

# WOOD RESEARCH Journal

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# Physico-Chemical Properties and Bioactivity of Resinous *Araucaria cunninghamii* extract

Aishah Agustian, Ganis Lukmandaru, Rizki Arisandi

## Abstract

Resin has been identified as a promising non-timber forest product with the potential to generate high economic value. *Araucaria cunninghamii* is recognized as one of the most prominent sources of resin in Indonesia. This study aimed to evaluate the potential of resin from *A. cunninghamii*, focusing on its extractive properties. A total of 20 g of resin was extracted by separation and successive extraction methods using *n*-hexane, ethyl acetate, and methanol solvents. Subsequently, the *n*-hexane extract was fractionated into neutral and acidic fractions. Subsequently, the acidic fraction underwent a saponification process, resulting in the isolation of an unsaponifiable fraction and a phenolic fraction. The components of analysis were identified through the utilization of a GC-MS analysis. The physicochemical test of the resin was conducted in accordance with the Indonesian National Standard (SNI 7636:2020), while the quantification of the total phenolic content was performed through the implementation of the Folin-Ciocalteu method. Furthermore, the measurement of antioxidant activity was conducted through 1,1-diphenyl-2-picryl-hydrazyl (DPPH) test (inhibition percentage). The results showed that the ethyl acetate extract exhibited the highest solubility. *Araucaria cunninghamii* contained a more dominant neutral fraction. Moreover, the highest level of total phenolic content was obtained in the *n*-hexane soluble fraction (6.84 mg GAE/g). A GC-MS analysis revealed the presence of oxygenated sesquiterpenes (31.5%), sesquiterpenes hydrocarbons (23.8%), and oxygenated diterpenes (19.9%) within the sample. Furthermore, the physicochemical tests exhibited ash content, acid number, and toluene insoluble content of 0.02%, 83.90 and 0.5%, respectively. *Araucaria cunninghamii* had relatively low antioxidant activity. In the phenolic fraction, antioxidant activity increased after partitioning of the *n*-hexane solubles. The phenolic fraction exhibited an increase in its inhibitory effect, with an increase from 19.5% to 28.8%. Further studies are necessary to detect phenolic and non-phenolic components affected by the intensity of antioxidant activity.

**Keywords:** Total phenolics, antioxidant activity, gum resin, fractionation, GC-MS

## Introduction

Sustainable forest practices yield a dual benefit to forest ecosystems, yielding both direct and indirect benefits. These practices facilitate the production of timber. Gum is generally divided into three categories: resin, rubber, and natural adhesive (gum). Resin is an exudate from plants that usually manifests in response to injury and undergoes a hardening process when exposed to air. A wide array of plant families has resins that are utilized widely. These include Araucariaceae, Pinaceae, Dipterocarpaceae, Burseraceae, and Styracaceae (Muhaimin *et al.* 2018). The Araucariaceae family is classified in the coniferous group. One of the genus in the family, *Araucaria*, is a well-known source of resin that produces various types of extractives. The natural diversity of plant exudates is classified into three different categories: resin, gum, or a mixture of gum and resin, which is usually referred to as gum resin (Seyfullah 2022). In Indonesia, coniferous plants belonging to the Araucariaceae family are renowned for their commercial resin production. One notable species within this family, *A. cunninghamii*, is a well-documented source of resin, but its utilization has not been widely developed (Marsusi *et al.* 1970).

Previous studies conducted in various countries have showed differences in the composition of resin in *A.*

*cunninghamii*. The oleoresin of *A. cunninghamii* from Australia has been found to contain a high concentration of diterpene components (Franich *et al.* 1999). In addition, the resin of *A. cunninghamii* from India is characterized by higher sesquiterpene hydrocarbons (Verma *et al.* 2014). Arachidonic acid components were identified as the major constituents in *A. cunninghamii* resin from South Africa (Matsabisa *et al.* 2019). Furthermore, in other species of the same genus, *A. heterophylla*, antioxidant activity has been detected in the gum (Samrot *et al.* 2020). As demonstrated in previous studies, there is considerable potential for further research to be conducted on the composition and utilization of *A. cunninghamii* resin. However, there was a paucity of data concerning the chemical characteristics and potential utilization of *A. cunninghamii* resin in Indonesia, with existing reports being general in nature. Therefore, this study aims to evaluate the extractive composition, acid-neutral fraction separation, physicochemical properties, and antioxidant activity of *A. cunninghamii* resin.

## Materials and Methods

### Resin Samples

The material used in the present study was resin extracted from a *A. cunninghamii* tree (with a diameter of

approximately 57 cm and annual ring number 42), which was located in the Faculty of Forestry at Universitas Gadjah Mada, Yogyakarta. Approximately 10–20 g of *A. cunninghamii* resin was dissolved in *n*-hexane, ethyl acetate, and methanol solvents, with the ratio of solvent to resin was set at 1:3 (60 mL of solvent). Extraction was conducted using a separation method and successive extraction method, with a hot plate stirrer employed for a duration of one hour. Subsequent to extraction, the solution underwent filtration, desiccation, and heating at approximately 100°C until the solvent had evaporated. The dried extract was then weighed, and the solubility was expressed as a percentage of the initial weight of the resin.

### Acid-Neutral Fractionation

A total of 1 g of the *n*-hexane extract of *A. cunninghamii*, extracted using the successive extraction method, was dissolved in dichloromethane and transferred to a separatory funnel. To this mixture, approximately 10% Na<sub>2</sub>CO<sub>3</sub> solution was added and shaken to produce two layers. The dichloromethane soluble fraction was washed with distilled water, followed by the addition of a sodium sulfide solution and a 24-hour standing period. The solvent was then evaporated to obtain the neutral fraction. Subsequently, the 10% Na<sub>2</sub>CO<sub>3</sub> soluble fraction was acidified using hydrochloric acid to achieve a pH of 3, and dichloromethane solvent was added in the same proportion until two layers were obtained. The dichloromethane-soluble layer was identified as the acidic fraction. The method similar to the one employed to obtain the neutral fraction was conducted. The solubility of the extract was calculated based on the initial weight of the *n*-hexane extract.

### Separation of Neutral Fraction by Saponification

Samples of the acidic fraction of *A. cunninghamii* were dissolved into 0.5 M KOH using heating for 1 hour. Subsequently, the solution was subjected to evaporation, after which the filtrate was added to a separatory funnel containing 100 mL of distilled water and 100 mL of dichloromethane. Furthermore, the separatory funnel was shaken and the chloromethane soluble fraction was transferred into an Erlenmeyer flask. This was subsequently combined with an adequate quantity of sodium sulfide solution, allowing for a 24-hour period of incubation. Thereafter, the solvent underwent evaporation in order to collect unsaponifiables fraction. Concurrently, the 0.5 M KOH soluble fraction was subjected to acidification with hydrochloric acid to achieve a pH of 3. This fraction was then combined with toluene solvent, resulting in the formation of two layers. The layer that was dissolved by the toluene solvent was subsequently transferred into an Erlenmeyer flask and dried (phenolic fraction).

### Component Identification Using GC-MS Analysis

The dried *n*-hexane extracts of the samples were subjected to gas chromatography-mass spectrometry (GC-

MS) analysis using GC-MS-QP 2010 (Shimadzu, Japan). The gas chromatography-mass spectrometry (GC-MS) analysis was performed under the following conditions: the RTX-5MS capillary column (30 m × 0.25 mm I.D. and 0.25 µm; GL Sciences, Tokyo, Japan); a column temperature ranging from 70°C (2 min) to 290°C at a rate of 5°C/min. The injection temperature was set at 200°C, while the detection temperature was fixed at 285°C. Compounds were identified by comparing experimental GC-MS data with the NIST-MS library (NIST 2011) and relevant studies. The quantification of lipophilic constituents was performed by calculating the relative area percentage, which was obtained through a computerized integrator based on peak areas in the total ion chromatography (TIC).

### Total Phenolic Content and Physico-Chemical Properties

The total phenolic content (TPC) was measured using the Folin-Ciocalteu method. Absorbance for standard solution testing was conducted against the blank at a wavelength of 765 nm using a visible spectrophotometer (model VIS-WPA S800+). The standard calibration curve was constructed at varying concentrations of gallic acid according to the absorbance of the sample (Arisandi *et al.* 2019; Arisandi *et al.* 2024). The total phenolic content was calculated based on the equivalent of milligrams of gallic acid per gram of dried extract (mg GAE/g). The analysis was conducted with two replicates, and the results were averaged. Furthermore, the physico-chemical property parameters tested included acid number, toluene insoluble material, and ash content, in accordance with the Indonesian National Standard (SNI) 7636-2020.

### Antioxidant Analysis

The antioxidant activity test was conducted by means of two measurements of all samples obtained by successive extraction methods. In addition, the fraction obtained from the separation of the *n*-hexane extract was tested. Each sample was added to a 4000 ppm DPPH solution (8 mg:2 mL), prepared in ethanol, and left to react at room temperature. After 30 minutes, the absorbance value was measured at a wavelength of 517 nm using a UV-VIS spectrophotometer. The results were then averaged based on the percent inhibition.

## Results and Discussion

### Resin Solubility

In the present study, the results of the successive extraction method are presented in Figure 1. The *A. cunninghamii* resin exhibited a high residual value of 55% of the total initial weight. The three solvents used in this study were found to be incapable of dissolving more than half of the initial weight of the resin. The ethyl acetate solvent was found to be the most effective, with a percentage of 27%, indicating a significant presence of semi-polar components.

The high percentage (44.2%) of ethyl acetate solubility was obtained through the separation method (Figure 2). Furthermore, the use of an *n*-hexane as a solvent did not yield a distinct solubility level compared to the levels produced by the other two solvents (10% vs. 9.71%). This outcome was due to the extraction process starting with *n*-hexane as the initial solvent. The low value of the extract with *n*-hexane solvent indicates the low solubility of the non-polar component. The use of methanol in conjunction with the separation method yielded a solubility percentage of 24.9% for the initial weight of the resin. The methanol as a solvent produced a low percentage of extract value, thereby indicating that methanol has yet to demonstrate effectiveness in dissolving resin of *A. cunninghamii*. A comparison of the two methods revealed methanol solubility percentage

resulting from the implementation of the separation method was three times higher than that achieved by the successive method.

This finding aligns with a previous study that reported the insolubility of *A. heterophylla* gum in methanol (Divvela *et al.* 2016). Conversely, the *n*-hexane extract of the oleoresin from *P. merkusii*, *P. oocarpa*, and *P. insularis* exhibited the highest yield when subjected to the same method and solvent (Sari *et al.* 2018). These results contrast with the findings of this study, which demonstrated the inability of non-polar solvents to dissolve *A. cunninghamii*. A similar trend was observed in copal resin, wherein non-polar solvents proved ineffective in facilitating dissolution (Lukmandaru 2014).

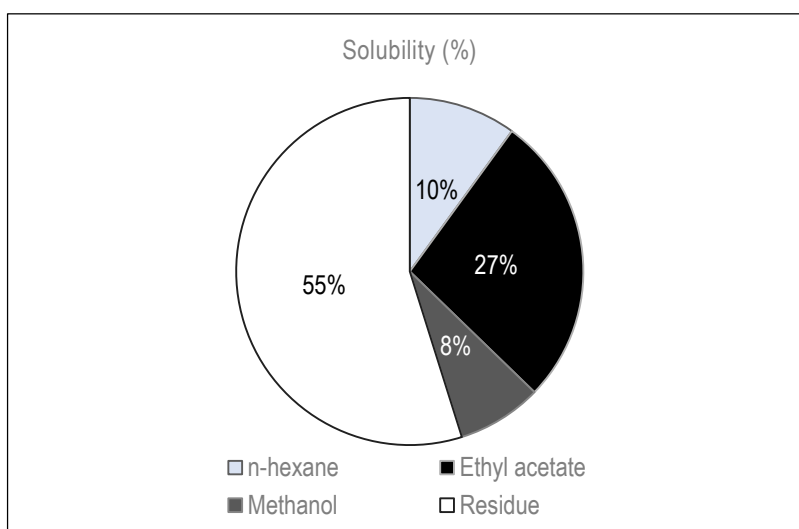


Figure 1. Solubility of *A. cunninghamii* resin through the application of successive extraction methods

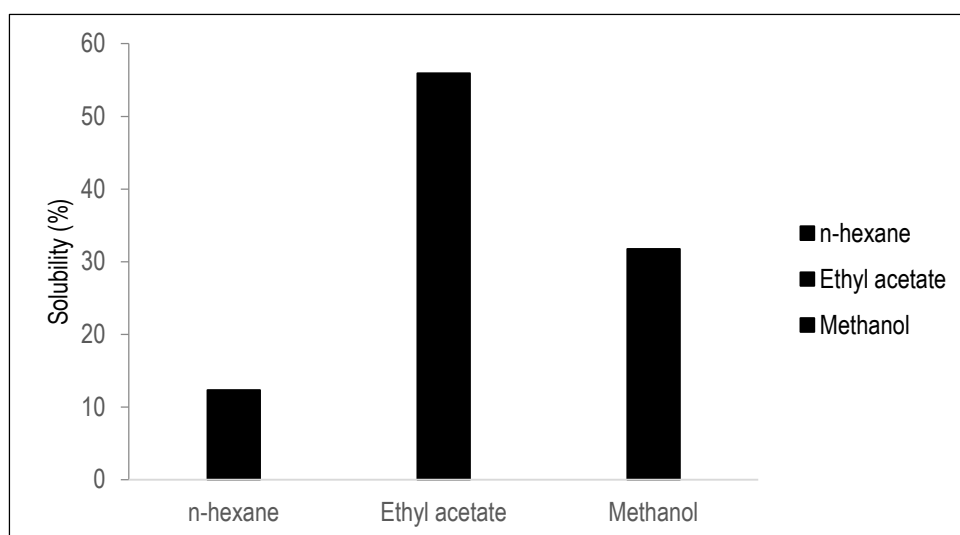


Figure 2. Solubility of *A. cunninghamii* resin through the application of separation method

### Yield of Acid Fraction and Neutral Fraction

As demonstrated in Table 1, *A. cunninghamii* exhibited a more pronounced neutral fraction value compared to its acid fraction value. In principle, the neutral fraction generally comprises unsaponifiable substances in alkali, glycerol, and a mixture of acids (fats and resins), while the acid fraction consists of fatty acids and resin acids (Baeza and Freer 2001; Lukmandaru 2012). In a previous study, copal from resin trees (*Agathis* sp.) of the *Araucariaceae* family exhibited a more dominant acid fraction (56 to 80%) compared to the neutral fraction (20 to 44%) (Lukmandaru 2017).

### Separation of Neutral Fraction by Saponification

A comparison of the unsaponifiables fraction (67.7%) of *A. cunninghamii* with the phenolic fraction (15.6%) revealed a significant difference in the relative dominance of each

fraction. The fraction dissolved in dichloromethane is a non-polar substance that has not been dissolved in *n*-hexane due to differences in polarity (Lukmandaru 2012). A previous study by EFSA Panel (2010) on gum resin from *Pinus oocarpa* Schiede species obtained an acidic fraction with a percentage ranging from 75.7% to 78.2% and an unsaponifiable fraction ranging from 19% to 20.1%. When evaluated in conjunction with the *softwood* group, the percentage of the unsaponifiable fraction of *A. cunninghamii* exhibited a more dominant value. Theoretically, the higher the unsaponifiable content, the greater the potential for pitch problems in the pulp and paper process. This phenomenon can be attributed to the low solubility of lipophilic components in water, which complicates their removal. Consequently, this may result in pitch-related issues during the pulping and papermaking processes (del Rio *et al.* 2009).

