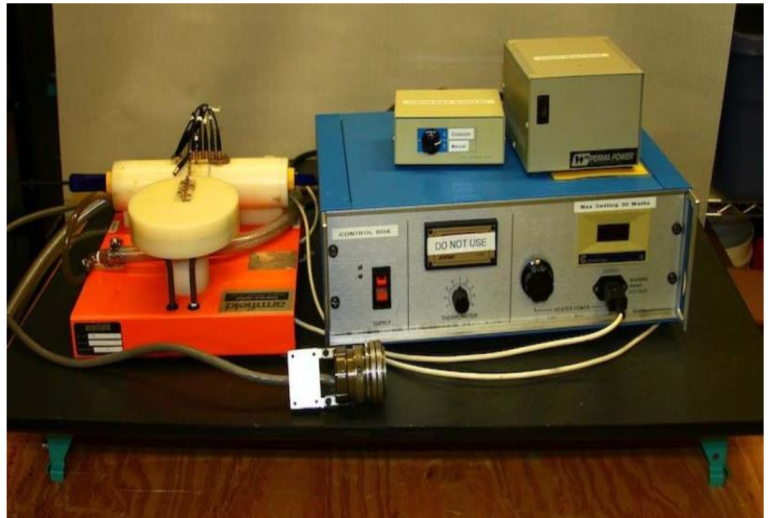


# WOOD RESEARCH Journal

## Journal of Indonesian Wood Research Society

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# Recent Research Activities in Solid and Liquid Bioenergy from Lignocellulosic Biomass

Jae-Hyuk Jang, Seung-Hwan Lee, Nam-Hun Kim

## Introduction

The increase in energy demand, the lack of petroleum resources, and concern over global climate change have placed great emphasis on the development of new alternative energy technologies that can be used to replace fossil transportation fuels (Himmel *et al.* 2007; Labbe *et al.* 2008; Lee *et al.* 2009a,b,c; Teramoto *et al.* 2008, 2009). In this context, many countries have initiated extensive research and development programs for bioenergy. Bioenergy can be classified into three kinds of solid, liquid, and gas bioenergy. For the effective production and utilization of these three types of bioenergy, different technologies are required (Figure 1). Lignocellulosic biomass, such as wood and agricultural residues, are widely distributed and easily accessible at relatively low costs. Of these, wood has the benefit of having a higher energy content per volume, lower ash content, and nitrogen content. In this review, recent research trends and advances in bioenergy from lignocellulosic biomass will be summarized from the author's point of view.

but burns rapidly. White charcoal, on the other hand, is covered with ash and is difficult to be ignited, but burns for a longer period. In addition, charcoal has attracted in many fields because of its unique characteristics. Charcoal has numerous tiny cavities resulting in a high surface area of approximately 300~600 m<sup>2</sup>/g. These cavities can absorb various substances including heavy metals. This property of charcoal has applications in various fields, such as soil modification, water purification, and the carbon industry. To obtain an effective carbonization process, it is important to understand the carbonization mechanism of wood.

The proposed mechanism involved in the transition from wood to charcoal is as follows: (1) water is evaporated up to a temperature of 150°C; (2) residual water is driven off of the wood structure between 150°C and 260°C; (3) decomposition and depolymerization of the wood begins breaking C-O and C-C bonds resulting in the evolution of water, CO, and CO<sub>2</sub>, between 260°C and 400°C; and (4) graphitic layers are formed above 400°C. It is also known that thermally induced decomposition and rearrangement reactions are largely terminated above 800°C, leaving a carbon structure (Mopoung 2008). Analysis of the pyrolysis of wood using a heating rate of 5°C min<sup>-1</sup> suggests that hemicelluloses are decomposed at temperatures ranging from 170~240°C, cellulose between 240~310°C, and lignin between 320~400°C (Zerriouh and Belkbir 1995). Kwon *et al.* (2010 and 2012) investigated the characteristics of the transition from wood to charcoal to understand the transformation mechanism and found that the volume, vessel diameter, and cell wall thickness of the wood decreased with increasing temperature.

## Solid Bioenergy

### Wood Charcoal

Wood charcoal is generally produced by pyrolysis at temperatures ranging from 600~1100°C under insufficient oxygen for complete combustion. Depending on the pyrolysis temperature and fire extinguishing system, charcoal can be classified into black and white charcoal (Kim *et al.* 2001). Generally, black charcoal is easy to ignite

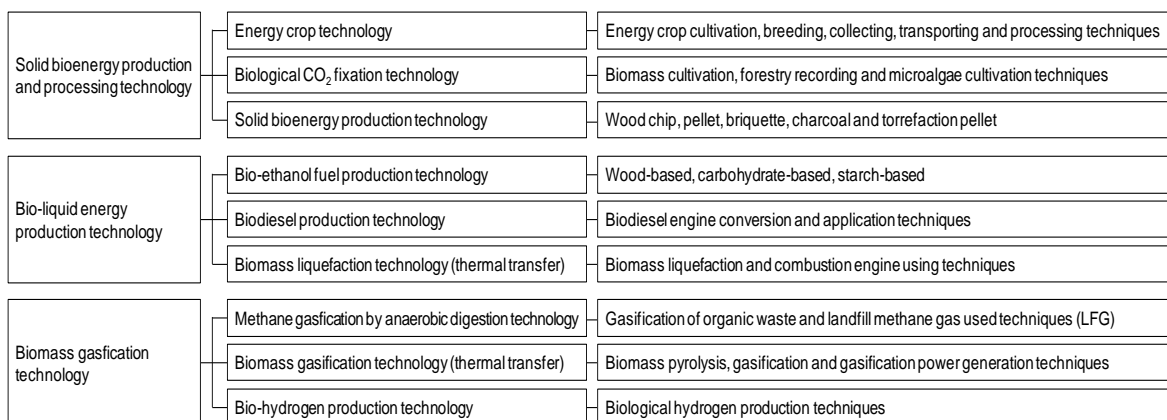


Figure 1. Classification of bioenergy technologies.  
(New & Renewable Energy Center, Korea Energy Management Corporation 2016).

On the other hand, the weight loss, pH, and heating value increased with the increase in the carbonization temperature. SEM images indicated that the layering structure of the cell walls of wood fibers and parenchyma cells were present at 330~340°C. However, the cell wall layering structures disappeared at temperatures over 350°C and changed radically into an amorphous-like structure. X-ray diffraction patterns showed that the cellulose crystalline structure was present at 340°C, but it was not detected over 350°C. From FT-IR spectroscopy, signals from the vibration of aromatic

rings had maximum intensities at 390°C, and those from ether groups decreased with increasing temperature. The heating value gradually increased from 4530 to 8200 cal/g over the temperature range of 200~1000°C, as shown in Table 1. Rhee and Cho (2008) also reported that the fuel ratio (fixed carbon/volatile combustible), carbon content, and heating value of the carbonization residue increased, but the yield of the residue decreased, with increasing carbonization temperature.

Table 1. The heating value of *Quercus variabilis* charcoals prepared at different temperatures (Kwon *et al.* 2010)

Temp.	Control	200°C	250°C	300°C	350°C	400°C	600°C	800°C	1000°C
Heating value (cal/g)	4326	4530	4728	5099	5871	6699	7239	8183	8200

### Wood Pellets

The pelletization of biomass involves the mass and energy densification of materials such as sawdust, straw, and other herbaceous energy crops with low bulk densities. This process reduces transportation costs and provides better handling, less dust formation, and more efficient feeding of the biomass into the pyrolysis process (Garcia-Maraver *et al.* 2011). In general, pellet quality depends on the chemical, mechanical, and physical properties of biomass in terms of thermal utilization (Kaliyan and Vance 2009; Oberberger and Thek 2004). Wood Pellets can be produced from roundwood but have mostly been made from cheaper waste residues derived from other wood processing activities, primarily sawdust and shavings from sawmills and

furniture factories. If made from roundwood, the full range of steps involving debarking, chipping, drying, and hammer milling must be done. Residues require less processing because they are already reduced in size, mostly bark-free, and dried (Spelter and Toth 2009). In either case, the moisture content is critical and must be confined within a range of approximately 12% to 17%. Pellets from different regions might be shown different properties (Kwon *et al.* 2009). Calorific value can be increased by the addition of other substrates, such as wood tar and wood vinegar (Kwon *et al.* 2010). Table 2 shows the characteristics of first-grade commercial wood pellets in several countries.

Table 2. Properties of first grade commercial wood pellets in several countries

Contents	United States <sup>1)</sup>	Germany <sup>2)</sup>	Austria <sup>2)</sup>	South Korea <sup>3)</sup>
Thickness (mm)	5.84-7.25	4-10	4-10	6-8
Length (mm)	>38.1	50	5 x thickness	<32
Bulk density (kg/m <sup>3</sup> )	640-737	1000-1400	>1120	>640
Moisture content (%)	<8	12	<10	<10
Ash content (%)	<1	1.5	<0.5	<0.7
Heating value (kcal/kg)	>4445	3704-4660	>4302	>4300

<sup>1)</sup> ISO 17225-1, 2014; <sup>2)</sup> Garcia-Maraver *et al.* 2011; <sup>3)</sup> Ahn *et al.* 2014.

### Torrefied Wood Pellets

Torrefaction of wood can be described as a mild form of pyrolysis at temperatures typically ranging between 200°C and 320°C (Van der Stelt *et al.* 2011). During torrefaction, the wood properties are altered to produce a higher fuel quality for combustion and gasification applications. The main principle of torrefaction from a chemical point of view is the removal of oxygen to produce a final solid product, torrefied wood, which has a lower oxygen/carbon ratio compared to the original wood. The thermal treatment not only disrupts the fibrous structure and firmness of the biomass but is also known to increase the

calorific value. Torrefied wood has more hydrophobic characteristics that make storage of torrefied wood more attractive in comparison to non-torrefied wood, because of the tendency of non-torrefied wood to rot. During torrefaction, wood is partly devolatilized leading to a decrease in mass, but the initial energy content of the torrefied wood is largely preserved in the solid product. Therefore, the energy density of torrefied wood is higher than that of the original wood, making it less expensive to transport per unit of energy (Van der Stelt *et al.* 2011). Figure 2 shows a comparison of a typical pelletization and torrefaction process (Bergman *et al.* 2005). The pelletization process comprises the steps of drying, size reduction,

steam pre-conditioning, densification, and cooling. However, the torrefaction process only consists of three steps, drying, torrefaction, and cooling. Table 3 summarizes the main characteristics of wood, torrefied wood, wood pellets, and

torrefied wood pellets. In summary, torrefied wood pellets have a more hydrophobic characteristic, higher strength, and higher density than of wood pellets (Bergman 2005).

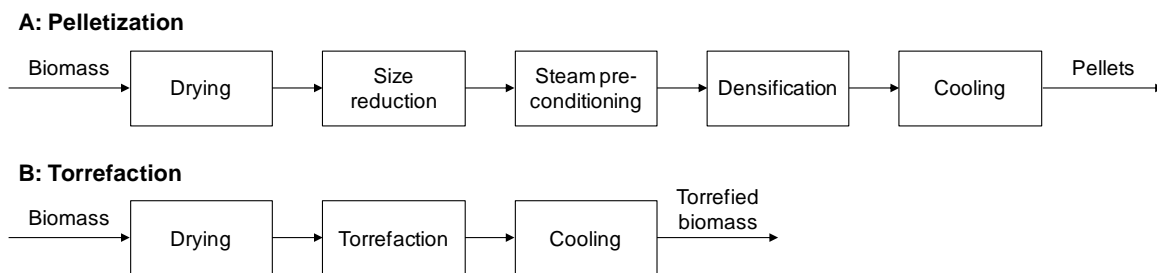


Figure 2. Schemes of pelletization (A) and torrefaction (B) processes.

Table 3. Characteristics of wood, torrefied wood, wood pellets, and torrefied wood pellets (Bergman 2005)

Contents	Wood	Torrefied Wood	Wood Pellets	Torrefied Wood Pellets
Moisture (wt%)	35	3	7	1
Net heating value				
Normal (MJ/kg)	10.5	19.9	16.2	21.6
Dry (MJ/kg)	17.7	20.4	17.7	22.7
Mass density (kg/m <sup>3</sup> )	550	230	650	850

### Liquid Bioenergy (Bioethanol)

Bioethanol is by far the most widely used biofuel for transportation worldwide. Production of bioethanol from lignocellulosic biomass is one way to reduce both the consumption of crude oil and environmental pollution. Biochemical conversion of lignocellulosic biomass through saccharification and fermentation is the primary pathway for bioethanol production. However, there are some difficulties in producing bioethanol from lignocellulosic biomass as a result of (1) the resistant nature of biomass to breakdown; (2) the variety of sugars that are released when the

hemicelluloses and cellulose polymers are broken down, and the need to find or genetically engineer organisms to efficiently ferment these sugars; and (3) the costs for collection and storage of low-density lignocellulosic biomass (Balat 2011). Figure 3 shows the basic process of producing bioethanol from lignocellulosic biomass, i.e., pretreatment, hydrolysis, fermentation, and product separation/distillation. A large number of pretreatment methods have been developed, including mechanical grinding, steam explosion, CO<sub>2</sub> explosion, ammonia fiber explosion, ozonolysis, hot water treatment, the organosolv process, and biological pretreatment (Kumar *et al.* 2009).

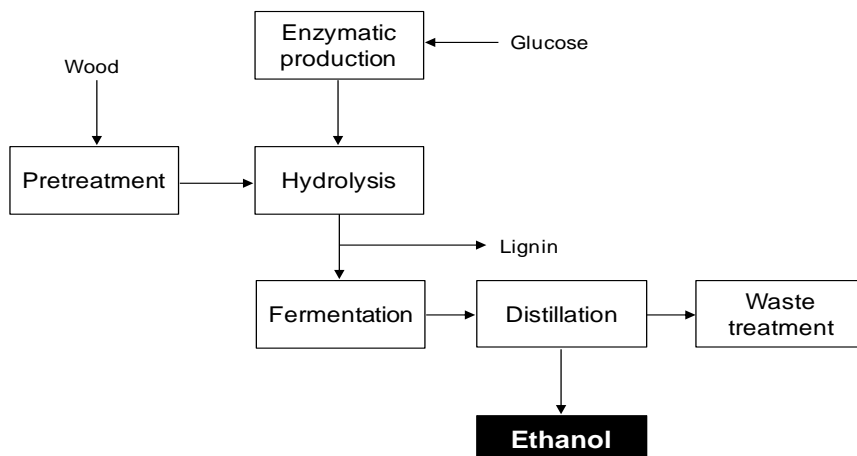


Figure 3. Production of bioethanol from lignocellulosic biomass.

The carbohydrate polymers in lignocellulosic materials must be converted to simple sugars before fermentation through a process called hydrolysis (Taherzadeh and Karimi 2007). The most commonly applied methods can be classified into two groups: chemical hydrolysis (dilute and concentrated acid hydrolysis) and enzymatic hydrolysis (Balat 2011). The dilute acid hydrolysis process involves a solution of approximately 1% H<sub>2</sub>SO<sub>4</sub> in a continuous flow reactor at a high temperature. Most dilute acid processes are limited to a sugar recovery efficiency of around 50% (Farooqi and Sam 2004). The acid concentration used in concentrated acid hydrolysis processes is in the range of 10–30%. This process provides complete and rapid conversion of cellulose to glucose and the conversion of

hemicelluloses to five-carbon sugars with little degradation (Iranmahboob and Nadim 2002). In contrast, enzymatic hydrolysis is a slow process because enzymatic hydrolysis of cellulose is hindered by the structural parameters of the substrate, such as the lignin and hemicellulose content, and cellulose crystallinity (Pan *et al.* 2006). On the other hand, enzymatic hydrolysis is an environmentally friendly alternative that involves using carbohydrate-degrading enzymes (cellulases and hemicellulases) to hydrolyze lignocelluloses into fermentable sugars (Keshwani and Cheng 2005). A comparison of the process conditions and performance of three cellulose hydrolysis processes is given in Table 4 (Hamelinck *et al.* 2005).

