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Variation in *Kayu Putih* (*Melaleuca leucadendron* LINN) Oil Quality under Different Farming Systems in Java, Indonesia

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Abstract

We compared the content and quality of *kayu putih* oil in leaf-twig samples from *Melaleuca leucadendron* LINN plantations with different farming systems in Java, Indonesia. In the monoculture plantation (Site G, Central Java) and single-crop *tumpangsari* (Site I, West Java), cineole content in oil was higher than in the multiple-crop *tumpangsari* (Site P, East Java). In the monoculture, cineole content was high in 10- to 26-year-old stands, but decreased in older stands. In the two sites with *tumpangsari* systems, cineole content did not decrease in older stands. Cultivation and soil tilling may mitigate soil degradation and contribute to sustaining *kayu putih* oil quality in plantations with *tumpangsari* systems as stands increase in age. Cineole content in *kayu putih* oil produced in the three plantations in Java Island, ranged 67 – 72%, indicating that under appropriate farming systems and site conditions, *kayu putih* oil is comparable in quality with aromatic oils from other myrtaceous species.

Key words: agroforestry, cineole, non-timber forest product, *tumpangsari* system

Introduction

Kayu putih oil is an important non-timber forest product (NTFP) in Indonesia and Southeast Asian countries. *Kayu putih* oil is an essential oil extracted from fresh leaves and twigs of *kayu putih* tree (cajuput or white-tea tree, *Melaleuca leucadendron* LINN[1], Myrtaceae) through water-steam distillation. In local communities, *kayu putih* oil is a multipurpose home medicine used for antibacterial properties (disinfectant, expectorant), as medication for stomach upsets and as insecticide (FAO 1992, 1995, Wibowo 1997).

In Indonesia, *kayu putih* oil is commercially produced in plantations. In Java Island, *kayu putih* trees were first planted in 1924 as a pioneer tree for reforestation of abandoned land of poor soils. After development of the commercial value of *kayu putih* oil, commercial production of the oil by the forest owner began in the 1960s.

Kayu putih oil quality depends on the content of 1,8-cineole, a pharmaceutically active component of aromatic oil, generally contained in myrtaceous shrubs and trees including *M. leucadendron* (Milthorpe *et al.* 1998). Doran (1999) reports that leaf oil extracted from species other than *Melaleuca alternifolia* and *Eucalyptus* spp. is not economically valuable due to low cineole content. However, this generalization may be insufficient. Cineole content in oil extracted from *M. alternifolia* and *Eucalyptus* spp. varies considerably with genotype. In addition, factors such as site quality, tree age, leaf age and season of the harvest also affect the oil quality (Butcher *et al.* 1994, Homer *et al.* 2000, Wildy *et al.* 2000, Lee *et al.* 2002). Therefore, it is assumed that the quality of *kayu putih* oil may be dependent on stand management system, stand age and site condition.

The oil quality from *Melaleuca* and *Eucalyptus* trees in Australia have been well documented in their native range of the distribution (Milthorpe *et al.* 1998, Homer *et al.* 2000), but less information is available for the quality from *M. leucadendron* in Indonesia. In this research, we compared cineole content among three *kayu putih* plantations with different stand management systems in Java, Indonesia. Stands ranging in age from 7 – 40 years were sampled to examine changes in oil quality in relation to stand age.

Materials and methods

Study sites and tree harvesting

Researches were conducted in *kayu putih* plantations managed by PT Perhutani (a forest enterprise) in Java: Ponorogo area in East Java (Site P), Indramayu area in West Java (Site I) and Gundih area in Central Java (Site G). The sites have different environmental conditions and agroforestry systems as stated below, but *kayu putih* oil is produced as a non-timber forest product (NTFP) in all of the plantations.

Site P (7°54'S, 111°36'E, 200 to 300 m asl) includes 2369.5 ha of *kayu putih* plantation ranging from 1- to 40-year-old stands, with average tree density of 2083 trees ha^{-1} (the tree was originally planted at 3 x 1 m spacing) and mean diameter at stem base (D_0) of 10.3 cm. Soil is composed of clayist volcanic ash soil with organic material (humus) content ranging from 3.1 to 4.3 %. Average rainfall in the last 10 years was 1952 mm yr^{-1}. In Site P, farmers cultivate maize (*Zea mays*) and cassava (*Manihot esculenta*) between the tree rows as companion crops. *Mimosa invisa* weeds infest the areas without weeding and twist around the tree and

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cassava stem. We categorized Site P as a multiple-crop *tumpangsari* system. *Tumpangsari* system is an improved shifting cultivation which combines agricultural crops with forest tree seedlings in the first years of reforestation program (Nair 1993, Gajaseni 1997).