Table 1. Composition of neutral fraction, acid fraction, unsaponifiables fraction, and phenolics fraction

Fraction	Solubility (%)
<i>n</i> -hexane solubles	
- Neutral	73.7
- Acid	7.16
Neutral fraction	
- Unsaponifiables	67.7
- Phenolics	15.6

### Identification of Chemical Components of *A. cunninghamii* resin

The GC-MS analysis detected the presence of six main chemical compound categories: oxygenated sesquiterpenes (31.5%), sesquiterpene hydrocarbons (23.8%), oxygenated diterpenes (19.9%), diterpenes (13.5%), resin acids (7.5%), and other compounds (3.8%) (see Figure 3, Table 2). In the oxygenated sesquiterpenes category, viridiflorol was the most abundant component, representing 22.3% of the category. Alpha-cadinol was the least abundant, with a percentage of 1.7%. Additionally, androstenediol was

identified with a minimal percentage (1.8%), obtained from another compound category, namely, steroids (3.8%).

As reported in the study by Verma *et al.* (2014), *A. cunninghamii* resin was found to contain a higher amount of sesquiterpenes. The present study found similar results, with the highest group being oxygenated sesquiterpenes. The abundance of diterpenes, followed by sesquiterpenes, in *A. cunninghamii* has also been observed in various pine species. This finding suggests that diterpenes are more abundant than monoterpenes and sesquiterpenes in these species.

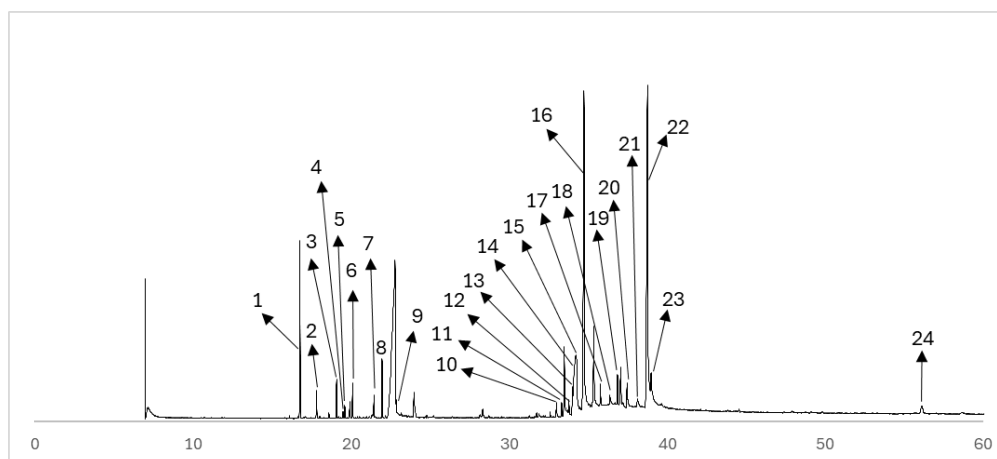


Figure 3. GC-MS chromatogram of the *n*-hexane solubles from *A. cunninghamii*

For example, labdane diterpenes are primarily present in pine species. In addition, it has been reported that  $\beta$ -caryophyllene and germacrene are the most abundant sesquiterpenes in certain coniferous species (Mofikoya 2020). The presence of resin acids, including isopimaric and pimaric acids, was also identified in the resin of *A.*

*cunninghamii*. Furthermore, isopimaric acid has been detected in copal resin (Lukmandaru 2017). A study undertaken previously has reported the presence of arachidonic acid, which is the main component of *A. cunninghamii* resin (Matsabisa *et al.* 2019).

Table 2. Chemical component of *n*-hexane soluble from *A. cunninghamii* resin

Peak	Retention Time (Minutes)	Compound	Formula	Similarity Index (%)	Concentration (%)
Sesquiterpene Hydrocarbons					23.8
1	16.79	Copaene	C <sub>15</sub> H <sub>24</sub>	96	6.14
2	17.84	Caryophyllene	C <sub>15</sub> H <sub>24</sub>	97	2.12
3	19.11	Copaene	C <sub>15</sub> H <sub>24</sub>	91	2.36
4	19.63	(-)-Aristolene	C <sub>15</sub> H <sub>24</sub>	88	1.67
5	19.94	.gamma.-Muuroloene	C <sub>15</sub> H <sub>24</sub>	94	1.81
6	20.12	isoledene	C <sub>15</sub> H <sub>24</sub>	88	2.26
12	33.81	.gamma.-Elemene	C <sub>15</sub> H <sub>24</sub>	78	1.71
13	34.03	Longifolene	C <sub>15</sub> H <sub>24</sub>	82	2.50
19	37.09	.beta.-Elemene	C <sub>15</sub> H <sub>24</sub>	82	3.20
Oxygenated Sesquiterpenes					31.5
7	21.47	Humulenol-II	C <sub>15</sub> H <sub>24</sub> O	85	1.87
8	21.99	Caryophyllene oxide	C <sub>15</sub> H <sub>24</sub> O	77	3.08
9	22.88	.alpha.-Cadinol	C <sub>15</sub> H <sub>26</sub> O	91	1.73
20	37.48	Ageratriol	C <sub>15</sub> H <sub>24</sub> O <sub>3</sub>	83	2.50
22	38.77	Viridiflorol	C <sub>15</sub> H <sub>26</sub> O	77	22.3
Diterpene					13.5
11	33.34	Thunbergen	C <sub>20</sub> H <sub>32</sub>	84	1.76
15	34.24	Hibaene	C <sub>20</sub> H <sub>32</sub>	81	7.42
23	39.01	Thunbergen	C <sub>20</sub> H <sub>32</sub>	82	4.28
Oxygenated Diterpenes					19.9
16	34.76	Verticicol	C <sub>20</sub> H <sub>34</sub> O	83	17.9
17	35.80	Thunbergol	C <sub>20</sub> H <sub>34</sub> O	84	2.02
Resin acids					7.50
10	33.02	Pimaric acid, TMS	C <sub>23</sub> H <sub>38</sub> O <sub>2</sub> Si	88	1.81
14	34.14	Isopimaric acid, TMS	C <sub>23</sub> H <sub>38</sub> O <sub>2</sub> Si	83	3.77
21	38.14	Agathic acid 15-methyl ester, TMS	C <sub>24</sub> H <sub>40</sub> O <sub>4</sub> Si	89	1.92
Other compounds					3.80
18	36.40	Androstenediol	C <sub>19</sub> H <sub>30</sub> O <sub>2</sub>	72	1.83
24	56.13	Lupenone	C <sub>30</sub> H <sub>48</sub> O	78	2.01

### Physico-Chemical Analysis

The ash content of a material is directly related to its mineral content (Amalia *et al.* 2018). The Indonesian National Standard (SNI) for super quality stipulates an ash content requirement of less than 0.02%. As demonstrated in Table 3, the resin satisfied these criteria. The resin produced a blackish residue, which was attributable to impurities. The acid number did not meet the SNI requirements (160-200). A direct relationship was observed between acid numbers (Table 3) and acid fraction percentage (Table 1). The acidic

fraction had a low level of acid number value. Moreover, the level of insolubility in toluene did not comply with the stipulated SNI requirements. As demonstrated in Figure 1 and Figure 2, the resin was found to be insoluble in *n*-hexane and toluene solvents, based on successive extraction or separation. It can be thus be concluded that the high level of insolubility in toluene is due to the polymerized component rather than the impurities. Another study reported the insoluble content of toluene in copal resin to be 35.89% (Lukmandaru 2017).

Table 3. Physico-chemical analysis of *A. cunninghamii* resin

No	Parameters	Physico-chemical properties of <i>A. cunninghamii</i> resin	Grade specification of SNI 7636:2020		
			I	II	III
1	Ash content (%)	0.02	≤ 0.04	≤ 0.05	≤ 0.08
2	Acid numbers	83.9	160- 200 (General required)		>30
3	Toluene insoluble content (%)	0.5	≤ 0.05	≤ 0.07	≤ 0.1

### Total Phenolic Content (TPC)

The total phenolic content (TPC) of the fractions derived from *A. cunninghamii* resin is presented in Table 4. The highest TPC level was found in the *n*-hexane soluble extract. This pattern is in line with the amount of phenolic fraction (see Table 1). The Folin-Ciocalteu method is not specific to phenolic compounds, as it can also react with other non-phenolic reducing compounds, potentially leading to an overestimation of the total phenolic content (van Alstyne 1995). The resin had a lower percentage of phenolic

fraction and had a more dominant unsaponifiable fraction. In an earlier study (Lukmandaru 2017), the TPC of an ethanol soluble extract from copal resin was found to be higher than the results of the present study. Theoretically, the higher TPC in plants indicates a strong antioxidant therapeutic potential. Phenolic components function as free radical acceptors and chain bond splitters. Phenolics have been shown to interfere with the rapid fractionation of lipids and other molecules by donating hydrogen atoms to radical components (Salim *et al.* 2020).

Table 4. The results of total phenolic content, antioxidant activity, and antioxidant activity of *n*-hexane fractionation separation from *A. Cunninghamii*

Fraction	TPC (mg GAE/ g)	AAO (%) Inhibition
<i>n</i> -Hexane	6.84	19.6
- Neutral	-	-
- Acid	-	-
- Phenolic	-	28.8
Ethyl acetate	5.53	13.3
Methanol	4.21	4.88

### Antioxidant Activity of *A. cunninghamii*

The results of the antioxidant activity measurement through the DPPH method are shown in Table 4. In this study, the concentrations that were determined for calculating the percentage of inhibition were 4,000 ppm, 2,000 ppm, 1,000 ppm, and 500 ppm, respectively. The capacity for high antioxidant activity is characterized by low concentrations but high percentages of inhibition. The highest percentage of inhibition was obtained observed in the *n*-hexane soluble, with an inhibition of percentage of 19.6%. This was followed by the ethyl acetate soluble, which exhibited an inhibition percentage of 13.3%. The methanol soluble demonstrated the lowest percentage of inhibition, with a result of 4.88%. This low inhibition percentage level can be explained by the low TPC level (Table 4). Theoretically, the greater the content of phenolic components in plants, the more significant the antioxidant potential (Salim *et al.* 2020). Meanwhile, the inhibition percentage of gallic acid, used as the control was 89.69%. The low percentage of antioxidant activity might be attributable to the presence of more neutral components that lack the potential for DPPH inhibition as an antioxidant activity.

The *n*-hexane soluble exhibited the most potent antioxidant activity. The subsequent stage involved the test

of the fractions derived from *n*-hexane soluble resin. It was found that the phenolic fraction was the only constituent that showed the observed inhibitory effect, while the other fractions demonstrated no inhibition, even at high concentrations. The inhibition percentage increased from 19.5% to 28.8% (phenolic fraction). Furthermore, the detection of terpenoid compounds (see Table 2) and antioxidant activity in the non-polar fraction (e.g., *n*-hexane) demonstrates that non-polar compounds can also contribute to antioxidant activity (Isnindar *et al.* 2024).

A previous study has examined the antioxidant properties of frankincense resin, revealing more potent antioxidant activity (Hacini *et al.* 2018). In addition, the antioxidant properties of the methanol soluble gums of *A. heterophylla* and *P. chilensis* exhibited a notable capacity to capture free radicals, with an enhancement in antioxidant potency observed as the concentration of the extract increased (Samrot *et al.* 2020). A previous study also observed low antioxidant activity values in copal resin due to the small amount of phenolic components (Lukmandaru 2017). Further studies are necessary to detect phenolic and non-phenolic components that affect the antioxidant activity. In addition, the employment of other instrumentation, such as HP-LC (high-performance liquid chromatography) or LC-MS

(liquid chromatography-mass spectrometry), is required to identify phenolic components.

### Conclusion

The use of ethyl acetate solvent resulted in the highest percentage of solubility in resin. The neutral fraction constituted the predominant fraction in the *n*-hexane solubles. The main compound categories of resin were identified as oxygenated sesquiterpenes, sesquiterpene hydrocarbons, and oxygenated diterpenes. The ash content (0.02%) met the Indonesian National Standard (SNI). Furthermore, the *n*-hexane soluble extract had the highest TPC level. The *n*-hexane solubles demonstrated the highest antioxidant activity. An increase in antioxidant activity was observed in phenolic fraction. In general, *A. cunninghamii* fractions exhibited relatively low antioxidant activity in comparison to gallic acid.

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# Oleoresin Yield and Gum Rosin Properties from Sulawesi and Sumedang Sub-lines of *Pinus merkusii* Wood

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## Abstract

Progeny testing can be performed to reach high oleoresin production from *Pinus merkusii*. This study aimed to determine and compare the oleoresin yields and rosin properties of 15-year-old *Pinus merkusii* wood of the Sumedang and Sulawesi sub-lines from the KPH Banyumas Barat plantation. Tree diameter and oleoresin yield were observed in 20 individual trees of each sub-line. Tree tappings were conducted by the drilling method for three days, which was replicated for five times over a 15-day observation period. Gum rosin samples were obtained from all trees by the hydro-distillation method. The results showed that the tree diameters at breast height and oleoresin yields of the Sumedang sub-line fell in the ranges 22.0–34.2 cm and 10.8–51.2 g/tree/3 days, respectively, whereas those of the Sulawesi sub-line fell within the ranges 19.4–31.2 cm and 11.6–50.4 g/tree/3 days, respectively. Based on t-test results, no significant difference was found between the two sub-lines. The gum rosin yields were 52–79% and 55–78% for the Sumedang and Sulawesi sub-lines, respectively. With regard to rosin properties, the softening point, acid number, saponification value, toluene-insoluble content, and volatile content were  $77.80 \pm 4.08^\circ\text{C}$ ,  $189.51 \pm 10.51$ ,  $216.54 \pm 10.51$ ,  $0.08 \pm 0.11\%$ , and  $3.78 \pm 3.56\%$ , respectively, for the Sumedang sub-line and  $66.35 \pm 6.55^\circ\text{C}$ ,  $78.15 \pm 2.92$ ,  $189.86 \pm 10.68$ ,  $208.02 \pm 10.50$ ,  $0.06 \pm 0.11\%$ , and  $9.82 \pm 2.95\%$ , respectively, for the Sulawesi sub-line. Significant effects of sub-line were only observed in terms of saponification value and volatile content, where the rosin from the Sumedang sub-line had better properties than the rosin from the Sulawesi sub-line. These differences indicate different compositions of chemical components of oleoresin or rosin between sub-lines.

**Keywords:** pine resin, gum rosin, resin distillation, yield, tree diameter

## Introduction

Rosin and turpentine oils from the distillation of *Pinus merkusii* Jungh et de Vriese oleoresin are the major commodities of Perum Perhutani in its non-timber forest products (NTFPs) division. For this reason, oleoresin tapping serves as a highly important supply-chain component in supporting the sustainability of its processing industry. Perum Perhutani has made various innovations, including the selection of superior trees, improvement of tapping methods, and improvement of the efficiency of the distribution chain to the mill.