Table 4. Comparison of conditions and performance of three hydrolysis processes (Hamelinck *et al.* 2005)

Contents	Consumables	Temperature(°C)	Time	Glucose Yield (%)
Dilute acid	<1% H <sub>2</sub> SO <sub>4</sub>	215	3 min	50-70
Concentrated acid	30–70% H <sub>2</sub> SO <sub>4</sub>	40	2–6 h	90
Enzymatic	Cellulase	50	1.5 days	75 → 95

### References

- Ahn B.J., Cho S.T., Choi D.H. 2014. Quality standards of solid bioenergy from woody biomass. Proceeding of Annual Meeting of Korean Forest Bioenergy Society. May 16th, 2014. Seoul, South Korea. pp. 33-36.
- Balat M. 2011. Production of bioethanol from lignocellulosic materials via the biochemical pathway: A review. *Energy Conversion and Management* 52: 858-875.
- Bergman P.C.A. 2005. Combined torrefaction and pelletisation: the TOP process. Report ECN-C-05-073. Petten, The Netherlands: ECN; 2005.
- Bergman P.C.A., Boersma A.R., Zwart R.W.R., Kiel J.H.A. 2005. Torrefaction for biomass co-firing in existing coal-fired power stations "biocoal". Report ECN-C-05-013. Petten, The Netherlands: ECN; 2005.
- Farooqi R, Sam AG. 2004. Ethanol as a transportation fuel. Centre for applied business research in energy and the environment (CABREE) climate change initiative, University of Alberta, Canada, April 29 2004.
- Garcia-Maraver A., Popov V., Zamorano M. 2011. A review of European standards for pellet quality. *Renewable Energy* 36: 3537-3540.
- Hamelinck C.N., Van Hooijdonk G., Faaij A.P.C. 2005. Ethanol from lignocellulosic biomass: Techno-economic performance in short-, middle- and long-term. *Biomass Bioenergy* 28: 384-410.
- Himmel M.E., Ding S.Y., Johnson D.K., Adney W.S., Nimlos M.R., Brady J.W., Thomas D.F. 2007. Biomass recalcitrance: Engineering plants and enzymes for biofuels production. *Science* 315: 5813-5815.
- Iranmahboob J., Nadim F. 2002. Monemi S. Optimizing acid-hydrolysis: a critical step for production of ethanol from mixed wood chips. *Biomass Bioenergy* 22: 401-4.
- ISO 17225-1. 2014. Solid biofuels- Fuel specifications and classes, Part 1: General requirements.
- Kaliyan N., Vance R. 2009. Factors affecting strength and durability of densified biomass products. *Biomass and Bioenergy* 33: 337-359.
- Keshwani D.R., Cheng J.J. 2009. Switchgrass for bioethanol and other value-added applications: A review. *Bioresources Technology* 100: 1515-23.
- Kim N.H., Kwon G.J., Hwang W.J., Lee S.J., Park H.S. 2001. Development of an efficient process for manufacturing charcoal-variation of temperature in a traditional kiln during carbonizing process-. *Journal Industry University Regional Consortium Center, Kangwon National University* 5: 43-48.
- Kumar P., Barrett D.M., Delwiche M.J., Stroeve P. 2009. Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. *Industrial & Engineering Chemistry Research* 48: 3713-29.
- Kwon G.J., Kim N.H., Cha D.S. 2009. Characteristics of the commercial wood pellets. *Journal of Forest Science*. 25(2): 127-130.
- Kwon G.J., Kwon S.M., Cha D.S., Kim N.H. 2010. Characteristics of pellet prepared from sawdust and wood-tar. *Journal of the Korean Wood Science and Technology* 38(1): 36-42.
- Kwon S.M. 2010. Transition characteristics of the wood cell walls during carbonization. Ph.D. thesis. Kangwon National University. Republic of Korea.
- Kwon S.M., Kim N.H., Cha D.S. 2009. An investigation on the transition characteristics of the wood cell walls during carbonization. *Wood Science and Technology* 43: 487-498.
- Kwon S.M., Kwon G.J., Jang J.H., Kim N.H. 2012. Characteristics of charcoal in different carbonization temperatures. *Journal of Forest Science* 28(4): 263-267.

- Labbe N., Lee S.H., Jeong M.K., Cho H.W., André N. 2008. Enhanced discrimination and calibration of biomass NIR data using nonlinear Kernel methods. *Bioresource Technology* 99: 8445-8452.
- Lee S.H., Teramoto Y., Endo T. 2009a. Enzymatic saccharification of woody biomass micro/nano-fibrillated by continuous extrusion process I-Effect of additives with cellulose affinity. *Bioresource Technology* 100: 275-279.
- Lee S.H., Teramoto Y., Endo T. 2009b. Enhancement of enzymatic accessibility by fibrillation of woody biomass using batch-type kneader with twin-screw elements. *Bioresource Technology* 101: 769-774.
- Lee S.H., Cho H.W., Labbe N., Jeong M.K. 2009c. Quick assessment of thermal decomposition behavior of lignocellulosic biomass by near infrared spectroscopy (NIR) and its statistical analysis. *Journal of Applied Polymer Science* 114: 3229-3234.
- New & Renewable Energy Center, Korea Energy Management Corporation. 2016. Classification of bioenergy technologies. <http://www.knrec.or.kr/knrec/11/KNREC110700.asp>. Accessed 11 July 2016.
- Obernberger I., Thek G. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass and Bioenergy* 27: 653-669.
- Pan X., Gilkes N., Saddler J.N. 2006. Effect of acetyl groups on enzymatic hydrolysis of cellulosic substrates. *Holzforschung* 60: 398-401.
- Rhee S.W., Cho Y.H. 2008. A study on characteristics of carbonization residue produced from woody biomass. *Journal of Korea Solid Wastes Engineering Society* 25(6): 533-539.
- Spelter H., Toth D. 2009. North America's wood pellet sector. Research Paper FPL-RP-656FPL, USDA, USA.
- Taherzadeh M.J., Karimi K. 2007. Acid-based hydrolysis processes for ethanol from lignocellulosic materials: a review. *BioResources* 2: 472-99.
- Teramoto Y., Lee S.H., Endo T. 2008. Pretreatment of Eucalyptus wood chips for enzymatic saccharification using combined sulfuric acid-free ethanol cooking and ball milling. *Biotechnology and Bioengineering* 99(1): 75-85.
- Teramoto Y., Lee S.H., Endo T. 2009. Pretreatment of woody and herbaceous biomass for enzymatic saccharification using sulfuric acid-free ethanol cooking. *Bioresources Technology* 99: 8856-8863.
- Van der Stelt M.J.C., Gerhauser H., Kiel J.H.A., Ptasinski K.J. 2011. Biomass upgrading by torrefaction for the production of biofuels: A review. *Biomass and Biotechnology* 35: 3748-3762.
- Zerriouh A, Belkbir L. 1995. Thermal decomposition of a Moroccan wood under a nitrogen atmosphere. *Thermochim Acta* 258: 243-248.

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# Softening Behaviour of Indonesian Wood Species

Wahyu Dwianto, Ikuho Iida, and Kazuya Minato

## Abstract

This paper deals with softening behaviour measurements of Indonesian wood species by static bending tests. Wood samples with a size of 110mm (R) x 10mm (T) x 4mm (L) were bending tested in air-dry at 20°C and 65% relative humidity (RH), in water saturation at 20°C, and in water saturation at 80°C to know the decreasing of modulus of elasticity (MOE) and modulus of rupture (MOR) due to moisture content (MC) and both moisture content and temperature (MCT) changes. The wood samples represented Randu (*Bombax ceiba*. L) as the lowest specific gravity, i.e. 0.27 to Lamtoro (*Leucaena glauca* (Willd) Benth) as the highest specific gravity, i.e. 0.81. The three-point static bending test was carried out by a mechanical testing machine with a load capacity of 100kgf, loading deflection speed of 5mm/min, a span distance of 80mm at a room with a temperature of 20°C and 65% RH for air-dry wood samples, and that for wet wood samples were conducted in a water bath at 20°C (change in MC) and 80°C (change in MCT), respectively. MOE and MOR increased linearly with specific gravity regardless of wood species. On the other hand, maximum deflection did not correlate with specific gravity for any MCT conditions. The relative MOE and MOR which were calculated in wet 20°C to air-dry were affected from hardly to strongly depending on the wood species. Meanwhile, they decreased extremely when saturated in water at 80°C regardless of wood species. The relative MOE and MOR due to the change in MC or MCT was independent of specific gravity, as well. Furthermore, chemical compositions of the wood species were analysed to clarify the main factors that affected the decreasing of MOE and MOR due to MC and MCT changes. The results showed that the percentage of lignin and hemicelluloses in each wood played an important role in decreasing the static bending properties. Relative MOE and MOR decreased with increasing lignin and hemicellulose contents. It can be concluded that the hygrothermal properties of lignin and hemicelluloses significantly affect the changes of elastic and strength properties of wood in softening conditions.

**Keywords:** softening behaviour, static bending tests, MOE, MOR, specific gravity, chemical compositions.

## Introduction

Various studies on wood softening techniques and its behaviour by heating in wet conditions, such as immersing in hot water, microwave heating (Norimoto and Gril 1989), and steaming (Makinaga *et al.* 1997) have been investigated. Wood softening techniques were also found in the smoke heat treatment process (Nomura 2002) to minimize the damage caused by twisting or collapse, log peeling process of raw material for plywood, or in the treatment process of wood chips into fibre for pulp raw material (thermo-mechanical pulping).

It has widely known that amorphous polymers of wood and other lignocellulose materials partly changed from a glassy state into a rubbery condition and experience a decrease in stiffness and strength when heated in wet conditions at certain temperatures (Hillis and Rozsa 1978). The behaviour depended on the glass transition temperature of cellulose, hemicellulose, and lignin (Goring 1963), where this did not occur in dry conditions. Hillis and Rozsa (1978) reported that hemicellulose glass transition temperature of fresh wood was around 70°C ~ 80°C, and that of lignin was between 80°C ~ 100°C. The addition of steam time will further reduce the transition temperature.

Some researchers have conducted difficult measurements to determine changes of stiffness (rigidity) and strength properties of wood in softening conditions, such as by thermal compression technique (Goring 1963),

vibration technique (Urakami and Nakato 1966), elastic shear modulus (Atack 1972), torsional loading (Hillis and Rozsa 1978), stress relaxation (Dwianto *et al.* 1999), or creep test (Takahashi *et al.* 2002). The measurement can be done more easily by static bending tests. Iida (1989) has investigated changes in the elastic properties and strength of 24 Japanese wood species by the static bending tests. The results showed that there was a difference in the average ratio of flexural strength, fracture strength, and maximum deflection between softwood and hardwood with the increasing moisture content and temperature. He considered that the hygrothermal properties of lignin greatly influence the changes in the flexural strength and fracture strength of the woods due to hygrothermal effects.

In the drying and manufacturing of wood and wood-based materials, variation of mechanical properties accompanied with the changes of moisture content and temperature is extremely important concerning the quality and yield of the products. However, the information for mechanical properties has scarcely been obtained not only for major tropical wood species but also abundant lesser-used and fast-growing tropical wood species. Especially when we intend to use those tropical woods, it may be essential to clarify the dependencies of mechanical properties on moisture content and temperature.

This study evaluated the decrease in mechanical properties of 15 Indonesian wood species caused by

changes in moisture content and temperature through static bending tests. Furthermore, chemical compositions of the wood species were analyzed to clarify the main factors that affect the decreasing of MOE and MOR due to moisture content and temperature changes and to empirically determine the relationship between the chemical compositions and the static flexural properties of the softening conditions. Some parts of these results have been published (Sudijono *et al.* 2004), but the wood species used in this experiment were supported by analysis of their chemical compositions to determine the factors causing their softening behavior.

## Materials and Methods

### Materials

Fifteen (15) wood species used in static bending tests and their respective air-dry specific gravities were Randu (*Bombax ceiba*. L; 0.27), Albizia (*Falcataria molucana* (L.) Nielson; 0.31), Angsana (*Pterocarpus indicus* Jacq.; 0.45), Durian (*Durio zibethinus* Murray; 0.45), Mindi (*Melia azedarach* (L); 0.46), Kecapi (*Sandoricum koetjape* (Burm.f.) Merr; 0.48), Manii (*Maesopsis eminii* Engl.; 0.50), Acacia (*Acacia mangium* Willd; 0.52), Agathis (*Agathis damara* (Lambert) Rich; 0.53), Bacang (*Mangifera foetida* Lour; 0.58), Nangka (*Artocarpus heterophylla* Lamk; 0.64), Mahogany (*Swietenia mahagoni* (L) Jacq; 0.65), Puspa (*Schima wallichii* (DC) Korth; 0.70), Rubber (*Hevea brasiliensis* (Willd.ex.ALJuss) Muell.Arg; 0.71), and Lamtoro (*Leucaena glauca* (Willd) Benth; 0.81). The wood samples represented Randu (*Bombax ceiba*. L) as the lowest specific gravity, i.e. 0.27 to Lamtoro (*Leucaena glauca* (Willd) Benth) as the highest specific gravity, i.e. 0.81.

The test sample size was 110mm (R) x 10mm (T) x 4mm (L). To get homogenous conditions, all the wood samples were water-saturated at room temperature for 12 hours and then were immersed into 80°C water for 3 hours.

### Static Bending Tests

The wood samples for the static bending test were divided into 3 conditions, as followed: (1) Air-dry condition at 20°C and 65% relative humidity (RH), (2) Water saturation at 20°C (wet 20°C), and (3) Water saturation at 80°C (wet 80°C) to evaluate the decrease in flexural strength (MOE) and fracture strength (MOR) caused by changes in moisture content (MC) and both moisture and temperature (MCT) factors. The air-dry wood samples were placed in an adjustable temperature and RH room to 20°C and 65% RH, respectively; before equilibrium moisture content. Wet wood samples were immersed in room-temperature water for more than a week after the pre-condition described above. Wood samples of the three conditions were taken from subsequently cut of their transverse direction and 4 repetitions for each condition.

The three-point static bending tests were carried out by a mechanical testing machine with a load capacity of

100kgf, loading deflection speed of 5mm/min, a span distance of 80mm at a room with a temperature of 20°C and 65% RH for air-dry wood samples, and that for wet wood samples were conducted in a water bath at 20°C (change in MC) and 80°C (change in MCT), respectively (Figure 1).

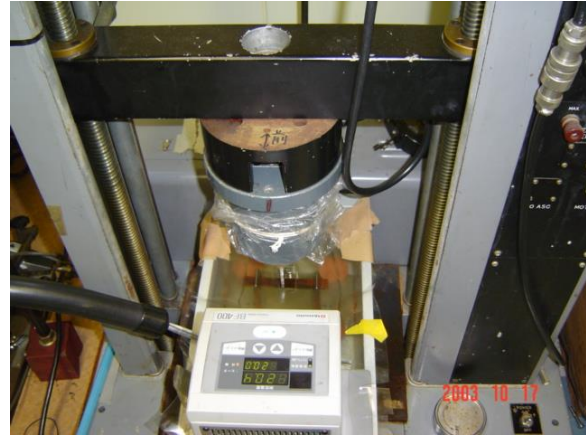


Figure 1. Static bending tests in a water bath.

### Chemical Analysis

Chemical composition, including extractive content,  $\alpha$ -cellulose, lignin, and hemicellulose, the 15 wood species were analysed by Wise and Klason lignin methods.

## Results and Discussion

### Mechanical Properties

Figures 2, 3, and 4 show the relationship between the air-dry specific gravity of the 15 wood species to their MOE, MOR, and maximum deflection values, respectively.

The values of static flexural properties test results of all the wood samples show that MOE and MOR increased linearly with increasing specific gravity and laid on a linear regression (Figure 2 and Figure 3). However, maximum deflection values of each wood species in the three conditions were widely fluctuation and were not correlated to specific gravity at any change in MC or MCT (Figure 4). It was probably due to different response of each wood species to MC and MCT changes.

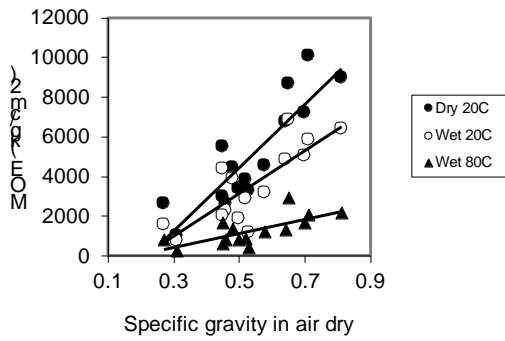


Figure 2. Relationship between MOE and air-dry specific gravity (Sudijono *et al.* 2004).

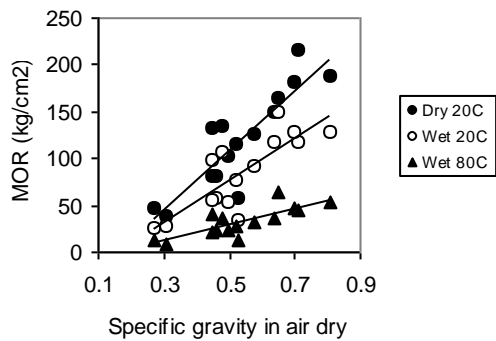


Figure 3. Relationship between MOR and air-dry specific gravity (Sudijono *et al.* 2004).

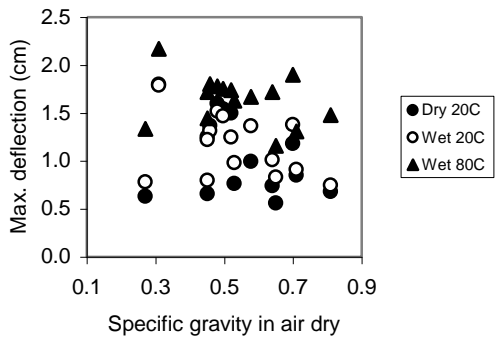


Figure 4. Relationship between maximum deflection and air-dry specific gravity (Sudijono *et al.* 2004).

To understand which wood species have more or less affected by changes of MC and both MCT regardless of specific gravity, relative modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated based on the value in air-dry at 20°C. The decreasing of relative MOE and MOR is shown in Figures 5 and 6, respectively.