Site I (6°31'S, 108°07'E, 0 to 40 m asl) includes 1308.2 ha of *kayu putih* plantation ranging from 7- to 37-year-old stands with tree density of 2020 trees ha^{-1} (the trees were originally planted at 3 x 1 m spacing, except in stands younger than 10 years where the trees were planted at 6 x 1 m spacing) and mean D_0 of 12.2 cm. The soil is pre-dominated by alluvial soil with organic material content ranging from 2 – 5 %. Annual precipitation of last 10 years was 1615 mm yr^{-1}. In Site I, *tumpangsari* system is also practiced between the trees and lowland rice (*Oryza sativa*). This site was categorized as a single-crop *tumpangsari* system. Trees grow well even in stagnated water during rainy season. *Imperata cylindrica* weeds infest areas where *tumpangsari* is not properly managed.

Site G (7°12'S, 110°54'E, 200 to 400 m asl) includes 2740.8 ha of *kayu putih* plantation with average tree density of 2648 trees ha^{-1} (the trees were originally planted at 2 x 1 m spacing) and mean D_0 of 11.3 cm. The soil is pre-dominated by volcanic ash with organic material content less than 5 %. Site G has poor soil conditions and is the driest among the sites, although no climate data were available. Site G represents a monoculture system, because the *tumpangsari* is practiced only in the first two years after transplanting, similar to teak plantations in Java. *I. cylindrica* weeds and *Eupatorium pubescens* infest the abandoned area and compete with the trees. See Budiadi *et al.* (in press) for detailed descriptions of each research site.

In each site, triplicate sample plots of 20 x 20 m were established in each of seven stand age-classes of *kayu putih* plantations. In total: 21 plots of 7- to 40-year-old stands in Site P, 21 plots of 7- to 37-year-old stands in Site I, and 21 plots of 10- to 35-year-old stands in Site G were established. Tree size and stand density was measured in each plot. Based on these data, ten representative trees were selected in each plot and harvested following ordinal harvesting method (Faculty of Forestry 1987).

Kayu putih oil extraction and cineole content analysis

Figure 1 illustrates the harvesting method of leaf-twigs and oil extraction process. In the method, branches of the sampled trees were pruned at about 10 cm above the sprouting base. Leaves and small branches (twigs with diameter < 5 mm) were separated from large branches, weighed and pooled in each plot. A composite sub-sample of 5 kg fresh weight of leaf-twigs was taken from the pooled sample in each plot for *kayu putih* oil extraction in the laboratory by water-steam distillation (FAO 1992) soon after harvesting. Our equipment has the capacity to extract *kayu putih* oil from 5 kg of fresh leaf-twig sample in a process that takes approximately five hours. Specific gravity of the oil extracted from each sub-sample was measured in the laboratory. For each plot, oil content (%) of leaf-twig samples was estimated using the ratio of oil weight to the fresh weight of the leaf-twig samples. Cineole content (%) in *kayu putih* oil was analyzed using phosphoric acid method of Scammell modified by Baker and Smith (Guanther 1948).

Statistical analysis

The agroforestry system at each site is a consequence of physical and ecological constraints. Although we did not measure physical and ecological factors such as temperature, rainfall, soil conditions, etc., we assumed that differences in agroforestry system and site conditions, explained above, are the main factors that affect *kayu putih* oil quality. The effect of stand age on oil content and cineole content was analyzed with simple linear regression using all 21 plots in each site. Where no significant age-effect was found, differences among sites were assessed using one-way ANOVA (SPSS for Windows Ver. 10.0.1). Where significant age-effect was found, differences among sites were assessed using one-way ANCOVA with stand age as the covariate. Multiple comparison among sites was conducted using Scheffe's test.