One way of selecting superior trees is by conducting *P. merkusii* progeny tests for oleoresin production, for example one which has been done in 2007 at the West Banyumas KPH plantation. In addition to producing trees with good growth characteristics (relatively large diameters and heights), relatively straight trunks, and resistance to attacks by pests and diseases, the progeny test is also designed for the main purpose of producing high oleoresin yield with a sub-line system based on the origin of the parent tree (Muslimin 2017).

Oleoresin production in several pines is affected by genetic factor (Tadesse *et al.* 2001; Siregar and Hatemer 2004; López-Álvarez 2023) as well as environmental factors (Gajšek *et al.* 2018; Sharma *et al.* 2018; Lukmandaru *et al.* 2020; 2021). The genetic effect on the oleoresin productivity of several sub-lines of *Pinus merkusii* progeny test was

observed by Muslimin (2013) and Nugrahanto *et al.* (2020), who proved the significant effect of the sub-lines. Research on oleoresin production and turpentine and rosin properties showed a significant effect of provenance differences (Sukarno *et al.* 2015; 2018). Genetic differences in pine trees, in addition, are thought to affect the quality of the rosin produced because it can cause variation in the chemical components contained in the rosin.

The first *P. merkusii* introduced to Java was narrow in its genetic base. Therefore, the genetic base of the species was expanded by introducing new genetic materials from varied sources. Sub-lines are genetic materials produced through a selection process that requires a number of tests before they can be released as varieties. This study used the Sumedang and Sulawesi sub-lines of *Pinus merkusii* whose seedlings were taken from the Sumedang and Sulawesi seedling seed orchards (SSO). This study is expected to provide more information with regard to rosin properties from tree breeding programs.

## Materials and method

### Sampling Site

Sampling was carried out in compartment 37C, Sumedang 2 Block IV for the Sumedang sub-line and in Sulawesi 2 Block VIII for the Sulawesi sub-line in October–December 2022. It took place in RPH Samudra, BKPH

Lumbir, KPH Banyumas Barat (07°20'00" S and 108°55'00" E, 300–500 m above sea level). The average daily temperature was 26.3°C, with a minimum temperature of 24.4°C and a maximum temperature of 30.9°C. With an average rainfall of 3500 mm/year, the site was classified as having B climate according to the Schmidt-Fergusson climate classification. The site was of a hilly topographic condition with a slope of 30–40°, and the soil was of the mediterranean soil (Alfisol) type from limestone with marl parent material (Muslimin et al. 2013).

### Oleoresin Tapping

A total of 20 selected healthy and straight trees for each sub-line were tapped using the drilling method. This tapping method was selected in order to produce cleaner oleoresin from the dirt. The selection of trees was based on the

uniform conditions for obtaining sunlight and nutrients. Oleoresin was harvested using the trunk drilling method at a height of ±50 cm above the ground, with a slope of 30–45° toward the trunk axis upward. The drilling depth was ±2–3 cm (10 mm of drill bit) from the outermost wood surface to the sapwood part. Pipes and plastic bags for collecting sap were installed to hold clear oleoresin of premium quality (Figure 1). After three days, the oleoresin collected was taken. Drilling was then carried out again in a different direction, and the pipes and plastic bags were reinstalled. All the oleoresin collected was taken and weighed using a digital scale. Drilling was performed with a total of five replications (over 15 days), and the average weight of oleoresin was calculated. The accumulated production was also calculated for a total of 15 days of observation. The oleoresin was held in a plastic bag, which was then stored at room temperature for six months.



Figure 1. Oleoresin tapping by drilling method

### Oleoresin Distillation

The weighed oleoresin was extracted for rosin through a hydro-distillation process (Figure 2). Due to the oleoresin's premium quality, the cooking process was carried out directly by putting the oleoresin (±100 g) into a two-necked flask, and then distilled water was added. The weight ratio of oleoresin to distilled water was 1:1.5. Heating was carried out at a temperature of 140°C for 1.5 hours. Once finished, the liquid-state rosin produced was poured into a cast and then maintained until it hardened (Figure 3). The gum rosin yield was calculated from the weight of rosin based on the initial oleoresin weight.



Figure 2. Hydro-distillation of *Pinus merkusii* oleoresin



Figure 3. Rosin obtained by hydro-distillation method

### Physico-chemical Properties of Gum Rosin

The softening point (ring and ball apparatus), acid number (acid-base titration), as well as solubility in toluene and ash content (gravimetry) were measured and compared according to the SNI 7636:2020 standard. These measurements were carried out with three replications

### Data Analysis

The obtained data was assayed for normality (Shapiro-Wilk test). The effects of sub-line on tree diameter, resin production, and physico-chemical properties of rosin were analyzed using an independent t-test (normal data distribution) and a Mann-Whitney test (non-normal data distribution). Statistically significant differences were set at a 95% confidence level. All statistical calculations were conducted using SPSS-Win 18.0.

## Results and Discussion

### Oleoresin Yield

Pine tree tapping was conducted by the drilling method to produce premium-quality oleoresin with maximum yield. In this method, oleoresin was flowed from a drill hole through a pipe that was inserted into the hole and immediately collected into a closed plastic bag to prevent direct contact with dirt and

water during tapping. Oleoresin collection was done with five replications once every three days. The results of measurements of tree diameter, three days' average oleoresin yield, and 15 days' accumulated oleoresin yield are presented in Table 1.

The average oleoresin yield of the Sumedang sub-line was higher (30.69 g/tree/3 days) than that of the Sulawesi sub-line (26.97 g/tree/3 days). Previous research obtained yield values of  $4.58 \pm 0.27$  g/tree/3 days and  $3.50 \pm 0.18$  g/tree/3 days for the Sumedang and Sulawesi sub-lines of 4-year-old *Pinus merkusii*, respectively (Muslimin 2013). The oleoresin yield from *Pinus merkusii* was moderate to high under genetic control (Soekarno *et al.* 2015; Nugrahanto *et al.* 2022). Another study was conducted on three sub-lines of *Pinus merkusii* progeny test (11 years) in the KPH Banyumas Barat plantation (Nugrahanto *et al.* 2020). It was found that the SSO of the Sumedang sub-line gave the highest results with an average oleoresin yield of  $17.43 \pm 0.38$  g/tree/3 days, while the East Java sub-line had an average oleoresin yield of  $12.53 \pm 0.34$  g/tree/3 days. The difference in value is thought to be due to the age of the tree at the time of tapping. Tree age is a factor that greatly affects pine oleoresin yield (Lateka *et al.* 2019), where the older the tree, the more pine oleoresin it produces.

The accumulated results from 15 days of observation showed average yield values of 153.45 g and 134.85 g for the Sumedang and Sulawesi sub-lines, respectively. These values are equivalent to oleoresin yields of 10.23 g/day and 8.99 g/day, respectively. As a comparison, an earlier work using the drilling method on 29-year-old *Pinus merkusii* stands (class age VI) in Tana Toraja obtained a value of 6.4 g/tree/day without stimulant treatment (Lempang 2017). From different provenances of *Pinus merkusii* in a Jember plantation, Soekarno *et al.* (2015) observed average oleoresin yields of 12.2–21.1 g/hole/tree/day. The average daily values were obtained at 4.15 g per tree (class age IV) and 9.10 g per tree (class age VII) per day in the pine stands of KPH Banyumas Timur using the bark chipping method for eight days of observation without wound renewal (Lukmandaru *et al.* 2018).

Table 1. Tree diameter and oleoresin yield from Sumedang and Sulawesi sub-lines

Trees number	Diameter (cm)		Oleoresin yield of tree/3 days (g)		Oleoresin yield of tree/15 days (g)	
	Sumedang	Sulawesi	Sumedang	Sulawesi	Sumedang	Sulawesi
1	34.2	30.6	33.8	31.2	169	156
2	31.8	26.9	36.8	31.8	184	159
3	29.8	26.4	23.2	20.6	116	103
4	25.9	26.1	34.8	22.2	174	111
5	29.3	24.9	27.0	14.8	135	74
6	23.6	20.5	30.0	11.6	150	58
7	28.2	28.9	22.4	26.6	112	133
8	24.3	20.8	40.8	15.2	204	76
9	26.4	27.0	29.8	19.8	149	99

10	23.3	32.7	20.0	20.8	100	104
11	25.0	28.5	34.2	19.8	171	99
12	24.2	24.0	10.8	41.8	54	209
13	22.0	22.1	28.8	39.0	144	195
14	30.5	21.9	32.2	34.4	161	172
15	31.5	24.6	28.4	39.2	142	196
16	32.2	29.4	37.4	44.8	187	224
17	27.7	19.4	27.0	11.6	135	58
18	29.0	26.5	40.8	26.0	204	130
19	25.8	31.2	51.2	17.8	256	89
20	29.6	29.6	24.4	50.4	122	252
Average	27.72	26.10	30.69	26.97	153.45	134.85
St. Dev	3.42	3.80	8.77	11.53	43.83	57.65
Coeff. var. (%)	12.34	14.56	28.56	42.75	28.56	42.75
t-test (prob)	0.16		0.25		0.25	

### Yield and Properties of Gum Rosin

The average yield of rosin for the Sumedang sub-line was 64.98%, while for the Sulawesi sub-line the average yield of rosin was 66.24%. Through different distillation processes on a laboratory scale, the rosin yields from *Pinus merkusi* grown in West Sumatra in previous studies ranged from 58% to 63% (Wiyono *et al.* 2003). It was also mentioned that the yield on a factory scale ranged from 60% to 69%. For comparison, the rosin yields of *P. oocarpa* and *P. patula* were 75.0% and 74.5%, respectively (Sarria-Villa *et al.* 2021).

The acid numbers of rosin of the Sumedang and Sulawesi sub-lines ranged from 168.3 to 203.36 and from 161.29 to 199.86, respectively. The average acid numbers for the Sumedang and Sulawesi sub-lines were 189.51 and 189.86, respectively. These ranges were still within the SNI requirements (160–200) and comparable to the acid numbers of trees from West Sumatra (Wiyono *et al.* 2003) but higher than acid numbers of trees of the Aceh provenance and Jember landrace (Soekarno *et al.* 2018). The saponification values of rosin were 216.55 for the Sumedang sub-line and 208.03 for the Sulawesi sub-line. Based on the average values, the saponification values obtained were still in accordance with the SNI standards but lower than those observed by Wiyono *et al.* (2003) and higher than those observed by Soekarno *et al.* (2018).

The comparatively high acid numbers in this study indicate that the concentrations of free resin acid in the rosin were quite large. This is thought to be because the oleoresin in this study had been degraded by the breakdown of unsaturated resin acid through the oxidation or hydrolysis process due to the storage time being too long, namely six months, hence generating high acid numbers. In addition, this study did not experiment with oleoresin dilution with turpentine, causing the free resin acid to increase. The quality of rosin produced for food grade purposes will decrease if the acid number is higher (Hidayat *et al.* 2021).

The toluene-insoluble content in rosin was 0.08% and 0.06% for the Sumedang and Sulawesi sub-lines, respectively, falling within the range of 0–0.4%. These values

met the SNI 7 636:2020 standard as they remained below the 0.1% threshold. The rosin from the Sumedang sub-line was of the third quality class (N), while the rosin of the Sulawesi sub-line was of the second quality class (WG), suggesting that the rosin from the Sumedang sub-line had a higher level of impurities than the rosin from the Sulawesi sub-line.

The permissible value of softening point of rosin based on SNI 7636:2020 is  $\geq 74^{\circ}\text{C}$ . Wiyono *et al.* (2003) observed values of 76–80 $^{\circ}\text{C}$ , and almost uniform values (76.0–76.5 $^{\circ}\text{C}$ ) were obtained by Soekarno *et al.* (2018) in previous works. The softening points of rosin of the Sumedang and Sulawesi sub-lines fell within the ranges 69–83 $^{\circ}\text{C}$  and 72–84 $^{\circ}\text{C}$ , respectively. Thus, the rosin from the Sumedang sub-line could be classified in the second quality class with an average softening point of 77.8 $^{\circ}\text{C}$ , while the rosin of the Sulawesi sub-line was in the super quality class with an average softening point of 78.15 $^{\circ}\text{C}$ . Based on these results, it can be concluded that the rosin from the Sulawesi sub-line had lower dirt/impurity content than the rosin of the Sumedang sub-line. The dirt content in rosin usually takes the form of turpentine or short-chain fatty acid organic compounds.

The volatile content of rosin from the Sumedang sub-line ranged from 0.4% to 10.4%, while the rosin from the Sulawesi sub-line had volatile content from 3.6% to 15.2%. Based on the volatile content, several rosin samples from the Sumedang sub-line belonged to the quality classes X to N (Table 2), while all rosin samples from the Sulawesi sub-line failed to meet SNI standards. An imperfect cooking process can prevent turpentines in oleoresin from evaporating completely, hence resulting in a decrease in softening point (Hidayat *et al.* 2021). Values in the range 2.1–2.3% were previously obtained by Soekarno *et al.* (2018). Meanwhile, the rosin obtained from the Sindang Wangi mill in West Java through the steam distillation process had softening points of 90 $^{\circ}\text{C}$  for WW quality rosin and 88 $^{\circ}\text{C}$  for X quality rosin (Khadafi *et al.* 2014).

Compared to the steam distillation process, the research direct contact (boiling) applied in this experiment is thought to cause a low softening point and a high level of evaporated parts due to the presence of turpentine. At

atmospheric pressure, turpentine has a boiling point of around 180°C and an operating time 3–4 times longer (Abdulgani 2002). However, the application of a high temperature will reduce the yield of rosin due to the quality degradation of the resin compounds.

### Sub-line Effect

In an earlier study, a significant genetic control on the secondary plant chemistry of *Pinus contorta* var. *latifolia* was observed (Ott et al. 2011). Based on independent t-test results, sub-line factor was found to have no significant effect on both tree diameter and oleoresin yield. It is thought that those properties are weakly genetically controlled. This indicates a strong environmental influence, with the two blocks observed here sharing similar hilly topographic conditions (slope of 30–40°). In addition, the trees of both sub-lines were the same in terms of age (15 years), treatment (no thinning), and tapping method. This trend was not observed by Muslimin (2013), who investigated five different sub-lines, including the Sulawesi and Sumedang sub-lines, and Nugrahanto et al. (2020), who also studied five different sub-lines.

Based on Mann-Whitney test and independent t-test results (Table 2), the difference in sub-lines only gave significant effects on saponification value and volatile content. It is assumed that the similar moisture and impurity content in both sub-lines would give similar yield and softening point. Saponification value is often associated with acid number. The high saponification value of the Sumedang sub-line indicates the presence of a higher proportion of short-chain carbon of resin acids with a low molecular weight in this sub-line than in the Sulawesi sub-line. The higher the saponification value, the lower the fatty acid content and the better the quality of the rosin. Conversely, the lower the saponification value, the higher the fatty acid content and the lower the quality of the rosin (Wijayanti et al. 2012). The rosin from the Sumedang sub-line had significantly lower volatile content than the rosin from the Sulawesi sub-line. It might be due to the lower monoterpene portions in the rosin of the Sumedang sub-line. The volatile part from monoterpene group such as pinene, carene, and camphene have been detected in oleoresin of *Pinus merkusii* (Sukarno et al. 2015). Further investigation with spectroscopic work is needed to find out more about the chemical composition of rosin.