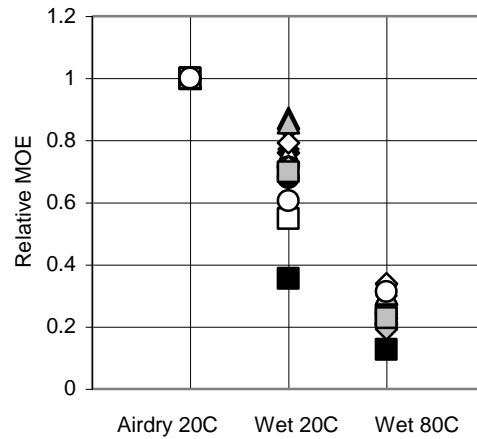


Figure 5. Decreasing of relative MOE due to changing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al.* 2004).

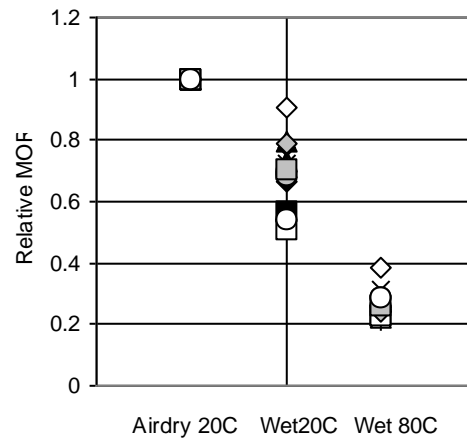


Figure 6. Decreasing of relative MOR due to changing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al.* 2004).

Legend: see Fig. 5.

The relative MOE significantly decreased with changes in MC and MCT (Figure 5). The decline in the relative MOE in wet at 20°C caused by changes in MC were very wide and could be separated into the less affected species group (between 0.8 and 0.7), i.e. Mahoni, Acacia, Nangka, Lamtoro, Puspa, and Bacang woods; and the moderate affected species group (between 0.6 and 0.5), i.e. Randu, Karet and Manii woods. However, most of them were strongly affected by changes in MCT. The relative

MOE in wet at 80°C decreased to 0.3 ~ 0.2 as a result of the change in MCT.

Agathis has most affected by changes in MC and MCT. The value of relative MOE decreased to 0.35 in wet at 20°C and fell to 0.12 in wet at 80°C. The decreasing of MOE due to changes of MC and MCT was regardless of specific gravity. For example, the relative MOE of Acacia, which has the same specific gravity as Agathis, has decreased only 0.76 in wet at 20°C, and 0.23 in wet at 80°C. Agathis was the only softwood in this experiment. It was considered that Agathis has a lower softening temperature than that of hardwoods.

The decreasing of relative MOR is shown in Figure 6. It was recognized that Mahoni wood has most resistance against the changes of MC and MCT compared with the other woods. The relative MOR of Mahoni wood only decreased to 0.9 with changes in MC and 0.4 with changes in MCT. The decrease in the relative MOR caused by changes in MC in wet at 20°C for other wood species can be determined and grouped into the moderate affected species group (between 0.8 and 0.65), i.e. Acacia, Nangka, Lamtoro, Puspa, and Bacang woods. Then the most affected species group (between 0.6 and 0.5), i.e. Agathis, Randu, Karet, and Manii woods. However, most of the relative MOR were decreased to 0.3 ~ 0.2 in wet at 80°C due to changes in MCTs for each wood species.

From the results, it was concluded that the response of the wood species against the changes of MC and MCT could be recognized as the most, moderate and less affected, as shown in Table 1.

Lida (1989) has been investigated the changes of elastic and strength properties of 24 Japanese wood species by static bending tests in an air-dry condition at 20°C and in water-saturated conditions at 20°C and 100°C. The results showed that there was a difference between the average ratios of young modulus (MOE), breaking stress (MOR), and breaking strain (maximum deflection) of softwoods and hardwoods when moisture content and temperature was increased. He reported that relative MOE and MOR due to change of moisture content for Japanese wood species were 0.52 and 0.62, respectively, and that due to change of temperature were 0.18 and 0.29, respectively. He concluded that the hygrothermal properties of lignin significantly affect the changes of elastic and strength properties of wood that are due to hygrothermal effects. The influence of moisture content changes to MOE and MOR values of the 15 Indonesia wood species were smaller than that of Japanese wood species. On the other hand, the influence of temperature changes was higher.

In this experiment, Agathis, as the only softwood, has most affected by changes of MC and MCT to its MOE and MOR. However, some Indonesian hardwoods were also easily affected by changes of MC to their MOR values, i.e.: Randu, Karet, and Manii woods; and almost all species affected by changes of MCT to their MOR values.

Table 1. Classification of the species based on relative MOE and MOR affected by increasing of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C) (Sudijono *et al.* 2004).

	In wet at 20°C			In wet at 80°C		
	Less	Moderate	Most	Less	Moderate	Most
MOE	Mahoni Acacia Nangka Lamtoro Puspa Bacang	Randu Karet Manii	Agathis		Mahoni Acacia Nangka Lamtoro Puspa Bacang Randu Karet Manii	Agathis
MOR	Mahoni	Acacia Nangka Lamtoro Puspa Bacang	Agathis Randu Karet Manii		Mahoni	Agathis Acacia Nangka Lamtoro Puspa Bacang Randu Karet Manii

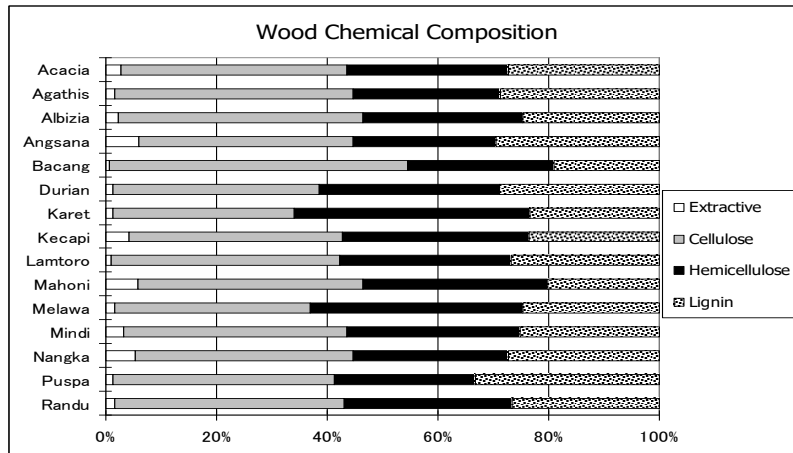


Figure 7. Percentage of  $\alpha$ -cellulose, hemicellulose and lignin content in 15 wood species (Yusuf *et al.* 2005)

The results of the chemical composition analysis are shown in Figure 7. The average percentage of  $\alpha$ -cellulose, hemicellulose, and lignin content of the 15 wood species were 40.5%, 31.0%, 25.9%, respectively, and the rest were extractive substances. Mahoni, Acacia, Nangka, Lamtoro, Puspa, and Bacang woods contained higher levels of  $\alpha$ -cellulose and lower levels of hemicellulose and lignin than the average content. On the other hand, Durian, Karet and Manii woods contained high levels of hemicellulose and lignin and lower levels of  $\alpha$ -cellulose than the average content.

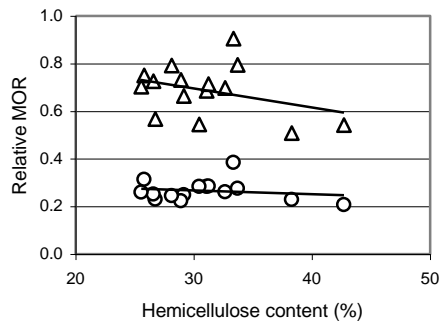
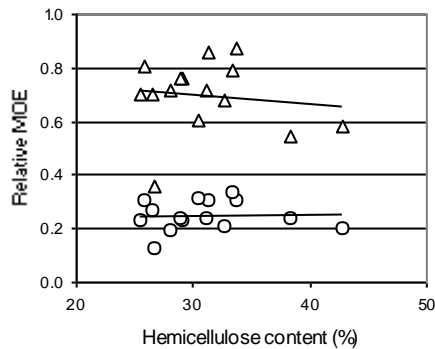


Figure 8. The relationship between the relative MOE and MOR with the percentage of hemicellulose.

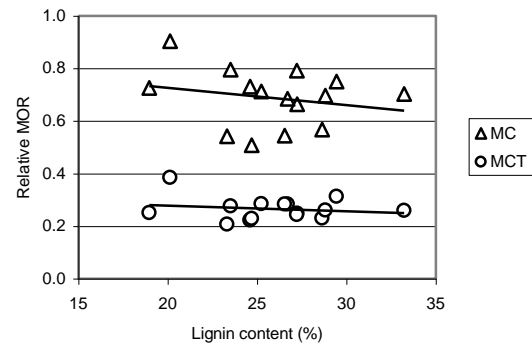
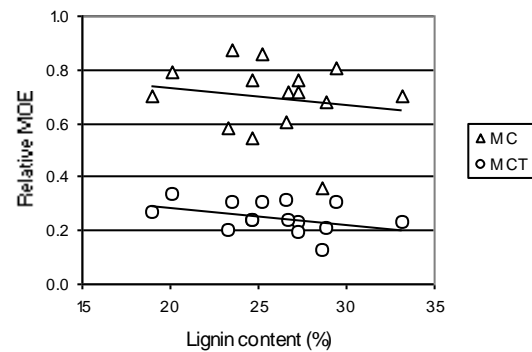


Figure 9. The relationship between the relative MOE and MOR with the percentage of lignin content.

Furthermore, a correlation was made between the relative MOE and MOR and the content of  $\alpha$ -cellulose, hemicellulose, and lignin to determine the main factors that influenced the decrease in MOE and MOR due to changes in MC and MCT. The correlation results indicated that the percentage of hemicellulose and lignin in wood species has a role in reducing the static bending properties under softening conditions. The relative MOE and MOR decreased with the increase of hemicellulose and lignin content,

particularly due to changes in MC (Figures 8 and 9). However, a decrease in the relative MOE and MOR due to changes in MCT has occurred even though these wood species have low hemicellulose and lignin content. This was indicated by a horizontal line of change in the MOE or MOR value.

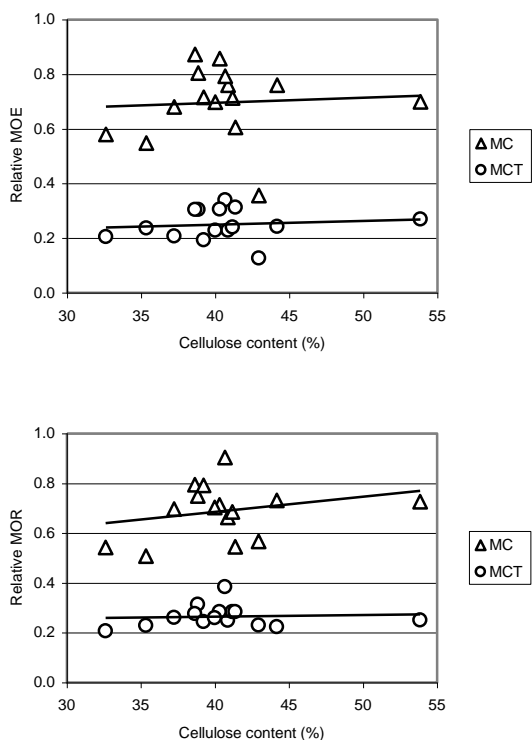


Figure 10. The relationship between the relative MOE and MOR with the percentage of cellulose content.

In contrast, the relative MOE and MOR increased slightly with increasing cellulose content, particularly under changing conditions of MC (Figure 10). This can be understood because cellulose is arranged in microfibrils where the crystal groups cannot be penetrated by water molecules. In addition, the softening temperature of cellulose was still above the treatment temperature in this study (above 80°C). So it can be concluded that the static flexural properties of wood in this softening condition depend on the percentage of cellulose, hemicellulose, and lignin, where wood species that have high cellulose content will be more resistant to changes in MC and MCT.

### Conclusions

From the results of the static bending tests, it was recommended that the wood species which were less or moderately affected by changes of moisture content to their MOE or MOR could be used for constructions, furniture, or window frame. We could separate the group into a heavy construction group for less affected wood species by

changes of moisture content, such as Mahoni, Acacia, Nangka, Puspa, and Bacang woods, and a light construction group for moderately affected wood species by changes of moisture content, such as Randu, Karet and Manii woods. The wood species, which were easily affected by increasing of moisture content and both moisture content and temperature, might be used for indoor, veneer or raw materials for particleboard.

### References

- Atack, D. 1972. On the characterization of pressurized refiner mechanical pulps. *Svenk Papperstid* 75: 89-94.
- Dwianto, W.; T. Morooka; M. Norimoto; T. Kitajima. 1999. Stress Relaxation of Sugi (*Cryptomeria japonica* D. Don) in Radial Compression under High-Temperature Steam. *Holzforchung* 53: 541-546.
- Dwianto, W.; Sudijono; S. Yusuf; I. Iida; K. Minato. 2005. Hubungan antara Komposisi Kimia dan Sifat Lentur Statis pada Kondisi Pelunakan. *Prosiding Seminar Nasional VIII MAPEKI*, Tangerang: A89-A95.
- Goring, D.A.I. 1963. Thermal softening of lignin, hemicellulose dan cellulose. *Pulp and Paper Magazine Canada* 64(12): 517-527.
- Hillis, W.E and A.N. Rozsa. 1978. The softening temperature of wood. *Holzforchung* 32(2): 68-73.
- Iida, I. 1989. Changes of elastic and strength properties in the direction perpendicular to the grain by moisture content changes and by heating in water. *Mokuzai Gakkaishi* 35: 875-881.
- Makinaga, M.; M. Norimoto; M. Inoue. 1997. Permanent fixation of bending deformation of wood by steam treatment. *Wood Research* 84: 39-41.
- Nomura, T. 2002. Dimensional stabilization of oil palm using smoke heat treatment. *Proceedings of the Forth International Wood Science Symposium*. Serpong: 36-42.
- Norimoto, M and J. Gril. 1989. Wood Bending using Microwave Heating. *Wood Research Institute*, Kyoto University, Kyoto, Jepang.
- Sudijono; W. Dwianto; S. Yusuf; I. Iida; Y. Furuta; K. Minato. 2004. Characterization of major, unused and unvalued Indonesian wood species I. Dependencies of mechanical property on the changes of moisture content and/or temperature. *Journal of Wood Science* 50: 371-374.
- Takahashi, C.; Y. Ishimaru; I. Iida; Y. Furuta. 2002. Creep behavior of wood in unstable states: In relation to the mechano-sorptive creep. *Proceedings of the Forth International Wood Science Symposium*. Serpong. p. 28.
- Urakami, H. and K. Nakato. 1966. The effect of temperature on torsional stress relaxation of wet Hinoki wood. *Journal of Japan Wood Research Society* 12:118-123.

Yusuf, S.; W. Dwianto; Sudijono; Y. Kawato; I. Iida; K. Minato. 2005. Characterization of fifteen Indonesian wood species from the physical, mechanical and chemical aspects. Proceeding of the Sixth International Wood Science Symposium, Bali – Indonesia: 98-102.

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# Thermal Conductivity of Teak Wood from Thinned Stands

Veriawan Setyo Wibowo and Joko Sulisty

## Abstract

Wood has been utilized as a heat conductor or insulator. Hence, this research aims to discover the thermal conductivity of teak wood using thinned stands from the Perhutani plantation forest. The samples obtained had varying moisture content and fiber direction, and were of distinct tree ages, at 12, 15, 20, 25, and 60 years. This result show that the thermal conductivity in air-dry conditions and fiber saturation points were 0.116 to 0.128 and 0.338 to 0.151 in W/Mk, respectively. The analysis of variance showed that the thermal conductivity of teak wood was affected by the interaction of fiber directions and moisture content but not significantly by tree age. Also, there was a weak relationship found between thermal conductivity and specific gravity in air-dry conditions and longitudinal direction.

**Keywords:** tree age, thinning, *Tectona grandis*, anisotropy, density

## Introduction

Wood is used as a raw material for various products, such as buildings or constructions, veneers, heat insulators, furniture, railway sleepers, sports equipment, etc. Also, the thermal properties of wood are necessary for several processes like wood drying, heat processing, building construction, and other fields of industry. Wood has a low thermal conductivity ( $k$ ) compared to other building materials due to its low density and hollow cellular structure.

Generally, teak species are classified as fancy and used in wooden industries in Indonesia. Recently, it has been supplied as young forms from community forests and thinned logs conventionally produced from 12, 15, 20, 25, and 60-year-old stands in the Perum Perhutani plantation forest. Although much research on the physical properties of young teak has been carried out (Marsoem *et al.* 2014; Hidayati *et al.* 2015), data on thermal conductivity are scanty.

Meanwhile, the thermal conductivity depends on several factors, namely species, density, moisture content, heat flow direction (anisotropy), alongside the inclination of grain (Suleiman *et al.* 1999), and correlates positively with the density of softwood and heartwood (Mauranen *et al.* 2015). Therefore, this research objective is to determine the thermal conductivity of teak wood from thinned stands at various ages and relate the values to its specific gravity.