Results and discussion

Stand age and *kayu putih* oil quality

In all sites, *kayu putih* oil content in leaf-twig samples did not change with stand age (R^2 = 0.010 – 0.087, P = 0.208 – 0.653, n = 21). Oil content ranged 0.45 to 1.27% throughout stand growth. Cineole content decreased with increasing stand age in Site G (Figure 2, R^2 = 0.294, P = 0.011, n = 21), while in Site P and Site I, cineole content remained constant (R^2 = 0.054, P = 0.310, n = 21 and R^2 = 0.001, P = 0.905, n = 21, for Site P and Site I, respectively). In Site G, where *kayu putih* trees were planted in monoculture, cineole content was about 74% in 10- to 26-year-old stands, but in older stands cineole content averaged only 68%. The oldest stand sampled in Site G was 35 years. Our results suggested that cineole content may decline further in older stands. In Site P and Site I with *tumpangsari* systems, cineole content averaged 67 – 72% throughout stand growth. These results showed that, given the ecological constraints of the site, plantation management through agroforestry system may prevent decline in *kayu putih* oil quality with increasing stand age.

In areas with poor soil and limited water like in Site G, farmers are forced to abandon *tumpangsari* after the first two years. In Site G, almost no soil tillage is conducted after *tumpangsari* is abandoned. This may result in soil degradation with increasing stand age and decreasing *kayu putih* oil quality in older stands. In contrast, in systems with *tumpangsari*, continuous soil tillage may activate soil bacteria and enhance decomposition of crop residue that is returned to the soil. In Site P and Site I this may mitigate soil degradation and contribute to sustaining *kayu putih* oil quality. However, not all of the plantations are adequate for *tumpangsari* due to unfavorable site conditions.

A *kayu putih* plantation with *tumpangsari* system (in East Java)

Harvested leaf-twigs of *kayu putih*

Leaf-twigs before extraction

Distillation process

Kayu putih oil product

Fig. 1. Harvesting of *Melaleuca leucadendron* LINN and processing in the factory. Photos are from the *Melaleuca leucadendron* plantation with multiple-crop tumpangsari (Site P) in East Java, Indonesia.

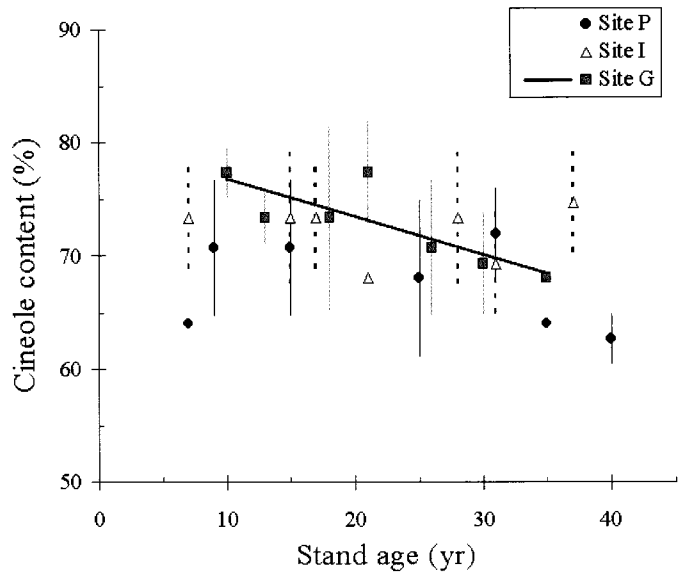

Fig. 2. Age-related changes in cineole content in *kayu putih* oil from the three *Melaleuca leucadendron* LINN plantations with different farming systems in Java, Indonesia. Symbols and error bars indicate the mean and one standard deviation for plots in the same age-class. The line indicates results of linear regression (using 21 plots) for Site G.

Table 1. Result of one-way ANOVA and ANCOVA with stand age as covariate for the effect of site (i.e. farming system) on oil content in leaf-twig samples and cineole content in *kayu putih* oil, respectively, for the three *Melaleuca leucadendron* LINN plantations with different farming systems in Java, Indonesia.

Sources	Sum of Squares	df	Mean Square	F	P
Oil content					
Site	1.14	2	0.57	31.16	0.000
Error	1.10	60	1.83×10^{-2}		
Total	2.24	62			
Cineole content					
Stand age	104.58	1	104.58	4.27	0.043
Site	339.58	2	169.79	6.94	0.002
Error	1443.61	59	24.47		
Total	317648.00	63			

Site differences in *kayu putih* oil quality

Differences in agroforestry system among the sites affected both oil content in leaf-twig samples and cineole content in *kayu putih* oil (Table 1). Oil content in leaf-twig samples was highest in the monoculture (Site G) and lowest in the multiple-crop *tumpangsari* (Site P) (Table 2, $P < 0.05$). Cineole content was higher in Site G and Site I than in Site P (Table 2, $P < 0.05$). These results indicated that when stands of the same age are compared, Site P with multiple crop *tumpangsari* system produces less oil of lower quality than in monoculture (Site G).

