small drill bit (6 mm) can be used to drill into the tree and the wood shavings can be collected and checked for the presence and depth of heartwood. The intensity of heartwood fragrance can be used by skilled practitioners to understand the maturity of the heartwood. While drilling has issues with insects and other pathogens gaining entry to the hole, in a vigorous tree the bark can quickly grow over the wound.

Figure 8.16 Examples of severe heartwood check damage

8.16 Heartwood rot

Fungi, bacteria and other pathogens can cause the heartwood of sandalwood trees to rot. They enter through wounds or damage where the heartwood is exposed (e.g. broken off branches in a storm). Trees are more susceptible to this if they are stressed. Fungal fruiting bodies on the bole are a sign that the tree is infected (Figure 8.17 left) and over time they can cause tree mortality (Figure 8.17 right).

Figure 8.17 Over time heartwood rot in sandalwood (left) can cause tree mortality (right)

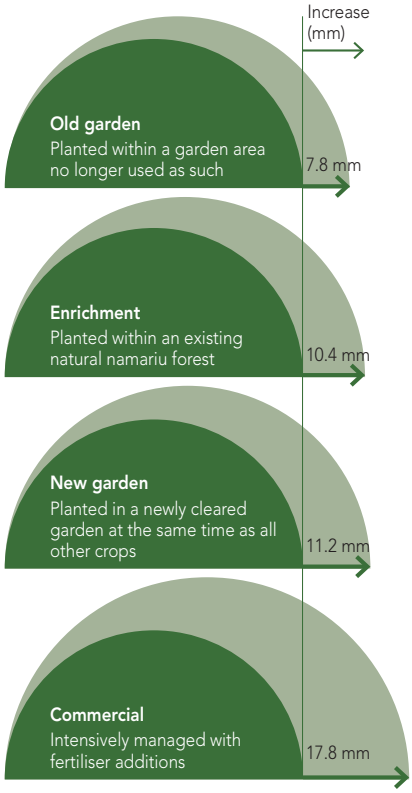
9 Tree and heartwood growth, and heartwood properties

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.

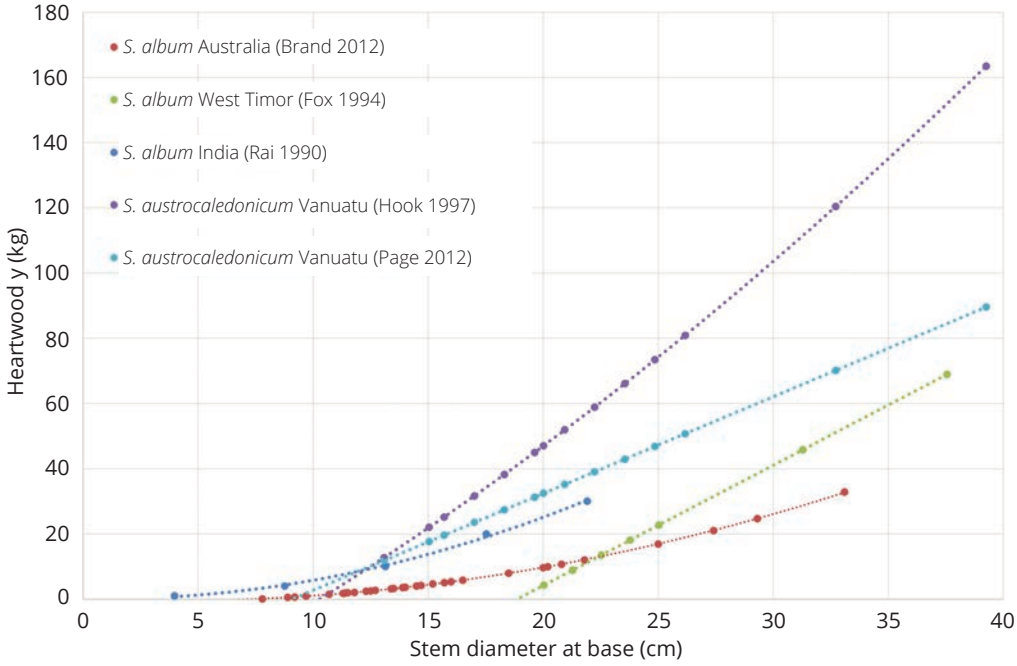


Figure 9.3 Heartwood development by five authors for *S. album* and *S. austrocaledonicum* for stem diameter standardised at the base (0.2 to 0.3 m from ground level). Data for Rai (1990), Fox (1994) and Hook (1990) were originally based on DBH and a conversion factor of 1.25 (*S. austrocaledonicum*)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