## Materials and Methods

### Material Preparation

The research material was teak (*Tectona grandis*) from thinning cuttings in Randublatung Forest Management Unit, Central Java, obtained from tree samples from the bottom part of the tree, with age variations of 12, 15, 20, 25, and 60 years. For each age, three trees were selected. Meanwhile, the wood material used was in the form of

randomly selected pieces free from defects and sound, which were cut and converted to produce specimen samples. These samples were used to test the heat conductivity of wood in a cylindrical shape with a 30 mm length and 25 mm diameter. The length dimensions were made in tangential and longitudinal directions (ASTM C177), while the samples for testing the water content and specific gravity were made with a size of 2 x 2 x 2 cm (British Standard 373-1957). Figure 1 describes the design scheme for making the specimens.

### Moisture Content Determination

The moisture content (MC) was determined for oven-dried, air-dry, and fiber saturation point (FSP) conditions at 0%,  $\pm 10\%$ , and  $\pm 30\%$ , respectively. Before weighing periodically, the 10% MC was obtained after air-drying the previously oven-dried samples, while the 30% MC was achieved after immersing the oven-dried samples in water for a certain time until they reached a constant dimension (length and diameter). Then, the sample conditioned for its MC was wrapped in aluminum foil and put into a box containing silica. Subsequently, the MC was determined using the oven-drying method, while the wood sample was weighed and dried at  $103 \pm 2^\circ\text{C}$  until the weight was constant. Also, the MC was determined, according to the formula  $\text{MC (\%)} = [(w_{\text{wet mass}} - w_{\text{dry mass}}) / w_{\text{dry mass}}] \times 100$ .

### Specific Gravity Determination

The specific gravity (SG) of the wood specimens was calculated as oven-dry weight and volume, alongside the density of water. Meanwhile, density was calculated as the ratio of oven-dry weight to conditioned volume as determined by the water displacement method.

### Thermal Conductivity Determination

The measurement of thermal conductivity (TC) was carried out using a modified Armfield heat conduction apparatus (Laboratory of Pusat Antar Universitas, Universitas Gadjah Mada) based on the ASTM C177 method with modifications (Figure 2). Then, it was placed in a horizontal position on the apparatus with the direction of heat propagation parallel to the radial direction of the wood. The measurement was conducted for three replications. The initial heating was set at 4 watt. The initial temperatures of specimens were in the range of 24 to 30°C. The heating duration was 130 minutes. The temperature changes at nine positions of the specimen (T1-T9) were recorded for every minute. The thermal conductivity values ( $k$ ) were calculated by the formula :

$$k = \frac{Q}{A} \frac{dx}{dt} \dots\dots\dots(1)$$

$Q$  = the amount of heat transferred in a time (10 watt)  
 $A$  = specimen width  
 $dx$  = specimen length (30 mm)  
 $dt$  = temperature gradient (T4-T6)

### Statistical Analysis

The variation of the contents' TC was analyzed using the general linear model procedure by three-way analysis of variance (ANOVA), followed by the Tukey HSD test ( $p=0.05$ ). The factors were arranged in a factorial design for three replications, and the statistical calculations conducted using SPSS-Win 12.0.

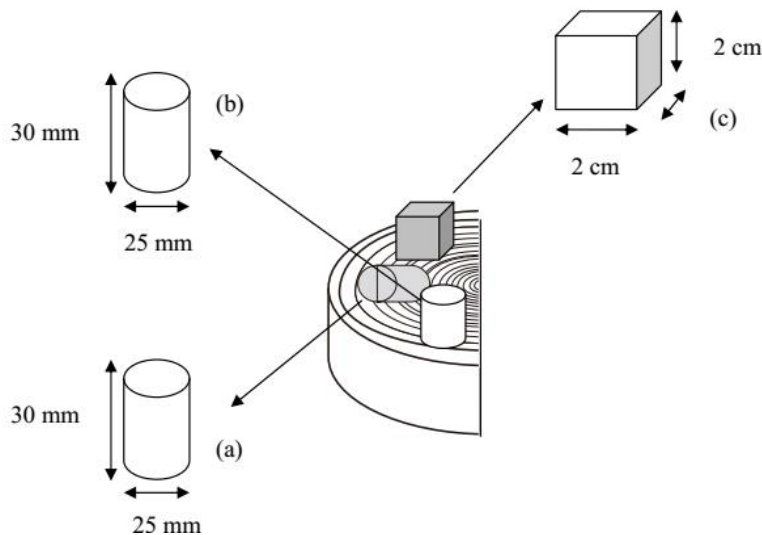


Figure 1. Schematic of the preparation process for samples in the longitudinal-tangential plane for thermal conductivity, moisture content, and specific gravity measurements.

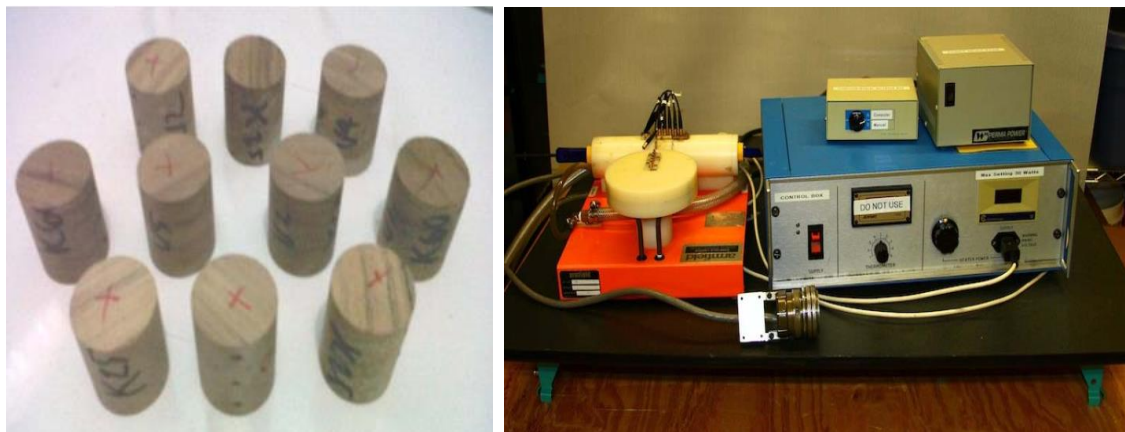


Figure 2. Specimens and instrument for measurement of thermal conductivity.

## Results and Discussion

This study relates the effect of MC to the value of TC from several tree ages with different fiber directions. The MC (air-dry) and FSP conditions ranging from 10 to 12% and  $30 \pm 1\%$ , respectively, were set to observe the effect on the TC values. Tables 1 and 2 present the range of the MC and SG measurement values. Meanwhile, the SG value was in the range of young teak from the Gunungkidul community forest (Marsoem *et al.* 2014) but higher than young teak, aged 10 years, from Randublatung FMU (Hidayati *et al.* 2015).

Table 3 shows the TC values of teak wood from various tree ages with fiber direction and MC factors, 0.116 to 0.128 in W/mK at the air-dry condition and 0.338 to 0.151 W/mK at FSP. Previous measurements (Prasojo *et al.* 2012) for teak wood obtained TC values of 0.110 W/mK (oven-dry) to 0.142 W/mK (FSP). The TC level in the FSP condition was higher than in the air-dry condition. Also, the

ANOVA results showed an interaction between MC and fiber direction ( $p > 0.01$ ), while the tree-age factor was not significantly affected. The post-hoc test result is presented in Figure 2. Meanwhile, the TC level was higher in the longitudinal than tangential direction at FSP but not in the air-dry conditions.

The TC value is very useful in processing wood, as a high value indicates the wood has good conductor properties, while a low value shows that the wood has poor conducting or good insulating properties. Also, the conductivity value of wood in the longitudinal direction had a heat conductivity value greater than 1 – 1.5 than the tangential and radial directions due to the transverse and parallel position of the fiber direction to the tree axis (Siau 1995; Sonderegger *et al.* 2011). In addition, the difference in the TC value is also strongly influenced by variations in the MC of the wood, as water has conductor properties that adequately transmit heat.

Table 1. Moisture content (%) of teak wood from various tree ages of thinned stands (mean of three trees)

Factors	Tree age (years)				
	12	15	20	25	60
Moisture content/axis direction					
Fiber saturation point / Longitudinal	30.90	31.05	31.05	31.12	30.97
Fiber saturation point / Tangential	31.02	30.71	30.38	30.62	30.09
Air-dry / Longitudinal	10.81	11.69	11.88	11.65	11.09
Air-dry / Tangential	11.92	12.52	12.22	12.56	11.20

Table 2. Specific gravity of teak wood from various tree ages of thinned stands (mean of three trees)

Factors	Tree age (years)				
	12	15	20	25	60
Moisture content/fiber direction					
Fiber saturation point / Longitudinal	0.58	0.59	0.57	0.58	0.58
Fiber saturation point / Tangential	0.57	0.58	0.57	0.58	0.57
Air-dry / Longitudinal	0.59	0.61	0.58	0.58	0.60
Air-dry / Tangential	0.59	0.61	0.59	0.58	0.60
Oven-dry / Longitudinal	0.62	0.62	0.64	0.61	0.62
Oven-dry / Tangential	0.62	0.64	0.63	0.61	0.63

Table 3. Thermal conductivity (W/mK) of teak wood from various tree ages of thinned stands (mean of three trees)

Factors	Tree age (years)				
	12	15	20	25	60
Moisture content/fiber direction					
Fiber saturation point / Longitudinal	0.148	0.148	0.148	0.150	0.151
Fiber saturation point / Tangential	0.139	0.142	0.144	0.138	0.143
Air-dry / Longitudinal	0.116	0.128	0.116	0.117	0.120
Air-dry / Tangential	0.121	0.122	0.124	0.119	0.125

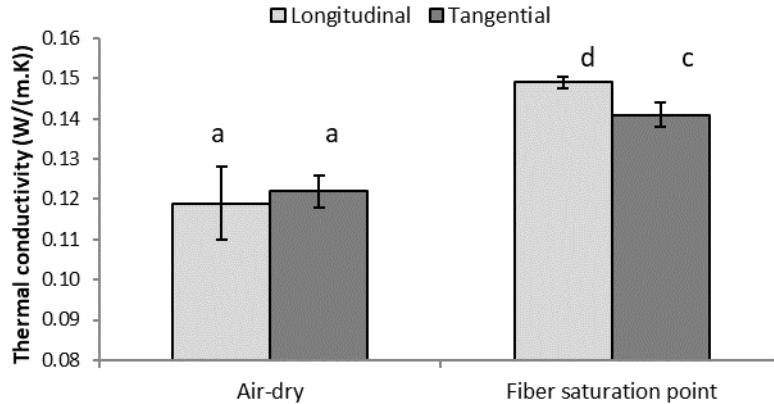


Figure 3. Thermal conductivity of teak wood related to fiber direction and moisture content. Mean of three trees, with the standard deviation error bar. The same letters are not statistically different at  $P < 0.05$  by Tukey's test.

Density is one of the most important factors that affect the thermal conductivity during the transmission of heat through the wood. Previously, significant correlations were found between the TC and SG as well as with strength properties for several species (Dünder *et al.* 2012). Figures 4 and 5 present the relationship between SG and TC at air-dry and FSP conditions. Furthermore, a strong relationship was found in the longitudinal direction at the air-dried condition in the various trends (Figure 4a). However, TC had an inverse trend with SG, particularly in the 20-years-old tree at the same condition (Figure 4b), while no consistent trend was observed between the two in a tangential direction (Figure 5b) at FSP. For longitudinal heat flow, the influence of density on the thermal conductivity was higher compared to the transversal heat flow due to the high portion of the secondary layer of the total cell wall and the orientation of microfibrils (Vay *et al.* 2015).

This present finding also showed that the variability of SG could not explain all the variable thermal conductivity variables at different conditions. However, TC was technically influenced by factors, such as wood species, density, widths of growth rings, the volumetric fraction of wood rays, and the latewood content. Other factors were the location in the cross-section of sapwood, heartwood, and juvenile wood, alongside on the stem (Olek *et al.* 2003). In addition, chemical content and type of extractives materials of wood are considerable factors affecting thermal properties (Yapici *et al.* 2011). In teak wood, as the tree age increased, the content of extractives increased (Lukmandaru and Takahashi 2008). Therefore, the chemical properties might also affect the obtained pattern of TC values. Therefore, the variations of TC can be attributed to variations of different anatomical and chemical features among the tree ages, which was not measured in this experiment.

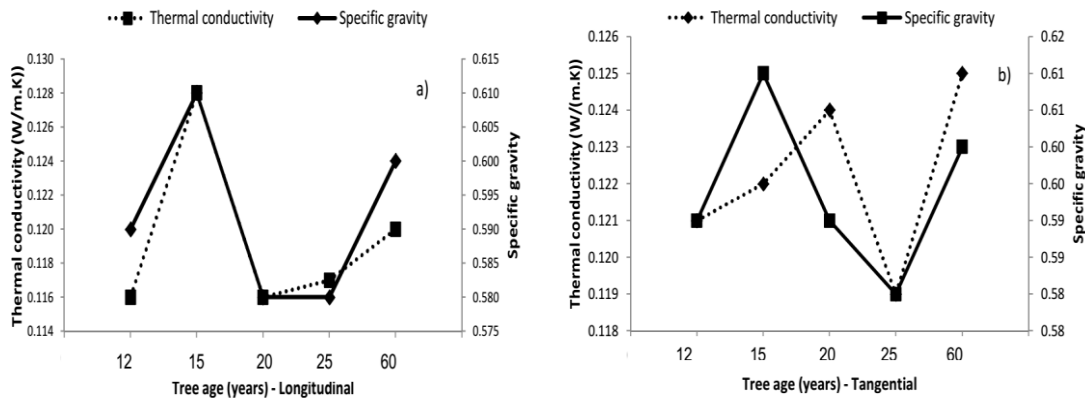


Figure 4. Thermal conductivity versus specific gravity in the longitudinal (a) and tangential (b) directions for teak wood from various tree ages at air-dry condition.

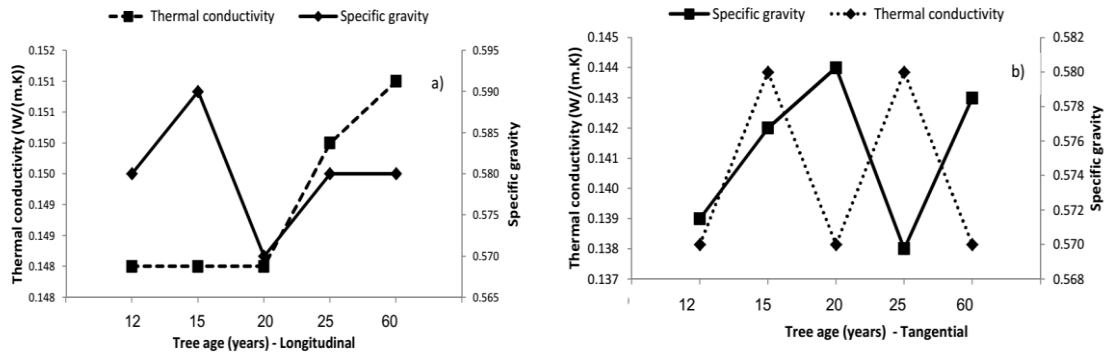


Figure 5. Thermal conductivity versus specific gravity in the longitudinal (a) and tangential (b) directions for teak wood from various tree ages at fiber saturation point.

### Conclusions

The thermal conductivity values from different tree ages were 0.116 to 0.128 W/mK at the air-dry condition and 0.338 to 0.151 W/mK at fiber saturation point. The tree ages did not have a significant effect on the conductivity, and no consistent trend was observed between specific gravity and the thermal conductivity values. Also, other indicated factors such as the orientation of microfibrils, widths of growth rings, volumetric fraction of wood rays and extractive content were likely to affect the values with increasing tree ages.