Site G is characterized by poor soil and low annual rainfall, and the *kayu putih* trees have acclimated to these environmental conditions. In Site G, high cineole content may be a survival mechanism under poor growing conditions. Under conditions that are limiting for plant growth, relative allocation to secondary substances increases (Kozlowski and Pallardy 1997, Lambers *et al.* 1998, Orcutt *et al.* 2000). Because *kayu putih* oil is a kind of defense chemical against herbivory and fungi, oil content and quality may increase in sites with poor growing conditions, such as Site G. In Site I, *kayu putih* tree is planted in single-crop *tumpangsari* with rice in rainy season. Stagnated water in Site I creates preferable growing conditions for *kayu putih*, which is dominant in swampy conditions, reflecting its common name, "swamp tea tree." *Kayu putih* trees grow well in Site I, which had the highest stand productivity of the three sites (Budiadi *et al.* in press). High cineole content in Site I (although slightly lower than that in Site G) was probably associated with high stand productivity. In Site P, where multiple-crop *tumpangsari* is practiced, biomass of leaf-twigs was comparable to that in Site G (Budiadi *et al.* in press). In this site, maize and cassava accumulate 1.5 to 5 times more N, P and K than the leaf-twigs of *kayu putih* (Budiadi, unpublished data). Because the crops

Table 2. Mean oil content in leaf-twigs and cineole content in *kayu putih* oil for the three *Melaleuca leucadendron* LINN plantations with different farming systems in Java, Indonesia. Different letters following mean values indicate significant difference ($P < 0.05$).

Site	n	Oil content (%)	SD	Cineole content (%)	SD
P (multiple-crop *tumpangsari*)	21	0.606 a	0.138	67.52 a	5.26
I (single-crop *tumpangsari*)	21	0.838 b	0.105	72.17 b	4.64
G (monoculture)	21	0.923 c	0.158	72.69 b	5.31

compete with the *kayu putih* trees for soil nutrients, multiple crop combination in Site P may be a limiting factor for allocation to secondary substances such as cineole in the *kayu putih* trees.

Our results suggested that *kayu putih* oil content and quality increases under poor growing conditions due to high allocation to secondary substances. In addition, oil content and quality increases when growing conditions are favorable and there is high allocation to both growth and secondary substances. Oil production may be lowest when the tree must compete with companion crops for soil nutrients.

Conclusion

Extracted leaf oil from natural forest and plantations of *Melaleuca* and *Eucalyptus* trees in Australia contain 65 – 93% cineole (Milthorpe *et al.* 1998, Wildy *et al.* 2000). Doran (1999) suggested that *kayu putih* oil extracted from *M. leucadendron* is low in cineole content and is not economically valuable. However, our results indicated that *kayu putih* oil from plantations in Java Island, especially from Site G and Site I, is comparable in cineole content with aromatic oils from other myrtaceous species. This indicated that under appropriate agroforestry systems and site condition, *kayu putih* oil could compete in the global market and have high economic value.

This research was done during the dry season when cineole content in leaves and twigs is highest during the year (Faculty of Forestry 1987). In addition, leaf-twig samples were at the optimum age for harvest. Further research should investigate variation in *kayu putih* oil quality with season and leaf-twig age (Wildy *et al.* 2000), as well as mineral nutrition in the leaf-twig samples (Epstein 1972, Wild and Jones 1988), as determinant factors of cineole content. Variation among *M. leucadendron* genotypes is also likely to be an important factor affecting *kayu putih* oil quality. An experiment comparing various genotypes of *M. leucadendron* originating from different regions in East Indonesia is currently being carried out in Yogyakarta region (Wibowo 1997, personal comm.). The results from such studies could lead to further improvements of the production of *kayu putih* oil and increase the economic value of this non-timber forest product.

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End Notes

[1] Synonym to *Melaleuca cajuputi* (see for example in Faculty of Forestry 1987) and *M. minor* (see for example in FAO 1992, Vantomme *et al.* 2002)