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Essence of Indonesia

The story of cajuput oil and its importance to the community

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Essence of Indonesia

The story of cajuput oil and its importance to the community

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Cover image: A worker harvests cajuput leaves by cutting branches and then stripping the leaves from the branches. Credit: A. Rimbawanto

FOREWORD

The unique aroma of cajuput oil is familiar to most Indonesians from birth. Used by households for treating ailments such as colds, stomach aches and insect bites, cajuput oil is part of Indonesian culture.

The oil is distilled from the leaves of the cajuput tree (*Melaleuca cajuputi* Powell subsp. *cajuputi*), which grows naturally across eastern Indonesia, Timor-Leste and the Top End of Australia. Other subspecies occur in southern Papua New Guinea, north Queensland, western provinces of Indonesia and up into Malaysia, Thailand, Myanmar and Vietnam. *Melaleuca cajuputi* is the sole melaleuca of about 290 species in the genus that grows naturally to the west of the Wallace Line.

The continuing high demand for cajuput oil in Indonesia combined with a growing population has resulted in a chronic lack of supply. Demand is also high in other South-East Asian countries, and globally. To cover the shortfall, imported eucalyptus oil is commonly blended with cajuput oil, but the quality of the blended product does not meet the Indonesian standard.

There has been a small increase in the plantation area of cajuput in Indonesia over the past decade; however, there remains enormous potential to increase both plantation area and oil production. While Indonesia remains a principal centre for the production of cajuput oil, Vietnam also is a significant producer, and cajuput is cultivated for commercial oil production in Malaysia and Thailand, with a small but growing industry in Fiji.

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.

The Center for Forest Biotechnology and Tree Improvement in Yogyakarta, Indonesia, in collaboration with CSIRO Forestry and Forest Products and with funding support from AusAID and ACIAR, initiated a selection and breeding program to increase the productivity of cajuput and the quality of oil produced from the species. This book on cajuput oil production was originally written in Bahasa Indonesia to highlight the importance of the species in the production of herbal medicine for Indonesians, and to document its cultivation and utilisation, genetic improvement and importance for the rural economy.

This is a fascinating species with significant cultural value and economic potential.

ACIAR is proud to publish the English version of this book on cajuput oil production, to facilitate a much greater reach of its valuable information and share Indonesia's vast experience in cultivating cajuput for oil production. In doing so, we hope we can assist the economic development of this important species throughout the ASEAN region by providing useful information for people who want to establish cajuput plantations and oil distilleries.

Andrew Campbell

Chief Executive Officer, ACIAR

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ACKNOWLEDGEMENTS

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The cajuput breeding program could not have been well implemented without policy support and funding from domestic institutions: Perhutani Research and Development Center in Cepu, Regional Forestry Service of Yogyakarta, Perhutani Gundih and Perhutani Madiun. The program also received funding and support from the Australian Government, particularly the Australian Centre for International Agricultural Research (ACIAR) and CSIRO Forestry and Forest Products.

This book was originally written by the authors in Bahasa Indonesia, and titled *Minyak Kayuputih dari Tanaman Asli Indonesia untuk Masyarakat Indonesia*.

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Introduction

1 INTRODUCTION

In almost every Indonesian household, a small bottle of cajuput oil is kept for remedying various health problems, such as colds, stomach aches, and insect bites, or just to warm the body of a newly bathed baby. Cajuput oil is part of Indonesian culture, so, unsurprisingly, demand continues to grow along with the growth in population.

Cajuput oil comes from *Melaleuca cajuputi* Powell subsp. *cajuputi* (Craven and Barlow 1997; Doran and Turnbull 1997; Brophy et al. 2013), formerly known as *Melaleuca leucadendron*. This species is native to the Maluku Islands, especially the islands of Ambon, Buru and Seram. However, the largest production of cajuput oil in Indonesia is on the island of Java, from the cajuput stands in the Perhutani region and the Forest Management Unit (FMU) of Yogyakarta. Nationally, cajuput oil production is about 400 tonnes (t) per year. This production rate has not changed much since 1996, when it was 300 t from Java and 90 t from Maluku (Gunn et al. 1996). The relatively stagnant production rate of cajuput oil is because of the limited development of new plantations. Meanwhile, natural stands in Maluku continue to deteriorate due to fire, land conversion or ageing.

The increasing demand for cajuput oil has not been matched by efforts to increase production. The cajuput stands managed by state-owned forest company Perhutani remained relatively unchanged for decades, covering an area of 17,826 hectares (ha). However, in the last five years the area has increased to 27,000 ha (Perhutani 2014), while in the Yogyakarta Special Region, Yogyakarta Forest Management Unit (FMU) manages cajuput stands of 4,471 ha. Yet, the potential for increasing plantation area and oil production is still very large. Apart from land

IMAGE 1

A cajuput plantation in Rimbajaya village, Biak, after pollarding at 1.5 m height

Credit: A. Rimbawanto

availability, efforts have also been made to improve the genetic quality of seed sources. Cajuput seed that produces high-yielding trees is already available and can be directly used for establishing cajuput plantations.

As a result of the high demand for cajuput oil in the country, which is estimated to be more than 3,500 t per year (Edy Tjugito, pers. comm., 25 January 2016), there has been a chronic lack of supply. To cover this shortfall, the industry has imported eucalyptus oil for blending with cajuput oil. According to the Indonesian Essential Oils Council (Dewan Atsiri Indonesia), cajuput and eucalyptus oils are defined as oils containing 1,8-cineole; therefore, mixing the two types of oil does not reduce the quality of cajuput oil, though the distinctive smell of cajuput oil is no longer prominent. However, Indonesian national standard SNI 3954:2014 stipulates that cajuput oil is obtained from distilling the leaves of cajuput plants (*Melaleuca* sp.) (National Standardisation Agency 2014), so blended oils do not meet the national standard.

The lack of cajuput oil supply is related to the source of raw materials. Cajuput natural stands in Maluku and monoculture plantations in Java are of low productivity, both in biomass and oil yield. In Maluku, stands generally comprise old trees that grow wild and there has been no effort to improve quality. Low biomass (leaf) productivity is caused by two factors: 1) Low plant quality (both genetically and physiologically); and 2) In cajuput plantations in Java, crop cultivation is not optimal and stands are generally intercropped; stocking ranges between 1,250 and 2,000 trees/ha.

In 1996, a selection and breeding program was initiated to increase the productivity of cajuput stands by increasing oil yields and levels of 1,8-cineole. The Center for Forest Biotechnology and Tree Improvement (CFBTI) in Yogyakarta, in collaboration with CSIRO Forestry and Forest Products and with funding support from AusAID and ACIAR, is the first and the only R&D institution in Indonesia that conducts research to improve the genetic quality of cajuput. Oil yield has been a major focus of breeding because this trait is more influenced by genetic factors than environmental factors and is, therefore, inherited (Doran et al. 1998). Through selection of superior individuals following the methods of plant breeding (Zobel and Talbert 1984), superior cajuput seeds have been produced with higher oil yields and 1,8-cineole content (Susanto et al. 2003). With the availability of these genetically improved seeds, one of the obstacles to the further development of cajuput stands has been overcome. The use of superior seeds for the development of cajuput plantations will help increase stand productivity and cajuput oil production.

In this book, we use the term cajuput 'plantation' rather than cajuput 'forest' because, in practice, cajuput plantations cannot be accurately referred to as forests. According to the FAO (2001), forests in the tropics (natural and planted) are stretches of land with a tree canopy covering more than 10% of an area of more than 0.5 ha; the trees must reach a minimum height of 5 metres. Cajuput trees are trimmed to a height of 1.5 metres every 9–12 months for ease of collecting leaves and, consequently, never meet either the height or canopy characteristic of the FAO's definition of forest.

Cajuput plantations in Java are an example of the successful domestication of a plant species. Although not native, the species grows well on dry marginal land in Java. The opportunity to develop the cajuput oil industry remains promising, given the large gap between supply and demand. Indonesia, as the world's largest producer of cajuput oil, has all the necessary factors – superior germplasm, land, climate, humans, financing – to take advantage of this opportunity. Currently, on a small scale, the construction of cajuput plantations and distilleries is being carried out for the communities in Rimbajaya village in Biak, Papua; Kampar district in Riau; North Lampung in Lampung; Gunungkidul in Yogyakarta; and Bangkalan in Madura. At the industrial scale, 4,000 ha of cajuput plantations and refineries are being established in Katupa village, Bima, West Nusa Tenggara.

This book aims to document information about the cajuput tree and its oil which remains part of the culture of Indonesian people.

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2

All about cajuput trees

2 ALL ABOUT CAJUPUT TREES

Melaleuca cajuputi subsp. *cajuputi* belongs to the genus *Melaleuca* in the family Myrtaceae. *M. cajuputi* comprises three subspecies (Craven and Barlow 1997):

- subsp. *cajuputi* R.Powell
- subsp. *cumingiana* (Turcz.) Barlow
- subsp. *platyphylla* Barlow.

In the old literature, its scientific name was *Melaleuca leucadendra* or *M. leucadendron* (Craven and Barlow 1997). This generic name is taken from the Greek *melas*, meaning black or dark, and *leucon*, meaning white, referring to the appearance of white branches and black tree trunks in the first species given the scientific name *Melaleuca leucadendra*, whose stems are sometimes black from burning.

The naming of cajuput seems to be based on the appearance of the bark of the tree, which tends to be whitish. In the eastern part of Indonesia, *Eucalyptus alba* is also called cajuput, because the stem bark is also whitish/bright. The mention of cajuput oil in the East Nusa Tenggara region often refers to oil distilled from the leaves of *E. alba* trees.

Melaleuca cajuputi is the only one of about 290 species of the genus *Melaleuca* that grows naturally to the west of Wallace's Line, whereas most species of the genus *Melaleuca*

IMAGE 2

M. cajuputi subsp. *cajuputi* in Namlea, Buru
Credit: A. Rimbawanto

IMAGE 3

M. cajuputi subsp. *platyphylla* in Papua New Guinea
Credit: JC Doran

are native to Australia. About 30 species grow naturally in the tropics, some of which are *M. argentea*, *M. cajuputi*, *M. dealbata*, *M. leucadendra*, *M. quinquenervia*, *M. saligna* and *M. viridiflora*. The wood is generally hard, of medium density, resistant to insects, and with a high silica content. Besides *M. cajuputi*, other species known as producers of essential oil are *M. quinquenervia* and *M. alternifolia* (Brophy 1999).

Research related to genetic structure of populations of *M. cajuputi* east and west of Wallace's Line, using an allozyme (isozyme) as a marker, showed that *M. cajuputi* originated from Australia, and then spread north and west because it could grow well in marginal soil (Lum 1993).

The word cajuput has been adopted in English to refer to the oil extracted from the leaves of this plant. According to Brophy et al. (2013), this word is thought to originate from the Indonesian word *kayuputih*, a name known for this species; the subsp. *cumingiana* is from the name of Hugh Cuming (1791–1865), an explorer and naturalist who collected many botanical, zoological and chronological specimens from the Malesian region; and the subsp. *platyphylla* is from the Greek platys, meaning wide, broad or flat, and *phyllon*, meaning leaves.

IMAGE 4

M. cajuputi subsp. *cumingiana* in South Sumatera
Credit: Bastoni (Forestry Research Institute of Palembang South Sumatera)

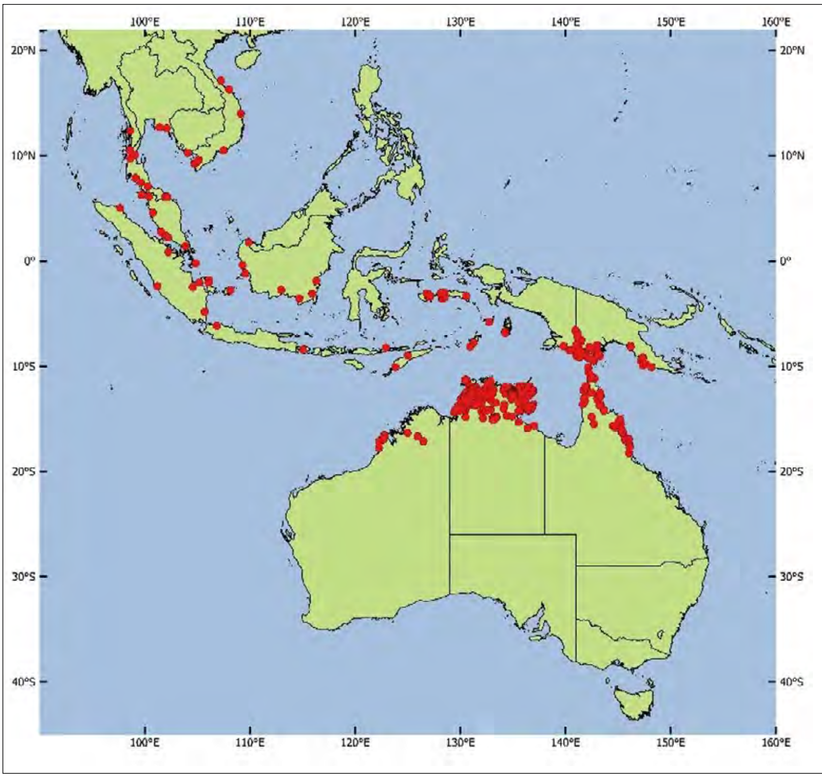

IMAGE 5

Natural distribution of *Melaleuca cajuputi*

Source: Brophy et al. 2013

2.1 Natural distribution

The natural distribution of *M. cajuputi* subsp. *cajuputi* covers north-western Australia (Western Australia and the Northern Territory) and Indonesia, namely Ambon, Buru, Seram and eastern Timor; subsp. *cumingiana* covers the western part of Indonesia (Sumatra, West Java and southern Kalimantan), Malaysia, Myanmar, Thailand and Vietnam; and subsp. *platyphylla* covers the northern part of Queensland, Australia, the south-western part of Papua New Guinea, and the southern part of Papua, Aru and Tanimbar in Indonesia (Brophy and Doran 1996).

In Seram, natural cajuput stands are found in the west along Hoamoal Bay over an area of approximately 120,000 ha (Brophy and Doran 1996; Idrus et al. 2016). Understorey species include *Chromolaena odorata* and *Imperata cylindrica* in the lowland plains and low undulating mountain ridges at 30–150 metres above sea level between Pelita Jaya village and Kotanea village. They generally grow in a gravelly, reddish soil which is slightly acidic.