### References

- American Society for Testing and Material. 1978. ASTM C177. Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the guarded-hot-plate apparatus. USA.
- British Standard Institution. 1957. BS 373 Methods of Testing Small Clear Specimen of Timber. London.
- Dündar, T.; Ş. Kurt; N. As; B. Uysal. 2012. Nondestructive evaluation of wood strength using thermal conductivity. *Bioresources* 7(3): 3306-3316.
- Hidayati, F.; J. Sulisty; G. Lukmandaru; T. Listyanto; H. Praptoyo; R. Pujiarti. 2015. Physical and mechanical properties of 10-year old superior and conventional teak planted in Randublatung, Central Java, Indonesia. *Jurnal Ilmu Teknologi Kayu Tropis* 13(1): 11-21.
- Lukmandaru, G.; K. Takahashi. 2008. Variation in the natural termite resistance of teak (*Tectona grandis* L.f.) as a function of tree age. *Annals of Forest Science* 65 (7): 708 p1 - p8.
- Marsoem, S.N.; V.E.Prasetyo; J. Sulisty; Sudaryono; G. Lukmandaru. 2014. Studi mutu kayu jati di hutan rakyat Gunungkidul. III. Sifat fisika kayu. *Jurnal Ilmu Kehutanan* 8(2): 75-88.
- Mauranen, A.; M. Ovaska; J. Koivisto; L. I. Salminen; M. Alava. 2015. Thermal conductivity of wood: effect of fatigue treatment *Wood Science and Technology* 49: 359-370.
- Olek, W.; J. Weres; R. Guzenda. 2003. Effects of Thermal Conductivity Data on Accuracy of Modeling Heat Transfer in Wood. *Holzforchung* 57: 317-325.
- Prasojo, A.; J. Sulisty; T. Listyanto. 2012. Konduktivitas panas empat jenis kayu dalam kondisi kadar air yang berbeda. *Prosiding Seminar Nasional MAPEKI XIV*. p. 97-101. Yogyakarta
- Siau, J.F. 1995. Wood : influence of moisture on physical properties. Department of Wood Science and Forest Products Virginia Polytechnic Institute and State University.
- Sonderegger. W.; S. Hering; P. Niemz. 2011. Thermal behavior of Norway spruce and European beech in and between principal anatomical directions. *Holzforchung* 65: 369-375.
- Suleiman, B. M.; J. Larfeldt; B. Leckner; M. Gustavsson. 1999. Thermal conductivity and diffusivity of wood. *Wood Science and Technology* 33: 465-473.
- Vay, O.; K.D. Borst; C. Hansmann; A. Teischinger; U. Muller. 2015. Thermal conductivity of wood at angles to the principal anatomical directions. *Wood Science and Technology* 49: 577-589.
- Yapici, F.I.; A. Ozcifci; R. Esen; S. Kurt. 2011. The effect of grain angle and species on thermal conductivity of some selected wood species. *Bioresources* 6(3): 2757-2762.
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# Inorganic Elements of Mangium Stem (*Acacia mangium* Willd) from Different Provenances

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## Abstract

This study aimed to investigate the ash content and concentrations of inorganic elements present in the stem of *Acacia mangium*. The tree samples (24 years) were collected from five different provenances (Sidei, West of Morehead, Daintree, Ellerbeck, and El Arish). Meanwhile, the disc samples were obtained from the trunk of each tree on the lower parts. The samples were collected from four radial positions (bark, sapwood, outer heartwood, inner heartwood), and the ash and insoluble acid contents were determined. Furthermore, the concentration of 5 elements (Ca, Mg, Fe, Mn, K, and Na) was measured by Atomic Absorption Spectrophotometry (AAS). The interaction of provenance and radial position factors affected ash and potassium contents. Also, acid insoluble ash and calcium contents showed a provenance factor effect. The barks obtained from the tree samples contained the highest concentrations of ash content and most of the elements. The wood and bark of El-Arish provenance showed the lowest (0.50–0.72%) and highest levels (4.75%) of ash content respectively. Furthermore, the highest amount of insoluble acid ash (3075 ppm) and calcium (4513 ppm) content was also measured in samples of El-Arish provenance, and radial position factor was a significant source of variation for Ca, Mg, Na, and Mn concentrations. Except Mg, the inner and outer portions of the heartwood mostly showed no significant difference in unprecedented element concentrations. Ash content was positively correlated with Ca in sapwood ( $r=0.39$ ) and Mn in bark ( $r=0.54$ ). In addition, moderate correlations were observed between Mg and Ca in heartwood ( $r=0.63$ ) and bark ( $r=0.54$ ) tissues. For ash and silica content, the comparatively low concentration on samples from El-Arish provenance are good options to improve wood quality for breeding programs.

**Keywords:** trace elements, silica, tree breeding, fast-growing, wood chemistry, mangium (*Acacia mangium*).

## Introduction

Mangium (*Acacia mangium*) is one of the most important timber plant commodities in the tropics. In Indonesia, this species is planted on a large scale through the Forest Estate Timbers program due to its fast growth, good adaptability, high resistance to diseases, and multi-purpose uses. Primarily, the mangium wood is used by the pulp and paper industries, especially at a young age.

Furthermore, the rise in the consumption of wood products has tremendously increased the demand for mangium. The wood is used as an alternative for non-pulp products (furniture, veneers, sawn-timbers, and other products) by extending its rotation cycle to meet the commercial size of the tree. Meanwhile, several studies have focused on assessing the feasibility of mangium wood and bark for panel construction as well as adhesive production (Korai *et al.* 2000; Yano *et al.* 2003; Firmanti *et al.* 2007; Subyakto *et al.* 2003; Subyakto *et al.* 2005). The properties of this wood are undoubtedly affected by its inorganic or mineral components, for instance, the high silica contents cause deterioration of the cutting tools (Shmulsky and Jones 2011) and resistance to damage caused by insects as well as marine borers (De Silva and Hillis 1980). In addition, other major inorganic components cause wood adhesion (Kanazawa *et al.* 1978), blackening (Takahashi 1996; Minato and Morita 2005), and tree growth (Kuhn *et al.* 1997).

Regarding raw materials, few studies have measured the quality of mangium based on its origin or tree breeding. Furthermore, the difference in seed source and the influence of climate affect the properties of wood. Previous studies based on tree geographical or differences in provenance have compared chemical properties and fiber dimensions of mangium wood (Syafii and Siregar 2006; Raphy *et al.* 2011) the wood's physical and mechanical properties (Hadjib *et al.* 2007). In the tree breeding programs for the production of high-quality raw materials, it is important to consider the properties of wood as a basis of selection criteria. There is little information on the chemical properties of mangium wood, particularly with regard to breeding programs. In addition, the inorganic components of mangium wood is less explored. Previous reports have examined the color, anatomical, and various chemical properties of mangium wood (Lukmandaru *et al.* 2011a, 2011b; Lukmandaru 2012; Nugroho *et al.* 2012). Therefore, this research aimed to determine variations in the value of inorganic matter content based on differences in provenance and radial direction. In addition, the degree of relationship between inorganic substance parameters was also analyzed.

## Materials and Methods

### Plant Materials

The "Provenances Trial Site" for mangium is located in the Wanagama Educational Forest, Gunungkidul Regency,

Jogjakarta Province (110° 30'38"~110° 33' 03"E and 7° 53' 25"~7° 54'52" S). The seeds were collected from several different provenances and seedlings were planted in 1984. The planting was conducted in a batch of five trees with a 4 x 4 m spacing in a full block design. Five straight trees (24 years, diameter range of 13-38 cm, with a tree height of 10-25 m), grown from the five provenances of *Acacia mangium* trees (compartment no. 17) were felled. The provenances were Sidei Papua (Indonesia), West of Morehead (Papua New Guinea), Daintree, Ellerbeck Red Cardwell, and El Arish (Queensland, Australia). The sample was a 5 cm thick disk cut at the base of the tree, and the bark of the stem was separated from the wood. Furthermore, each disc was subdivided into 4 sections in the radial direction i.e bark, sapwood, as well as outer and inner heartwood. Each section from two opposing radii was converted into wood powder by drilling and was combined to form a single sample.

### Measurements of Ash, Insoluble Acid Ash, and Inorganic Elements Contents

To determine the ash content, the wood samples (2 g, oven-dry wood) were subjected to calcination in a muffle furnace around 600°C according to ASTM D-1002 (2002). The ash content is calculated on the basis of the initial weight percentage of the powder. It was then treated with 12 M HCl to dissolve the silica according to TAPPI (1992). To completely evaporate the silica in the solution, it was re-ignited in the muffle furnace at 600°C. The Shimadzu 6200 atomic absorption spectrophotometer (AAS) (flame emission) was used to determine the elements of ash content, namely calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), potassium (K), and sodium (Na).

### Statistical Analysis

An analysis of variance (two-way) was performed using SPSS version 10.0. The effect of provenance and radial direction on the measured parameters assayed as a normal data distribution was calculated in the general linear model (95 % confidence level). The Duncan multiple series tests were also applied for posthoc analysis. Also, correlation analysis (Pearson) was performed to evaluate the influence of silica and other elements on the ash content.

## Results and Discussion

### Ash and Acid Insoluble-ash Contents

The metals in the ash come in the form of various salts including oxalates, phosphates, silicates and other minerals (Sjostrom 1981). The ash content value obtained from this study (Table 1) (0.5 ~ 1.1%) was higher than the previous record (0.2%) and 0.6% for hybrid acacias (CABI 1996). Meanwhile, the high value is probably due to the older mangium trees used. The ANOVA of ash content showed that there were a significant provenance and radial position interaction (Table 2). On the contrary, the values of ash content between sapwood and heartwood were slightly different while the bark showed the highest values (Table 1). Bark samples had a greater content of ash than sapwood or heartwood, and this result was similar to the reports of Shanavas and Kumar (2003); Tsuchiya *et al.* (2010); Martinez-Pérez *et al.* (2015).

The values in the inner heartwood area reached 1.55% and were in the range of 1.0~1.5% in the samples of Daintree, Sidei, and Ellerbeck provenances (Table 1). Generally, the smallest average values were obtained in the samples of El-Arish provenance both in sapwood (0.57%) and heartwood (0.50~0.72%). However, the highest level (4.75%) was observed for bark at the same provenance. The amount of ash content that has declined from heartwood to sapwood was observed in Daintree, Sidei, and Ellerbeck provenances.

Measurement of insoluble acid ash content was used to determine the silicate and silica contents in wood (TAPPI 1992). Unlike the ash content, the insoluble acid parameter did not show interactions on both factors even though it had a significant effect. Furthermore, Daintree and bark tissue samples had the highest values among provenances and radial position respectively (Figure 1.) A high value is certainly not expected in woodworking since silica causes metal tools to become dull (Shmulsky and Jones 2011). ANOVA showed that genetic factors are affecting the value of the ash and insoluble acid contents since the trees are planted on relatively homogeneous sites. Previously, the provenance factor significantly affected color properties but not for extractive contents, pH values, and buffer capacities of mangium wood (Lukmandaru *et al.* 2011a, 2011b; Lukmandaru 2012). In addition, following the wood anatomical properties, Sidei and Daintree are more appropriate provenances among those examined for the *Acacia mangium* tree breeding programs in Indonesia (Nugroho *et al.* 2012). Due to low values of ash and silica contents, this finding suggests El-Arish provenance will improve wood quality in future breeding programs.

Table 1. Ash and inorganic element contents (% dry-wood weight) of *A. mangium* stem by provenance and radial position.

Provenances	Positions	Ash (%)	AIC (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	Fe (ppm)	Mn (ppm)
Daintree	Inner heartwood	1.26(0.18)c	940(592)	485(197)	145(66)g	178(51)	144(83)	nd	0.08(0.04)
	Outer heartwood	1.01(0.23)c	5800(275)	1296(432)	130(85)g	282(33)	168(67)	nd	0.05(0.01)
	Sapwood	0.93(0.17)d	910(178)	132(33)	252(0.4)f	287(52)	39(26)	nd	0.25(0.03)
	Bark	2.93(0.65)b	4000(868)	11746(5764)	250(0.8)f	377(62)	70(16)	196(328)	1.41(1.10)
Sidei	Inner heartwood	1.55(0.57)c	1290(815)	470(416)	208(28)fg	231(64)	152(26)	35(70)	0.11(0.05)
	Outer heartwood	1.06(0.22)cd	1860(688)	766(582)	311(235)e	246(84)	136(94)	26(42)	0.84(0.05)
	Sapwood	0.85(0.01)cd	337(175)	136(116)	252(548)f	287(52)	52(16)	501(1120)	0.62(0.88)
	Bark	2.70(0.45)b	4412(1506)	3919(4703)	210(78)fg	257(173)	61(4)	28(16)	0.99(1.06)
Ellerbeck	Inner heartwood	1.18(0.16)c	1287(979)	484(249)	164(75)fg	194(91)	159(31)	nd	0.11(0.07)
	Outer heartwood	1.10(0.15)c	2037(705)	542(387)	148(71)g	174(113)	126(50)	9(21)	0.06(0.02)
	Sapwood	0.69(0.21)d	1420(256)	1918(4093)	251(0.8)f	270(62)	35(24)	23(53)	0.23(0.07)
	Bark	2.84(0.28)b	4712(867)	4662(3269)	249(0.5)f	346(87)	38(27)	92(67)	1.06(0.53)
West of Morehead	Inner heartwood	0.68(0.08)cd	1010(483)	606(219)	40(15)h	139(69)	112(47)	2(1.87)	0.08(0.03)
	Outer heartwood	0.86(0.23)cd	1300(1064)	623(406)	49(26)h	207(60)	105(26)	nd	0.08(0.01)
	Sapwood	0.75(0.13)cd	1220(315)	1759(3739)	251(0.5)f	278(50)	43(25)	0.80(0.83)	0.22(0.07)
	Bark	2.52(0.79)b	4025(567)	8132(6218)	248(1)f	329(48)	49(6)	54(37)	1.17(0.03)
El Arish	Inner heartwood	0.50(0.49)d	1366(802)	344(291)	240(113)f	184(148)	137(74)	9(12)	0.08(0.02)
	Outer heartwood	0.72(0.35)c	1375(742)	547(470)	186(134)g	110(94)	101(81)	10(24)	0.22(0.12)
	Sapwood	0.57(0.15)d	1600(141)	5852(6170)	240(0.5)f	266(43)	65(19)	36(29)	1.27(1.19)
	Bark	4.75(0.23)a	5960(1046)	11309(7772)	248(1)f	373(63)	45(4)	384(476)	0.52(0.84)

Remarks: AIA = acid insoluble ash content; Ca = calcium; K = potassium; Mg = magnesium; Na = sodium; Fe = iron; Mn = manganese. Mean of 5 trees (24 years), with the standard deviation in parentheses. The same letters on the same column are not significantly different at  $p < 5\%$  by Duncan's test.

Table 2. Provenance and radial direction analysis of variance in ash and inorganic element contents

Source of variation	df	Mean square						
		Ash	AIA	Calcium	Potassium	Magnesium	Sodium	Manganese
Provenance (A)	4	0.4**	2397492**	30406691*	26745**	7052	1721	0.410
Radial position (B)	3	27.9**	62446559**	275166497**	55817**	109977**	45892**	3.680**
A x B	12	1.58**	901570	19560868	14745**	10028	1272	0.266
Error	74	0.1	533908	11449470	5756	6647	2521	0.268

Remark: AIA = acid insoluble ash content, \*\* Significant at the 1% level; \* significant at the 5% level

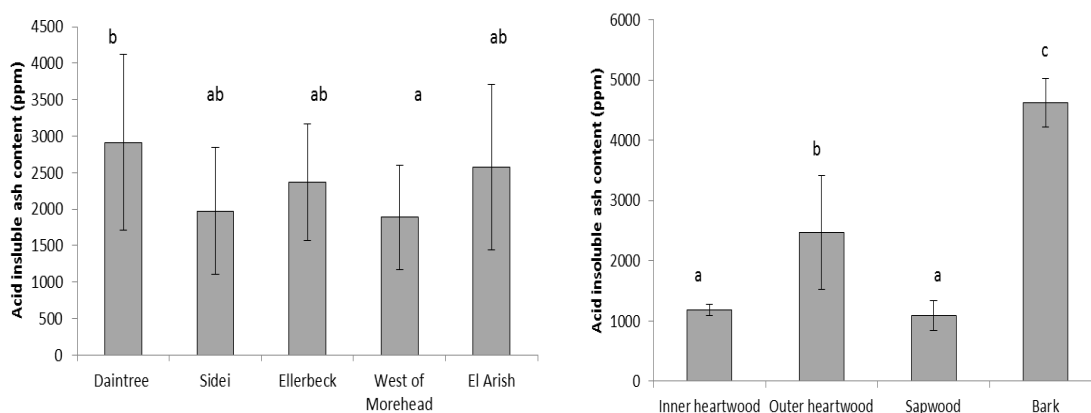


Figure 1. Acid insoluble ash content (ppm) of *Acacia mangium* stem by provenance and radial position. Mean of 5 trees (24 years), with the standard deviation in the error bar. The same letters are not significantly different at  $p < 5\%$  by Duncan's test.

### Inorganic Elements

The high content inorganic elements observed were Ca, K, and Mg, commonly found in wood (Fengel and Wegener 1984). Generally, Ca was the most abundant element followed by K or Mg while the least was Mn (Table

1), and Fe was not detected in several parts. High Ca levels were caused by the presence of Ca-oxalate crystals in sieve cells and longitudinal parenchyma (Fengel and Wegener 1984). The obtained values for the K concentration was lower but Ca, Mg, and Fe were in the range compared to those of teak wood (Lukmandaru *et al.* 2009).

The ANOVA of K content showed significant provenance and radial position interaction, indicating that their effects are varied (Table 2). Furthermore, the sapwood and bark regions exhibited a higher K concentration than the heartwood for samples from Daintree, Ellerbeck, and west of Morehead (Table 1). The maximum levels are obtained in the outer sapwood of Sidei provenance (311 ppm), while the lowest was found in the inner heartwood of West of Morehead provenance (40 ppm). Moreover, the ANOVA showed that a significant effect of the provenance factor was obtained in Ca content. According to Duncan's test, Ca contents in the El-Arish samples were significantly higher compared to those of Sidei provenance (Figure 2). Also, significant differences between the Ca content and the silica content were obtained in teakwood (Kjaer *et al.* 1999). Theoretically, the functions of K in plants is mainly for electrochemical role whereas Ca has a mechanical function in the cell wall (Okada *et al.* 1987). However, the exact economic significance of the Ca and K content is unknown. In the future, the wide range measured in this study should be considered in the breeding program. The radial positioning factor significantly influenced the content of Ca, Mg, Na, and Mn (Table 2), while Fe showed no normal distribution. Okada *et al.* (1993a, b) observed three patterns of radial nutrient distribution on wood. Type 1 showed element concentrations increased outward from the pith across the heartwood-sapwood boundary, while the pattern was reversed in Type 2. Furthermore, there was a peak in element concentration at the heartwood sapwood boundary in Type 3. The pattern Mg content was Type 1, Na, and K were Type 2 (Fig. 3), while Fe (Sidei provenance only) and Mn were Type 3 (Fig. 4). The highest levels of K, Mn, and Na in cortical tissue were observed with Duncan's test.