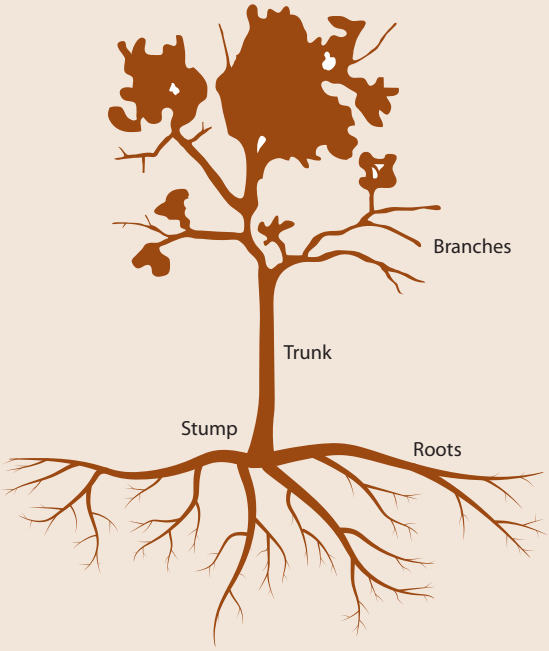


Figure 9.4 Heartwood oil is contained within the roots, stumps, trunks and main branches of a sandalwood tree

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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.

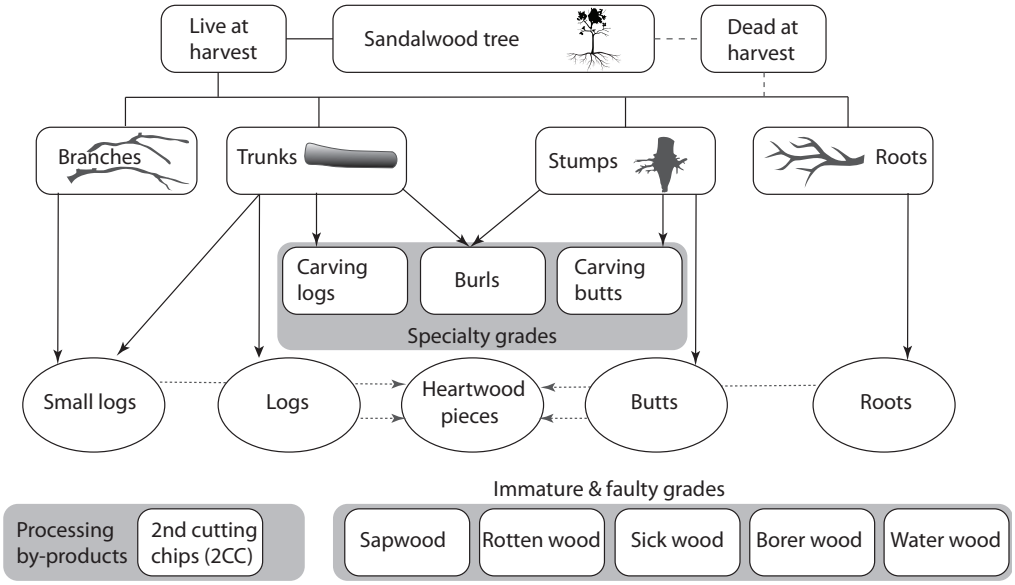

Figure 11.1 The sandalwood products are based on the tree structure and include four product categories: (1) specialty; (2) typical (within ovals); (3) faulty; and (4) by-products

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

13 Further reading

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