In natural stands, *M. cajuputi* subsp. *cajuputi* grows in areas with a minimum temperature of 17–22 °C and a maximum of 31–33 °C; average annual rainfall is 600–1,750 mm. It is found in swamps and coastal plains (Brophy and Doran 1996).

IMAGE 6

A worker harvests cajuput leaves by cutting branches and then stripping the leaves from the branches.

Credit: A. Rimbawanto

IMAGE 7 Cajuput naturally regenerating from root suckers in Pelita Jaya village, West Seram; leaves are harvested from these areas for distillation.

Credit: A. Rimbawanto

IMAGE 8 A cajuput area after fire in Namlea, Buru Island

Credit: A. Rimbawanto

IMAGE 9

General appearance of cajuput trees; a main characteristic is the brightly coloured, whitish bark.

Credit: A. Rimbawanto

2.2 Characteristics of cajuput trees

Cajuput trees generally have a single stem. Tree height can reach 25–40 metres and diameter 1.2 metres. The tree has a fairly dense canopy, with green leaves, and a whitish bark (Image 9).

Trunk

The length of the trunk can vary from 2 metres to 35 metres, with hanging branches. The whitish bark is layered, with an irregularly peeling surface (Image 10).

The wood is classified as hardwood. Although the trunk can reach diameters that are suitable for sawn boards, this is generally not done because the wood's high silica content can easily dull saw blades. Instead, the wood is usually used for poles and the soft bark for wrapping.

IMAGE 10

Appearance of cajuput tree bark

Credit: A. Rimbawanto

IMAGE 11 Various forms of cajuput leaves
Credit: A. Rimbawanto

Leaf

The leaves are small and rather thick with a short stem, and form an alternate pattern on the branch. Each leaf is oval-shaped, 40–140 mm long and 7.5–60 mm wide, with a pointed apex and base, veins almost parallel and a flat margin. The leaf surface is hairy and grey-to-brownish or dark green. The leaves are filled with oil glands and when squeezed emit the smell of cajuput oil (Brophy et al. 2013). In dry climates, the odour can be smelled just by rubbing the leaves.

However, the shape, size and colour of the leaves can vary (Image 11). This variation appears to have no effect on oil yield and 1,8-cineole content. Cajuput oil has antibacterial and anti-inflammatory properties, and has traditionally been used to treat ailments such as colds, influenza, and itching due to insect bites. It is used as a fragrance in soaps, cosmetics, detergents and perfumes.

Flower

The flower of the cajuput tree is classified as compound (hermaphrodite) and shaped like a bell. Each flower has five white petals with yellowish-white pistils, and multiple yellow filaments. The flowers grow on the tips of the branches (Brophy et al. 2013).

The time and intensity of flowering in the *Melaleuca* genus varies between species and growing environments. In Gunungkidul, for example, flowering occurs between February and May, and the fruit (capsule) is ready for harvest from November onwards. It takes nine months from the formation of flower buds to mature fruits (Baskorowati et al. 2008). In Buru and Seram, flowering commences in July (Gunn et al. 1996), and in northern Vietnam the flowering season is from June to October (Schmidt and Thuy 2004).

IMAGE 12 Display of cajuput flowers
Credit: A. Rimbawanto

Pollination

Insects are the main agents of pollination in *M. cajuputi*; in fact, almost all species in the genus *Melaleuca* are pollinated by insects. For cajuput, Kartikawati (2008) reported several pollinating insects from the Hymenoptera and Lepidoptera orders. Baskorowati et al. (2010) observed various species of insects visiting *M. alternifolia* flowers in New South Wales, Australia, including honey bees.

Information related to the viability of pollen was reported by Hendrati et al. (2002); pollen viability was tested using agar media. Newly taken pollen had a viability of 66%. After storage for 3 and 4.5 months in an airtight bottle at 3–5 °C, the viability dropped to 35% and 4%, respectively. Information about pollen viability is useful when pollinating artificially.

Crossbreeding is common in cajuput (Kartikawati 2005). In the cajuput seed orchard in Gunungkidul, most trees were self-incompatible. Self-incompatible trees when mated cannot produce seeds. Self-incompatibility is a plant mechanism to avoid inbreeding. Similar results were reported by Baskorowati et al. (2010) in *M. alternifolia*, and by Barlow and Forrester (1984) in other species in the genus *Melaleuca*.

IMAGE 13 Pollinating insects on cajuput plants
Source: Kartikawati 2008

IMAGE 14 Cajuput fruit, or capsule
Credit: A. Rimbawanto

Fruit

Cajuput fruit is referred to as a capsule. Each capsule contains a mixture of viable seeds and 'chaff' that originates from unfertilised ovules and other debris from within the capsule. Fertilised seeds are generally solid and blackish-brown, while the unfertilised ovules are generally rather flat and light brown in colour. Cajuput plants begin to produce capsules with abundant seeds at the age of two years; the percentage of seeds that germinate is generally above 80% (Kartikawati et al. 2014).

Cajuput seeds are very small, and each capsule contains 10–30 seeds; one gram of seeds can produce 3,000–6,000 germinants (germinating plants). The seeds are classified as orthodox, i.e. their water content can be reduced to 5% and if stored at low temperatures (4–10 °C) they can survive for several years (Willan 1987).

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3

Cultivating cajuput

3 CULTIVATING CAJUPUT

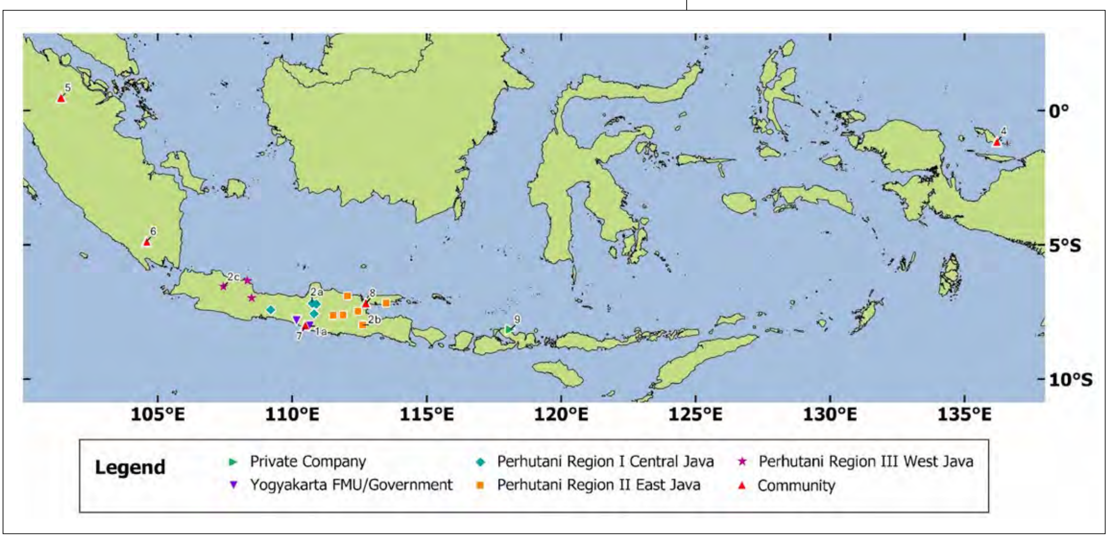
Cajuput has been cultivated for a long time. Cajuput plantations in Java, including those in Gundih managed by Perhutani, were first planted in 1926 in the Dutch colonial era, using seeds from Buru Island (Doran et al. 1998). Since then, cajuput cultivation in Java has expanded to more than 27,000 ha. However, this plantation estate is relatively small compared to the 120,000 ha of natural stands in the Maluku Islands (Idrus et al. 2016).

With the production capacity of the natural stands in Maluku Province declining due to genetic, environmental and social factors, the cajuput plantation resource in Java (see Image 15) has played an important role in supplying cajuput oil. Almost 75% of the national production of cajuput oil is now produced from cajuput plantations in Java. Getting accurate data on production and demand for cajuput oil is almost impossible. Based on figures published by Gunn et al. (1996), the national production of cajuput oil is almost 400 t/year, and it comes from two sources: the cajuput industry in Java (300 t/year) and the cajuput industry in Seram, Buru and Ambon (90 t/year).

However, based on information from cajuput oil businesses, oil production from Seram and Buru is estimated to be more than 300 t/year (May 2017, pers. comm.), far higher than the figure (90 t) in Gunn et al. (1996). According to the 2015 Central Bureau of Statistics (Maluku

IMAGE 15 Map showing locations of cajuput plantation resources in Indonesia

Credit: P. Macdonell, Forest Industries Research Centre, University of the Sunshine Coast, Queensland, Australia



Province BPS 2016), cajuput oil production from Maluku Province was only 26.65 t. Official figures from Perhutani indicate that their annual production is 296 t (Perhutani 2014); annual production from Yogyakarta is 40 t. Using production assumptions based on information from industry sources, the total national cajuput oil production may be as much as 650 t/year.

Oil production from the Maluku Islands is also low, partly because oil yields from natural stands are low (0.6%), (distillers in Seram and Buru, 2017, pers. comm.). Factors that cause this low oil production are the poor genetic quality of the trees in natural stands and the way the stands are managed. Another factor is the process of oil distillation which is still traditional, using a wooden pot and a source of steam heated with a wood fire, such that the steam production and condensation process take place in an inefficient way.

IMAGE 16 Cajuput plantations aged six months in Katupa village, Bima, West Nusa Tenggara

Credit: A. Rimbawanto

In addition to the existing cajuput plantations in Java, since 2015 commercial investments in cajuput plantations in Bima, West Nusa Tenggara, have created an additional area of 4,000 ha. This plantation resource is an important source of livelihoods for the community in Sanggar district, Bima regency. To establish the plantations, more than 500 people worked in nurseries and planting. More employment will be available when the cajuput trees are ready to be harvested and the distillation plant becomes operational. This new cajuput plantation is expected to boost the cajuput oil industry in Indonesia, so that it can reduce imports of substitute eucalyptus oil.

3.1 Nursery

Nursery considerations

Seed quality plays an important role in the cultivation of plants, and good quality seeds help promote successful plant establishment. The nursery elements that must be considered are (Sukijan 2015):

- Seed quality: Seed quality embraces physiological and genetic factors. Physiologically good seeds have a high germination rate and good vigour; genetic qualities are related to the genetic superiority of seeds. Superior seeds are seeds developed through plant breeding that have led to productive plants in the right environment. For cajuput, superior seeds are produced in seedling and clonal seed orchards and are already available in sufficient quantities.

- Polybags: Polybags are used for growing cajuput seedlings, particularly in small and temporary nurseries, because they are cheap and widely available. The most popular size is 6 cm × 10 cm. In large-scale and permanent nurseries, polytube containers are now widely used because they produce seedlings with better root quality and form.

- Germination/propagation/growing media: The availability of raw materials may determine what propagation medium to use. Cajuput seeds are very small and are first sown in boxes until they have germinated. An important requirement for the germination medium is good porosity so that its moisture content remains optimal, and to prevent triggering the development of diseases such as damping off; good porosity also makes it easy to transplant seedlings into the growing medium. The nutrient content of germination media can be low because the seedlings are only present in it for a short time and they can also use nutrients stored in their cotyledons. When growing the seedlings in the polybags and polytubes, the medium must have the following physical properties: 1) be light and have a low bulk density to facilitate ease of transport of seedlings to the field; 2) have good porosity to avoid waterlogging; and 3) have a high water-holding capacity so that it dries slowly. In general, germination media can be based on fine sand, and growing media can be based on topsoil, organic fertiliser/compost, and sand in a ratio of 3:2:1. If the soil already contains enough sand, adding sand to the mixture is unnecessary. Cajuput seedlings can also be raised in pure soil, though their growth will be slower.

- Shade: High intensity sunlight can kill or inhibit the growth of young cajuput seedlings. Shade of about 60% is required during the first two months. The shade can then be gradually reduced towards no shade to harden the seedlings ahead of planting in the field.

IMAGE 17

Beds of seed germination boxes

Credit: A. Rimbawanto

Germination

Cajuput seeds are germinated by sowing them in boxes on a fine sand medium. The boxes are then kept at lower temperature (25–27 °C) and high humidity (91–94%). To prevent any fungal infections, the sowing medium first needs to be sterilised by heating it to 100 °C (heat sterilisation). Water for sprinkling onto the medium should be clean. To conserve moisture, the boxes can be covered with plastic and then periodically watered as necessary. Spraying fungicides may also be necessary to prevent the growth of pathogenic fungi.

Because of their small size, the cajuput seeds first need to be mixed with fine sand and this mixture spread evenly across the surface of the medium in the box. Good seed will commence germination on the fifth day after sowing. From the seventh day on, the germinants will have developed two pairs of leaves and are ready to be transplanted into the growing medium.

Tending and maintaining seedlings

Given the very small size and delicate nature of germinants, transplanting into polybags or polytubes should be done in the morning (8 am – 10am) or evening (4 pm – 5 pm) to avoid the sun's heat. To maintain a high humidity, the beds of transplanted seedlings should be enclosed in plastic or receive a periodical fogging every day. Seedling beds should be shaded by up to 60% using shading net for two months. Rapid growth will occur after the shade is removed. At about three months old, the seedlings will be ready for planting; they will have reached a height of 20–30 cm and a stem diameter of more than 2 cm. Seedlings that are too large because they are more than three months old can be top-pruned to reduce transpiration (water loss) so that they are not stressed when planted.

IMAGE 18

Condition of seedlings that have germinated and are ready to be transplanted into polytubes

Credit: A. Rimbawanto

IMAGE 19

Condition of seedlings in polytubes four weeks after transplanting

Credit: A. Rimbawanto

Vegetative propagation by cuttings

Cajuput can also be propagated by vegetative means through shoot cuttings. This is a common way of producing large numbers of superior clones that have high oil yield, high biomass production (leaves) and high levels of 1,8-cineole. Cuttings are easily obtained from juvenile shoots on young plants (aged 1–2 years) or from mature trees that have been pruned; pruning can stimulate the growth of new juvenile shoots. Sources of stem cuttings can be in the form of seedlings that grow in pots/polybags, trees that grow in the field, or plants that are hedged near the nursery specifically for shoot production.