Table 2. Gum rosin properties from Sumedang and Sulawesi Sub-line

Rosin properties	Sub-line Sumedang (n = 20)				Sub-line Sulawesi (n = 20)				t-test/ Mann-Whitney (prob.)	Indonesia National Standard (SNI 7636:2020)
	Min	Max	Average (Sd)	CV (%)	Min	Max	Average (Sd)	CV (%)		
Yield (%)	52	79	65.05 (7.48)	11.4	55	78	66.35 (6.55)	9.87	0.56	-
Softening point (C°)	69	83	77.80 (4.08)	5.2	72	84	78.15 (2.92)	3.73	0.52	XB: ≥78; X: ≥78; WW: ≥78; WG: ≥76; N: ≥74
Acid number	168.30	203.36	189.51(10.51)	5.5	161.29	199.86	189.86(10.68)	5.6	0.91	160-200
Saponification number	184.43	230.01	216.54(10.51)	4.8	185.83	224.40	208.02(10.50)	5.0	0.01*	170-220
Solubility in toluene (%)	0	0.40	0.08 (0.11)	137.5	0	0.40	0.06 (0.11)	183.3	0.62	XB: ≤0,02; X: ≤0,02; WW: ≤0,05; WG: ≤0,07; N: ≤0,1
Volatile content (%)	0.40	10.40	3.78 (3.56)	94.1	3.6	15.2	9.82 (2.95)	30.0	0.01>*	XB: ≤2; X: ≤2; WW: ≤2, WG: ≤2,5; N: ≤3

Remark: \* significant at 95% confidence level in Mann Whitney test. CV = coefficient of variation, Sd = standard of deviation, min = minimum, max = maximum

### Conclusions

There were no significant differences in tree diameter and oleoresin yield between the Sulawesi and Sumedang sub-lines. With regard to rosin properties, significant differences were observed in saponification value and volatile content, where the Sumedang sub-line provided better quality. Although the oleoresin studied here was of premium quality, some test samples did not meet SNI standards. The use of the hydro-distillation method in this experiment might have caused a decrease in softening point and high volatile content of rosin.

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# Strength and Stiffness of Wooden Building using Static Equivalent Analysis

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## Abstract

Wooden buildings can be used to support tourism infrastructure in the West Java region including to enhance resilience to disasters, especially earthquakes. This research aimed to study the behavior of wooden buildings due to designed earthquake loads. Three dimensional structural analysis were applied to obtain parameters of the strength and stiffness behavior of the building against lateral loads. The scopes of the research were: the building functions as part of the tourism support infrastructure in Stamplat, Indragiri Village, Bandung Regency, West Java, as a lodging building. The building uses a frame system concept with the main components being beams and columns of yellow Meranti wood (*Shorea faguatiana*). The size of the building is 30 m<sup>2</sup>. All cross-sections of beams and columns are rectangles. The static-based shear load is calculated using equivalent static analysis. The stiffness (drift) is calculated according to Indonesian earthquake code SNI 1726:2019. Design the capacity of columns and beams (strength) using reference to Indonesian National Standard SNI 7973:2013. Results of this research indicated that the nominal capacities of bending moment and shear forces of the columns and beams meet the requirements according to Indonesian timber code SNI 7973:2013. The drift of the building due to the equivalent static earthquake load in the main direction of the building does not exceed the permit limits; the stiffness of the building meets the requirements according to Indonesian seismic code SNI 1726:2019. Mechanically laminated technology provides benefits, even though the quality (class strength) of the wood is limited. If designed properly, it can be used as an earthquake-resistant building.

**Keywords:** Strength, stiffness, wooden bulding, static equivalent, based shear.

## Introduction

Wood, in terms of strength class II-III, generally has a limited cross-sectional size. In designing of buildings in earthquake-prone locations, the placement of columns and main beams are the major concern, so that the capacity of the cross-sectional components can function optimally to distribute internal forces due to dead loads, live loads, rain loads, and lateral loads (earthquakes).

Innovation in engineered wood is the choice in this study, based on the consideration of the need to form wood with the dimensions and cross-sectional sizes as needed, using medium-grade wood. The goal is to produce earthquake-resistant buildings with a frame system, with the main components being columns and beams using mechanical lamination technology.

Analysis of building structures against lateral loads is essential to determine the strength and stiffness behavior of building structures. The goal is that when the building is used during its service life and if an earthquake occurs, there will be no structural damage that can result in loss of life or damage to the structural components of the building.

This research focuses on the use of wood as a main member of buildings to support tourism infrastructure in Stamplat, Indragiri Village, Bandung Regency, West Java.



Figure 1. Location of wooden house construction in this research (Pranata *et al.*, 2022).

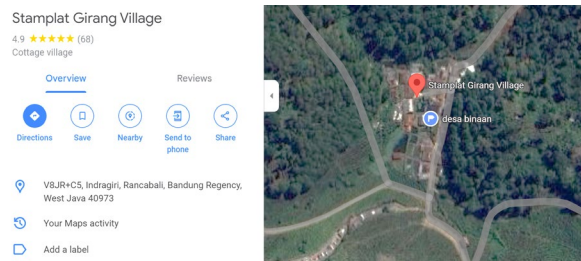


Figure 2. Google maps location of the wooden building in Stamplat, Bandung Regency, West Java.

This research aimed to study the behavior of wooden buildings which is designed for earthquake loads. The function of the building is as a guest house.

The scope used in the research is that the building functions as part of the tourism support infrastructure, located at Stamplat, Indragiri Village, Bandung Regency, West Java, as a lodging building. Figure 1 shows the planned location of the wooden building, which is near the Rancabali tea plantation. Meanwhile, Figure 2 shows the location of Google Maps coordinates, namely -7.1189 and 107.3404.

Previous research, namely studying the behavior of wooden buildings, both one-story and multi-storey, was carried out, among others, by Furqoni (2010), namely researching elevated houses against earthquakes. Manthani and Fauzan (2019) conducted research to study the behavior of the traditional West Sumatran building structures under earthquake loadings. Diredja *et al.* (2019) conducted research to study the structural performance of residential buildings using Mahogany Glulam wood. Research regarding the performance evaluation of low-rise buildings has also been carried out by Pranata *et al.* (Pranata *et al.*, 2021). Mahapatni *et al.* (Mahapatni *et al.*, 2023) have also carried out research on the analysis and design of traditional Balinese buildings.

Mechanical laminated wood is made by combining two or more wood laminae to obtain a larger cross-sectional size. Potential horizontal shear due to internal force mechanisms can be prevented by fasteners installed at certain intervals. This product is used as a structural component for wide-span buildings. Beams are joined mechanically using fasteners (Fraserwood, 2024; Pranata *et al.*, 2013).

### Materials and Methods

The building uses a frame system concept (Pranata *et al.*, 2022) with the main components being beams and columns of yellow Meranti wood (*Shorea faguatiana*). The size of the building is 30 m<sup>2</sup> or 6m x 5m. All cross-sections of beams and columns are rectangles. The dimension of the column is 100mm x 200mm, the main beam dimension is 100mm x 200mm, the secondary beams and roof ring beams dimensions are 100mm x 100mm, and the roof beam dimension is 100mm x 100mm.

### The Designed Earthquake Load

The lateral or designed earthquake load was calculated using equivalent static analysis according to Indonesian earthquake SNI 1726:2019 (BSN, 2019), with  $S_{DS}$  parameters of 0.92g and  $S_{D1}$  of 0.51g (PusGen, 2021). The stiffness (drift) was calculated according to Indonesian earthquake SNI 1726:2019 (BSN, 2019).

The design of the capacity (strength) of columns and beams implemented SNI 7973:2013 (BSN, 2013). References to residential building live loads referred to the Indonesian loading code SNI 1727:2020 (BSN, 2020). The three-dimensional structure analysis using the equivalent

static method was carried out using SAP2000 software (CSI, 2013).

### Physical and Mechanical Properties of yellow Meranti (*Shorea faguatiana*)

In this research, data on the physical properties (specific gravity) and mechanical properties of wood (modulus of elasticity, modulus of rupture, compressive strength, and shear strength) of yellow Meranti (*Shorea faguatiana*) wood species using references from the Wood Handbook (FPL, 2021) as shown in Table 1.

Table 1. Physical and mechanical properties of yellow Meranti (*Shorea faguatiana*) species (FPL, 2021).

References	MoE (MPa)	MoR (MPa)	F <sub>c</sub> (MPa)	F <sub>v</sub> (MPa)	SG
FPL., 2021	9000	55.2	40.7	10.5	0.46

MoE is the elastic moduli of timber that used as main beams, main columns, secondary beams, and roof-beams. MoR is the modulus of rupture of timber. F<sub>c</sub> is the compression strength of timber. F<sub>v</sub> is the shear strength of the timber. SG is the specific gravity of the timber.

### Equivalent Static Analysis

The equivalent static analysis is a simplified technique to substitute the effect of earthquake for a static force distributed laterally on a structure. The total applied-based forces (V) are evaluated in the two main axes of the building (Beer *et al.*, 2018).

Equivalent static analysis can be used as a method of analysis to estimate the force on the structures due to lateral or earthquake load. This analysis can be used on low-rise buildings (Faiz and Kumar, 2023).

Table 2. Parameter of design spectra (PusGen, 2021).

Parameters	Value
PGA MCEG	0.5137g
S <sub>s</sub> MCEr	1.1467g
S <sub>1</sub> MCEr	0.5160g
T <sub>L</sub>	20 sec.
T <sub>o</sub>	0.11
T <sub>s</sub>	0.55
S <sub>DS</sub>	0.92
S <sub>D1</sub>	0.51

In this research, the equivalent static earthquake load was calculated based on procedures in accordance with Indonesian earthquake code SNI 1726:2019 (BSN, 2019). The parameters required for calculating the static base shear force using design spectra data obtained from the Indonesian

earthquake map (PusGen, 2021) are shown in Table 2. Peak Ground Acceleration (PGA) is the surface acceleration of the mapped Maximum Considered Earthquake Ground Motion (MCEG) peak,  $S_s$  is the acceleration parameter of the Maximum Considered Earthquake (MCE) spectral response of the earthquake map in the short period, 5 percent attenuation,  $S_1$  is the acceleration parameter of the MCE spectral response of the earthquake map in the period of 1 second,  $T_L$  is a long period transition map,  $T_0$  is  $0.2 S_{D1}/S_{DS}$ ,  $T_s$  is  $S_{D1}/S_{DS}$ , and  $S_{DS}$  is the acceleration parameter of the spectral response for short periods (attenuation 5 percent),  $S_{D1}$  is the acceleration parameter of the spectral response for a period of 1 second (attenuation 5 percent) (BSN, 2019).

### Provisions for Strength of Building Components

Column and beam as a structural members of the wooden buildings can be designed by referring to Load and Resistance Factor (LRFD) method in the Indonesian timber code SNI 7973:2013 (BSN, 2013).

The design for factored compressive load on the column member can be calculated using Equation 1. The design for factored bending moment for column and beam members can be calculated using Equation 2. Furthermore, the design for factored shear force for column and beam members can be calculated using Equation 3. The stiffness behavior of the beam, namely deflection due to live load, can be calculated using Equation 4, the value of which must not exceed the allowable limit.

$$P_u \leq P' \quad (1.a)$$

$$P' = F'_c \cdot A \quad (1.b)$$

$$F'_c = F_c \cdot C_M \cdot C_t \cdot C_F \cdot C_i \cdot C_p \cdot K_F \cdot \phi \cdot \lambda \quad (1.c)$$

$$M_u \leq M' \quad (2.a)$$

$$M' = F'_b \cdot S_x \quad (2.b)$$

$$F'_b = F_b \cdot C_M \cdot C_t \cdot C_L \cdot C_F \cdot C_{fu} \cdot C_i \cdot K_F \cdot j \cdot \lambda \quad (2.c)$$

$$S = I_x / y \quad (2.d)$$

$$V_u \leq V' \quad (3.a)$$

$$V' = F'_v \cdot \frac{2 \cdot b \cdot d}{3} \quad (3.b)$$

$$F'_v = F_v \cdot C_M \cdot C_t \cdot C_i \cdot K_F \cdot j \cdot \lambda \quad (3.c)$$

$$\delta_{max} = L/400 \quad (4)$$

where:

- $P_u$  = factored compression load of column (N)
- $P'$  = the value of adjusted compression force (N)
- $F'_c$  = value of adjusted compression strength (MPa)
- $A$  = bruto cross-section of the column (mm<sup>2</sup>)
- $M_u$  = factored bending moment (N.mm)
- $M'$  = value of adjusted bending moment (N.mm)
- $F'_b$  = value of adjusted bending strength (MPa)

- $S_x$  = elastic section moduli (Hibbeler, 2023) (mm<sup>3</sup>)
- $V_u$  = factored shear force (N)
- $V'$  = value of adjusted shear force (N)
- $F'_v$  = value of adjusted shear strength (MPa)
- $I_x$  = moment of inertia (Goodno, 2021; Hibbeler, 2023) (mm<sup>4</sup>)
- $b$  = width of beam (mm)
- $Q$  = moment of static of beam cross-section (mm<sup>3</sup>)
- $\delta_{max}$  = maximum permitted deflection of beam (mm)
- $L$  = length of beam (mm).

### Provisions for Stiffness of Building

Guest houses with functions for the tourism support infrastructure are included in the risk category IV based on the Indonesian earthquake code (BSN, 2019). In the design of earthquake-resistant buildings, the deformation limit ( $\Delta_{max}$ ) for wooden buildings is categorized as other buildings can be calculated using Equation 5.

$$\Delta_{max} = 0.01 \times h_{sx} \quad (5)$$

where:

- $h_{sx}$  = the story height.

## Results and Discussion

### Structural Analysis of Wooden Building

In this research, the building has dimensions of 6m x 5m, with the function being a guest house. Figure 3 shows a schematic 3D model including beams, columns, and roof structure (Pranata et al., 2022; Pranata et al., 2023). Analysis of the 3D structure was carried out with SAP2000 software (CSI, 2013).

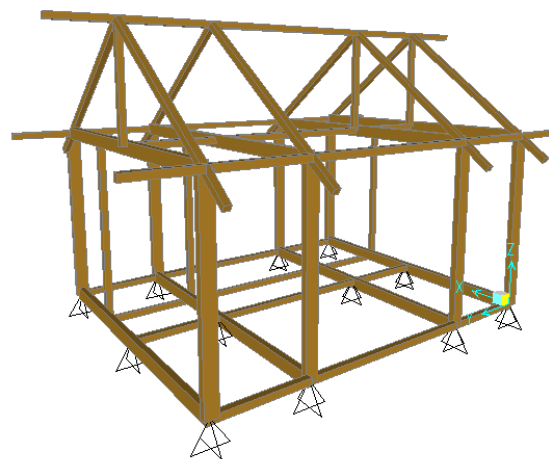


Figure 3. 3D model of the guest house in this research.

Indonesian loading codes (BSN, 2020) are used to determine live loads and superimposed dead loads that act during the service life of the guest house. The weight of the

wooden curtain, batten structure, and rain loads were modeled and calculated based on the tributary area, which were acting on the roof beams. The height of the main column is 3 meters. The total height of the building at the top of the roof is 4.8 meters.

Table 3. Results obtained from modal analysis.

Mode	Period (sec.)	Status
1	0.23	Translation x-direction
2	0.22	Translation y-direction
3	0.19	Rotation z-direction

Results obtained from model analysis using SAP2000 software are shown in Table 3, with the result that the first two modes are translations, and the third mode is rotation.