Systematic differences among the different radial directions were not observed for Ca content because of the less mobile element. Mg and Ca are adsorbed on negatively charged exchange sites or incorporated in the form of pectates or the lignin matrix (Meerts 2002). Na and K, which belong to the alkali metal in the periodic table, showed a similar radial distribution pattern, and a slightly different pattern was observed between Ca and Mg (alkaline earth metal). The radial distribution pattern of Fe, Ca, and Mn levels are in accordance with that of sugi wood but not for Na content (Okada *et al.* 1987). In *Robinia pseudoacacia* wood, the content of Ca, Mg, and Na increased from the heartwood to the sapwood (Passialis *et al.* 2008).

Generally, no significant differences were observed between the inner and outer heartwood parts. This is probably since there is no living tissue in the heartwood and no physiological reaction has occurred (Okada *et al.* 1987). Furthermore, the difference concentration in several inorganic elements is thought to be related to the heartwood formation such as phenolics formation and pH value changes. The high level of Na in the heartwood (Figure 3) may be related due to counter ions for phenolics (weak acid). In addition, high levels of K, Mg, and Mn in the sapwood are assumed to be related to their role as co-factors in enzymatic reactions in the cytoplasm (Kramer and Kozlowsky 1960; Okada *et al.* 1987). The concentrations of Mg increased significantly from inner heartwood towards bark which is probably due to the decrease in wood cation binding capacity due to the ageing of cells and a decrease of pectic material (Meerts 2002).

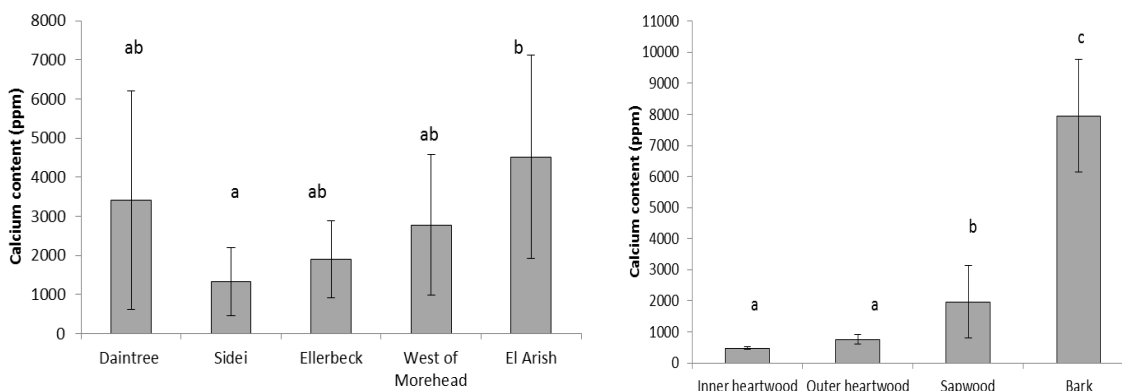


Figure 2. Calcium content (ppm) of *Acacia mangium* stem by provenance and radial position. Mean of 5 trees (24 years), with the standard deviation in the error bar. The same letters are not significantly different at  $p < 5\%$  by Duncan's test.

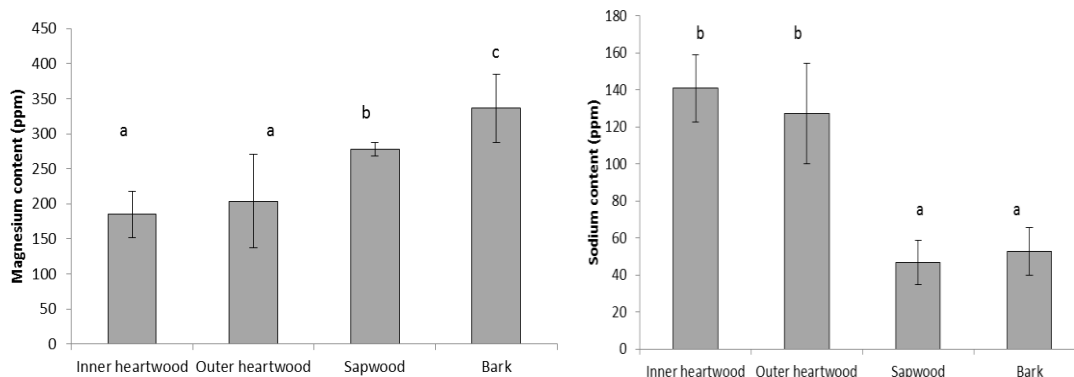


Figure 3. Magnesium and sodium content (ppm) of *Acacia mangium* stem by radial position. Mean of 5 trees (24 years), with the standard deviation in the error bar. The same letters are not significantly different at  $p < 5\%$  by Duncan's test.

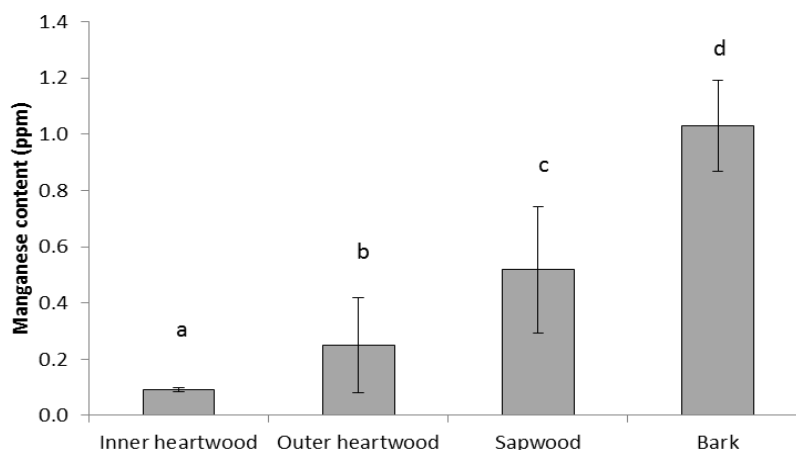


Figure 4. Manganese content (%) of *Acacia mangium* stem by radial position. Mean of 5 trees (24 years), with the standard deviation in the error bar. The same letters are not significantly different at  $p < 5\%$  by Duncan's test.

### Relationship between Extractive Compounds and Total Extractive Contents

The correlation between the parameters of each stem part is presented in Table 3-5. In the heartwood part, the strongest relationship was observed between Ca and Mg content ( $r=0.63^{**}$ ) among inorganic elements, and ash content correlated moderately with K content ( $r=0.30^*$ ). A negative moderate relationship was measured between ash and insoluble acid content ( $r=-0.41^*$ ) for the sapwood region. Only a few significant relationships were found for the inorganic element and silica in the same region, i.e. between insoluble acid ash and K content ( $r=-0.44^*$ ). In the bark part, moderate positive correlations were obtained between the ash and Mn contents ( $r=0.54^*$ ). Of the inorganic elements-silica, the strongest positive correlation was measured between insoluble acid ash and Fe contents ( $r=0.61^{**}$ ).

There was no common pattern in the correlation between ash and insoluble acid contents for all stem parts. Therefore, the variation of silica is independent of ash

content, and this is contradictory to the results presented by Abasolo *et al.* (2001), where a strong correlation between ash and silica contents in several rattan species was obtained ( $r=0.96$ ). Insoluble acid ash level moderately correlated with Fe level in sapwood and bark tissues but negatively correlated with K in the tissue. Silica affects the cuticular transpiration and  $\text{CO}_2$  uptake of plants (Abasolo *et al.* 2001), while Fe is present in biologically more active parts of the tree. This correlation is interpreted to mean that Fe and silica may be more active due to the high number of living cells in sapwood and inner bark parts.

It is also noticed that positive moderate correlations were observed between Mg and Ca contents in heartwood ( $r=0.63^{**}$ ) and bark ( $r=0.54^{**}$ ) regions. Mg and Ca belong to the alkaline earth metal group (IIA). This correlation may be linked to the role of the two elements in cell and membrane production (Kramer and Kozlowsky 1960; Okada *et al.* 1987; Cutter and Guyette 1993). Furthermore, it should be noted that the values in the bark part are influenced by atmospheric deposition. However, it is not known why such a correlation was not observed in the sapwood region.

Table 3. Pearson's correlation among ash content and inorganic element contents in *Acacia mangium* sapwood

Content	Acid insoluble ash	Iron	Potassium	Calcium	Magnesium	Natrium	Manganese
Ash	-0.41*	0.09	0.39*	-0.32	0.01	-0.38	-0.36
Acid insoluble ash		0.42*	-0.44*	0.40	-0.25	-0.07	0.09
Iron			0.24	-0.04	-0.21	-0.01	-0.07
Potassium				-0.23	0.31	-0.26	-0.26
Calcium					0.32	0.32	0.00
Magnesium						0.14	-0.34
Sodium							0.34

Table 4. Pearson's correlation among ash content and inorganic element contents in *Acacia mangium* heartwood

Content	Acid insoluble ash	Iron	Potassium	Calcium	Magnesium	Natrium	Manganese
Ash	0.28	0.17	0.30*	0.00	0.26	0.19	0.11
Acid insoluble ash		0.08	0.14	-0.24	-0.19	-0.16	0.10
Iron			0.44**	-0.19	-0.16	0.06	0.17
Potassium				0.16	0.26	0.29	0.09
Calcium					0.63**	0.35*	-0.29*
Magnesium						0.42**	-0.35*
Sodium							-0.10

Table 5. Pearson's correlation among ash content and inorganic element contents in *Acacia mangium* bark

Content	Acid insoluble ash	Iron	Potassium	Calcium	Magnesium	Natrium	Manganese
Ash	0.44*	0.34	0.09	0.30	0.28	-0.15	0.54*
Acid insoluble ash		0.61**	0.11	-0.10	0.14	0.24	-0.22
Iron			0.11	-0.22	0.07	0.20	-0.27
Potassium				0.29	0.41	-0.12	0.21
Calcium					0.54**	0.22	-0.22
Magnesium						0.02	0.20
Sodium							0.10

Remark: \*\* Significant at the 1% level; \* significant at the 5% level

### Conclusions

The ash, silica, and inorganic element contents of mangium wood were measured to evaluate the effect of provenance and radial position factors. The ash content ranged 0.5~1.1%, and 2.5~4.7% for wood and bark respectively. A significant interaction was observed for ash content where the lowest level was found in the wood of El-Arish provenance. Furthermore, the amounts of insoluble acid ash content were 300-5800 and 4000-6000 ppm for wood and bark respectively, with provenance and radial position significant influencing factors. The highest amount was observed in El-Arish samples. The results of inorganic element measurement were Fe 0~500 ppm (wood) and 28~384 ppm (bark); K 40~311 ppm (wood) and 210~250 ppm (bark); Ca 130~5850 ppm (wood) and 3919~11746 ppm (bark); Mg 0~500 ppm (wood) and 28~384 ppm (bark); Na 35~65-168 ppm (wood) and 38~70 ppm (bark); Mn 0.05~1.27 ppm (wood) and 0.52~1.41 ppm (bark). The significant interaction between provenance and radial position factors was measured in K content. Ash content was negatively moderately correlated with insoluble acid on a moderate level in the sapwood. On a positive level with insoluble acid ash content, the bark was moderately

correlated. Meanwhile, moderate correlations were calculated between Mg and Ca contents in heartwood and bark regions. In the sapwood region, the highest correlation degree was between insoluble acid ash and K contents. The comparatively low values of ash and acid soluble ash contents of El-Arish provenance make it is more suitable for improving wood quality by tree breeding.

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### References

- Abasolo, W.P.; M. Yoshida; H. Yamamoto; T. Okuyama. 2001. Silica in Several Rattan Species. *Holzforchung* 55: 595-600.
- ASTM International. 2002. D1102 Test Methods for Ash in Wood. *Annual Book of ASTM Standards 2002, Section 4: Construction*. West Conshohocken, PA. p. 175.
- CABI. 1996. PROSEA Timber Trees. CABI Publishing.

- Cutter, B.E.; R.P. Guyette. 1993. Anatomical, Chemical and Ecological Factors Affecting Tree Species Choice in Dendrochemistry Studies. *Journal of Environmental Quality* 22: 611-619.
- De Silva, D.; W.E. Hillis. 1980. The Contribution of Silica to the Resistance of Wood to Marine Borers [*Syncarpia glomulifera*, turpentine, *Bankia australis*]. *Holzforschung* 34(3): 95-97.
- Fengel, D.; G. Wegener. 1984: Wood chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin.
- Firmanti, A.; K. Komatsu; S. Kawai. 2007. Effective Utilization of Fast-growing *Acacia mangium* Willd Timber as a Structural Material. *Jurnal Ilmu dan Teknologi Kayu Tropis* 5: 29-37.
- Hadjib, N.; Y.S. Hadi; D. Setyaningsih. 2007. Sifat Fisis dan Mekanis Sepuluh Provenans Kayu Mangium (*Acacia mangium* Willd.) dari Parung Panjang, Jawa Barat. *Jurnal Ilmu dan Teknologi Kayu Tropis* 5: 7-11.
- Kanazawa, H.; T. Nakagami; K. Nobashi; T. Yokota. 1978. Studies on the Gluing of the Wood. Articles. XI. The Effects of Teak Wood Extractives on the Curing Reaction and the Hydrolysis Rate of the Urea Resin. *Mokuzai Gakkaishi* 24: 55-59.
- Kramer, P.J.; T.T. Kozlowsky, 1960. *Physiology of Trees*. McGraw-Hill Book Company, Inc. New York Toronto London.
- Kjær, E.D.; S. Kajornsrichon; E.B. Lauridsen. 1999. Heartwood, Calcium and Silica Content in Five Provenances of Teak (*Tectona grandis* L.). *Silvae Genetica* 48: 1-3.
- Korai, H.; P. Nigel; T. Liem. 2000. Properties of *Acacia mangium* Particle Board II. Proceedings the 4th Pacific Rim Bio-based Composite Symposium. Bogor. pp. 189-194.
- Kuhn, A.J.; W.H. Schröder, J. Bauch. 1997. On the Distribution and Transport of Mineral Elements in Xylem, Cambium, and Phloem of Spruce (*Picea abies* [L.] Karst.). *Holzforschung* 51(6): 487-496.
- Lukmandaru, G.; T. Ashitani, K. Takahashi 2009. Color and Chemical Characterization of Partially Black-Streaked Heartwood in Teak (*Tectona grandis* L.f.). *Journal of Forestry Research* 20: 377-380.
- Lukmandaru, G.; L.S. Gustomo; I.G.N.D. Sayudha, V.E. Prasetyo. 2011a. Studi Keasaman dan Kapasitas Penyangga pada Kayu Mangium. *Prosiding Seminar Nasional MAPEKI XIII*, Bali, p. 388-396.
- Lukmandaru, G., I.G.N.D. Sayudha; L.S. Gustomo; V.E. Prasetyo. 2011b. Pengukuran Kadar Ekstraktif dan Sifat Warna Kayu *Acacia mangium* dari Lima Provenans. *Prosiding Seminar Nasional MAPEKI XIII*, Bali, p. 372-380.
- Lukmandaru, G. 2012. Komposisi Ekstraktif pada Kayu Mangium (*Acacia mangium*). *Jurnal Ilmu dan Teknologi Kayu Tropis* 10(2): 150-158.
- Minato, K.; T. Morita. 2005. Blackening of Diospyros Genus Xylem in Connection with Boron Content. *Journal Wood Science* 5: 659-662.
- Martínez-Pérez, R.; F.E. Pedraza-Bucio; R. Orihuela-Equihua; P. López-Albarrán; J.G. Rutiaga-Quiñones. 2015. Calorific Value and Inorganic Material of Ten Mexican Wood Species. *Wood Research* 60 (2): 281-292.
- Meerts, P. 2002. Mineral Nutrient Concentrations in Sapwood and Heartwood: A Literature Review. *Annals of Forest Science* 59: 713-722.
- Nugroho, D.N.; S.N. Marsoem; K. Yasue; T. Fujiwara; T. Nakajima; M. Hayakawa; S. Nakaba; Y. Yamagishi; H.O. Jin; T. Kubo; R. Funada. 2012. Radial Variations in the Anatomical Characteristics and Density of the Wood of *Acacia mangium* of Five Different Provenances in Indonesia. *Journal of Wood Science* 58: 185-194.
- Okada, N.; Y. Katayama; T. Nobuchi; Y. Ishimaru; H. Yamashita; A. Aoki. 1987. Trace Elements in the Stems of Trees I. Radial Distributions in Sugi (*Cryptomeria japonica* D. Don). *Mokuzai Gakkaishi* 33(12): 913-920.
- Okada, N.; Y. Katayama; T. Nobuchi; Y. Ishimaru; A. Aoki. 1993a. Trace Elements in the Stems of Trees V. Comparisons of Radial Distributions among Softwood Stems. *Mokuzai Gakkaishi* 39(10): 1111-1118.
- Okada, N.; Y. Katayama; T. Nobuchi; Y. Ishimaru; A. Aoki. 1993b. Trace Elements in the Stems of Trees VI. Comparisons of Radial Distributions among Hardwood Stems. *Mokuzai Gakkaishi* 39(10): 1119-1127.
- Passialis, C.; E. Voulgaridis; S. Adamopoulos; M. Matsouka. 2008. Extractives, Acidity, Buffering Capacity, Ash and Inorganic Elements of Black Locust Wood and Bark of Different Clones and Origin. *Holz als Roh- und Werkstoff* 66: 395-400.
- Raphy, K.M.M.; E.V. Anoop; P. Aruna; V.V. Sheena; V. Ajayghosh. 2011. Provenance Variation in Wood Chemical Properties of *Acacia mangium* Willd. and *Acacia auriculiformis* Cunn., Grown in a Wet Humid Site in Thrissur District of Kerala, South India. *Journal of Indian Academy of Wood Science* 8(2): 120-123.
- Shanavas, A.; B.M. Kumar. 2003. Fuelwood Characteristics of Tree Species in Homegardens of Kerala, India. *Agroforestry Systems* 58(1): 11-24.
- Sjostrom, E. 1981. *Wood Chemistry: Fundamentals and Applications*. Academic Press, New York, p. 102.
- Shmulsky, R.; P.D. Jones. 2011. *Forest Products and Wood Science: An Introduction, Sixth Edition*. John Wiley & Sons, Inc. p. 45.
- Subyakto, L.; Suryanegara; Sudijono; M. Gopar; B. Prasetya, B. Subiyanto. 2003. Development of Binderless Particleboard from *Acacia mangium* Bark. *International Symposium on Sustainable Utilization of Acacia mangium*. JSPS-LIPI Core University Program. p. 119-123.
- Subyakto, L.; Suryanegara; M. Gopar; K.W. Prasetyo. 2005. Utilization of *Acacia mangium* Willd) Bark for Particleboard with Low Phenol Formaldehyde Content. *Jurnal Ilmu dan Teknologi Kayu Tropis* 3: 20-23.