The formation of young shoots of cajuput can be stimulated by wounding plant stems or upright growing branches. Because of cajuput's high sprouting ability, in a short time young shoots will develop from the wound scar. These shoots make ideal cuttings when aged 1–2 months. Older shoots can have a reduced ability to form roots from the cuttings. The right time to harvest these shoots is when they reach a length of 30–40 cm (Longman 1993). For producing cuttings in large quantities, clonal hedges of superior plants/trees dedicated to this requirement need to be established.

The propagation of shoot cuttings should be done in temperature-regulated enclosures where the humidity is controlled by mist or fogging. If no fogging facilities are available, the beds can be enclosed in plastic covered by shading net that provides 50–75% shade. Soil dominated by clay minerals has been shown to be the best rooting medium for cajuput shoot cuttings. To speed up the formation of roots, shoot cuttings can be dipped in a solution of root hormone such as Rootone F. Cuttings should be watered regularly to keep moisture content high (90% or more), and fungicide should be sprayed as necessary to prevent the development of pathogenic fungi.

3.2 Planting

Land management

Establishing cajuput plantations is no different from other species. To create a suitable environment for seedling growth, field preparation may include clearing the land of trees, stumps and shrubs. Newly planted seedlings need loose soil and to be free from weed competition; there should be enough moisture in the soil so that they can quickly establish and adapt to their new environment. There are two ways of preparing land for establishing a tree plantation. The first is to cultivate all the soil thoroughly using tractor-driven machinery. The second is to cultivate the soil locally at the point around the planting holes using manual tools. The optimal planting hole for cajuput seedlings is 25 cm × 25 cm with a depth of 30 cm. To encourage rapid establishment, the soil used in the planting holes can be mixed with compost or a phosphorus fertiliser such as TSP or SP-36. However, it is worth noting that too much fertiliser might burn the roots. As the trees grow, the cajuput plants will compete with other plants for light, water, nutrients and space. Therefore, it is important to manage grass and weeds. Land can be cleared manually, mechanically using heavy equipment, or with herbicide, depending on the field conditions and costs.

Spacing

The productivity of cajuput plantations for oil production is determined by the weight or biomass of leaves harvested. The more weight of leaves obtained per unit area, the more productive the plantation. The cajuput plantations in Java that use intercropping systems have a 4 m × 2 m spacing; the 4 m between rows is used by farmers to grow crops. If a cajuput plantation is managed as a monoculture, the spacing can be between 2 m × 1 m and 1 m × 1 m, or between 5,000 and 10,000 trees/ha. The aim of this closer spacing is to maximise leaf production and promote early crown closure, thus reducing weed competition.

Planting time

As with other types of plants, the ideal time to plant cajuput is during the rainy season. However, if planting in the dry season or in an area with low rainfall, a moisture absorbent material called Aquasorb can be added into the planting hole. Aquasorb can bind water that is in the soil and then release it to be absorbed by the plant roots. Supplementary hand-watering might be required to ensure a good survival rate.

Fertilisation

Cajuput does not require highly specific growing conditions. It grows well on calcareous marginal lands, in areas of low rainfall, and in areas with a long dry season. In Java, cajuput is widely planted in grumosol (Vertisol) soils, formed from volcanic limestone and tufa rock which are generally alkaline (Ilmu Geografi 2015), and in latosol soils (Alfisol and Oxisol soil orders). In its natural distribution, cajuput grows in the rainfall range of 600–2,000 mm/year.

The productivity of a cajuput plantation can be measured from the production of leaf biomass. The more leaf production per ha per year, the more productive the plantation. The biomass of leaves harvested can be increased by applying fertiliser. To maintain nutrient availability in the soil, fertilisation is particularly needed to replace the nutrients harvested with the leaves. NPK (nitrogen, phosphorus, and potassium) and TSP (triple superphosphate) fertilisers can be used once a year at the start of the rainy season, at a rate of 10–20 grams per tree.

Soil fertility in cajuput plantations can also be maintained in part by returning the leafy biomass after distillation and composting to the harvested plantation. About 30–50% of the leaf volume is used as fuel in the refinery, so 50–70% can potentially be wasted if not processed into compost and returned to the field.

3.3 Harvesting leaves

Newly planted cajuput trees will be ready to harvest at the age of three years; at this age the oil content has been maximised and a stable oil yield can be obtained. At harvesting, the cajuput tree is cut back to a height of 1.5 m. In cajuput plantations in Java, harvesting is carried out every 9–12 months. Workers cut branches with diameters of 0.5 cm and above, and all the twigs with leaves that have grown during this period are removed.

The best time for harvesting is in the dry season; harvesting is generally avoided in the rainy season because the water content of the leaves is too high. Wet biomass is unfavourable to the distillation businesses because harvesting wages are based on harvested leaf weight. Oil quality can also be affected, as the odour of the oil can be masked by a damp, musty smell. Based on experience in Perhutani, cajuput trees can remain productive until the age of 40 years.

In Buru and Seram islands, only the leaves are collected, being separated/pulled directly from the branches, with twigs and branches retained on the tree. The harvested leaves are generally less than six months old. Due to repeated burning – common practice in this area – most existing cajuput plants are shrubs originating from cajuput root suckers.

3.4 Cajuput plantations in Java

Several areas in Java are suitable for cajuput plantations. For example, areas with rainfall below 2,000 mm/year and with calcareous soil in East and Central Java are centres of cajuput plantations and oil production.

Cajuput plantations in Java are generally intercropped with food crops, such as corn, peanuts and dry rice. This is achieved by making the tree rows either 4 m or 3 m apart. Intercropping is done to meet the community's need for food and provide additional income. The negative side of intercropping is that it lowers the biomass production of cajuput leaves because fewer trees are planted, and these trees must compete with the food crops for water and nutrients. Consequently, the average production of leaves per tree is only 2–3 kg per leaf crop (Sumari, June 2017, pers. comm.).

Cajuput plantations at Perhutani

Cajuput plantations in Java are mostly planted by state-owned forest company Perhutani, which manages an area of 27,320 ha in several forest management units (FMUs):

- Perhutani Region 1 in FMUs of Telawa, Gundih, Surakarta and West Banyumas
- Perhutani Region 2 in FMUs of Pasuruan, Mojokerto, Madiun Tuban, Madura and Nganjuk
- Perhutani Region 3 in FMUs of Purwakarta, Indramayu, and Kuningan.

For location details, see Image 15.

Cajuput oil production in 2011 at Perhutani amounted to 265 t with an average oil yield of 0.7% (Perhutani 2014). Leaf production generally fluctuates with the intensity of tree maintenance and fertilisation, seasonal factors, and farmer behaviour. The average leaf production per tree in the Perhutani plantations is 1–3 kg per harvest (Perhutani Ponorogo 2016 MKP Factory, pers. comm.). These yields are relatively low because each tree has the potential to produce 5–7 kg of leaves per harvest (Kartikawati et al. 2014).

IMAGE 20

Cajuput plantations which have been pruned at 1.5 m height

Credit: A. Rimbawanto

IMAGE 21

Cajuput leaves ready to be distilled

Credit: A. Rimbawanto

IMAGE 22 Spent leaves being turned into briquettes for fuel

Credit: A. Rimbawanto

The cajuput leaves are harvested every nine months, especially in the dry months. Harvesting of cajuput leaves includes twigs and branches no more than 0.5 cm in size. The presence of twigs and branches creates air cavities in the pile of leaves, allowing hot steam to reach the leaves during the oil distilling process. Harvested cajuput leaves are processed into cajuput oil at the Perhutani oil distillation plants at Madiun, Gundih and Mojokerto.

IMAGE 23

Leaves in distillation pots before being compacted and having the steam-proof lids secured

Credit: A. Rimbawanto

Cajuput plantations at FMU Yogyakarta

At FMU Yogyakarta, the total plantation area is 4,471 ha, with plant density varying from 1,000 to 2,000 trees per hectare. This variation in density is partly due to tree death because of intercropping. Leaf production also varies, from 2 kg to 3 kg per tree at each harvest (Sumari, June 2017, pers. comm.).

Production of leaves and oil in FMU Yogyakarta is relatively stable. Data from 2003 to 2011 (KPH Yogyakarta 2012) showed leaf production varied from 4,107 t to 4,746 t, and oil production from 39.5 t to 44.7 t. From these figures, it can be estimated that the average oil yield is 0.9%.

FMU Yogyakarta manages two large-scale distillation plants, in Sendangmole and in Gelaran. The Sendangmole plant is classified as a modern plant with three stainless-steel pots, each with a capacity of one tonne of leaves; a steam generator unit; and a cooling unit to separate oil from water vapour. This factory can process 9 t of leaves and produce 80 kg of oil daily.

The productivity of the Yogyakarta cajuput plantations could be improved by replanting old plantations where the age of the trees is over 35 years, and by increasing the number or trees in the existing plantation. In addition, there could be some intensification of land use by better regulating the pattern of planting in intercropping systems. Using superior cajuput seeds and fertilising the plants would also increase productivity.

IMAGE 24 Cajuput stand intercropped with cash crops

Credit: A. Rimbawanto

IMAGE 25

Workers fill pots with leaves and unload leaves after distillation.

Credit: A. Rimbawanto


lenovo

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4

Improving the genetic quality of cajuput plants

4 IMPROVING THE GENETIC QUALITY OF CAJUPUT PLANTS

In the previous chapter, we discussed the productivity of cajuput in its natural distribution in the Maluku Islands and in plantations in Java for the cajuput oil industry in Indonesia. From the area of the existing cajuput plantations in Java and the natural stands in Maluku, it is estimated that the production of cajuput oil can meet at least half of the national demand. However, the available data shows that national cajuput oil production is still well below even half of the estimated national demand. This can be attributed to many factors; especially low productivity of biomass and oil yield (Doran et al. 1998).

According to Doran et al. (1998), cajuput has been planted in Java since 1926 and is thought to originate from a narrow genetic source. At that time, it was planted in Gundih for the purpose of reforestation. Subsequently, this resource was used to produce essential oils, with further plantings on a large scale, especially on marginal lands. However, these plantings were done using low genetic-quality seeds collected from plantation boundary trees and other mature stands in plantation areas of *M. cajuputi* subsp. *cajuputi* in Java. For a long period, no attempt was made to improve the genetic quality of the species. Hence, both the productivity of stands and oil yield remained low, the latter at only about 0.6–0.8%. Efforts to increase plant productivity and oil yield by selecting trees with high oil production did not produce superior trees because the genetic diversity of the cajuput population in Java was then very narrow.

4.1 Cajuput breeding strategy

Three steps can be taken to increase cajuput oil production in Indonesia:

1. Boost the productivity of individual cajuput plants by improving their genetic quality. This can be achieved by breeding genetically improved seeds.
2. Increase the plantation area and the production of leaf biomass for the distillation industry.
3. Revitalise and renew the oil distillation plants. More effective and efficient refining units can increase the quantity and quality of cajuput oil.

Integrating these three approaches will increase national cajuput oil production. In this chapter, we focus on step 1, improving the genetic quality of cajuput plants.

According to Zobel and Talbert (1984), tree breeding is a systematic effort to assemble genetic diversity to produce individuals that are better suited to the desired goals. To achieve these goals, breeding aims to utilise genetic differences between individuals in the population to change the expression of economically important traits such as biomass production and yield (Finkeldey and Hattemer 2007). There are three main activities in a breeding program: selecting individuals with superior qualities; crossbreeding among these superior individuals; and testing the progeny for improved performance (Funda and El-Kassaby 2012), while allowing ‘backwards’ or ‘forwards’ selection to the breeding population.

In Indonesia, the cajuput breeding program was initiated and carried out by the Indonesian Center for Forest Biotechnology and Tree Improvement (CFBTI) in collaboration with the CSIRO, Australia, through several Australian Government assistance programs provided by AusAID and ACIAR. This breeding program aimed to increase the productivity of cajuput plants, oil yield and, especially, levels of 1,8-cineole. Brophy et al. (2013) state that cajuput populations vary in oil yield from about 0.4% to 1.2% and in 1,8-cineole content from 3% to 60%. Meanwhile, according to Winara et al. (2012), cajuput in Wasur National Park in Papua has an oil yield of 1.07%.