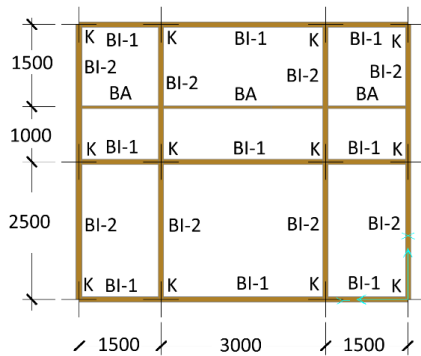


Figure 4. Numbering of main columns, main beams and secondary beams (unit length: mm).

Table 4. Results obtained from analysis: Deflection of beams.

Beam	Length (mm)	Deflection (mm)	Permission limits (mm)	Check
BI-1	1500	0.97	3.75	Ok
BI-1	3000	2.67	7.50	Ok
BI-2	2500	1.37	6.25	Ok
BA	1500	1.70	3.75	Ok
BA	3000	5.12	7.50	Ok

Figure 4 shows the numbering of main and secondary beams. Table 4 shows the results of structural analysis, which are the deformation of the building due to factored loads. Permission limit is calculated using Equation 4. Considering that this is an elevated building, it is very important to study the deflections in the floor elevation beams, so that the building meets the comfort requirements during its service life.

Table 5. Results obtained from analysis: Drift due to designed earthquake on x-direction.

Direction	Displ. (mm)	Drift (mm/mm)	Permission limits	Status
X	4.78	0.0016	0.010	Ok
Y	3.72	0.0013	0.010	Ok

Table 5 shows results of drift of the building due to design-equivalent static loads in the main direction, which are x-direction and y-direction. These results indicate that the drift that occurs at an elevation of +3 meters of the building does not exceed this limit according to SNI 1726:2019 (BSN, 2019). Permission limit is calculated using Equation 5. Ductility of the structure is identified as a requirement in the structural design of wooden buildings [Jorissen and Massimo, 2011].

Table 6. Results of column and beam members capacity check.

Member	Design Type	Factored Load	Capacity	Status
Column (K)	Axial	11.66 kN	436.6 kN	Ok
	Moment	0.35 kN.m	36.8 kN.m	Ok
	Shear	0.23 kN	140.0 kN	Ok
Main Beam (B1)	Moment	0.38 kN.m	36.8 kN.m	Ok
	Shear	0.41 kN	140.0 kN	Ok
Main Beam (B2)	Moment	0.59 kN.m	36.8 kN.m	Ok
	Shear	0.45 kN	140.0 kN	Ok
Sec. Beam (BA)	Moment	0.07 kN.m	73.6 kN.m	Ok
	Shear	0.06 kN	56.0 kN	Ok
Roof-Beam	Moment	0.34 kN.m	73.6 kN.m	Ok
	Shear	0.82 kN	56.0 kN	Ok

Table 6 shows the results of column and beam capacity calculations. The factored loads are obtained from the results of structural analysis under maximum load combination. Calculation of compression capacities were carried out using Equation 1a, capacities due to flexural moments were carried out using Equation 2a, and shear capacities were carried out using Equation 3a.



Figure 6. Construction process of the wooden guest house (Pranata et al., 2022).



Figure 7. The wooden guest house after completion (Pranata *et al.*, 2022).

The results of this calculation indicate that the main beams, secondary beams, and columns have a higher capacity than the working loads, so that the structure is safe during its service life. Figure 6 shows the construction process of a wooden building. Figure 7 shows a wooden building with a function for a guest house that has been completed.

Structural analysis considers the beam stiffness aspect, which is deformation due to gravity load, the strength aspect, which is the capacity of both beams and columns, and the building stiffness aspect due to earthquake load. The study in this research shows that beam deflection as shown in Table 4 needs to be a concern so that the building meets the design requirements according to SNI 7973:2013 (BSN, 2013), even though the beam and column capacity analysis (Table 6) shows results that appear to be over capacity.

There are basic assumptions in the calculation of the adjusted design values, according to the condition where the building was built. The temperature of the area ranges from 5° to 25° C. The function of the building meets the criteria for a residential house.

Since the wooden building has a low mass that which means it is equivalent to reduced horizontal base shear load even during strong earthquakes, wooden buildings might be a good choice in high seismic zone regions (Porcu, 2017). A general earthquake diagnosis method can be used to evaluate the lateral performance of wooden houses using the calculation of lateral load-carrying capacity (Mitani *et al.*, 2022). The calculation of the response and limit strength of the building is used to evaluate the performance of wooden houses due to lateral or earthquake load.

### Conclusions

The behavior of wooden buildings studied in this research is strength and stiffness. The nominal capacities of bending moment and shear forces of the columns and beams meet the requirements and the value is lower than the maximum factored load combination. These results indicated that the strength of the building met the requirements according to Indonesian timber code SNI 7973:2013. The

research results show that the drift of the building due to the equivalent static earthquake load in the main direction of the building does not exceed the permit limits. These results indicated that the stiffness of the building meets the requirements according to Indonesian seismic code SNI 1726:2019.

Mechanically laminated technology used in the main beam of a wooden house affects the results of deflection of beams. Results indicated that the deflection of beams does not exceed the permitted limits.

Overall, analysis of timber structures based on three dimensional structural analysis provides benefits, namely predicting the strength and stiffness behavior of wooden buildings. Even though the quality (class strength) of the wood is limited, if designed properly, it can be used as an earthquake-resistant building.

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# The Effect of Burning Time on the Yield and Quality of Liquid Smoke from Sengon Wood Waste (*Falcataria moluccana*)

Muhamad Indra Nurzaman, Andi Tri Lestari, and Dini Lestari

## Abstract

This study aims to determine the effect of burning time on the yield and quality of liquid smoke produced from sengon wood waste (*Falcataria moluccana*). The research method employed was an experimental design with a completely randomized design (CRD), consisting of three pyrolysis time treatments: 90 minutes, 120 minutes, and 150 minutes, each with three replicates. The parameters observed included yield, color, floating material, pH, phenol content, acetic acid content, and specific gravity. The results showed that the duration of combustion had a significant effect on the yield and acetic acid content of the liquid smoke, but no significant effect on pH, phenol content, and specific gravity. The highest yield was obtained at a combustion time of 150 minutes, with an average value of 23.07%, while the lowest yield was obtained at 90 minutes, with an average value of 15.90%. The pH value of the liquid smoke ranged from 3.07 to 3.16 and was classified as quality category II based on SNI 8985:2021. The phenol content exceeded the standard limit, while the acetic acid content and specific gravity mostly met the requirements of quality category II.

**Keywords:** Liquid smoke, sengon wood, burning time, yield, quality

## Introduction

Indonesia is known as one of the world's largest forest product producers, especially in timber production. Currently, various wood processing industries have grown rapidly to meet the demand for building construction materials, furniture, paper manufacturing, and other products. According to Badan Pusat Statistik (2022), roundwood production in Indonesia in 2022 reached approximately 64.65 million m<sup>3</sup> based on the results of the Quarterly Forestry Data collection. Until now, Indonesians have generally used sengon wood waste only as fuel (Pambudi 2018). This waste, in the form of sawdust, is usually left to rot or burned after drying. Sengon wood waste has not been optimally utilized. One alternative technology that can be applied to overcome this waste problem is to process wood waste into liquid smoke.

Liquid smoke is a black liquid produced from biomass, such as wood, bark, and other biomass waste, including forestry waste and industrial forest products, through a process called pyrolysis (Ridhuan *et al.* 2019). Pyrolysis is a thermochemical decomposition process that occurs in organic materials (biomass) through heating with little or no oxygen. In this process, the raw material undergoes chemical structure breakdown and becomes a gas phase (Ridhuan *et al.* 2019).

According to Fauzan and Ikhwanus (2017), the quality of liquid smoke is determined by its phenol content and acidity level because both play a major role as antibacterials. The higher the phenol content and acidity level, the higher the ability of liquid smoke to kill microorganisms. According to research by Putra *et al.* (2020), the phenol content of liquid smoke from sengon and avocado wood has the potential to inhibit bacterial growth. According to Arif *et al.* (2024), it was

reported that 75% grade 2 sengon wood liquid smoke has antimicrobial properties and is effective for use as an antiseptic.

Pyrolysis time affects the yield, pH, and density of the liquid smoke produced (Handayani and Sa'diyah 2022). Based on several previous studies, this study will use pyrolysis burning times of 90 minutes, 120 minutes, and 150 minutes. Although these studies provide preliminary information on changes in liquid smoke quality due to changes in pyrolysis duration, the time range used is relatively limited and only covers teak and mahogany. This time range is not sufficient to describe the characteristics of liquid smoke changes in other types of wood, such as sengon, which has a different chemical structure. Sengon wood has a different composition of lignin, cellulose, and hemicellulose compared to mahogany, so it has the potential to show different pyrolysis times. According to Shobib *et al.* (2023), sengon has a low lignin content of only 5%, with cellulose at 27% and hemicellulose at 41%. Meanwhile, teak has a high lignin content of 25%, cellulose of 32%, and hemicellulose of 8%. Mahogany wood has a lignin content of 21%, cellulose of 47%, and hemicellulose of 3%. Therefore, this study explores longer pyrolysis times. This study aims to determine the effect of pyrolysis burning time on the yield of liquid smoke produced from sengon wood powder. The results of this study are expected to provide information regarding the effective pyrolysis time for producing the yield and quality of liquid smoke from sengon wood powder.

## Materials and Methods

### Tools and Materials

The equipment used was a 10 kg capacity pyrolysis apparatus made of aluminum equipped with a thermometer,

an LPG stove as a heat source, weighing bottle, 50 mL burette, distiller, 250 mL Erlenmeyer flask, 250 mL, 500 mL, and 1000 mL beakers, 100 mL measuring cup, a stove, a spray flask, a 1000 mL measuring flask, a 10 mL micro burette, an analytical balance, a water bath, glass stirrer, pH meter, pycnometer, 25 mL pipette, 5 mL and 10 mL measuring pipettes, 1 mL, 5 mL, and 10 mL volumetric pipettes, spectrophotometer, 30 mL test tubes, thermometer, analytical balance.

The materials used were sengon wood powder (*Falcataria moluccana*), distilled water, phosphoric acid (H<sub>3</sub>PO<sub>4</sub>), hydrochloric acid (HCl), 0.1% phenolphthalein indicator, 5% methyl orange indicator, 0.025 N potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>), potassium iodide (KI) crystals, 4-aminoantipyrine solution, 0.5 N ammonium hydroxide (NH<sub>4</sub>OH) solution, 1 N and 4 N sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) solutions, 0.1 N bromate-bromide solution, 0.05% starch indicator solution, potassium ferricyanide solution (K<sub>4</sub>Fe(CN)<sub>6</sub>), 2.5 N sodium hydroxide solution (NaOH), buffer solution, phosphate buffer solution, 0.1 N sodium hydroxide standard solution (NaOH), anhydrous sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>), sodium thiosulfate (Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>) 0.025 N, potassium hydrogen phosphate powder (K<sub>2</sub>HPO<sub>4</sub>), potassium dihydrogen phosphate powder (KH<sub>2</sub>PO<sub>4</sub>).

### Stages of Liquid Smoke Production

The liquid smoke production process begins with the preparation of raw materials in the form of sengon wood powder. The wood powder is cleaned to remove various impurities that can affect the final result. The raw materials are weighed to determine the exact amount used in each treatment. The drying stage is carried out for seven days under direct sunlight. During the drying period, the wood powder is weighed periodically to monitor the moisture content (Mariyamah *et al.* 2024). The pyrolysis process is carried out using 600 g of raw material for each time variation, namely W1 90 minutes, W2 120 minutes, and W3 150 minutes, with each temperature group undergoing the pyrolysis process three times. During the pyrolysis process, the temperature was maintained at 300 °C using a pyrolysis device equipped with a thermometer as a temperature controller, so that temperature stability could be monitored and controlled consistently throughout the combustion.



Figure 1. Pyrolysis Process

### Liquid Smoke Quality Analysis

The liquid smoke from Sengon wood produced by pyrolysis was then tested for yield, color, floating matter, pH, phenol, acetic acid, and specific gravity.

#### Yield

According to Sahrum *et al.* (2021), yield is the ratio between the liquid smoke produced and the weight of the raw material used before combustion. Yield is determined by calculating the weight of the material used against the weight of the liquid smoke produced from each treatment and then calculating the average. This yield can be calculated using the following formula:

$$\text{Yield} = \frac{\text{Liquid smoke volume (mL)}}{\text{Sawdust volume (mL)}} \times 100\%$$

#### Color

A total of 25 mL of liquid smoke was placed in a test tube, and then the color of the sample was observed against a white background. Color testing was carried out by visually observing the sample using the sense of sight (SNI 8985:2021).

#### Floating Materials

The floating material test is conducted by adding 25 mL of liquid smoke to a test tube, then observing the presence or absence of floating material in the test sample using the sense of sight/eyes against a white test tube background (SNI 8985:2021).

#### pH

pH testing is carried out using a pH meter, which must first be calibrated using at least 2 buffer solutions. After the calibration process, the electrode is rinsed with mineral-free water and dried using a soft tissue paper. Next, the electrode is immersed in the test sample until the pH meter shows a stable reading. The reading that appears on the pH meter display is then recorded (SNI 8985:2021)

#### Phenol

This method is based on the principle of oxidation-reduction reactions, in which phenolic compounds in the sample undergo oxidation by the *Folin-Ciocalteu* reagent, which consists of phosphomolybdic acid and phosphotungstic acid in basic conditions, while the reagent undergoes reduction to form a blue complex. The intensity of the blue color formed is proportional to the total phenol concentration in the sample (Rotty *et al.* 2017). The total phenolic content is calculated using the formula quoted from (Susanty and Bachmid 2016):

$$\text{Phenol content} = \frac{c \times v}{m}$$

Explanation :

c = equivalent concentration of gallic acid (mg GAE/L)

v = volume of extract solution used (mL)

m = mass of extract used (g)

### Acetic Acid

Acetic acid testing using the ditritsi test. Titration is an analytical method used to determine the amount of dissolved substances quantitatively. This technique involves a complete chemical reaction between the analyte (titrant) and the reagent (titrant). A titrant with a known concentration will react with the titrant to measure the concentration of the substance (Indrajaya *et al.* 2021). The data obtained will then be calculated using the following formula:

$$\text{Total Acidity (\%)} = \frac{(V \text{ NaOH} \times N \text{ NaOH} \times \text{Acetic Acid BM}) \times \text{FP}}{\text{Sample weight} \times 1000} \times 100\%$$

Explanation :

V NaOH : volume used (mL)  
N NaOH : normality (0,01N)  
FP : dilution factor

Acetic Acid BM : 60 g/mol

### Density

Based on (SNI 8985:2021), density testing using a pycnometer involves weighing equal volumes of liquid smoke and water at 20 °C sequentially in the pycnometer. The results are then converted into relative density  $d_{20}^{20}$  using the following equation:

$$d_{20}^{20} = \frac{m_2 - m_0}{m_1 - m_2}$$

Explanation :

m<sub>0</sub> : mass, in grams, of the empty pycnometer  
m<sub>1</sub> : mass, in grams, of the pycnometer filled with water  
m<sub>3</sub> : mass, in grams, of the pycnometer filled with liquid smoke

Table 1. Quality of Liquid Smoke from SNI 8985:2021

No	Characteristics	Unit	Requirements	
			Grade 1	Grade 2
1	Color	-	Yellow to brown	Yellow to brown
2	Floating Material	-	None	None
3	pH	-	1,50 - 2,75	2,76 - 4,50
4	Density	-	1,0050 - 1,0500	1,0050 - 1,0500
5	Acetic Acid	%	8,00 - 15,00	1,10 - 7,99
6	Phenol	%	Maximum 2,0	Maximum 2,0

### Data Analysis

This study used a one-way analysis of variance (ANOVA) method at a significance level of 5%. One-way ANOVA is a statistical technique that aims to compare the means of three or more independent groups influenced by one independent variable (factor). This method is used to evaluate whether there are statistically significant differences between these groups (Montgomery 2017).