- Syafii, W.; I.Z. Siregar. 2006. Sifat Kimia dan Dimensi Serat Mangium (*Acacia mangium* Willd.) dari Tiga Provenans. *Jurnal Ilmu dan Teknologi Kayu Tropis* 4: 28-32.
- Takahashi, K. 1996. Relationships between the Blackening Phenomenon and Norlignans of Sugi (*Cryptomeria japonica* D. Don.) Heartwood I. A Case of Partially Black Heartwood. *Mokuzai Gakkaishi* 42: 998-1005.
- Tsuchiya, Y.; H. Shimogaki; H. Abe; A. Kagawa. 2010. Inorganic Elements in Typical Japanese Trees for Woody Biomass Fuel. *Journal of Wood Science* 56: 53-63.
- TAPPI. 1992. Acid Insoluble Ash Content. TAPPI Test Methods 1992-1993. TAPPI Press, Atlanta, Georgia.
- Yano, H.; S. Ogawa; C.M.E. Susanti. 2003. The Direct Conversion of *Acacia mangium* Bark into Waterproof Wood Adhesives. *International Symposium on Sustainable Utilization of Acacia mangium*. JSPS-LIPI Core University Program. p. 96-99.

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# Antifungal and Antioxidant Activities of Lipophilic Compounds from *Swietenia mahagoni* (L.) Jacq. Leaves

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## Abstract

The investigation on the *n*-hexane lipophilic extractives of *Swietenia mahagoni*, alongside the antifungal and antioxidant properties was conducted. The leaf sample was collected from 2- and 3-years-old trees in *Perhutani* enterprise of Temanggung, Central Java, Indonesia. In addition, the antifungal activity was tested using the white-rot of *Phanerochaete chrysosporium*, while the antioxidant property involved the DPPH (1,1-diphenyl-2-picrylhydrazyl) method. The results show antifungal of 28.6% and 37.5% growth inhibition in 2- and 3 -years-old leaf, respectively, while 21.7% and 25.4% antioxidant activity were also recorded. Furthermore, the GC-MS results showed the domination of *S. mahagoni* leaf by fatty acids and hydro-carbons, while the terpenoids and steroids were in minor quantities. These components possibly exhibit growth inhibitory and antioxidant effects against *P. chrysosporium* and DPPH radicals, respectively.

**Keywords:** *S. mahagoni*, leaves, lipophilics, antifungal, antioxidant, hydrocarbons

## Introduction

*Swietenia mahagoni* (L.) Jacq. is a member of the Meliaceae family, which is native to Jamaica, Hispaniola, The Bahamas, Southern Florida and Cuba. This species has been introduced and utilized in plantations located in South East Asian countries, including Indonesia (Panda *et al.* 2010; Rahman *et al.* 2014), where it was chosen as a species for afforestation, through *Perhutani* (state own enterprise). Furthermore, *S. mahagoni* has good characteristics as a fancy wood with beautiful dark red color and the timber has been utilized for home building and furnitures.

Various parts of the *S. mahagoni* have been utilized traditionally in the remediation of various disease, including diabetes, diarrhea, malaria, and hypertension. Previous researchers have also identified a tetracyclic triterpene namely cyclomahogenol (Chakraborty *et al.* 1971), alongside two limonoids, termed swiemahogins A and B (Chen *et al.*; Naveen *et al.* 2014), as well as fatty acids and hydrocarbons in the plant leaves (Mousa *et al.* 2014)

Essential fatty acids are one of the dominant lipophilic components of the leaves, possibly extracted using nonpolar solvents, e.g., *n*-hexane. Moreover, the interaction between antifungal compounds and fungi are assumed to occur following a either direct or indirect connection between the fatty acid component and cell membrane (Avis and Bélanger 2001). Conversely, some edible plants, including *Urtica dioica*, *Cardamine hirsuta*, *Cichorium intybus* and others containing carotenoids and tocopherols were reported as good sources of lipophilic antioxidant (Burton and Traber 1990; Lagouri 2015).

*S. mahagoni* is one of the potent sources of allelopathy, which inhibits the growth and development after a plant to plant interaction (Gniazdowska and Bogatek 2005). These bioactive compounds also tend to play roles

against other organisms, e.g., fungi, resulting from the ability to neutralize free radicals as an antioxidant agent. However, there are limited reports focused on evaluating the antioxidant and antifungal activity of lipophilic components of *S. mahagoni* leaf. This research is, therefore, aimed at investigating the *n*-hexane extracts of *S. mahagoni* leaf, and also the possible investigate the antifungal and antioxidant activities.

## Materials and Methods

### Sample Collection and Extraction

The young leaf of *S. mahagoni* selected from the 2 and 3 years-old trees were collected from *Perhutani* Enterprise in Temanggung, Central Java, Indonesia. A total of three individual trees were selected for each age, and the green leaf were cut into small pieces of 15 g weight. These were successively macerated in *n*-hexane for three days at room temperature, followed by the evaporation of solutions to dryness, using a rotary evaporator machine, and the output was then weighed. The yield of extractives was calculated on the basis of fresh leaf sample.

### Antifungal Activity

The antifungal test required the use of *Phanerochaete chrysosporium* (white-rot), and prior to assay, the fungi strain was incubated on a PDA medium petri dish at 25±1 °C in order to ensure that most of the plate surfaces are covered. Therefore, the growth inhibitory capacity of *S. mahagoni n*-hexane extracts against *P. chrysosporium* was conducted according to Lukmandaru (2013), where the 1000 ppm concentration sample was prepared, and 300 µl of extract was spread on the surface of 20 ml PDA medium in a Petri-dish (diameter of 9 cm) with final concentration of

12.3 mg/cm<sup>2</sup>. Therefore, the solution was dried at a room temperature in 1 h prior to inoculation, and a blank experiment was performed on the sample without extract. These tests were conducted in three replications, while the steroid,  $\beta$ -sitosterol, isolated from *P. merkusii* bark was adopted as the positive control. The growth inhibition capacity was evaluated using equation 1 as follows:

$$\text{Growth inhibition (\%)} = \frac{A_0 - A_1}{A_0} \times 100 \quad (1)$$

Where  $A = \pi \times (d/2)^2$ ,  $d$  = diameter of sample growth,  $A_0$  is growth inhibition of blank and  $A_1$  is growth inhibition of sample.

### Determination of DPPH Radicals Scavenging Activity or Antioxidant Activity

The antioxidant activity was evaluated by reacting 0.1 ml extract in dimethyl sulfoxide (DMSO) with a concentration of 1000 ppm and 3 ml of DPPH (1,1-diphenyl-2-picrylhydrazyl) 0.004% in methanol. The reaction product stood for 30 minutes at ambient temperature, and the sample absorbance was read at 517 nm, using the UV-Vis spectrophotometer (model SP-3000 Nano, Optima, Tokyo, Japan). Furthermore, the antioxidant activity was calculated using equation 2:

$$\text{DPPH scavenged (\%)} = \frac{A_0 - A_1}{A_0} \times 100 \quad (2)$$

where  $A_0$  and  $A_1$  represent the absorbance of blank and sample, respectively (Baba and Malik 2015).

### GC-MS Analysis

The GC-mass spectrometry (GC-MS) data were obtained using a GCMS-QP 2010 (Shimadzu, Japan), after 1  $\mu$ l of sample (1 mg/ml) was directly injected to the machine, under the following condition: Rtx-5MS capillary column (30 m x 0.25 mm I.D. and 0.25  $\mu$ m; GL Sciences, Tokyo, Japan); temperature of column ranging from 100 °C (1 min) to 320 °C at 5 °C/min; injection at 250 °C; and detection at 320 °C; acquisition mass range of 50-700 amu

(?), using helium as the carrier gas. The sample mass spectrum was compared to data collected at the NIST library, while the peak relative method was applied for the quantification of individual substances.

### Statistical Analysis

The results from two different ages (2 and 3 years-old) were analysed with the independent t-test (95% confidence level), using SPSS 25 (IBM, USA).

### Chemicals

Gallic acid (97.5%), quercetin ( $\geq 95\%$ ), 1,1-diphenyl-2-picrylhydrazyl, and potato dextrose agar (PDA) were purchased from Sigma Aldrich (Germany).

## Results and Discussion

### Extractives Content

The *n*-hexane leaf extraction of *S. mahagoni* yielded 0.9% and 0.7% for the 2- and 3-years-old leaf, respectively, based on the fresh sample. Therefore, Independent t-test was performed to ascertain the effects of aging on the yields, indicating the amount of *n*-hexane extract affected by age of trees ( $p < 0.02$ ) (Table 1).

In comparison, the yield was lower using *n*-hexane than petroleum ether for both *S. mahagoni* and *S. macrophylla* leaves from Egypt, with values ranging from 1.9 to 2.1 % (Mousa *et al.* 2014). The polarity index between *n*-hexane and petroleum ether are about similar (0.1). This indicates that the lower result of yield extractives than study reported by Mousa *et al.* (2014) is might due to different cite of sample rather than the use of the solvent. Further, the yield and composition of extractives tend to also vary with respect to age (Pereira 1988) and species (Wilkes 1984). However, the experiment of this study has a comparable similar range of value with others, including the four species of *Terminalia* leaf at 0.74 to 1.89 % (Rakholiya *et al.* 2015).

Table 1. Independent t-test of each parameter

Parameter	t-test for equality of means		
	T	Sig. (2-tailed)	df
<i>n</i> -Hexane extract	0.45	0.02*	4
Fungal growth inhibition	-0.68	0.54ns	4
Radical scavenging activity	-1.28	0.27ns	4
Mono- and sesquiterpenes	1.73	0.16ns	4
Fatty acids and hydrocarbons	-3.12	0.04*	4
Steroid and triterpenoid	0.31	0.77ns	4

ns=not significant, \*=significant at 0.05 level

## GC-MS Analysis

The GC-MS analysis detected the following lipophilic constituents: monoterpenes-sesquiterpenes, fatty acids-hydrocarbons, and steroids-triterpenoids, as shown in Table 2 and Figure 1. Based on the ages, significant differences were only recognized in the concentration of fatty acids and hydrocarbons group ( $p = 0.04$ ), while mono- and sesquiterpenes, as well as steroids and triterpenoids group were not considerably affected by age ( $p > 0.05$ ) (Table 1). In addition, the 2-years-old samples possessed relatively higher concentrations of mono-sesquiterpenes, including

cyclohexanebutanol, perhydroazulene, and blumenol C, and a similar trend was observed with the steroids and triterpenoids. However, the reverse pattern was observed in terms of fatty acid and hydrocarbon content, while octacosane was the most dominant hydrocarbon in all samples, which was followed by tetratetracontane, hentriacontane, and heneicosane. A previous study by Mousa *et al.* (2014) reported on the presence of eicosane, heneicosane, and octacosane in the leaf of *S. mahagoni*, *S. macrophylla*, and *Trichilia connaroides* (Senthilkumar *et al.* 2012; Hossain *et al.* 2013).

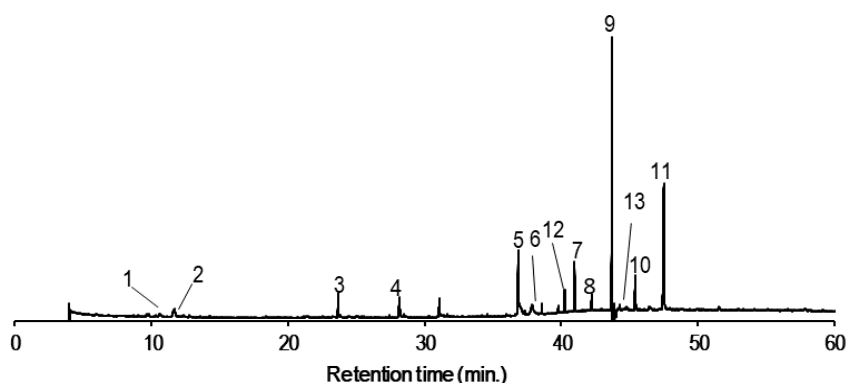


Figure 1. GC-MS chromatogram of *n*-hexane extracts of *S. mahagoni* leaf; 1. Cyclohexanebutanol, 2. Perhydroazulene, 3. Blumenol C, 4. Pentadecanoic acid, 5. Eicosane, 6. 2-methylhexacosane, 7. Heneicosane, 8. 2-methyloctacosane, 9. Octacosane, 10. Hentriacontane, 11. Tetracontane, 12. Squalene, 13. Stigmast-5-en-3-ol, oleate.

With regard to the steroids and triterpenoids present, a comparably higher amount of squalene was detected in the 2-years-old samples. It is assumed that the amount of squalene was changed along with the growth of the age depending on variety either increased or decreased. Squalene is considered as a precursor of sterols and triterpenoids. Hence, the lower amount of squalene signified that squalene has been converted to other phytomolecules.

This indicates that squalene at the age of 3 years has been converted to other components so that its content decreased. Related to the presence of squalene in the plants, previous studies have also identified squalene in the leaves of *Dysoxylum mollissimum*, *Trichilia clausenii* and *Dysoxylum gaudichaudianum*, included in the Meliaceae family (Ragasa *et al.* 2013; Ragasa *et al.* 2014; Pupo *et al.* 1996).

Table 2. *n*-hexane extract compounds from *S. mahagoni* leaf

No	Ret. time [minute]	Constituents	Concentration [%]		Similarity index [%]
			2 yr	3 yr	
		<b>Mono- and sesquiterpene</b>	<b>3.36</b>	<b>0.39</b>	
1	11.58	Cyclohexanebutanol	0.56	0.24	72
2	11.70	Perhydroazulene	1.32	0.16	77
3	23.66	Blumenol C	1.49	tr	92
		<b>fatty acids and hydrocarbons</b>	<b>87.12</b>	<b>94.45</b>	
4	28.14	Pentadecanoic acid	0.87	3.19	73
5	38.58	Eicosane	0.65	0.22	91
6	39.79	2-methylhexacosane	0.55	0.45	88
7	40.97	Heneicosane	3.77	3.99	95
8	42.23	2-methyloctacosane	1.95	0.69	94
9	43.74	Octacosane	38.63	53.19	95
10	45.41	Hentriacontane	7.97	3.54	96
11	47.51	Tetracontane	32.72	29.17	97
		<b>Steroid and triterpenoid</b>	<b>3.81</b>	<b>3.43</b>	
12	40.25	Squalene	2.71	2.99	97
13	44.27	Stigmast-5-en-3-ol, oleate	1.10	0.44	54

## Antifungal Activity

Figure 2 shows the result of antifungal evaluation, where the leaf of 2 years-old *S. mahagoni* had lower activity than the 3 years leaf. However, no significant differences were observed using t-test ( $p > 0.05$ ) for that fungal measurement between 2 and 3 years leaves, as shown in Table 1. Compared to positive control of  $\beta$ -sitosterol, the both leaves outcomes were in the lower inhibition level. The growth inhibition tendencies were 28.6% and 37.5%, respectively, which was half the activity of the positive control (54.51%).