The breeding program began in 1995, with expeditions to collect seed and leaves of *M. cajuputi* subsp. *cajuputi* from natural stands in the Maluku Islands: Buru Island (Ratgelombeng and Masarete villages); Seram Island (Pelita Jaya, Waipirit and Cotonea villages); Ambon Island

TABLE 1

Family information (parent tree or seedlot) of cajuput plants selected for the base population of the breeding program

Seedlot	Family number code	Oil yield (W/W% DW)	1,8-cineole (%)	Provenance	Latitude (E)	Longitude (S)	Altitude (metres above sea level)
MM2033	1	3.88	47	Ratagelombeng, Buru	03° 08′ 33″	126° 54′ 36″	40
MM2054	2	2.53	62	Masarete, Buru	03° 22′ 38″	127° 08′ 12“	20
MM2057	3	2.45	59	Masarete, Buru			
MM2060	5	2.84	59	Masarete, Buru			
MM2064	25	1.01	32	Masarete, Buru			
BVG2913	8	3.35	47	Waipirit, Seram	03° 19′ 43″	128° 20′ 20″	10
BVG2919	9	3.02	57	Pelita Jaya, Seram	03° 03′ 00″	128° 08′ 00″	100
BVG2920	10	2.79	52	Pelita Jaya, Seram			
BVG2923	11	1.82	67	Pelita Jaya, Seram			
BVG2936	12	2.82	64	Cotonea, Seram	03° 04′ 22″	128° 06′ 30″	30
BVG2937	13	1.82	54	Cotonea, Seram			
BVG2941	14	2.93	60	Cotonea, Seram			
BVG2971	15	2.17	63	Suli, Ambon	03° 37′ 02″	128° 18′ 40″	60
BVG2976	18	2.32	59	Suli, Ambon			
DL786	19	2.78	59	Wangi, NT Australia	13° 09′ 00″	130° 35′ 00″	30
DL1705	20	2.96	55	Port Keats, NT Australia	14° 14′ 02″	129° 31′ 11″	5
DL1787	21	4.85	47	Beagle Bay, WA Australia	16° 58′ 33″	122° 40′ 04″	10
DL1797	22	3.47	52	Beagle Bay, WA Australia			
DL1803	23	3.59	58	N Broome, WA Australia	17° 46′ 00″	122° 16′ 00″	10
Gundih	24			Gundih, Central Java	07° 11′ 07″	110° 54′ 19″	60

W/W%: weight of oil / weight of leaves (percentage)
DW: dry weight
NT: Northern Territory; WA: Western Australia
Source: Doran et al. 1998

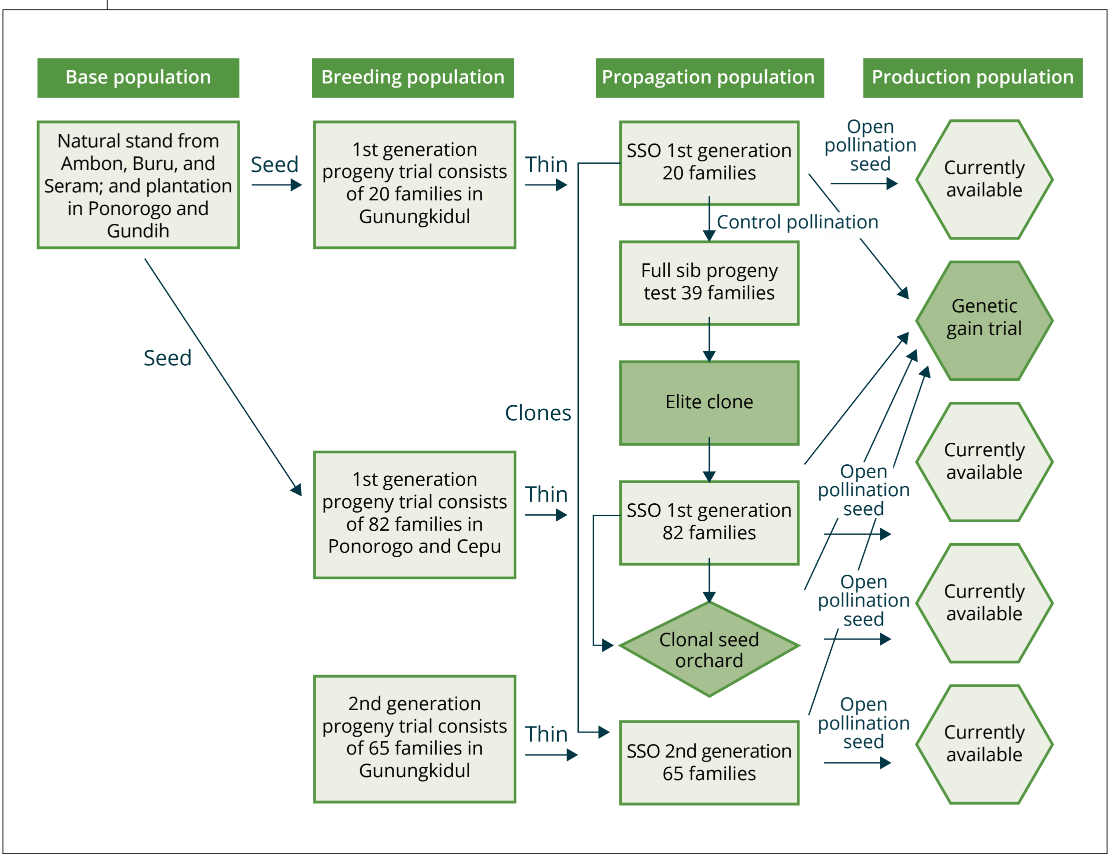
(Suli village); and north-western Australia, in the Northern Territory (Wangi and Port Keats) and in Western Australia (Beagle Bay and north of Broome). In total, leaves and seed from 256 trees from 23 natural populations (provenances) were collected. Leaf was used for oil screening based on oil yield percentage and 1,8-cineole content following laboratory tests using distillation and gas chromatography, respectively. After oil screening, only 19 trees with seed available were selected to be included in the breeding base population established as a first-generation progeny (F-1) trial. Information on each family used is presented in Table 1. Individual trees in the progeny test were selected based on the following criteria: biomass; high oil yields and 1,8-cineole levels; good germination ability; and adaptability to the new growing environment (Doran et al. 1998).

Studies on several species of plants have found that oil yield and 1,8-cineole content have high diversity and a high heritability value. This means that these traits are strongly controlled by genetic factors. The 1,8-cineole content in some eucalyptus species is also known to have high heritability values. In *M. alternifolia*, the individual heritability for oil yield reached 0.92, while the individual heritability for 1,8-cineole content reached 0.51 (Doran et al. 2002). A heritability value close to 1.0 indicates that almost all of the variability in a trait comes from genetic rather than environmental differences. In *Eucalyptus camaldulensis*, the individual tree heritability value for 1,8-cineole was 0.5 (Doran and Matheson 1994) and in *E. kochii* it was 0.83 (Barton et al. 1991). A similar approach to that used to improve oil production in *M. alternifolia* was adopted for *M. cajuputi*.

A diagram of the strategy for breeding cajuput in Indonesia is presented in Image 26.

IMAGE 26 The breeding strategy for cajuput in Indonesia

Source: Source: Kartikawati, Nirsatmanto et al. 2021



4.2 Cajuput seed orchards

A seed orchard is composed of selected individual plants that are genetically superior and which are managed for seed production (El-Kassaby 2000). The cajuput breeding program carried out by CFBTI has established several seed orchards over several years. Cajuput seed orchards are established at various stages of selection in the breeding program so that increases in oil yield and 1,8-cineole content are captured in seed production and distribution.

Seedling seed orchard

A seedling seed orchard (SSO) consists of superior trees grown from seed following natural/open or controlled pollination of trees selected in the breeding program. These orchards generally produce seeds with a broader genetic base through open pollination, where the superior female parent is known but the male parent is unknown (El-Kassaby and Askew 1998).

The cajuput breeding program has established three first-generation SSOs, one each in Gunungkidul, Ponorogo and Cepu (see Image 27), based on 20, 82 and 82 families, respectively.

First-generation seedling seed orchard in Gunungkidul

The Gunungkidul SSO was established to meet the demand for superior seeds and to promote the establishment of highly productive plantations in the Special Region of Yogyakarta, where cajuput is an important source of regional income.

First planted as a first-generation progeny trial (F-1) in Petak 95 Paliyan (Gunungkidul) in 1998 covering an area of 0.9 ha, it was later converted to a seed orchard after evaluation and selection based on growth and oil properties. Twenty families from 11 provenances were tested: Ratgelombeng and Masarete (Buru Island); Waipirit, Pelita Jaya, and Cotonea (Seram Island); Suli (Ambon Island); Wangi (Northern Territory, Australia); Port Keats (Northern Territory, Australia); Beagle Bay (Western Australia); and north of Broome (Western Australia). Seed from a plantation at Gundih, Central Java, was used as a control.

Evaluation and selection of superior families were based on growth, oil yield, and 1,8-cineole content as a percentage of total oil. The first selection was done in April 1999 based on plant growth only (tree height and diameter). Half of the trees that showed poor growth were removed.

IMAGE 27 Map showing established cajuput seed orchards

Credit: P. Macdonell, Forest Industries Research Centre, University of the Sunshine Coast, Queensland, Australia

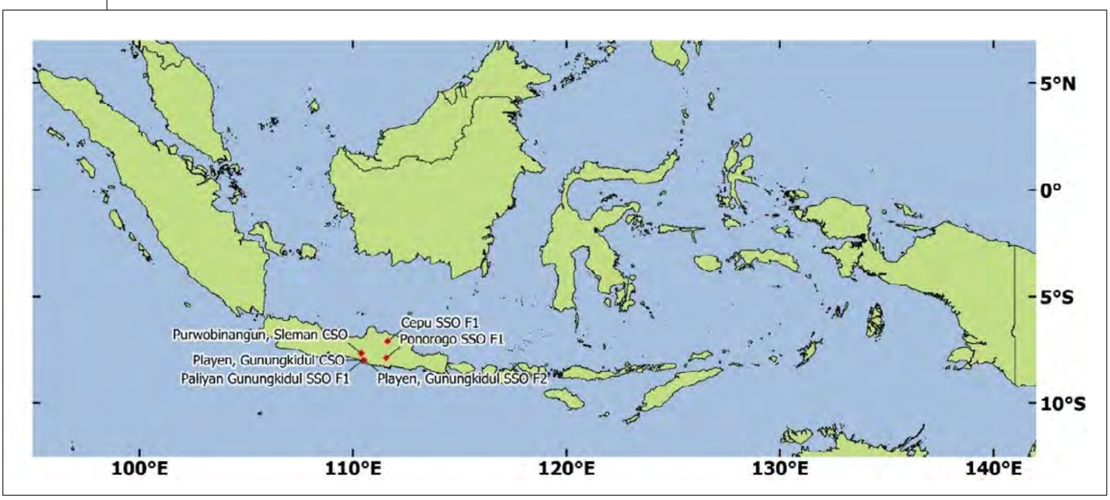


IMAGE 28 Cajuput superior seeds were presented to the Governor of the Special Region of Yogyakarta at a special ceremony held at CFBTI in 2004.

Credit: A. Rimbawanto

The second stage selection was done in April 2000, at age 23 months, and was based on oil yield and 1,8-cineole content. Oil was analysed using laboratory distillation and gas chromatography (Susanto et al. 2003). This second evaluation (Susanto et al. 2003) showed that the provenance groups from Ambon Island produced the highest oil yield, an average of 2.1%, while the provenance groups from the Northern Territory produced the lowest (1.5%). The Gundih control had an oil yield of 1.4%. According to Brophy et al. (2013), oil yields in *M. cajuputi* range from 0.4% to 1.2%, which is much lower than was found in this study. In contrast, the highest 1,8-cineole content was found in provenances from the Northern Territory of Australia (55.7%), and the lowest from Western Australia (47.4%). This indicates that levels of oil yield and 1,8-cineole content are not necessarily directly related. There was also variation in oil yield and 1,8-cineole content between families of the same provenance; the highest recorded were 4.78% and 73.9% for oil yield and 1,8-cineole content, respectively.

This first-generation SSO in Paliyan, Gunungkidul, has produced seeds that give progeny with an average oil yield of 2.0% and 1,8-cineole content of 65%. Average oil yield and 1,8-cineole content from plantations in the Special Region of Yogyakarta had previously been 0.8% and 52%, respectively (Kartikawati et al. 2016). In 2004, the superior seed was released by the Minister of Forestry as the Cajuput KPP-01 Superior Seed, in accordance with Ministry of Forestry Decree No. 372 / Menhut-VIII / 2004. A package of this superior seed was supplied to the Governor of the Special Region of Yogyakarta (Image 28) to revitalise cajuput plantations in Yogyakarta.

First-generation seedling seed orchards in Ponorogo and Cepu

The seedling seed orchards in Ponorogo and Cepu were established using a greater number of families than in the Gunungkidul SSO. This provides a broader genetic basis for selection and is expected to increase the quantity and quality of the seeds produced in seed orchards. There is also more potential for crossbreeding between families.

The seed orchards were established in 2000 in Ponorogo (1.2 ha) and Cepu (0.8 ha). To minimise inbreeding, the initial plots were established using a modified randomised complete block design, which prevents related trees being close to each other (Varghese et al. 2015). Each orchard had 6-tree plots of 82 families with four replications; spacing was 3 m × 2 m.

The first selection was based on growth, with a selection intensity of 50%, i.e. tree numbers were reduced from six to three trees per plot. The second selection was based on oil yield and 1,8-cineole content criteria, with the 10% worst families (eight out of 82 families) being removed; then, for the remaining families, the two worst trees in each plot were removed, i.e. the best tree in each plot was retained (Image 29). Subsequently, the 10 best individual trees from the top-ranking families were selected to be used as material in the development of second-generation SSOs and a clonal seed orchard.

IMAGE 29 Controlled pollination on selected parent trees

Credit: NK Kartikawati

IMAGE 30 Final selection of trees for the cajuput seedling seed orchard in Ponorogo (left) and after selection (right)

Credit: NK Kartikawati

IMAGE 31

Second-generation seedling seed orchard
Credit: NK Kartikawati

Second-generation seedling seed orchard

The establishment of a second-generation (F-2) SSO is intended to combine several improved genetic resources from the first-generation SSOs. In this way, the genetic diversity of the breeding populations can be maintained at a higher level, thereby increasing the potential to obtain seeds of better genetic quality (Rimbawanto et al. 2009).

In 2009, a 0.65-ha F-2 SSO was planted in Playen, Gunungkidul (Image 31). It consists of 65 families. The genetic material used was from open pollination seed of the F-1 SSOs in Paliyan, Cepu and Ponorogo, and controlled pollination seed from the Ponorogo seedling seed orchard. The 65 families were each represented by 3-tree plots with six replications in a modified complete block design; spacing was 3 m × 2 m.

The F-2 SSO was converted from a progeny test. The first selection was based on leaf biomass and the second selection was based on oil content, with the best tree in each plot being retained. Nguyen Thi Hai et al. (2019) reported that there were no genetic correlations among growth, oil concentration and 1,8-cineole content. To simultaneously improve both oil concentration and 1,8-cineole content, index selection was used.

Clonal seed orchard

A clonal seed orchard (CSO) is established using vegetatively propagated material sourced from superior trees. Consequently, the superior traits of this material are identical to those of the parent tree. Seeds are produced faster in a CSO because the trees are already mature. In general, a CSO is composed of 30 to 50 clonally unrelated mother trees (Funda and El-Kassaby 2012).