### Yield

The liquid smoke yield is the percentage of results obtained from the pyrolysis process in each treatment, namely W1 90 minutes, W2 120 minutes, and W3 150 minutes. The percentage yield was obtained by comparing the volume of liquid smoke (mL) produced with the volume of sawdust (mL) used, then multiplying the result by 100%. The effect of pyrolysis time on liquid smoke yield in this study is shown in Table 2.

### Results and Discussion

Table 2. Liquid Smoke Yield Results

Treatment	Repetition			Average (%)
	1	2	3	
W1	16,6	14,9	16,2	15,90 ± 0,73
W2	19,3	19,7	20,6	19,87 ± 0,54
W3	24,4	22,4	22,4	23,07 ± 0,94

Table 2 shows that treatment W1 had an average yield of 15.90%, W2 had 19.87%, and W3 had 23.07%. These results indicate that the highest or best yield was obtained in treatment W3, which was 150 minutes, while the lowest yield was found in treatment W1, which was 90 minutes. Next, a

variance analysis was conducted at a level of 0.05 using the SPSS application on each repetition to determine the effect of the burning time tested on the yield produced. The test results can be seen in Table 3.

Table 3. Results of Analysis of Variance (ANOVA) for Liquid Smoke Yield

Source of variance	Sum of Squares	df	Mean Square	F	Sig.
Treatment	77,34	2	38,67	45,2	0,000241
Error	5,13	6	0,86		
Total	82,47	8			

Note : Sig ≤ 0,05 : Values are significantly different (*Significant*), Sig ≥ 0,05 : Values are not significantly different (*Non-Significant*)

Based on the ANOVA test results in Table 3, the significance value of 0.000241 is smaller than 0.05, so the analysis results show that the treatment has a significant effect on liquid smoke yield. Thus, there is a very significant difference between the time treatments on liquid smoke yield.

Based on the results of the study, the yield produced in treatment W1 had an average yield of 15.90%, W2 was 19.87%, and W3 was 23.07%, indicating that the duration of pyrolysis combustion affects the amount of yield produced. In line with the research conducted by Handayani and Sa'diyah (2022), it states that the yield of liquid smoke tends to increase with the increase in pyrolysis time. The amount of liquid smoke condensation is also influenced by the duration of combustion, because the longer the pyrolysis process

lasts, the more the conversion of liquid smoke will increase. According to Komarayanti *et al.* (2018), the longer the pyrolysis time, the more raw materials are decomposed due to the longer contact time with heat. This is because the higher the pyrolysis temperature, the more liquid smoke is produced, as higher temperatures increase the speed of the pyrolysis reaction, thereby increasing the ability to decompose organic compounds (Ridhuan *et al.* 2019).

#### Liquid Smoke Quality Analysis

The average values of the liquid smoke quality analysis results are presented in Table 4, and the results of the analysis of variance (ANOVA) are presented in Table 5.

Table 4. Results of liquid smoke quality analysis

Parameter	Treatment (Average)			Description
	W1	W2	W3	
Color	Brown	Brown	Brown	Meets Standards
Floating Material	Yes	Yes	Yes	Does Not Meet Standards
pH	3,16 ± 0,04	3,15 ± 0,06	3,07 ± 0,07	Meets Standards
Phenol (%)	3,2 ± 0,10	2,85 ± 0,06	3,42 ± 0,37	Does Not Meet Standards
Acetic Acid (%)	6,07 ± 0,13	5,91 ± 0,33	7,48 ± 0,72	Meets Standards
Density (g/cm <sup>3</sup> )	1,026 ± 0,0016	1,0273 ± 0,0012	0,9903 ± 0,0009	Meets Standards

Table 5. Calculated F values of the variance analysis.

Parameter	F calculated	Sig.
Yield	45,2	0,00024
pH	1,553	0,286
Phenol	3,407	0,103
Acetic Acid	6,99	0,0271
Density	0,002	0,998

Note : Sig ≤ 0,05 : Values are significantly different (*Significant*), Sig ≥ 0,05 : Values are not significantly different (*Non-Significant*)

## Color

Based on Table 4, it is evident that all treatments, W1, W2, and W3, produced relatively uniform colors, namely brown. These results indicate that even though there were variations in treatment times of 90, 120, and 150 minutes, the changes that occurred did not affect the color. Thus, it can be concluded that the color of the product in all treatments meets SNI quality standards, which is in the yellow to brown category.

The color of the sengon wood liquid smoke produced in this study is darker than the results of the study conducted by Arif *et al.* (2024), which found that sengon wood liquid smoke has a clear yellow color because the study involved a distillation process. According to Izza *et al.* (2022), the dark color of liquid smoke is caused by the presence of tar compounds in the liquid smoke. Tar is a compound that is basically black in color, toxic, and has a high molecular weight. Therefore, to obtain liquid smoke that is free of tar content, further distillation is needed to produce liquid smoke with a clearer color.

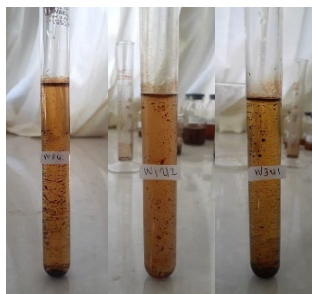


Figure 2. Color of liquid smoke

## Floating Materials

Table 4 shows that in all treatments W1, W2, and W3, floating materials were found, indicating that increasing the time from 90 to 150 minutes did not eliminate the presence of floating materials. The floating materials detected in the pyrolysis results are generally tar or heavy hydrocarbon compounds that are not completely degraded. Further purification processes, such as distillation, are needed to reduce the tar and floating material content so that the quality of the liquid smoke produced is better. Therefore, all treatments in this floating material are declared not to meet the SNI 8985:2021 quality standard.



Figure 3. Floating material in liquid smoke

## pH

Based on the results of the study, the pH values produced in Table 4 for treatment W1 had an average pH value of 3.16, W2 of 3.15, and W3 of 3.07, which means that the values were below 7, indicating that the solution was acidic. The pH value decreases as the temperature and pyrolysis time increase (Handayani and Sa'diyah, 2022). A low pH value indicates that liquid smoke has antimicrobial and sterilizing properties (Swastawati *et al.* 2022). This is because a low pH value affects the shelf life and storage capacity of products, as at low pH, microbes or bacteria that interfere with the preservation process tend to be unable to live and multiply well (Izza *et al.* 2022).

The pH value of sengon wood liquid smoke produced in this study is higher than the results of a study conducted by Arif *et al.* (2024), which found that sengon wood liquid smoke has a pH value of 3.1, 3.0, and 2.9. When compared to the quality standards set by SNI 8985:2021, all treatments fall into quality category 2. Thus, all treatments, W1, W2, and W3, meet the SNI standard in Quality Category II, with relatively stable pH values between treatments.

Based on Table 5, the significance value is greater than 0.05, specifically 0.286. Therefore, it can be concluded that the treatments applied do not have a significant effect on the tested parameters.

## Phenol

Based on the data in Table 5 it shows that the average phenol content exceeds the maximum limit set in the SNI standard. The highest value is found in treatment W3 with an average of 3.42%, and the lowest is found in treatment W2 with an average of 2.85%. When compared to the quality standards set by SNI 8985:2021, none of the treatments met the SNI quality requirements.

According to Seri Maulina *et al.* (2018), the longer the combustion or pyrolysis process is carried out, the higher the phenol content in the liquid smoke. The temperature in the pyrolysis process is one of the factors that can increase the content of phenolic compounds, as explained by Seri Maulina *et al.* (2018). However, the duration of heating also has a significant effect on pyrolysis results. The longer the raw material is heated, the longer it is exposed to heat, causing more components in the raw material, such as lignin, to decompose. According to Swastawati (2022), this causes the phenol content to be higher because more lignin decomposes. According to Rigling *et al.* (2023), phenolic compounds are important compounds in smoke products. The importance of phenolic compounds in liquid smoke is that phenolic compounds function as aroma and flavor enhancers specific to smoked products. Liquid smoke contains phenolic chemicals that can form hydrogen bonds with bacterial proteins and damage their structure, thereby inhibiting bacterial growth (Ribeiro *et al.* 2015).

According to Sahrum *et al.* (2021), the phenol content, when associated with pH and total titratable acid in liquid smoke in each treatment, obtained a relationship whereby the

higher the phenol content in liquid smoke, the lower the pH value produced, meaning that the total titratable acid in liquid smoke will be higher. and vice versa, when the phenol content is low, the pH becomes high, and the titratable acidity becomes low. This relationship was proven in this study, where the liquid smoke from sengon wood had high phenol and acid content but produced low pH. This is because sengon wood sawdust has components such as hemicellulose and cellulose, which, when decomposed, will produce organic acid compounds such as acetic acid.

The results of the ANOVA test for phenol content in Table 5 show that the significance value is greater than 0.05, namely 0.103. Therefore, it can be concluded that the treatment given has no significant effect on the parameters tested.

### Acetic Acid

Based on the data in Table 4, it can be seen that the highest acid content was found in treatment W3, with an average of 7.48%, and the lowest was found in treatment W2, with an average of 5.91%. According to Fadillah and Alfiarty (2015), an increase in combustion time tends to increase the acetic acid content in liquid smoke. This occurs because the longer the process takes, the more biomass is decomposed and produces organic acid compounds. Based on the SNI 8985:2021 standard, the acetic acid contained in the liquid smoke from this study meets the quality requirements for liquid smoke, namely quality 2.

The results of the ANOVA test for acid content, shown in Table 5, indicate that the significance value is less than 0.05, specifically 0.0271. Therefore, it can be concluded that the duration of combustion has a significant effect on the acid content being tested.

### Density

Table 4 shows that the highest specific gravity value was in treatment W2, with an average value of 1.0273, while the lowest specific gravity value was in treatment W3, with an average value of 0.9903. The results of this study are in line with the research by Handayani and Sa'diyah (2022), which shows that the longer the pyrolysis time, the lower the density of the liquid smoke. From these test results, it was also found that there was no significant change in the specific gravity of liquid smoke over the pyrolysis time. Treatment W3 had an average liquid smoke density of 0.9903 due to the dominance of light organic fractions or water and low dissolved compound content. Specific gravity measurements are also greatly influenced by temperature. The higher the pyrolysis temperature, the more cellulose, hemicellulose, and lignin are decomposed and condensed into smoke liquid containing acetic acid, methanol, and phenol, thereby increasing its density (Triastuti *et al.* 2019). When compared to the SNI 8985:2021 quality standard, treatments W1 and W2 are declared to meet the quality standard, while treatment W3 does not meet the standard because it is below the specified minimum limit.

The results of the ANOVA test for specific gravity shown in Table 5 indicate that the significance value is greater than 0.05, namely 0.998. Therefore, it can be concluded that the treatments given have no significant effect on the parameters tested.

### Conclusions

The results of the yield data calculations show significant results, meaning that the duration of pyrolysis combustion affects the yield of liquid smoke produced from sengon wood waste.

Based on SNI 8985:2021, the 90-minute treatment meets quality standards for color, pH (quality category 2), acetic acid (quality category 2), and specific gravity, while the parameters of floating material and phenol do not meet the standards. The 120-minute treatment shows similar results, meeting quality standards for color, pH (quality category 2), acetic acid (quality category 2), and specific gravity, but failing to meet quality standards for floating materials and phenol. The 150-minute treatment met quality standards for color and pH (quality category 2), but not for acetic acid (quality category 2). Additionally, the parameters of floating matter, phenol, and specific gravity did not meet the standards.

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# Visual Tree Assessment (VTA) of Tree Health in the Green Belt of Southern Ring Road, Mataram City

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## Abstract

Green belts play a crucial role in urban green spaces by providing shades, filtering air pollutants, and enhancing city aesthetics. This study aims to evaluate the health condition of trees along the South Ring Road green belt in Mataram City using the Visual Tree Assessment (VTA) method. VTA assesses tree vitality and structural stability based on observable external indicators, such as cracks, swellings, and crown asymmetry. A census approach was applied to a total of 1,432 trees. The results revealed that 77% of the trees were categorized as low risk, 21% as moderate risk, and 2% as high to extreme risk. The most common types of defects observed included stem cankers, dead branches, and decay. Recommended management actions include regular pruning, selective felling, the use of biological pesticides, and relocation of severely affected trees. This research provides a valuable foundation for developing effective tree risk management strategies in urban environments.

**Keywords:** Visual Tree Assessment, green belt, tree risk, tree health.

## Introduction

Urban green spaces (UGS) are essential elements in urban spatial planning, serving to maintain ecological balance by preserving natural vegetation including trees, shrubs, and grasses. Trees, as the main components of UGS play a vital role in improving air quality, reducing noise pollution, enhancing urban aesthetics, and providing thermal comfort for city residents. Therefore, maintaining and ensuring the sustainability of urban tree health is of great importance. According to Law No. 26 of 2007 concerning Spatial Planning, Article 29 Paragraph (2), requires that urban areas allocate at least 30% of their total area for green open space (Nasyavina, 2023). Furthermore, the Regulation of the Minister of Public Works No. 5 of 2008 states that urban green space functions not only as an infiltration and conservation zone but also as a balancing element between built and natural environments.

Mataram City, as the capital of West Nusa Tenggara Province (NTB), contains various forms of urban green spaces one of which is the roadside green belt along major roads such as Jalan Langko, Jalan Udayana, Jalan Pejanggik, Jalan Majapahit, and Jalan Lingkar. The green belt of Jalan Lingkar Selatan serves as a vital urban feature that function as the city's "green lung," providing shade, supporting transportation corridors, and offering open spaces close to daily human activities. However, trees in this area face multiple stress factors caused by both environmental and anthropogenic pressures, including road paving, improper pruning, vehicular emissions, noise, and natural events such as strong winds and heavy rainfall. Such pressures gradually decrease tree vitality (Syahraeni et al., 2022). Preliminary observations revealed that Jalan Lingkar Selatan is one of the busiest transportation routes,

particularly during rush hours (07:00 and 16:00), increasing the potential risks from unhealthy trees. If not properly managed, declining tree conditions may cause hazards such as falling branches or uprooted trees, potentially damaging infrastructure or threatening human safety (Agung et al., 2019).

Mataram City frequently experiences extreme weather events characterized by strong winds, which often result in tree failures causing property damage and casualties (Latifah et al., 2020). Unstable soil conditions and shallow root systems further reduce tree stability, particularly in large specimens thus increasing the risk of uprooting during strong winds or heavy rain (Arisanti et al., 2022). Moreover, biotic factors such as pest infestations and fungal attacks further deteriorate tree health (Pertiwi, 2019). Given the complexity of these problems, a reliable and systematic assessment method is required to visually identify tree conditions, analyze their health status, and formulate management recommendations for urban green space authorities and related stakeholders.