Older leaves showed higher antifungal activity compared to younger leaves. Similar result was reported from previous research on *Melaleuca leucadendron* leaf oil, where in some concentration oils from 5 years old trees showed lower antifungal activity against *Fusarium oxysporum*, *Thanatephorus cucumeris*, and *Rhizopus oryzae* compared to oils from 10 years old trees (Pujiarti *et al.* 2012). This result might be caused by the higher concentration of certain compounds from the older tree. The appearance of antifungal effect of *S. mahagoni* leaf extracts and  $\beta$ -sitosterol are shown in Figure 3.

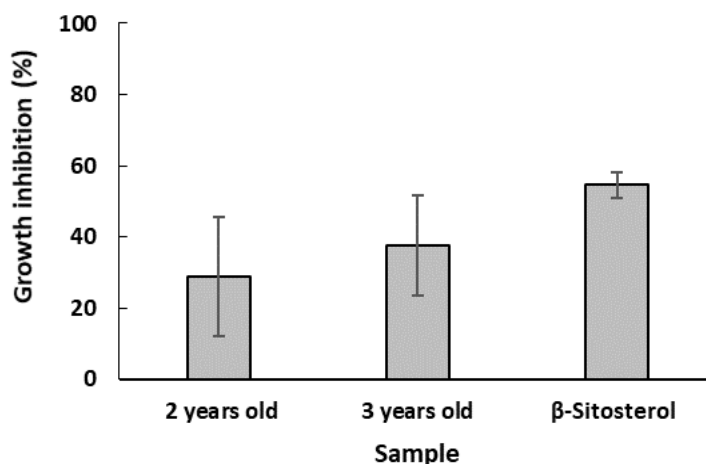


Figure 2. Antifungal activity of *n*-hexane extracts of *S. mahagoni*.

The GC-MS results showed the relatively higher amount of fatty acids and hydrocarbons in both samples, compared to other groups. This phenomenon possibly influences the growth inhibition characteristics of *S. mahagoni n*-hexane extracts against *P. chrysosporium*. In addition, the antifungal performance was attributed to the presence of four hydrocarbon compounds, encompassing

octacosane, tetracontane, hentriacontane, and heneicosane. Those constituents were predicted to act as antifungal agents in *Cryptococcus neoformans* (Passos *et al.* 2002), while a prior study has shown the presence of comparably higher hydrocarbon amounts in seeds and leaves of *Caryocar brasiliensis*.

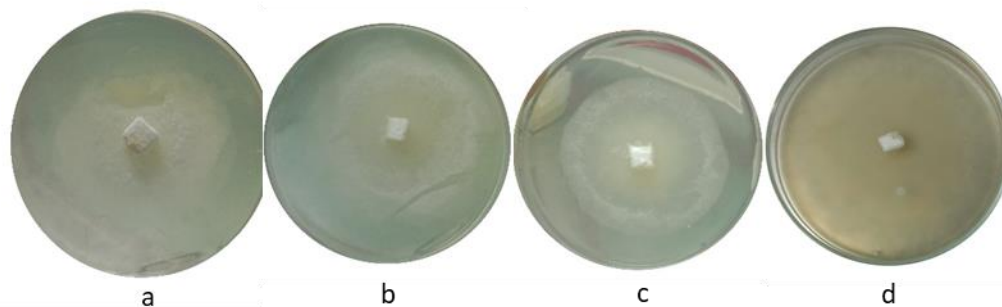


Figure 3. Appearance of growth rate of *P. chrysosporium* against *n*-hexane extracts from 2 -years-old leaf (a), 3 -years-old leaf (b),  $\beta$ -sitosterol (c), and control (d)

In addition, the leaf of *S. mahagoni* also contained low levels of mono- sesquiterpene, triterpenes, and steroids, suggested to confer inhibitory properties against *P. chrysosporium*. In addition, the monoterpene and sesquiterpene presented with hydrocarbon (perhydroazulene) and oxygenated structures (cyclohexanebutanol and blumenol C), and antifungal activity is demonstrated, despite their minor quantity.

Other constituents detected in *S. mahagoni* were related to the triterpenoids and steroids groups, where squalene and stigmast-5-en-3-ol oleate were identified in low concentrations. Furthermore, the *n*-hexane leaf extracts are generally known to contain low molecular terpenes and waxes, which belonged to the lipophilic fraction, and are thus capable of exhibiting antifungal activities (Ribera and Zuñiga 2012). Lukmandaru (2013) reported the inhibitory effect of squalene and triterpene on the mycelium growth of *Cladosporium cladosporioides*, while cytotoxic activity of triterpenoids, e.g., squalene, extracted from the leaves of *Dysoxylum gaudichaudianum* have previously been

reported against colon and breast cancer cells (Ragasa *et al.* 2014).

### Antioxidant Activity

Figure 4 shows the results of DPPH test, where the leaf of 2 and 3 years-old leaf demonstrated respective inhibition values of 21.7% and 25.4%. This shows a relatively lower activity in the samples from 2 years-old, although both showed less values compared to standards of galic acid, catechin, and quercetin. In addition, the values obtained were four times lower than the positive controls, and prior comparative research with the seeds (Bera *et al.* 2015), leaves (methanol and aqueous extracts) (Naveen and Urooj 2015), also ascertained poorer antioxidant activity in the *n*-hexane *S. mahagoni* extracts. Conversely, the low inhibition of DPPH was attributed to the low amount of phenyl propanoid or phenolic compounds, being the main contributor during antioxidant assay (Iravani and Zolfaghari 2011). Table 1 shows no significant difference between ages ( $p > 0.05$ ), based on the t-test.

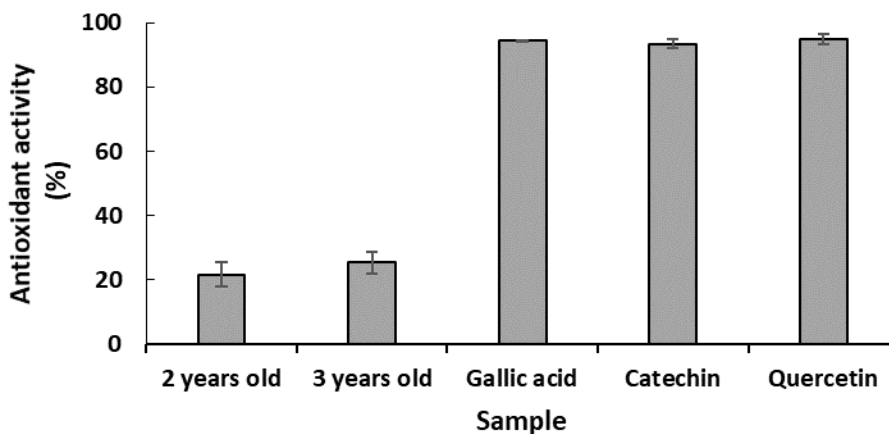


Figure 4. Antioxidant activity of *n*-hexane extracts of *S. mahagoni* leaf.

The *n*-hexane extract constituents of *S. mahagoni* were highly dominated by fatty acids and hydrocarbons, alongside the small quantity of mono-, sesqui, triterpenoids, and steroids. Furthermore, the effective antioxidant component include compounds with the ability to donate proton and stabilize DPPH to DPPH-H, while constituents with hydroxyl structure capably contribute as proton donors, including 1,8-cineole, which is a monoterpene identified in the essential oil of *Eucalyptus globulus* (Luis

*et al.* 2015). Table 2 showed some mono-sesquiterpenoids with hydroxyl structural component, including cyclohexanebutanol and blumenol C, which were identified in low concentrations. In addition, pentadecanoic acid of the fatty acids and hydrocarbons groups were also detected, and Figure 5 shows the chemical structure of all compounds. These compounds in Figure 5 are, therefore, assumed to be weak antioxidants, with possible contribution in the *n*-hexane extracts of *S. mahagoni*.

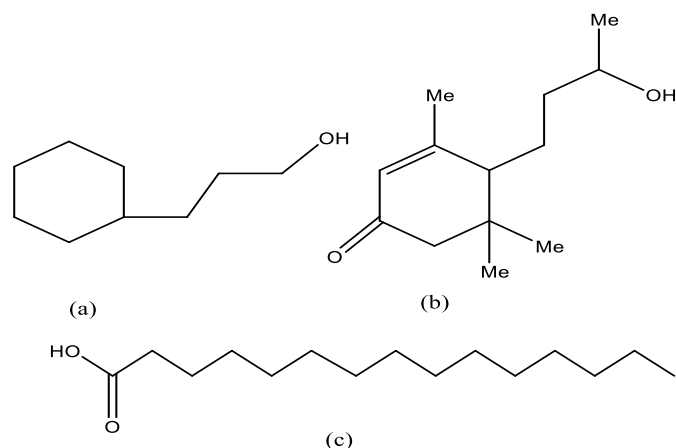


Figure 5. Chemical structure of cyclohexanebutanol (a), blumenol C (b), and pentadecanoic acid (c)

### Conclusions

Based on GC-MS performance, the constituents of the *n*-hexane extracts of *S. mahagoni* leaf (2 and 3 years-old) were dominated by fatty acids and hydrocarbons, alongside terpenoids and steroids which were detected in minor quantities. In addition, both ages showed weak growth inhibition capacity against *P. chrysosporium*, and poor radical scavenging activity against DPPH. The antifungal activity of *S. mahagoni* was, therefore, suggested to have been influenced by hydrocarbons, including octacosane and tetracosane, while the antioxidant effects were attributed to the terpenoids present, including blumenol C and cyclohexanebutanol.

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### References

- Avis, T.J.; R.R. Bélanger. 2001. Specificity and mode of action of the antifungal fatty acid cis-9-heptadecenoic acid produced by *Pseudozyma flocculosa*. *Applied and Environmental Microbiology* 67(2): 956-960.
- Baba, S.A.; S.A. Malik. 2015. Determination of total phenolic and flavonoid content, antimicrobial and antioxidant activity of a root extract of *Arisaema jacquemontii* Blume. *Journal of Taibah University for Science* 9(4): 449-454.
- Bera, T.K.; K.Chatterjee; D. Ghosh. 2015. In-vitro antioxidant properties of the hydro-methanol extract of the seeds of *Swietenia mahagoni* (L.) Jacq. *Biomarkers and Genomic Medicine* 7(1): 18-24.
- Burton, G.W.; M.G. Traber. 1990. Vitamin E: Antioxidant activity, biokinetics, and bioavailability. *Annual Review of Nutrition* 10: 357-82.
- Chakraborty, D.P.; S.P. Basak; B.C. Das; R. Beugelmans. 1971. Cyclomahogenol, a new tetracyclic triterpene from *Swietenia mahagoni*. *Phytochemistry* 10(6): 1367-72.
- Chen, Y.Y.; X.N. Wang; C.Q. Fan; S. Yin; J.M. Yue. Swimahogins A and B, two novel limonoids from *Swietenia mahogany*. *Tetrahedron Letters*. 2007; 48 (42): 7480-7484.
- Gniazdowska, A.; R. Bogatek. 2005. Allelopathic interactions between plants: Multi site action of allelochemicals. *Acta Physiologiae Plantarum* 27(3): 395-407.
- Hossain, M.A.; W.A.S. Al-Toubi; A.M. Weli; Q.A. Al-Riyami; J.N. Al-Sabahi. 2013. Identification and characterization of chemical compounds in different crude extracts from leaves of Omani Neem. *Journal of Taibah University for Science* 7(4): 181-8.
- Iravani, S.; B. Zolfaghari. 2011. Pharmaceutical and nutraceutical effects of *Pinus pinaster* bark extract. *Research in Pharmaceutical Sciences* 6(1): 1-11.
- Lagouri, V. 2015. Lipophilic antioxidants. In : *Lipids and Skin Health*. Ed. by Pappas, A. Springer Science, New York, USA.
- Luis, A.; A. Duarte; J. Gominho; F. Domingues; A. Duarte. 2015. Chemical composition, antioxidant, antibacterial and anti-quorum sensing activities of *Eucalyptus globulus* and *Eucalyptus radiata*. *Industrial Crops and Products* 79: 274-282.
- Lukmandaru, G. 2013. Antifungal activities of certain components of teak wood extractives. *Jurnal Ilmu Teknologi Kayu Tropis* 11(1): 11-18.
- Mousa, O.M.; M.Y. Issa; H.I. El-Askary; M.E. Zalabani; A.A. Sleem. 2014. Lipodial composition and bioactivity of leaves and bark of *Swietenia mahagoni* and *Swietenia*

- macrophylla* Grown in Egypt. Wood Journal of Pharmaceutical Research 3(4): 188-212.
- Naveen, Y.P.; G.D. Rupini; F. Ahmed; A. Urooj. 2014. Pharmacological effects and active phytoconstituents of *Swietenia mahagoni*: A review. Journal of Integrative Medicine 12(2): 86-93.
- Naveen, Y.P.; A. Urooj. 2015. Phytochemical, proximate composition and antioxidant potential of *Swietenia mahagoni* Leaves. Asian Journal of Pharmaceutical Research 5(3): 161-6.
- Panda, S.P.; P.K. Haldar; S. Bera; S. Adhikary; C.C. Kandar. 2010. Antidiabetic and antioxidant activity of *Swietenia mahagoni* in streptozotocin-induced diabetic rats. Pharmaceutical Biology 48(9): 974-979.
- Passos, X.S.; A.C.M. Castro; J.S. Pires; C.F. Garcia; F.C. Campos; O.F.L. Fernandes; J.R. Paula; H.D. Ferreira; S.C. Santos; P.H. Ferri; M.R. Silva. 2002. Composition and antifungal of essential oils of *Cayocar brasiliensis*. Pharmaceutical Biology 41(5): 319-24.
- Pereira, H. 1988. Variability in the chemical composition of plantation eucalyptus (*Eucalyptus globulus* Labill.). Wood and Fiber and Science 20(1): 82-90.
- Pujiarti, R.; Y. Ohtani; H. Ichiura. 2012. Chemical compositions, antioxidant and antifungal activities of *Melaleuca leucadendron* Linn. leaf oils from Indonesia. Wood Research Journal 3(1): 23-9.
- Pupo, M.T.; P.C. Vieira; J.B. Fernandes; M.F.G.F. da Silva. 1996. A cycloartane triterpenoid and  $\omega$ -phenyl alkanolic and alkenoic acids *Trichilia clausenii*. Phytochemistry 42(3): 795-8.
- Ragasa, C.Y.; O.B. Torres; L.O. Bernardo; E.H. Mandia; M. Don; C. Shen. 2013. Glabretal-type triterpenoids from *Dysoxylum mollissimum*. Phytochemistry Letters 6(4): 514-8.
- Ragasa, C.; Y. Vincent; A.S.N. Mariquit; M.D.L. Reyes; E.H. Mandia; G.G. Oyong; C. Shen. 2014. Chemical constituents and cytotoxicity of the leaves of *Dysoxylum gaudichaudianum* (A. Juss.) Miq. Der Pharma Chemica 6(5): 182-7.
- Rahman, S.M.; M.A. Ashikur; T.E. Hira; M.Y. Mian; I. Ahmed; M.M. Rahman. 2014. Antioxidant and antimicrobial activities of flower and bark extract of *Swietenia mahagoni* (L.) Jacq. Journal of Pharmacognosy and Phytochemistry 2(6): 185-8.
- Rakholiya, K.; K. Mital; K. Nagani; A. Patel; S. Chanda. 2015. Comparative analysis and simultaneous quantification of antioxidant capacity of four terminalia species using various photometric assays. Wood Journal of Pharmaceutical Research 4(4): 1280-96.
- Ribera, A.E.; G. Zuniga. 2012. Induced plant secondary metabolites for phytopathogenic fungi control: A review. Journal of Soil Science and Plant Nutrition 12(4): 893-911.
- Senthilkumar, N.; S. Murugesan; K.B. Vijayalakshmi. 2012. GC-MS-MS analysis of *Trichilia connaroides* (Wight & Arn.) Benth (Meliaceae): A tree of ethnobotanical records. Asian Journal of Plant Science and Research 2(2): 193-197.
- Wilkes, J. 1984. The Influence of rate of growth on the density and heartwood extractives content of eucalypt species. Wood Science and Technology 18: 113-120.
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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.

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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.

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  - 3.1. Title
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    - References
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4. Other rules:
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  - 4.2. Values between are written using this symbol ( $\frac{\square}{\square}$ ), e.g. 3.75  $\frac{\square}{\square}$  8.92%.
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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.

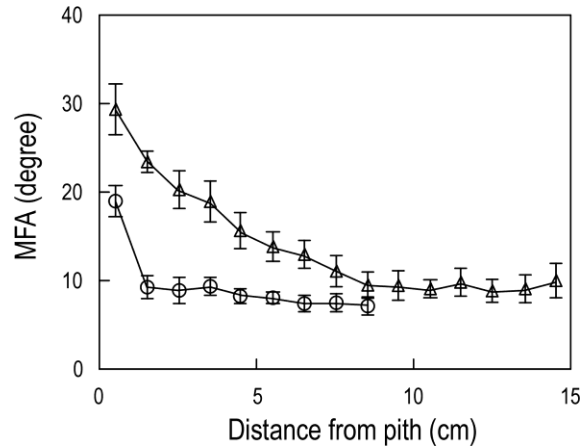


Figure 3. Radial variation of microfibril angle of the S2 layer in tracheid. Open circle, *Agathis* sp.; open triangle, *Pinus insularis*; Bars indicate the standard deviation. (Source: Ishiguri *et al* 2010)