In 2008, a 0.5-ha cajuput CSO was established at Playen, Gunungkidul, and Purwobiangun, Sleman (Image 32). The intent was to produce seeds from selected clones to further improve the genetic quality of the seeds produced. The clones were superior individuals from the

IMAGE 32

Clonal seed orchard of cajuput in Purwobinangun, Sleman
Credit: NK Kartikawati

TABLE 2

Material sources for the clonal seed orchard at Playen, Gunungkidul

Clone no.	Source of clone	Provenance / Land race
1	Family 9, SSO Ponorogo	Suli, Ambon
2	Family 10, SSO Ponorogo	Suli, Ambon
3	Family 18, SSO Ponorogo	Suli, Ambon
4	Family 28, SSO Ponorogo	Suli, Ambon
5	Family 47, SSO Ponorogo	Pelita Jaya, Seram
6	Family 67, SSO Ponorogo	Gundih, Central Java
7	Family 71, SSO Ponorogo	Gundih, Central Java
8	Family 72, SSO Ponorogo	Gundih, Central Java
9	Family 76, SSO Ponorogo	Gundih, Central Java
10	Family 78, SSO Ponorogo	Gundih, Central Java
11	Family 8, SSO Cepu	Suli, Ambon
12	Family 9, SSO Cepu	Suli, Ambon
13	Family 10, SSO Cepu	Suli, Ambon
14	Family 12, SSO Cepu	Suli, Ambon
15	Family 18, SSO Cepu	Suli, Ambon
16	Family 24, SSO Cepu	Suli, Ambon
17	Family 28, SSO Cepu	Suli, Ambon
18	Family 34, SSO Cepu	Pelita Jaya, Seram
19	Family 45, SSO Cepu	Pelita jaya, Seram
20	Family 78, SSO Cepu	Gundih, Central Java
21	Family 2, SSO Paliyan	Masarete, Buru
22	Family 5, SSO Paliyan	Masarete, Buru
23	Family 9, SSO Paliyan	Pelita Jaya, Seram
24	Family 10, SSO Paliyan	Pelita Jaya, Seram
25	Family 11, SSO Paliyan	Pelita Jaya, Seram
26	Family 12, SSO Paliyan	Cotonea, Seram
27	Family 14, SSO Paliyan	Cotonea, Seram
28	Family 18, SSO Paliyan	Suli, Ambon
29	Family 23, SSO Paliyan	Waterbank, Western Australia
30	Family 25, SSO Paliyan	Masarete, Buru

SSOs in Paliyan, Ponorogo and Cepu. The 30 clones (see Table 2) were each represented once in a plot, with eight replications.

In 2015, seeds from this CSO were first released by the Minister of Environment and Forestry (Decree No. 352/Menlhk-Setjen/2015). They have been widely used in large-scale plantings in Bima, Biak, Bali, Lampung, Madura, Bangka Belitung and other locations (see Image 15). These plantations have higher oil concentration and 1,8-cineole levels than plantations grown from unimproved seed.

4.3 Genetic improvement

The level of genetic improvement in a species reflects the success of a breeding program. In the cajuput breeding program, Susanto et al. (2003 and 2008) estimated the expected genetic gain on the oil properties and growth from the first-generation cajuput seedling seed orchards at Paliyan and Ponorogo. These are shown in Table 3.

To verify the achievement of the breeding program, it is necessary to establish a genetic gain trial. The trial is a tool for verifying genetic gain of improved seeds compared to unimproved seeds. In general, realised genetic gain will be lower than expected due to several factors. The cajuput realised genetic gain trial was established in 2007 in Gunungkidul (7° 58' 59" S, 110° 30' 33" E) using two seedlot improved seeds and three seedlot unimproved seeds in a randomised complete block design with eight replicates and 3 m x 3 m spacing. Evaluation was conducted at two years of age. The realised genetic gain of cajuput from the breeding program was ± 9% for 1,8-cineole content and ± 17% for oil yield (Kartikawati et al. 2016). The magnitude of the genetic gain of improved against unimproved seed in the genetic gain trial is shown in Table 4.

One of the factors that causes the difference in magnitude between estimated and realised genetic gain is the reproductive dynamics in seedling seed orchards (Kartikawati et al. 2016). Many factors play a role in the flowering and fertilising process in the seed orchard for producing improved seed. Pollen contamination from outside the seed orchard is often reported and can reduce the success of the breeding program. Pollen from outside the seed orchard is wild and has not been improved. On the other hand, asynchronous flowering and an unbalanced fertility rate inside the seed orchard can also reduce the genetic gain (Varghese et al. 2008). Various reproduction problems in the seed orchard influence the quality of the seeds (Weng et al. 2008; Prescher 2007). Variation in flowering time causes non-random mating so that recombinant genes are not optimal, and genetic diversity is less than that of the parent trees in the seed orchard. Fertility variation in the seed orchard can lead to dominance by a certain family, causing the difference between predicted and realised gain.

4.4 Managing a cajuput seed orchard

Seed orchards are established from selected trees, with crossing expected among these selected trees in the seed orchard. However, sometimes the environment does not support random mating and we need to manage the seed orchard so that it is in the ideal condition for optimising crosses. The purpose of seed orchard management is to maximise the genetic potential of the trees through the seed produced. Several requirements are necessary to realise this potential. An ideal seed orchard has simultaneous flowering patterns, random mating patterns (panmixia), large effective population sizes, and no contamination from pollen external to the plantation (Kang et al. 2001). A study by Susanto et al. (2003) reported that oil yield in cajuput is strongly controlled by genetic factors with a heritability of 0.4, while 1,8-cineole concentration was found to have a heritability of 0.54.

A case study of the performance of the seedling seed orchard in Paliyan, Gunungkidul, revealed the following insights:

- Monitoring of flowering showed that more than 70% of individuals flowered at the same time, enabling potentially high levels of crossbreeding. The overlapping family index value was more than 0.8 (Kartikawati 2015). Some trees did not flower or flowered asynchronously.

- The fertility rate and effective population size were monitored to determine the fertility level of individuals in the seed orchard. An ideal seed orchard has a fertility rate of 1.0. In 2011, 2012 and 2013, the Paliyan SSO's fertility rates were 1.39, 1.25 and 1.43, respectively (Kartikawati 2016). This indicates that this seed orchard tends to have balanced fertility levels.
- Patterns of crossbreeding and pollen dispersal in the seed orchard were observed. In a good seed orchard, crossbreeding is random. Using DNA markers, Kartikawati et al. (2013) found that outcrossing within the orchard predominated at the Paliyan SSO.
- Genetic structure and pollen dispersal observed using DNA markers (eight simple sequence repeat (SSR) primers) in the Paliyan SSO tended to panmictic (characterised by random mating) with an average of 17 pollen donors (Nep) and an

TABLE 3

Estimated genetic gain of four traits in the first-generation cajuput seedling seed orchards at Paliyan and Ponorogo

Trait (mean)	Seedling seed orchard		Genetic gain (%)	
	Paliyan[a] (age 2 years)	Ponorogo[b] (aged 3 years)	Paliyan[a]	Ponorogo[b]
Height (m)	2.5	3.2	15	11.8
Diameter (cm)	2.9	5.3	20	20.4
Content of 1,8-cineole (%)	50.8	39.4	10	4.9
Oil yield (W/W% DW)	1.7	3.8	21	14.0

W/W%: weight of oil / weight of leaves (percentage)
DW: dry weight
a) Susanto et al. 2003, b) Susanto et al. 2008

TABLE 4

Genetic gain of 1,8-cineole content and oil yield of improved and unimproved seeds collected from several seed sources

Seed source		Realised genetic gain (%)
	Average 1,8-cineole content (%)	
Improved	41.11	9.35
Unimproved	37.59	
	Oil yield (W/W% DW)	
Improved	50.74	17.5
Unimproved	43.22	

W/W% DW: weight of oil / weight of leaves (percentage)
DW: dry weight
Source: Kartikawati et al. 2016

average pollen dispersal distance of 43 m. On the other hand, genetic structure showed that the parent trees have high genetic diversity (observed heterozygosity (Ho) = 0.480, expected heterozygosity (He) = 0.755), but approximately 5% of alleles were not inherited by the offspring. However, 11.6% of genotypes contained a mismatch, indicating pollen contamination from nearby unselected cajuput trees (Kartikawati, Rimbawanto et al. 2021).

- Inferior trees could be removed to prevent contamination by unwanted pollen. The effects of pollen contamination from unimproved trees on genetic quality has been widely reported in other species (Stoehr and Webber 2017; Gonzaga et al. 2016; Yang et al. 2017).

According to the research conducted in the Paliyan (Gunungkidul) seed orchard, some efforts are needed to support the development of an ideal seed orchard. Honeybee hives should be installed in the seed orchard to maximise outcrossing and random pollination among all plants. Honeybee hives have been placed in some eucalypt seed orchards in Australia, where they have increased pollen transfer and outcrossing rates, and viable seed production (Moncur et al. 1995).

To increase pollinator abundance, it is also essential to provide suitable habitat. Planting heavy-flowering, unrelated species near the orchard, species that do not flower at the same time as cajuput, will help keep the bee population healthy. Abundant food sources will encourage pollinators to forage for insects inside the seed orchard.

To promote optimal random mating, flowering should be stimulated on non-flowering trees in the seed orchard. Many species have had flowering stimulation, including *Picea abies* by hormone and insecticidal treatments (Rosenberg et al. 2012), *Eucalyptus nitens* by nitrogen fertiliser and paclobutrazol (Williams et al. 2003), and *Tamarindus indica* and *Tectona grandis* by root pruning and stem girdling (Mondal et al. 2019).

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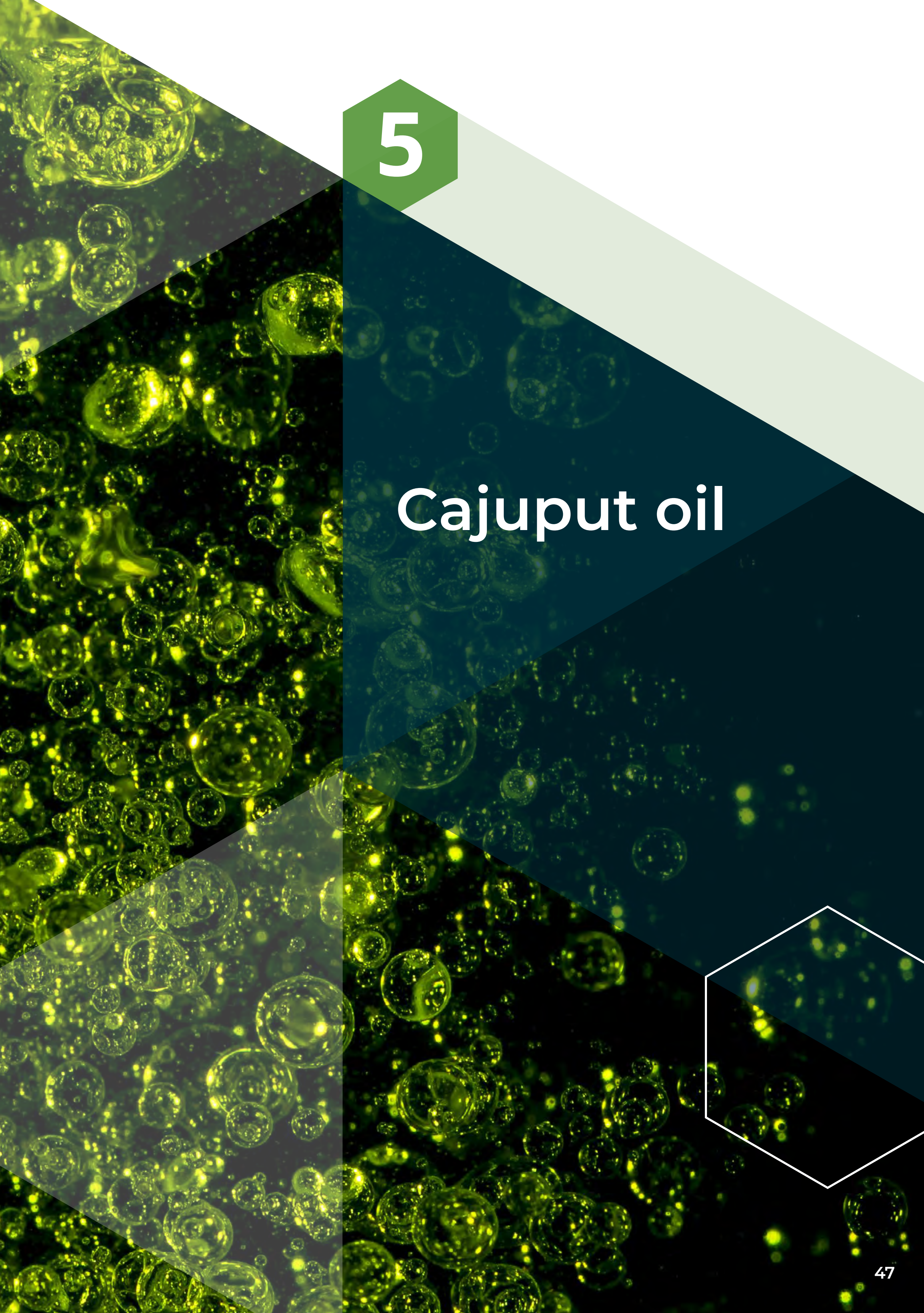
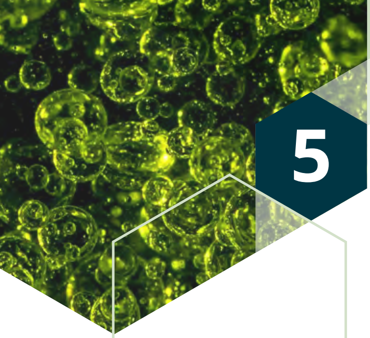


5

Cajuput oil



5 CAJUPUT OIL

Cajuput oil, or cajeput oil as it is sometimes known as in international trade, is an essential oil obtained by distilling the leaves and twigs of cajuput plants (*Melaleuca* spp.) (National Standardisation Agency 2014). Source species include *M. cajuputi* R.Powell subsp. *cajuputi* (1809) synonyms *M. leucadendron* var. *minor* Duthie (1876) and several species from other Myrtaceae families, including *Asteromyrtus symphyocarpa* (F.Muell.) Craven (Syn. *M. symphyocarpa* F.Muell.) (Doran 1999a), *A. lysicephala* and *A. magnifica* (Brophy and Doran 1996). However, not all these species are commercially viable because of the small oil yield and low 1,8-cineole content (Table 5).

The natural stands of *Asteromyrtus symphyocarpa* in Wasur National Park, Papua, are traditionally harvested and distilled; however, oil production is only 0.5–1 t per year (Siarudin et al. 2013; Winara et al. 2012). In the following sections, we consider the differences in oil content and composition between various cajuput oil-producing species; the nature of cajuput oil and its quality standards; how to produce cajuput oil; and the cajuput oil-refining industry in Indonesia.