One relevant and effective approach is the Visual Tree Assessment (VTA) method developed by the International Society of Arboriculture (ISA). VTA is a non-destructive technique for visually evaluating tree health through the identification of external indicators such as cracks, cavities, swellings, and crown asymmetry (Hanum et al., 2020). The method involves three systematic stages: visual observation, potential failure analysis, and the formulation of management or mitigation recommendations (ISA, 2013). The advantages of VTA include practicality, efficiency, and the ability to provide immediate management recommendations such as pruning, crown reduction, or tree replacement. The method has been widely applied in urban areas worldwide and in several major cities in Indonesia, such as Jakarta and

Salatiga (Lestari, 2022). Visual assessment of crown, stem, and root conditions can also serve as a basis for estimating wood quality, since structural damage to trees indicates a decline in wood properties such as specific gravity and mechanical strength (Yuwono *et al.*, 2022). However, its application in the green belts of Mataram City remains limited.

Based on the aforementioned background, this study aimed to evaluate the health condition of trees along the Southern Ring Road green belt in Mataram City using the VTA method. Specifically, the study aims to (1) identify tree species along the green belt of Jalan Lingkar Selatan, (2) analyze tree risk categories based on the VTA method, and (3) provide preventive and mitigation recommendations for identified risks. The results of this study are expected to serve

as scientific data for the local government and environmental managers in developing targeted tree risk mitigation strategies, thereby enhancing public safety and maintaining the ecological sustainability of urban trees.

## Materials and Methods

### Time and Place of Research

This study was conducted along the green belt of the Southern Ring Road, Mataram City, from August to September 2025. The location of the study area is shown in Figure 1.

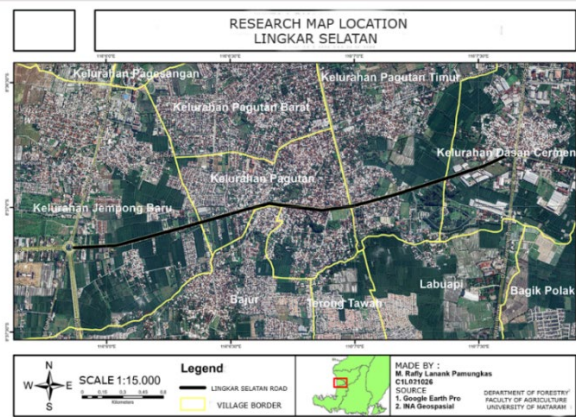


Figure 1. Map of the Research Location (Southern Ring Road Green Belt, Mataram City)

### Research Tools and Objects

The objects of this study were trees growing along the green belt of Jalan Lingkar Selatan. The tools used in this study include a hagameter, camera, laptop, measuring tape, tally sheet, writing instruments and others.

### Methodologies

Tree risk assessment was conducted using the Visual Tree Assessment (VTA) approach developed by the International Society of Arboriculture (ISA). This method focuses on identifying visual indicators of tree risk and damage to evaluate tree stability and safety. An overview of the assessment process is illustrated in Figure 2.

Figure 2. Tree Risk Assessment Form Based on the International Society of Arboriculture (ISA, 2013)

## Data Analysis

- a. Identification of Trees Composing the Green Belt  
Tree species along the green belt were identified by observing morphological characteristics such as leaf shape, flower structure, and stem characteristics.
- b. Risk Categorization of Green Path Trees  
Tree risk identification along the Mataram City green belt was carried out using the Visual Tree Assessment (VTA) method. The analysis referred to the Tree Risk Assessment evaluation form developed by the ISA, classifying tree risk levels into four categories, as shown in Tables 1 and 2.

Table 1. Types of Possible Tree Damage and Their Impacts (Matrix 1)

Likelihood of Failure	Likelihood of Impacting Target			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat Likely	Likely	Very Likely
Probable	Unlikely	Unlikely	Somewhat Likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat Likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Source : *International Society of Arboriculture (ISA)*

Table 2. Likelihood of Tree Damage and Its Impacts (Matrix 2)

Likelihood of Damage and Its Impact	Negligible	Minor	Significant	Severe
Very Likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat Likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Source : *International Society of Arboriculture (ISA)*

### Recommendations for Prevention and Control of Green Belt Tree Health

Recommendations for managing the green belt and reducing tree risk levels along the Southern Ring Road were formulated based on an analysis of existing tree damage and risk data combined with a literature review approach. The

literature review method was employed to collect information from relevant scientific publications on tree risk management and mitigation practices. By analyzing contributing factors and existing mitigation strategies from other regions, comprehensive recommendations were developed to minimize tree risk levels in the study area.

## Results and Discussion

### Overview of the Research Location

The research was conducted along the Southern Ring Road area in Mataram City, West Nusa Tenggara Province. This road serves as one of the main transportation corridors connecting the eastern and western parts of Mataram City and provides access to suburban areas such as Sekarbela and Pagutan. Administratively, the Southern Ring Road traverses several urban villages, including Pagutan Barat, Karang Genteng, and Jempong Baru. The area is characterized by flat topography with elevations below 50 meters above sea level. Vegetation along the roadside consists mainly of shade trees and shrubs, with several vacant spaces that remain underutilized. Functionally, Jalan Lingkar Selatan acts as a major corridor for transportation

and goods distribution and is an integral component of Mataram City's spatial planning.

### Identification of Tree Species Along the Jalan Lingkar Selatan

Identification of tree species along the Southern Ring Road revealed the composition and dominance patterns of vegetation within the green belt. The results showed that the most dominant tree species was Tanjung (*Mimusops elengi*), with 624 individuals, representing 43.58% of the total population. This dominance reflects a planting design that emphasizes a single species, likely due to the desirable traits of *Mimusops elengi*, such as dense canopy, strong rooting system, and high tolerance to urban environmental stress. Other major species included Glodokan tiang (*Polyalthia longifolia*) and Kenari (*Canarium indicum*), with 208 and 207

individuals, respectively, each comprising about 14% of the total trees. These species possess slender crowns and upright growth forms, making them suitable for narrow roadside green belts. The presence of other species such as Kapur naga, Mahogany, Flamboyant, and Trengguli indicates attempts at vegetation diversification, although their proportions remain relatively low. Diversification is essential to minimize ecological risks associated with monoculture planting, such as vulnerability to pests, pathogens, and environmental stress. According to Kusmana and Hikmat

(2015), biodiversity in urban vegetation enhances ecological functions and improves landscape resilience to both biotic and abiotic disturbances. The inclusion of multiple species in urban green spaces can enrich ecosystem structure and strengthen urban resilience to climate change and human-induced disturbances. Therefore, continuous implementation of vegetation diversification strategies is necessary in planning and managing urban green spaces, particularly in densely populated areas such as Mataram City.

Table 3. Identified Tree Species Along the Southern Ring Road (Jalan Lingkar Selatan), Mataram City

No	Local Name	Scientific Name	Total	Frequency (%)
1	Tanjung	<i>Mimusops elengi</i>	624	43.58
2	Glodokan tiang	<i>Polyalthia longifolia</i>	208	14.53
3	Kenari	<i>Canarium indicum</i>	207	14.46
4	Kapur naga	<i>Calophyllum soulattri</i>	140	9.78
5	Mahoni	<i>Swietenia mahagoni</i>	54	3.77
6	Flamboyan	<i>Delonix regia</i>	41	2.86
7	Trengguli	<i>Cassia fistula</i>	33	2.30
8	Ketapang	<i>Terminalia catappa</i>	29	2.03
9	Nangka	<i>Artocarpus heterophyllus</i>	25	1.75
10	Waru	<i>Hibiscus tiliaceus</i>	18	1.26
11	Mangga	<i>Mangifera indica</i>	17	1.19
12	Kersen	<i>Muntingia calabura</i>	10	0.70
13	Jambu biji	<i>Psidium guajava</i>	4	0.28
14	Klengkeng	<i>Dimocarpus longan</i>	4	0.28
15	Trembesi	<i>Samanea saman</i>	4	0.28
16	Asam Jawa	<i>Tamarindus indica</i>	4	0.28
17	Matoa	<i>Pometia pinnata</i>	3	0.21
18	Jambu bol	<i>Syzygium malaccense</i>	2	0.14
19	Sawo hijau	<i>Chrysophllum cainito</i>	4	0.28
20	Beringin	<i>Ficus benjamina</i>	1	0.07
Total			1.432	100.00%

### Tree Damage Assessment

The results of the tree health assessment along the green belt of Jalan Lingkar Selatan, Mataram City recorded a total of 5,798 damage cases across 1,432 trees, representing various types of defects. The most frequent damage was trunk canker, with 1,361 cases (23.47%), followed by galls or burls on branches totaling 1,033 cases (17.82%), and dead or missing bark with 560 cases (9.66%). The dominance of damage affecting trunks and branches indicates a substantial compromise of tree structural integrity, which may reduce ecological functionality and increase the likelihood of

structural failure. In addition, other major forms of damage included 462 cases (7.97%) of dead branches and 440 cases (7.59%) of root lifting. These findings are consistent with the study by Arisanti et al. (2022), who reported similar physical damage patterns along urban greenways, such as broken branches, trunk injuries, and conditions that pose potential hazards to road users. Collectively, these results reinforce the view that dead branches and trunk-related damage constitute primary structural issues for trees planted in urban green belts. Quantity of Tree Damages/Diseases is illustrated in Figure 4.

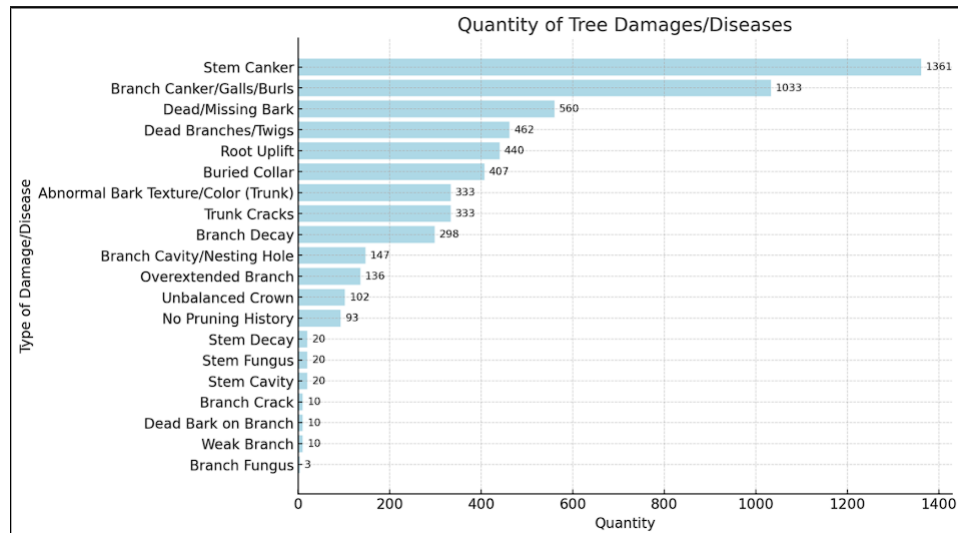


Figure 4. Types of Tree Damage Observed Along the Southern Ring Road Green Belt, Mataram City

Although several damage categories occurred at relatively low frequencies, such as fungal growth on branches (0.05%), branch cracks (0.17%), and dead bark branches (0.17%), these conditions still warrant attention. Even limited occurrences of fungal infection and decay can accelerate the deterioration of tree health if not managed appropriately. Santoso (2020) reported that fungal attacks on stems or branches intensify structural weakening and increase the

potential for tree failure, particularly during extreme weather events. Field observations further indicated that trees exhibiting open wounds, decay, or dead branches tend to produce lower-quality wood. This observation supports previous studies showing that the physical condition of standing trees is closely related to fundamental wood properties, including specific gravity and air-dry moisture content (Putro *et al.*, 2020).

Types of Damage to Trees on Jalan Lingkar Selatan is illustrated at Figure 5.

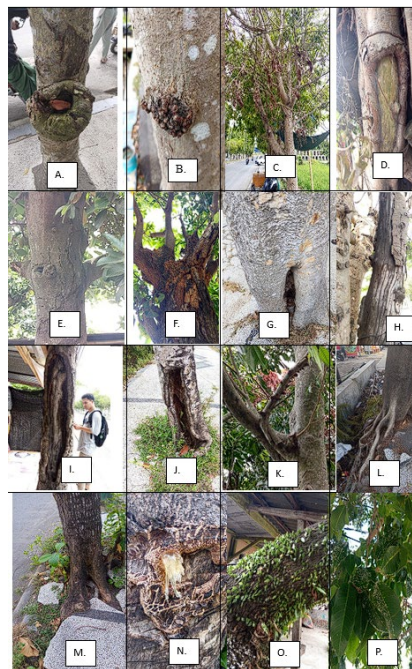


Figure 5. Types of Damage to Trees on Jalan Lingkar Selatan: A.) Canker B.) Brum C.) Dead Branches D.) Hollow Trunks E.) Trunk Cracks F.) Weak Branches G.) Trunk Cavities H.) Termite Houses I.) Dead Bark J.) Trunk Decay K.) Fungi L.) Buried Root Necks M.) Uprooted Roots N.) Gummosis O.) Epiphytes P.) Leaf Pests

Structural defects such as stem cracks, wood decay, cavities, and cankers reduce fiber continuity and the effective cross-sectional area of intact wood (Yang et al., 2017). From a wood science perspective, visual defects identified through Visual Tree Assessment (VTA) are closely associated with the degradation of fundamental mechanical properties of wood. Defects such as internal decay, stem cavities, and extensive canker development reduce residual wall thickness, which is a critical determinant of bending strength and overall stem stability. Previous studies have demonstrated that even moderate levels of decay may result in disproportionate reductions in modulus of elasticity (MOE) and modulus of rupture (MOR), particularly when degradation occurs near the neutral axis of bending (Yang et al., 2017; Jelonek et al., 2020).

Prolonged decay processes and physiological stress also contribute to reductions in wood density and specific

gravity. Trees subjected to chronic biotic and abiotic stress tend to form wood with heterogeneous tissue structure and irregular anatomical characteristics, which further diminish mechanical reliability. In this context, VTA indicators such as hollow stems, open wounds, and extensive bark mortality function as practical proxies for internal wood deterioration, allowing practitioners to infer potential mechanical weakening without destructive sampling.

Although VTA does not directly quantify mechanical parameters, its principal strength lies in integrating visual symptoms with established biomechanical principles. Consequently, trees exhibiting multiple structural defects should be regarded as having substantially reduced mechanical performance, even when external dimensions or apparent vigor suggest adequate structural capacity.

