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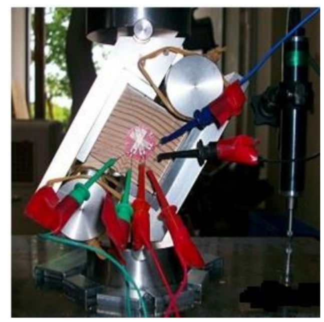

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Mechanical Properties of Compressed Wood with Various Compression Ratios

Buan Anshari, Akihisa Kitamori, Kiho Jung, Kohei Komatsu, and Zhongwei Guan

Abstract

This paper investigates five groups of compressed wood (CF), four of them made from compressed Japanese cedar with four different compression ratios (CR) of 33%, 50%, 67% and 70% and one without compression (control). The specimens were conditioned in relative humidity (RH) of 60% with moisture content (MC) of 12%. Mechanical properties tested were shear modulus in LR, LT and RT planes by single cube test method, Young's modulus in the L, R, T directions and poisson's ratios in all planes. Results showed that in comparison with control specimen, the average improvement on density with CR improvement were 25%, 75%, 175% and 261% corresponding to CRs of 33%, 50%, 67% and 70% respectively. It was also found that Young's modulus in the L and T directions increased significantly with the increase of CR. Shear modulus of RT plane increased with the rise of CR. Poisson's ratios tended to decrease with increasing compression ratio of CW.

Keywords: Mechanical properties, compression ratio, compressed wood, Japanese cedar

Introduction

Wood is a hygroscopic material where relative humidity (RH) change in air causes a considerable fluctuation of moisture content (MC) in wood, which results in appreciable dimensional changes. The anisotropic nature of wood cell structure contributes to different elastic properties and swelling-shrinkage behaviour in three distinct directions: longitudinal (L), radial (R) and tangential (T). There would be more significant moisture-dependent behaviour for a compressed wood that is made of low density softwood through densification in the radial direction under a specific pressure and heat treatment conditions. Compressed wood, assuming its pre-conditioned MC lower than that of the ambient one, is likely to swell after absorbing moisture from the ambient in order to reach equilibrium moisture content.

Wood densification by thermal transverse compression has attracted many researchers as a process to improve the strength and surface properties of low-density wood species, such as surface hardness and abrasion resistance. Dwianto *et al*. (1998) studied sugi wood (*Cryptomeria japonica* D.Don) densification with heat fixation. With the densification level of 50% from original thickness (CR), the retentions of the modulus of elasticity (MOE) and the modulus of rupture (MOR) for compressed sugi by heating at the optimum condition were 89% and 81% respectively. Zhou *et al*. (2000) investigated the bending creep behaviour of hot-press wood under cyclic moisture condition. It was concluded that the thickness swelling increased with moisture cycle, which led to increase in the dimension of hot-press specimen by the end of cyclic moisture sorption.

Heger *et al*. (2004) investigated mechanical and durability performance of Thermo-Hydro-Mechanically (THM) densified wood. The mechanical, physical and durability properties of THM post treated densified wood were studied. The research was aiming to investigate the chemical changes of wood constituents during THM post-treatments of densified wood and to optimise the high steam treatment process as well as to obtain stable compressed wood with improved hygroscopicity, strength and durability. Densification of wood under saturated steam at 140°C improves the mechanical properties of wood and reduces wood hygroscopicity.

Yoshihara and Tsunematsu (2007a) examined the bending and shear properties of compressed wood (CW). Bending test series were conducted for sitka spruce (*Picea sitchensis* Carr.) with various compression ratios (CR). The results showed that Young's modulus increased with increasing of compression ratio when it was determined by load–strain relationship. Modulus of elasticity of CW in the longitudinal direction (E_L) with CR of 33%, 50%, 60% and 67% increased to 25, 26, 28 and 30 GPa respectively in comparison with those of normal sitka spruce with E_L=13 GPa. Yoshihara and Tsunematsu (2007b) also studied the elastic properties of compressed sitka spruce by conducting tension tests and bending tests to measure Young's modulus in radial (R) and tangential (T) directions and Poisson's ratio as well as shear modulus on the cross section. The results showed that Young's modulus in radial direction (E_R) decreased with the increasing of compression ratio, whereas that in the tangential direction (E_T) showed converse tendency, Poisson's ratio (ν_{RT}) decreased with increasing of compression ratio.

Kutnar *et al*. (2008) studied mechanical properties of Viscoelastic Thermal Compression (VTC) wood as specimen mentioned above. The modulus of rupture (MOR) and modulus of elasticity (MOE) were examined. Kutnar study showed the bending properties of VTC wood (MOR and MOE) were significantly increased due to the increased of density. The bonding performance of VTC wood was better than those of control specimen without thermal compression. Jung *et al*. (2008) applied compressed wood made of Japanese cedar, as a substitute for high density hardwood, to make shear dowels. CW with its annual ring radial to loading direction (0°) had an unique double shear performance characteristic and showed good properties as a dowel material by virtue of its strength and rich ductility. Kitamori *et al*. (2010) also studied the mechanical properties of compressed sugi subject to its various compression ratios. The results indicated that elastic shear modulus and strength on the L and T plane increased almost in proportion to density, but there is no significant improvement of those on the L and R plane. Young's modulus increased with increasing compression ratio mainly in L direction. This paper investigates the relation of mechanical properties, which are essential for numerical modelling. Mechanical properties of compressed wood with four CRs and normal wood as comparison were obtained, which cover modulus of elasticity in longitudinal, radial and tangential directions of wood, shear modulus and Poisson's ratios in all principle planes.