TABLE 5

Oil yield and 1,8-cineole content of several oil-producing cajuput species

Species	Oil yield (% fresh weight)	1,8-cineole content (%)
Melaleuca cajuputi subsp. *cajuputi*	0.4–1.2[a]; 1.07[b]	3–60[a]
M. cajuputi subsp. *cumingiana*	0.5–0.7[d]	0–1.7[d]
M. cajuputi subsp. *platyphylla*	Chemotype I: 0.2–0.6[d]	0[d]
	Chemotype II: 0.1–1.2[d]	0.3[d]
Asteromyrtus symphyocarpa	0.16–0.33[b,c]; 1–1.3[e]	68–80[b,c]; 39–70[e]
A. lysicephala	0.7–2.3 (dry weight)[d]	47–51[d]
A. magnifica	2.6–2.7 (dry weight)[d]	34–36[d]

Source: a) Doran 1999a, b) Winara et al. 2012, c) Siarudin and Widiyanto 2014, d) Brophy and Doran 1996, e) Brophy 1999

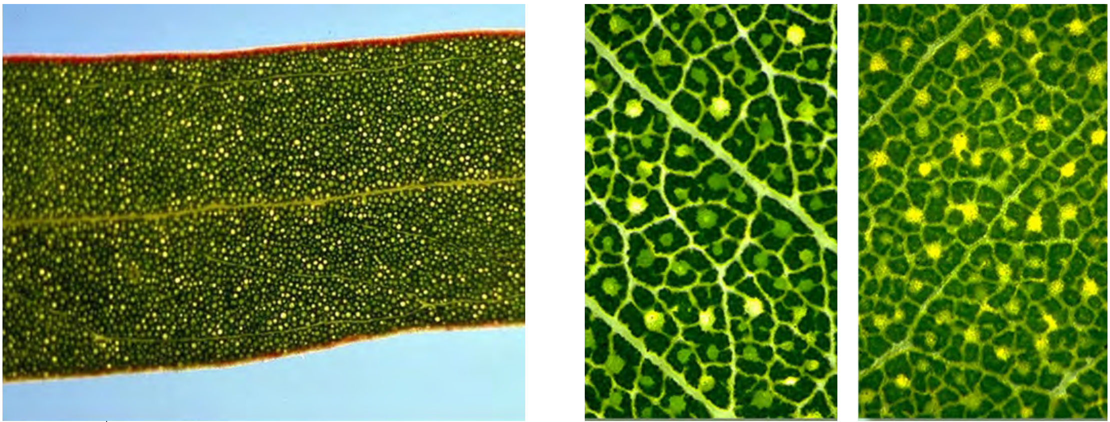


IMAGE 33 Example of the appearance of oil glands on eucalyptus leaves
Credit: The Australian National Botanic Gardens

5.1 Factors that influence the production and composition of essential oils in plants

Essential oils can be sourced from many parts of a plant: the flowers, fruit, seeds, leaves, branches, stems, bark, roots and rhizomes. Essential oils from the genera *Melaleuca*, *Asteromyrtus* and *Eucalyptus* are usually sourced from the leaves where they occur in oil glands, normally within the leaf blade but occasionally in emergent oil glands, depending on the species. In some species of Myrtaceae, the oil glands are not visible but, typically, oil glands in fresh leaves can be seen by holding the upper surface towards a light source; the oil gland will be seen as a clear white, yellowish, or green structure in the leaf tissue (Image 33). In *M. alternifolia*, oil glands of diameter 80–150 μm (micrometres) are located adjacent to the epidermal layer and spread evenly on both sides of the leaf (Butcher 1994; List et al. 1995). The oil glands are first formed in young leaves; more develop as the leaf expands and reach a maximum just ahead of full expansion of the leaf (List et al. 1995).

The concentration of oil in leaves is sometimes influenced by the density and size of the oil glands, for example in *Eucalyptus polybractea* (King et al. 2006). However, overall, the correlation is poor. In *M. alternifolia*, oil concentrations were found to be influenced mainly by the size (volume) of the oil glands (List et al. 1995).

The production of essential oils by a plant is influenced by intrinsic (genetic, leaf type and age) and extrinsic (environmental) factors. These factors are responsible for variations that occur in the quantity and composition of essential oils, both among plants in one species and between different plant species (Boland et al. 1991; Flück 1963). In addition, Boland et al. (1991) claim that differences in oil extraction and analysis techniques can cause differences or variations in oil composition and yield.

Genetic factors

Much research has been done to prove that genetic factors influence the production of secondary metabolites; for example, terpene production in *Mentha* species is controlled by a relatively simple gene system (Hefendehl and Murray 1972; Murray et al. 1972). In other species, this trait is genetically more complex, such as terpene production in pine (Birks and Kanowski 1988), monoterpene production in *Pinus contorta* (White and Nilsson 1984), and oil concentration and 1,8-cineole content in

E. camaldulensis and *M. alternifolia* (Doran 2002; Doran et al. 2002; Shelton et al. 2002). Most of the recent studies on gene control of biosynthesis in *M. alternifolia* were done by researchers at the Australian National University. Keszei et al. (2010) revealed that the terpinen-4-ol compound in *M. alternifolia* was formed by a rearrangement of a specific gene product called sabinene hydrate synthase, which emerged from ongoing gene duplication and ensuing transformations of the current 1,8-cineole synthase. Research by Webb et al. (2013) showed that the flux of precursor metabolites made available for the terpene synthase enzymes influences the oil yield of *M. alternifolia*.

Variations in the quantity and chemical composition of essential oils that are controlled by genetic factors have usually been found to be highly heritable. This is what drives plant breeders to increase the production of essential oils of a plant species through breeding programs.

Type and age of leaves

The accumulation of essential oils in organs, tissues and cells of a plant organism depends on the growth phase (ontogeny) of the plant (Sangwan et al. 2001). The concentration of essential oils in an organ can also increase and decrease. This occurs because compounds undergo metabolism, they transfer to other organs, or they disappear through evaporation and resinification (Flück 1963). However, there is no general pattern in the comparison of oil concentration from juvenile, intermediate and adult leaves, and it appears to be highly dependent on the species (Doran 1991). Examples of differences in essential-oil concentration according to the phase of ontogeny occur in several *Eucalyptus* species. For instance, young leaves of *E. citriodora* frequently have a higher oil concentration than mature leaves (Sangwan et al. 2001); and oil concentration from the leaves of the mature crown of *E. polybractea* was less than that from leaves of coppice growth (Brooker et al. 1988). On the contrary, oil concentration in leaves of juvenile-intermediate regrowth was lower than that of mature leaves of *E. nitens* (Franich 1986), *E. camaldulensis* (Doran and Bell 1994) and *E. radiata* (Kar 2003). In cajuput, oil yield increases with age (Utomo 2012); a coppice at age six months had an oil yield (W/W% fresh weight) of 0.44% and at age 12 months 1.01%.

In addition to changes in oil yield, the concentration of essential-oil constituents also changes with ontogeny in cajuput (Utomo 2012) and in *E. camaldulensis* (Doran and Bell 1994). Both species experience an increase in 1,8-cineole content along with increased leaf age, while in *M. alternifolia* changes in monoterpenoids with ontogeny were also reported by Southwell and Stiff (1989).

The concentration and composition of essential oils in plants are also influenced by the generative phase. For example, the oil concentration of *Erigeron canadensis* peaks during inflorescence formation and gradually decreases during and after blooming (Gora et al. 2002). However, the opposite occurs in *Anethum graveolens* (Huopalahti and Linko 1983) and *Salvia officinalis* (Máthé Jr et al. 1992; Perry et al. 1999; Perry et al. 1996). Meanwhile, in *M. alternifolia* there is no clear evidence that flowering or fertilisation influences oil concentrations (Butcher 1994; Drinnan 1997). However, leaves of both this species and cajuput are harvested before the onset of flowering.

Environmental factors

Environmental factors can also affect the production of essential oils. Flück (1963) states that extrinsic factors which are most influential in the production of secondary metabolites are rainfall, temperature, humidity, sunlight, and the physical, chemical and microbiological properties of soil.

Water stress tends to reduce oil concentration in some plant species, for example in *Pinus*, *Abies* and *Pseudotsuga* (Gershenzon 1984), *E. camaldulensis* (Doran and Bell 1994) and *M. alternifolia* (Drinnan 1997). By contrast, several understorey species such as *Marjorana hortensis*, *Menta piperita* and *Satureja* respond to water stress by slowing growth; as the size of the leaves becomes smaller, the number of oil glands remains the same, so oil concentration increases (Charles et al. 1990; Gershenzon 1984; Simon et al. 1992).

The concentration of essential oil in a plant is also influenced by temperature. For example, Curtis (1996) found that *M. alternifolia* oil concentrations more than doubled when the temperature was increased from 15/10 °C (day/night) to 30/25 °C, with an increase of 1.27 mg/g/°C; oil concentration then decreased at 35/30 °C. Increases in the average daily temperature three months before the harvesting period were associated with an increase in oil concentration in *M. alternifolia* at a rate of 1.02 mg/g/°C (Murtagh and Smith 1996).

5.2 The characteristics of cajuput oil

Chemical composition

The chemical composition of essential oils varies greatly, depending on the species and the area of origin. In extreme cases, one plant species may give oils of different chemical composition even within the one stand of trees. These different forms are called 'chemotypes'. A chemotype, or 'physiological form' as it was once called, was defined by Penfold and Willis (1953) as 'plants in naturally occurring populations which cannot be separated on morphological evidence, but which are readily distinguished by marked differences in chemical composition of their essential oils'. Chemical forms do not appear to be the result of site differences, seasonal variation, leaf ageing effects or hybridisation. Information about the chemotype is very important because it affects the quality and function of essential oils. Therefore, essential oils are usually sold under specific names and with a list of the contents.

The chemical composition of cajuput oil produced from *M. cajuputi* subsp. *cajuputi* appears to belong to only one chemotype; the main component is 1,8-cineole (Brophy et al. 2013). However, Sakasegawa et al. (2003) argue that there are three chemotypes based on their 1,8-cineole content: high, low and without 1,8-cineole.

Besides 1,8-cineole (which makes up 3–60%), cajuput oil comprises alcoholic sesquiterpenes, namely globulol (trace 9%), viridiflorol (trace 16%) and spathulenol (trace 30%). Other components commonly found in relatively smaller amounts are limonene (trace 5%), β-caryophyllene (trace 4%), humulene (trace 2%), viridiflorene (0.5–9%), α-terpineol (1–8%), α-selinene (0–3%), β-selinene (0–3%) and caryophyllene oxide (trace 7%). Cajeputol compounds are not found in oil from *M. cajuputi* subsp. *cajuputi* but are found in the *platyphylla* and *cumingiana* subspecies (Barbosa et al. 2013; Brophy and Doran 1996; Doran 1999a, 1999b; Silva et al. 2007). To determine the chemical composition, oil is analysed using gas chromatography and mass spectrometry (Table 6).

As mentioned above, 1,8-cineole is usually the main compound in cajuput oil; it is also found in many other types of essential oils. 1,8-cineole with the chemical formula $C_{10}H_{18}O$ is a terpenoid compound in which the 1 and 8 positions of the 1-methyl-4-isopropyl cyclohexane ring are bridged by an oxygen atom, the resulting compound being a bicyclic ether. At least 260 types of essential oils contain 1,8-cineole (Guenther 1987).

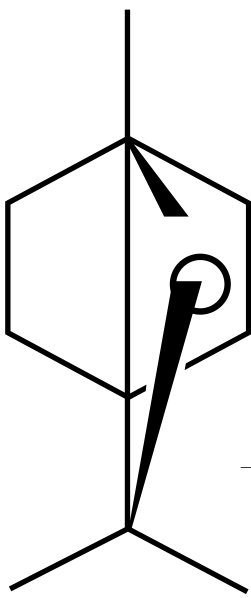


IMAGE 34

The chemical structure of 1,8-cineole

Source: Brophy and Doran 1996

TABLE 6

Composition of cajuput oil (*M. cajuputi* subsp. *cajuputi*)

Compound	Concentration (%)		
	Source 1	Source 2	Source 3
α-pinene	1.0	0.1–1.6	1.29–4.16
α-thujane	0.2	0–0.2	0.22–0.31
β-pinene	1.1	0.1–1.6	0.79–2.90
β-myrcene			0.31–0.95
sabinene	0.1		
α-phellandrene	0.5	0–1.9	
α-terpinene	0.1	0–0.3	
limonene	4.1	0.3–5.0	4.45–8.85
1,8-cineole	48.8	3.2–58.5	44.76–60.19
Y-terpinene	0.2	0–0.8	1.82–6.72
p-cymene	0.6	0.1–0.6	
terpinolene	0.1	0–0.2	0.93–3.62
α-gurjunene	0.1		
linalool	0.1	0–0.9	0–0.42
β-caryophyllene	1.1	0.3–3.7	3.78–7.64
terpinen-4-ol		0–0.5	0.63–0.81
aromadendrene	0.9	0–3.2	0–0.27
alloaromadendrene	0.3		
humulene	0.4	0.1–1.8	0.53–0.88
β-farnescene	0.1		
viridiflorene	6.1	0.5–8.6	
α-terpineol	5.5	0.9–8.3	5.93–12.45
β-silenene	0.9	0–2.7	
α-silenene	0.8	0–3.0	
bicyclogermacrene	0.6	0–3.9	
$C_{15}H_{24}O$	0.3		
palustrol	0.1		
caryophyllene oxide	1.1	0.1–7.3	
globulol	2.1	0.2–9.2	1.28–2.70
viridiflorol	1.3	0.2–15.6	0–0.36
$C_{15}H_{26}O$	0.3	0–0.9	
$C_{15}H_{26}O$	0.4		
$C_{15}H_{26}O$	0.5		
spatulenol	8.3	0.4–30.2	
Y-eudesmol		0–1.8	
α-eudesmol		0–6.4	
β-eudesmol		0–6.7	
carene			0.29–1.18
cedrene			0–0.61
Y-terpineol			0.36–2.06
ocimenol			0.09–0.20
β-eudesmene			1.29–3.51
patchoulene			0.77–4.37
garmacrene D			0.17–0.54
cubenol			0–1.15
eugenol			2.91–4.85
2-pentanone			0.88–1.91

Source: 1) Brophy and Doran 1996; 2) Doran 1999a; 3) Pujiarti, Ohtani, and Ichiura 2011

Levels of 1,8-cineole in cajuput oil vary, a trait that is usually controlled by genetic factors derived from the parent trees and passed on to their progeny. In addition to these genetic factors, the content of 1,8-cineole in oil tends to decrease with increasing plant age; the opposite occurs with β-caryophyllene compounds (Pujiarti et al. 2011).