### Category Risk Tree

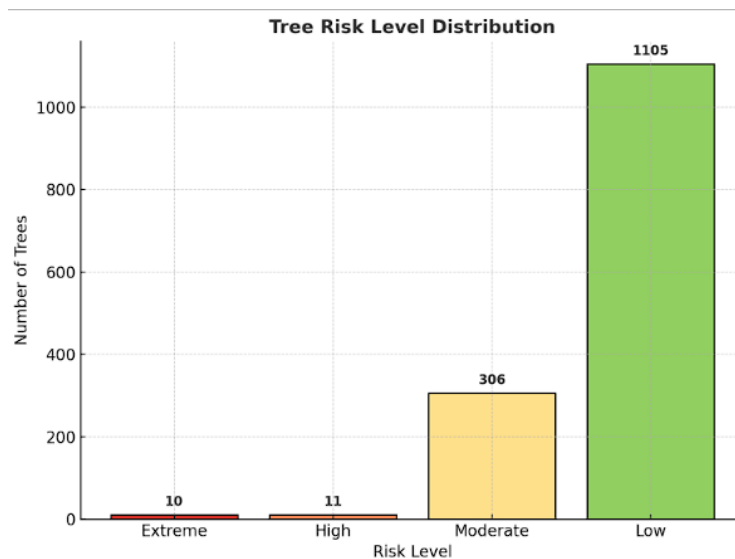


Figure 6. Distribution of Tree Risk Categories Along the Southern Ring Road (Jalan Lingkar Selatan), Mataram City

Tree risk assessment using the Visual Tree Assessment (VTA) method follows a structured procedure that begins with a systematic visual inspection of the tree crown, stem, and root collar to identify structural defects such as cracks, cavities, open wounds, and signs of wood decay that may reduce tree stability (Li et al., 2022). Each identified defect is evaluated using an ordinal rating scale (e.g., low, moderate, and high) to represent the severity of damage and the likelihood of structural failure. The use of standardized rating scales helps ensure consistency and comparability of risk assessments across large tree populations in urban environments (Li et al., 2022).

VTA assessments are typically conducted by evaluators with professional backgrounds in forestry, arboriculture, or urban tree management and with practical experience in recognizing indicators of structural weakness and decay (Smiley et al., 2017). The visual assessment results are then integrated into a VTA risk matrix, which

combines the likelihood of tree failure with the potential consequences of failure based on target presence, such as pedestrians, vehicles, or infrastructure, to generate a final risk rating (Smiley et al., 2017; van Haften et al., 2021). This matrix-based approach allows complex biomechanical and environmental factors to be translated into practical risk categories that support evidence-based decision-making for urban tree management and public safety (Li et al., 2022).

The results of the tree risk assessment along the green belt revealed notable variations in tree risk levels. Based on the analysis, the majority of trees were categorized as low risk, totaling 1,105 individuals (approximately 77%). This finding suggests that most trees remain in relatively safe condition, with minimal potential for structural failure or harm to nearby targets.

A total of 306 trees (around 21%) were classified as medium risk. Trees within this category require increased monitoring and appropriate maintenance, as their risk level

could escalate if left unmanaged. In contrast, only 11 trees (about 1%) were identified as belonging to the high-risk category. Although relatively few, these trees should be prioritized for management intervention, as they pose potential hazards to pedestrians, motorists, and surrounding infrastructure.

The most critical classification is the extreme-risk category, comprising 10 trees (approximately 1%). Despite their small proportion, these trees are of serious concern and must be addressed immediately. Trees within this category exhibit a very high likelihood of structural failure, posing an immediate threat to public safety and nearby facilities.

Overall, the distribution of risk levels indicates that tree management practices in the green belt are generally effective, as most trees fall within the low-risk category. However, the presence of trees in the medium, high, and extreme categories necessitates more targeted management strategies. Recommended management actions include routine pruning and maintenance for medium-risk trees; structural evaluation and technical interventions such as branch load reduction or reinforcement for high-risk trees; and selective felling or replacement for extreme-risk trees to minimize potential hazards.

Table 4. Trees Classified Under the Extreme-Risk Category Along the Southern Ring Road (Jalan Lingkar Selatan), Mataram City

Code	Tree Species	Diameter	Height	Target	Tree Damage	Risk Category
12A	<i>Delonix regia</i>	26	7	Pedestrians and Drivers	Brum, Cracked Trunk, Nails, Canker, Hollow Main Trunk, Dead Bark, Dead Branches	Extreme
21A	<i>Delonix regia</i>	31	6	Pedestrians and Drivers	Brum, Nails, Canker, Hollow Main Trunk, and Dead Branches on the Crown	Extreme
171A	<i>Canarium indicum</i>	41	13	Pedestrians and Drivers	Brum, Rotten Trunk, Hollow Main Trunk, Canker, Unbalanced Crown, Dead Branches	Extreme
177A	<i>Canarium indicum</i>	25	12	Pedestrians and Drivers	Brum, Rotten Trunk, Hollow Main Trunk, Canker, Unbalanced Crown, Dead Branches	Extreme
1140C	<i>Delonix regia</i>	33	8	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker, Dead Branches	Extreme
1179C	<i>Delonix regia</i>	30	7	Pedestrians and Drivers	Brum, Dead Branch, Hollow Main Trunk, Canker, Dead Branch	Extreme
1216C	<i>Delonix regia</i>	34	10	Pedestrians and Drivers	Brum, Nails, Canker, Hollow Main Trunk and Dead Branches on the Crown, Dead Branches	Extreme
1339C	<i>Canarium indicum</i>	30	7	Pedestrians and Drivers	Brum, Canker, Open Wounds, Cracks, Decay, Dead Branches	Extreme
1333C	<i>Canarium indicum</i>	54	9	Pedestrians and Drivers	Brum, Canker, Open Wounds, Cracks, Decay, Dead Branches	Extreme
1318C	<i>Calophyllum soulattri</i>	25	5	Pedestrians and Drivers	Brum, Canker, Open Wounds, Cracks, Decay, Dead Branches	Extreme

Trees classified under the extreme-risk category consistently exhibited severe wood-related defects, including hollow main trunks, extensive decay, cracks, open wounds, and canker formation. From a biomechanical standpoint, the coexistence of these defects indicates a critical reduction in residual load-bearing capacity. The loss of intact wood fibers and the presence of internal voids substantially weaken bending resistance and increase susceptibility to brittle failure.

In large diameter trees, such as *Canarium indicum*, internal decay may not be proportionally reflected by external stem dimensions, leading to overestimation of structural strength if wood degradation is not considered. The extreme-risk classification therefore reflects not only the likelihood of failure but also the advanced deterioration of wood mechanical properties, reinforcing the need for immediate management intervention in high-target urban areas.

Table 5. Trees Classified Under the High-Risk Category Along the Southern Ring Road (Jalan Lingkar Selatan), Mataram City

Code	Tree Species	Diameter	Height	Target	Tree Damages	Risk Category
67A	<i>Canarium indicum</i>	28	12	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker	High
91A	<i>Canarium indicum</i>	54	19	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker	High
146A	<i>Calophyllum soulattri</i>	13	7	Pedestrians and Drivers	Brum, Nails, Hollow Main Trunk.	High
162A	<i>Calophyllum soulattri</i>	15	8	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker, Trunk Decay	High
175A	<i>Canarium indicum</i>	24	9	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker, Nails	High
1151C	<i>Delonix regia</i>	44	5	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker	High
1160C	<i>Delonix regia</i>	24	5	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker	High
1165C	<i>Canarium indicum</i>	10	4	Pedestrians and Drivers	Brum, Hollow Main Trunk, Dead Branch	High
1187C	<i>Canarium indicum</i>	28	10	Pedestrians and Drivers	Brum, Hollow Main Trunk, Dead Branch	High
1199C	<i>Canarium indicum</i>	32	8	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker, Dead Branch	High
1234C	<i>Canarium indicum</i>	15	5	Pedestrians and Drivers	Brum, Hollow Main Trunk, Canker, Open Wounds	High

Based on Table 5, a total of eleven trees were classified as high-risk. These trees were predominantly of three species: *Canarium indicum*, *Calophyllum soulattri*, and *Delonix regia*. In general, the primary causes of high risk among these trees were structural defects in the main trunk, including cavities, cankers, and external loads such as inserted nails. Additionally, symptoms such as trunk rot, dead crown branches, open wounds, and burls were also identified, further increasing the likelihood of structural failure.

The high level of risk in these trees was primarily attributed to the combination of large tree dimensions (diameter and height) and extensive structural damage. The primary potential targets affected by these risks are pedestrians and motorists. This condition is associated with the trees' location along the Southern Ring Road green belt, a zone characterized by high traffic intensity. The presence of high-risk trees in such areas poses safety hazards to road users, particularly during extreme weather events such as strong winds or heavy rainfall.

In addition to structural damage, the presence of nails and open wounds further accelerates the deterioration of tree health. Nails embedded in the trunk may act as entry points for pathogens, while open wounds facilitate fungal infection and internal decay. Under such conditions, the mechanical stability of the trees is compromised, thereby increasing the likelihood of failure or collapse.

### Tree Risk Reduction Recommendations

Pruning is one of the most commonly applied preventive techniques to address crown imbalance, overgrown branches, and dead twigs. According to Abimanyu et al. (2019), regular pruning improves tree health and reduces the likelihood of damage resulting from disproportionate crown loads. Pruning also reduces crown

moisture, thereby minimizing fungal growth and decay potential.

Selective felling should be implemented for trees exhibiting severe structural damage, including extensive trunk cankers, large cracks, or deep trunk cavities. Pertiwi et al. (2019) emphasize that tree removal should be based on systematic monitoring results, such as those obtained through the Forest Health Monitoring (FHM) method, to ensure that decisions are objective and data-driven. Proper felling not only reduces the risk of tree failure but also provides space for the regeneration of healthier vegetation.

The application of pesticides particularly biological or plant-based formulations represents an environmentally friendly alternative for disease and pest control. Safe'i et al. (2019) demonstrated that pests and pathogens, such as stem and branch fungi, can be effectively managed using eco-friendly pesticide formulations that do not harm soil microorganisms or induce resistance. The application of pesticides should be tailored to the specific pathogen type and infestation level and conducted exclusively by trained personnel.

Target relocation is an essential mitigation strategy for trees situated near vital infrastructure or densely populated public spaces. Trees exhibiting extensive damage or a history of structural instability should be relocated to safer areas. This process should incorporate proper transplantation techniques to ensure the survival of relocated trees. Abimanyu et al. (2019) recommend that relocation be performed during the tree's dormant phase, accompanied by careful root handling and post-transplant maintenance.

Recommended management actions include routine pruning and maintenance for medium-risk trees; structural evaluation and technical interventions such as branch load reduction or reinforcement for high-risk trees; and selective

felling or replacement for extreme-risk trees to minimize potential hazards.

### Conclusions

Based on the results of data analysis and discussion, several conclusions were drawn as follows:

1. Vegetation identification along the green belt of Jalan Lingkar Selatan, Mataram City, revealed the presence of 20 tree species comprising a total of 1,432 individuals. The most dominant species was Tanjung (*Mimusops elengi*) with 624 individuals (43.58%), followed by Glodokan Tiang (*Polyalthia longifolia*) and Kenari (*Canarium indicum*), each representing approximately 14% of the total population.
2. The damage assessment identified a total of 5,798 cases, with the most prevalent types being trunk cankers (23.47%), branch galls or burls (17.82%), and dead or missing bark (9.66%). The high incidence of trunk and branch damage indicates that many trees suffer from structural deficiencies, reducing their ecological and shading functions while increasing the risk of failure. Risk assessment results using the Visual Tree Assessment (VTA) method showed that most trees fell within the low-risk category (77%), followed by medium-risk (21%), while high-risk (1%) and extreme-risk (1%) trees although few still require serious attention due to their potential to cause significant hazards.
3. Recommended management strategies include: (a) regular pruning to remove dead branches, correct crown imbalance, and prevent disease development; (b) the use of environmentally friendly pesticides to control pests and pathogens; (c) selective felling of severely damaged or high-risk trees; and (d) target relocation or establishment of safety zones around extreme-risk trees to minimize potential hazards.

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# WOOD RESEARCH Journal

## Journal of Indonesian Wood Research Society

### Annals of the Wood Research Journal

Wood Research Journal is the official journal of the Indonesian Wood Research Society. This journal is an international medium in exchanging, sharing and discussing the science and technology of wood.

### Aims and Scope

The journal publishes original manuscripts of basic and applied research of wood science and technology related to Anatomy, Properties, Quality Enhancement, Machining, Engineering and Constructions, Panel and Composites, Entomology and Preservation, Chemistry, Non Wood Forest Products, Pulp and Papers, Biomass Energy, and Biotechnology. Besides that, this journal also publishes review manuscripts which topics are decided by the Editors.

### Imprint

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Manuscripts will be accepted for publications are those discussing and containing results of research on wood science and technology, and reviews on specific topics, which are decided by the Editors and have not been published elsewhere. Authors are requested to correct the manuscripts accepted for publications as suggested by the Reviewers. Editors could change positions of Figures and Tables.

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3. Manuscripts compositions:
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  - 3.2. Complete name of Authors
  - 3.3. Abstract
  - 3.4. Key words
  - 3.5. Texts:
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    - Materials and Methods
    - Results and Discussion
    - Conclusions (and Suggestions)
    - References
    - Name and complete address of Authors
    - Appendix
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  - 4.2. Values between are written using this symbol (~), e.g. 3.75 ~ 8.92%.
  - 4.3. Editors could modify Figures without changing their substantial meaning.
  - 4.4. References are arranged from A to Z.
  - 4.5. References in text are written as this example: (Palomar *et al.* 1990; Arancon 1997).
  - 4.6. Examples of writing of References: Altschul, S.F.; T.L. Madden; A.A. Schäffer; J. Zhang; Z. Zhang; W. Miller; D.J. Lipman. 1997. Gapped BLAST and PSI-BLAST: A New Generation of Protein Database Search Programs. *Nucleic Acids Res.* 25: 3389-3402.

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### Example of Table and Figure

Table 1. Effects of temperature on *in vitro* growth of seedlings.

Temp. (°C)	Shoot length (mm)	Number of leaf	Fresh weight (g)
25	59.2 ± 10.6 <sup>c</sup>	4.5 ± 0.8 <sup>a</sup>	0.29 ± 0.13 <sup>a</sup>
27	88.5 ± 9.3 <sup>a</sup>	4.8 ± 0.9 <sup>a</sup>	0.40 ± 0.12 <sup>a</sup>
29	75.0 ± 11.1 <sup>b</sup>	3.8 ± 0.6 <sup>a</sup>	0.30 ± 0.07 <sup>a</sup>

Note: Values (average ± standard deviation) with different letters are statistically significant according to Tukey's multiple comparison test. Data were recorded after 4 weeks of culture. MS medium was used as a basal medium without any PGRs. Number of sample = 10.

Source: Chujo *et al.* 2010.

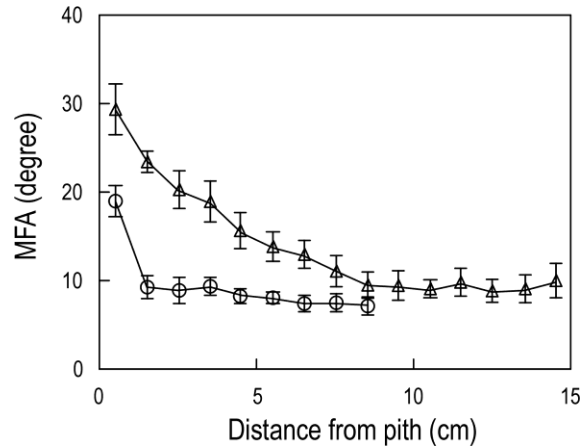


Figure 3. Radial variation of microfibril angle of the S2 layer in tracheid. Open circle, *Agathis* sp.; open triangle, *Pinus insularis*; Bars indicate the standard deviation. (Source: Ishiguri *et al.* 2010)