1,8-cineole has therapeutic properties and the potential for healing in the following ways:

- antimicrobial (Sato et al. 2007)
- analgesic (Liapi et al. 2007; Santos and Rao 2000)
- anti-inflammatory (Juergens et al. 2003; Juergens et al. 2004; Santos and Rao 2000; Santos et al. 2004)
- antibacterial (Carson et al. 2002; Cuong et al. 1994; Pattnaik et al. 1996)
- antioxidant (Saito et al. 2004)
- antispasmodic (Bastos et al. 2009; Coelho-de-Souza et al. 2005; Nascimento et al. 2009)
- antiviral (Matthys et al. 2000)
- hypotension (Lahlou et al. 2002; Pinto et al. 2009)
- increased blood flow to the brain (Našel et al. 1994)
- mucolytic (Kehrl et al. 2004).

In addition to these therapeutic properties, Sadiyah et al. (2015) revealed that inhalation of the aroma of cajuput oil influenced alpha, beta and gamma brain waves and short-term memory.

Cajuput oil also has an anti-termite function (Sakasegawa et al. 2003).

Physicochemical properties

The physicochemical properties of cajuput oil – specific gravity, optical rotation, refractive index and solubility in ethanol – are shown in Table 7.

Cajuput oil is usually yellowish, pale yellow, greenish, sometimes bluish-green, and even colourless/clear (National Standardisation Agency 2014; Doran 1999a). The blue-green colour is linked to the presence of azulene compounds that can develop at high oil boiling points, and which are a result of chemical reactions between copper (if the distillation kettle is made of copper) and certain compounds found in cajuput oil (Lowry 1973). Cajuput oil has a distinctive camphor aroma, like eucalyptus oil which is also rich in 1,8-cineole, but lighter and more fruity (Lawless 1995).

TABLE 7

Physicochemical properties of cajuput oil

Characteristic	Gundih[1)]	Sukun[1)]	Gunungkidul[1)]	Commercial[2)]	SNI
Specific gravity	0.879–0.882[a]	0.700–0.901[a]	0.905–0.912[a]	0.915–0.930[b]	0.900–0.930[a]
Optical rotation (°)	−1.30 to −1.92	−2.47 to −0.98	−2.37 to −1.10	−4 to −0.90	−4 to 0
Refractive index @20 °C	1.469–1.470	1.468–1.470	1.467–1.470	1.464–1.467	1.450–1.470
Solubility in ethanol	1:1.00–1:10[c]	1:1.00–1:1.33[c]	1:1.33–1:9.67[c]	≥1:1.00[d]	Clarity with volume ratio 1:1

SNI: Indonesian national standard
a) Specific gravity @ 20 °C; b) Specific gravity @ 15 °C; c) Solubility in ethanol 70%; d) Solubility in ethanol 80%
Sources: 1) Pujiarti et al. 2011, 2) Penfold and Morrison *cited in* Doran 1999a

5.3 Distilling cajuput oil

Cajuput oil is obtained by distilling cajuput leaves. There are two common distillation methods to extract cajuput oil: 1) water and steam distillation and 2) direct steam distillation.

Water and steam distillation

In this method of distillation, there is no direct contact between the leaves and the water because they are separated by a perforated screen inserted some distance above the bottom of the distillation vessel (pot) which is filled with water (Image 35). The water is heated from below using a fire under the pot, and the saturated steam rises at low pressure through the leaves. The steam coming out of the pot, which is a vaporous mixture of water vapour and oil, passes into a condenser which converts the vapour into a liquid condensate. The condensate (a mixture of oil and water) is separated by a separator using the principle of gravity, i.e. water with a greater density will be at the bottom and oil will be at the top. The disadvantage of this system is that it is difficult to stabilise the temperature and pressure of the water vapour because it is very dependent on the intensity of the fire.

This distillation system is commonly used in traditional cajuput distilleries, particularly in the Maluku Islands (Image 36). The traditional distillery is usually very simple and consists of a clay furnace, and a distillation vessel made from planks of *marsego* wood (local timber) butted together with cajuput bark as a sealant. A cooling tub with copper tubing within (condenser) is also made of wood planks covered by a plastic sheeting. The vessel and the condenser are connected using a stainless-steel pipe. The fuel that is commonly used is firewood, but it can also be dried, spent leaves of earlier distillations.

In the Maluku Islands, the general process of extracting cajuput oil in a traditional cajuput oil distillery begins with leaves stripped directly from the branches of naturally

IMAGE 35 Diagram of the process of distilling cajuput oil using the water and steam system

Credit: Blog Rumah Mesin

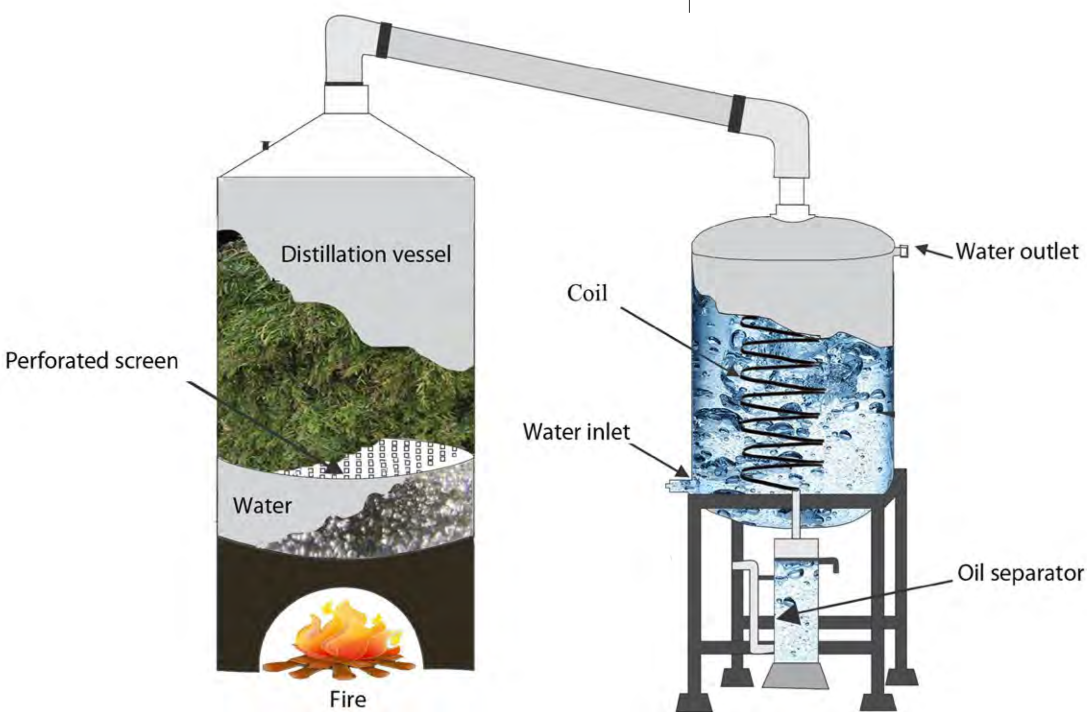


IMAGE 36 Traditional cajuput oil distillery in Seram Island

1. Furnace
2. Firewood
3. Distillation vessel/pot
4. Cooling tub
5. Condensate outlet

Credit: Prastyono

growing cajuput coppices (Image 6). The coppice leaves are approximately six months' old after the previous harvest.

Only the cajuput leaves are placed onto the perforated screen in the pot. The quantity of leaves processed depends on the capacity of the pot. A 110-cm-tall pot with a diameter of 150 cm can accommodate up to 500 kg of leaves.

After packing with leaves, the pot is tightly closed by placing cajuput bark between the pot and the lid to prevent vapour leakage. The fire is started after the pot is loaded with leaves. The distillation process is completed when there is no cajuput oil in the liquid coming out of the condensate outlet, indicating that the oil in the leaves has been fully extracted. Typically, in a 150–500 kg pot capacity, oil extraction may take about 3–4 hours. Loading and unloading the leaves takes about two hours. Based on the experience of traditional distillation in West Seram, 500 kg of fresh leaves produces 4 kg of cajuput oil – an oil yield of 0.8%.

IMAGE 37 Three 2-tonne-capacity pots and the gantry crane for loading and unloading at the cajuput distillery at Sendangmole, Gunungkidul

Credit: Prastyono

Direct steam distillation

In this system there is no direct contact between the raw materials, water or fire. Saturated steam at higher pressure than atmospheric is generated in a boiler that is separate from the pot containing the leaves (Image 38). A pipe carries the steam to the pot. The condensation processes resemble those of the water and steam system. The advantage of this direct system is that temperature and steam pressure can be better controlled.

This distillation system is widely used in large-scale or modern cajuput oil distilleries, although it is also used in small-scale or portable distilleries. The processes of producing steam and distilling the leaves are further described below.

Producing steam

Steam is made in a boiler (Image 39) containing water which has been softened to reduce the concentration of dissolved minerals such as calcium and magnesium. This prevents the formation of crust in the pipes. To boil the water, the heat energy is generated from 5-kg briquettes made of spent cajuput leaves and twigs – distillation waste that has been dried and compacted. The steam pressure in the boiler is kept constant and below 750 kilopascals (kPa) by regulating the fire and the volume of water in the boiler.

Distilling the leaves

The steam flows into a header tank and is distributed evenly into pots at a pressure of 250–300 kPa. The condensate starts to vaporise after 0.5 to 1.5 hours and this process is completed after approximately four hours.

IMAGE 38 Diagram of the process of distilling cajuput oil using the direct steam system

Credit: Blog Rumah Mesin

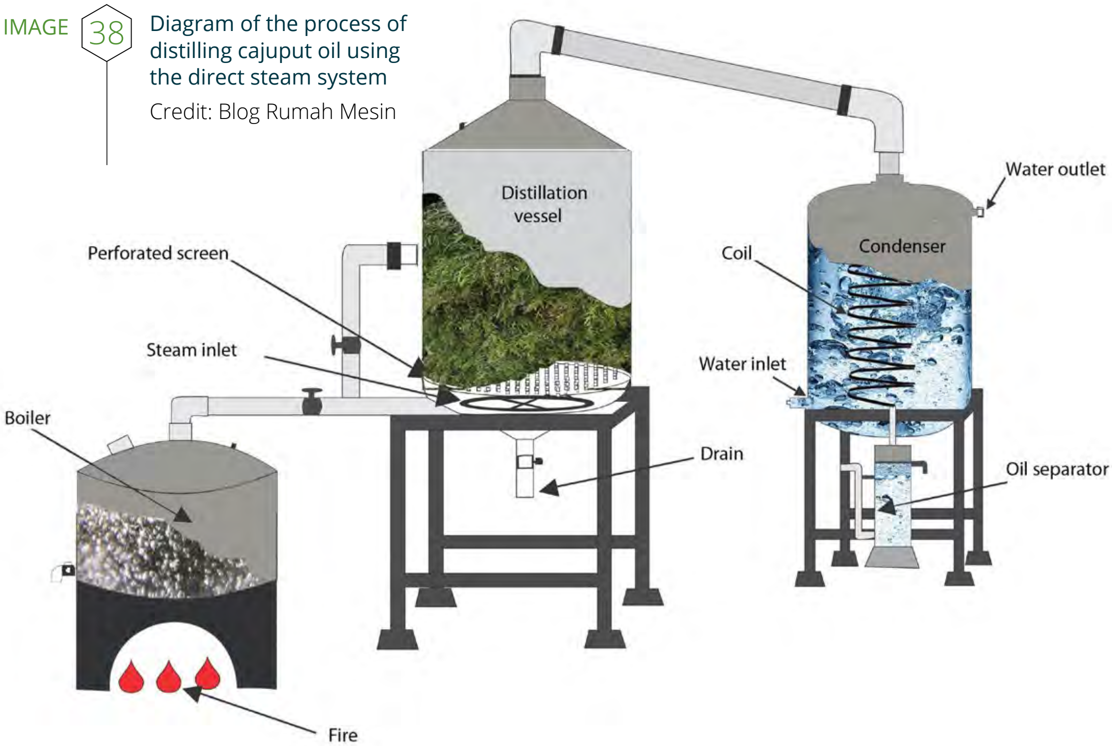


IMAGE 39 A boiler in a cajuput oil distillery at Sendangmole, Gunungkidul

Credit: JC Doran

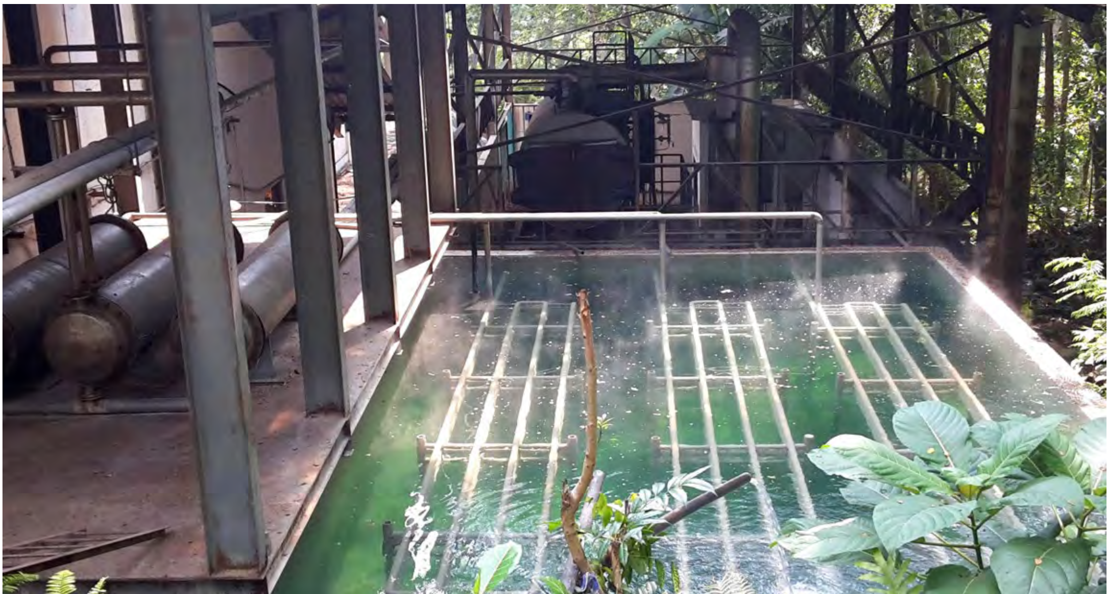


IMAGE 40 Condensers of the cajuput oil distillery (left) and water-cooling tank (right) at Sendangmole, Gunungkidul

Credit: Prastyono

Cooling and separating the oil and water

The mixture of water vapour and oil from the pot flows in a pipe through a cooling tub (condenser) (Image 40). The water coolant in the condenser is circulated to maintain a relatively low temperature. A blower is used to reduce the temperature of the water flowing into the cooling tub (Image 41). The condensate, consisting of oil and water which are not miscible, is accommodated in a separator, the cajuput oil at the top and the water below because of differences in density. The oil is then channelled from the separator to an oil collector (Image 42).

IMAGE 41 A blower reduces the temperature of water flowing into the condensers at Sendangmole cajuput oil distillery, Gunungkidul.

Credit: Prastyono

IMAGE 42 Oil separator (right) and collector (left) at Sendangmole cajuput oil distillery, Gunungkidul

Credit: Prastyono

IMAGE 43 Cajuput spent leaves and twigs drying after removal from the distillation pots (left) are then made into briquettes (right).

Credit: Prastyono

The leaf and twig waste in the pot is then removed using a motorised pulley and dried for making the briquettes that fire the steam boilers. This waste, after drying, can also be used as a substitute for firewood in home industries (Suharto et al. 2007), and as materials for manufacturing activated charcoal (Sutapa and Hidayat 2011), wood pellets (Tyas 2015) and compost fertiliser (Rahmawati et al. 2016).

5.4 Quality testing

The quality of cajuput oil traded in Indonesia must meet the Indonesian national standard SNI 3954:2014 (National Standardisation Agency 2014) (Table 8). This SNI standard can also be used to determine the purity of traded cajuput oil. The quality class of cajuput oil is based on its 1,8-cineole content: oils with levels of more than 60% are classified as premium class, between 55% and 60% as first class, and between 50% and 54.9% as standard class. Cajuput oil with 1,8-cineole content of less than 50% will be blended with eucalyptus oil with high 1,8-cineole content by the packaging industry to meet SNI standards (Edy Tjugito, pers. comm., 22 April 2021). Other measures of the quality and purity of cajuput oil are colour, odour, specific gravity, refractive index at 20 °C, optical rotation, and solubility in 80% ethanol.

Colour is determined by observation; good cajuput oil is yellowish or greenish in colour, or even colourless. Odour is determined by smell; good cajuput oil must have the distinctive odour described earlier in this chapter (see the section on physicochemical properties earlier in this chapter).

Cajuput oil specific gravity is a ratio of the weight of cajuput oil to the weight of water at the same volume and temperature. The specific gravity of cajuput oil required by the SNI standard is between 0.900 and 0.930 at 20 °C.

The refractive index of the oil is measured using a refractometer. It measures the refraction of light incident on the surface of the oil at a constant temperature. A simple method of measuring the refractive index of a liquid has been shown by Gluck and Massalha (2012). Its value is strongly influenced by the concentration of long-chain components, including terpenes such as 1,8-cineole contained in essential oils. The more long-chain components, the higher the oil density and the higher the refractive index. Oil colour

TABLE 8

Indonesian national standards for cajuput oil

Characteristics	Requirements	
Colour	Colourless, yellowish or green	
Odour	Typical cajuput	
Specific gravity @ 20 °C	0.900–0.930	
Refractive index @ 20 °C (nD20)*	1.450–1.470	
Optical rotation	(−) 4° to (+) 0°	
Solubility in ethanol 80%	Clarity with volume ratio 1:1	
Grade 1,8-cineole (%)	>60	= premium class
	55–60	= first class
	50 – <55	= standard class

* n=index, D=wavelength, 20=temperature
Source: National Standardisation Agency 2014

also affects the refractive index value; the clearer the oil, the higher the refractive index (Pujiarti et al. 2011). The SNI standard requires that the refractive index of cajuput oil at 20 °C has a value between 1.45 and 1.47.

The optical rotation of the oil is measured using a polarimeter. It measures the rotation of the orientation of the plane of polarisation about the optical axis of linearly polarised light as it travels through oil of 10 cm thickness (National Standardisation Agency 2014). The dextro optical rotation is marked (+) and the levo optical rotation is marked (−). The magnitude of the optical rotation of the oil is influenced by its constituents. The SNI standard requires the optical rotation value of cajuput oil to be between (−) 4° and (+) 0°.

The solubility of essential oils in ethanol is influenced by its constituent chemical compounds. Essential oils containing non-oxygenated terpenes are more difficult to dissolve in ethanol than those with oxygenated terpenes. Based on the SNI standard, cajuput oil is declared soluble if it produces a clear solution when mixed with 80% ethanol with a volume ratio of 1:1.

5.5 Cajuput oil distillation industries

The cajuput oil distillation industries in Indonesia can generally be divided into two categories: small-scale or household distilleries, and large-scale distilleries or cajuput distillation plants (*Pabrik Minyak Kayuputih* or PMKPs). Small-scale industries are common in the Maluku Islands. They use very simple technologies and leaves harvested from natural cajuput stands. In the 1990s, the Maluku Islands of Buru, Ambon, Seram and other islands had an annual oil production of 90 t (Gunn et al. 1996). In 2014, the Province of Maluku BPS (Bureau of Statistics) recorded cajuput natural stands of ± 250,000 ha in the Maluku Islands: ± 50,000 ha in West Seram district, ± 120,000 ha in Buru district, ± 20,000 ha in West South-east Maluku district and ± 60,000 ha in Central Maluku district (Idrus et al. 2016). However, cajuput oil production has decreased according to official figures. BPS data shows that in 2014 and 2015 cajuput oil production from the Maluku Islands was only 19.9 t and 26.7 t, respectively (Maluku Province BPS 2016). These figures are, however, far below the unofficial figures collected from cajuput oil businesses. Oil production from Seram and Buru islands was estimated to be more than 300 t annually. This huge difference in figures is because not all traded cajuput oil is officially recorded.

Large-scale distilleries are operated by Perhutani and Forest Management Unit/FMU or *Kesatuan Pengelolaan Hutan*/KPH Yogyakarta (formerly managed by the Provincial Forestry Service of Yogyakarta). Perhutani has 24,000 ha of plantations and operates eight distilleries with an installed capacity of 400 t oil/year. The distilleries are in three regional divisions (redivs):

- Central Java Rediv (PMKP Krai-Grobogan)
- Java East Rediv (PMKP Sukun-Ponorogo, PMKP Kupang-Mojokerto, PMKP Srui-Pasuruan)
- West Java and Banten Rediv (PMKP Jatimunggul-Indramayu, PMKP Ciminyak-Sukabumi, PMKP Tonjong-Kuningan and PMKP Majalengka-Majalengka).

FMU Yogyakarta, with approximately 4,000 ha of plantations, has two large distilleries, PMKP Sendangmole (Gunungkidul) and PMKP Gelaran (Gunungkidul), and three smaller distilleries, PMKP Dlingo (Bantul), PMKP Kediwung (Bantul) and PMKP Sermo (Kulon Progo). The five distilleries can produce 40 t of cajuput oil per year. PMKP Sermo (Kulon Progo) has stopped operations since 2011 because its 63 ha of cajuput plantation in Kulon Progo regency was incorporated into a wildlife reserve.

The cajuput oil distillation industry is classified as labour intensive because it employs a large workforce for leaf picking, distillation and transport. For example, PMKP Krai-Grobogan employs 70 people in the distilleries and 300 leaf pickers in the plantations (Doran et al. 1998), while PMKP Sendangmole and PMKP Gelaran-Gunungkidul each employ about 132 leaf-pickers, 28 people for transport, 10 for making fuel briquettes and 20 in the distilleries. In addition, farmers are involved in intercropping agricultural crops at the same time as they are maintaining the cajuput plantations.

5.6 Prospects of the cajuput oil industry

Further development of the cajuput oil industry is dependent on two main factors: the availability of raw materials, and an industry that efficiently processes these raw materials into oil. It is not difficult to find areas in Indonesia that meet the growing requirements of cajuput. The species grows naturally in areas with rainfall between 1,200 and 2,500 mm/year and in soils of low fertility; in Java, cajuput also grows well in limestone soils. The soils and environments in Bali, Sulawesi, West Nusa Tenggara, East Nusa Tenggara and Maluku can also support its growing requirements. So, in principle, there is no need to import substitute oil if the industry in Indonesia can be developed, and the demand for cajuput oil for domestic consumption is expected to continue to grow as the population grows. At present, the volume of imports of eucalyptus oil is estimated to be six times the volume of cajuput oil produced domestically, which means that 100 ml of packaged cajuput oil consists of 83 ml of eucalyptus oil and only 17 ml of cajuput oil. It is ironic that cajuput oil obtained from a native Indonesian species cannot meet domestic demand and that eucalyptus oil must be imported to make up the shortfall.

The cajuput oil packaging industry

The main users of cajuput oil produced in Indonesia are pharmaceutical factories and small-to-medium enterprises (SMEs) in the Maluku Islands that pack the oil into bottles ready for consumers' use. At least 65 brands of packaged cajuput oil produced domestically are available in Indonesian markets and most label that the oil content is 100% pure cajuput oil, even though this is not the case. Distillers in Piru-West Seram, Suli-Ambon and Namlea-Buru suggest that adulteration with eucalyptus and turpentine oil is generally done by oil traders.

If access to superior seeds is opened to the wider community, this may bring more SMEs into the distillation and packaging areas of the cajuput oil industry. The current retail

TABLE 9

Packaged brands of cajuput oil in the Indonesian market

No.	Cajuput oil brand	No.	Cajuput oil brand	No.	Cajuput oil brand
1	Amanah	23	Cap Rumah	45	Naga Mas
2	Ambon Namlea	24	Cap Scorpio	46	Nusaroma
3	Antimo	25	Cap Tawon	47	Oriburu
4	Arueo	26	Cap Tiga Tangkai	48	Pavettia
5	Baby Huki	27	Catrelle	49	Perhutani
6	BCO	28	Cussons Baby	50	Pulau Buru
7	Beta	29	Eka Jaya	51	Puri
8	Caju Puti	30	GamaFresh	52	Pusaka Buru
9	Cap 19	31	Gundih	53	Raja
10	Cap Ayam	32	Happy Green	54	Rejeki Jaya
11	Cap Cemara	33	Hijau Buru	55	Revina
12	Cap Daun Kayu Putih	34	Kasih Iboe	56	SafeCare
13	Cap Eriwakang	35	Kayoo	57	Sidola
14	Cap Gading	36	Kayuputihburu	58	Sio Mama
15	Cap Gajah	37	Konicare	59	SPB
16	Cap Kelinci	38	Lansida	60	Swasti
17	Cap Kijang	39	Manise	61	Tambora Botanica
18	Cap Kuda Bangau	40	Mata Kael	62	Tanqa Hello Kitty
19	Cap Lang	41	Menjangan Kasuari	63	Tresno Joyo
20	Cap Merpati Putih	42	Mikapoe	64	Triple R
21	Cap Nona Po	43	Minyakoala	65	Walikukun
22	Cap Rajawali	44	Mutiara		

price of cajuput oil in 60 ml packages ranges from IDR20,000 (AUD1.93) to IDR30,000 (AUD2.89). Price differences are related more to trademark than quality.

A quick search through the Google search engine found 65 packaged brands of cajuput oil (Table 9).

Financial analysis

Investment in the further development of the cajuput oil industry appears promising, although financial analyses to assess feasibility are limited. An analysis for existing SMEs dealing in cajuput oil in West Seram district indicated a benefit:cost ratio of 1.9 (Souhuwat et al. 2013). However, profitability and return on investment are strongly influenced by oil yield. The higher the oil yield of a cajuput plantation, the higher the profit (Astana 2005).

Financial analysis of a large-scale cajuput oil industry business has rarely been done because existing businesses of this type are in the public sector. A study of the financial feasibility of a 5-ha cajuput plantation was reported by Prastyono et al. (2020). The assumptions used in this analysis are shown in Table 10.

This study showed that a small-scale cajuput plantation is financially feasible as indicated by the high net present value and internal rate of return. The net present value of this 5-ha plantation over 25 years at a 9.2% discount rate was IDR757,171,972.00 (AUD72,991.26), or IDR151,434,394.32 (AUD14,598.25) per hectare, while the internal rate of return was 72.74%. This study also suggests that investing in a cajuput plantation planted with improved seeds is more profitable than investing in bamboo, *Falcataria moluccana*, palm oil or coffee plantations.

TABLE 10

Assumptions used in financial feasibility study of a 5-ha cajuput plantation

Assumption	
Plant price	IDR3,100 (AUD0.30)/unit
Number of plants per hectare	2,500
Cost of plants per hectare	IDR8,525,000 (AUD821.21)
Other plantation establishment cost per hectare	IDR14,387,500 (AUD1,386.95)
Total plantation establishment cost per hectare	IDR22,912,500 (AUD2,208.76)
Operating costs per hectare in year 1	IDR24,461,250 (AUD2,358.06)
Operating costs per hectare in year 2 onward	IDR16,548,000 (AUD1,595.22)
Leaf production of the first harvest in year 1	7.4 kg/plant
Leaf production of the second harvest	3.7 kg/plant
Leaf production of the third harvest onward	3.7 kg/plant
Oil yield in the first and second harvest	1.05%
Oil yield in third harvest onward	1.3%
Oil production in the first harvest	174.83 kg/ha
Oil production in the second harvest	86.47 kg/ha
Oil production in the third harvest onward	107.06 kg/ha
Leaf harvesting cycle	9 months
Farmgate oil price	IDR250,000 (AUD24.10)/kg
Life of cajuput plantation	25 years
Area of plantation	5 ha
Plant survival rate	90%
Discount rate	9.2%

Source: Prastyono et al. 2020

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