Materials and Methods

Sample Preparation

Japanese cedar (*Cryptomeria japonica* D. Don) was used for preparation of compressed wood specimens for mechanical property tests and dimensional change in R, and T directions. The average oven-dry density of the cedar plate was 322 kg/m^3. A compressed wood made of lower grade timber through densification processes requires wood with free of knot and no defect to ensure that it could be compressed in the radial direction. The level of densification which also known as compression ratio (CR) can be represented as follows:

$$CR = \frac{t_0 - t_1}{t_0} \text{ x } 100(\%) \quad \text{.. (1)}$$

where t_0 and t_1 are the thickness of the wood plate in the radial direction before and after the compression treatment, respectively as illustrated in Figure 1.

Figure 1. Typical thickness before (t_0) and after compression (t_1)

Manufacturing Processes of Compressed Wood

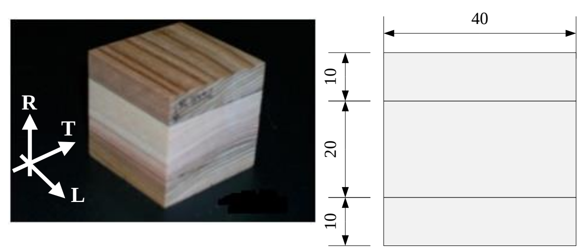
After conditioning processes, the wood plates were densified using pressing machine. In this research, standard pressing machine with maximum pressure force of 2000kN was used. The pressing processes were carried out without applying steam and fixation.

In general, densification processes are performed in three stages:

- Pre-heating. Before compressing the specimen, steel plates of compression machine were heated to a desired temperature of 130°C for about an hour.
- Pressing. The specimen is pressed by upper plate until it reaches a specified thickness, i.e. 15 mm, 20 mm. The pressure was held for 30 minutes before cooling.
- Cooling. Steel plate was cooled down using water circulation system by maintaining pressure and targeted thickness on the specimen to reduce its temperature down to the room temperature. It takes about one to 1.5 hours to complete this process.

Specimens for Elasticity Test

Specimens of 40 mm (L) × 40 mm (R) × 40 mm (T) were prepared for elasticity test. In order to obtain compressed wood with 40 mm thickness in radial direction, three plates of compressed wood were laminated. Three plates of compressed wood with thickness of 20 mm for inner part and two plates of 10 mm thickness as outer parts, as shown in Figure 2. Epoxy adhesive was used to bond the laminates and a clamp pressure of 1MPa was applied.



a. 3D View b. RT plane view

Figure 2. Typical size of specimen for elastic property tests

Two types of test were undertaken to obtain elastic properties of compressed wood with various compression ratios, i.e. shear tests to determine shear modulus of the CW in LT, LR and RT planes and compressive tests to determine Young's modulus in L, R, T directions and Poisson's ratios in three main planes. There were total of 32 cube specimens with size of 40 mm × 40 mm × 40 mm which were consisted of eight specimens for each of three compression ratios and eight specimens for the normal wood.

Density was obtained by weighing each sample before and after densification process divided by its volume. Measurements of moisture content were carried out by storing the specimens in an oven set up with a constant temperature of 105°C until no significant change in weight. Moisture content was then determined by calculating the decreased weight of specimen divided by its initial weight in percentage. It took about 3 to 4 weeks to reach the oven-dry condition.

Experimental Tests

Elastic property were tested to obtain shear modulus, Young's modulus and Poisson's ratios of the normal wood and compressed wood with various compression ratios. Such properties are essential input data for numerical modelling of timber structures using compressed wood. All samples for mechanic property tests were conditioned in chamber with relative humidity of 60% and targeted moisture content of 12%.

Shear tests were performed to determine shear modulus in all planes of compressed wood and normal wood using Single Cube Apparatus (SCA). Hassel *et al* (2009) developed the SCA method to determine shear properties of softwood. A 50 kN-capacity load cell was used to apply compressive load to specimens through the SCA using an Instron 1125 Universal Testing Machine at a cross-head speed of 0.5 mm/min. In order to measure strains in three directions, a tri-axial strain gauge type FRA-10-11 was bonded at back side of the specimen coincided with the main axis plane and 45° from the main axis as shown in Figure 3.

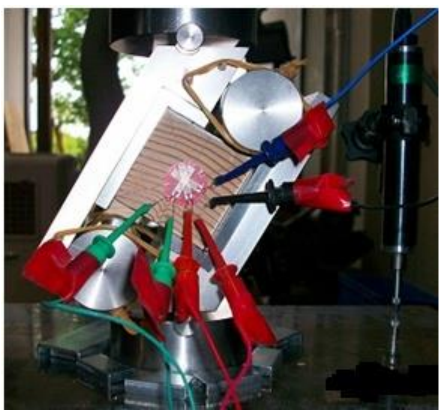


Figure 3. Setting up shear test with the SCA method

Six planes are possible to be tested: RT, TR, LT, TL, LR and RL where the first letter represents the shear direction and the second letter represents the perpendicular direction to the load in the observed plane.

As an example to determine shear modulus on RT plane with load direction inclined 31° from R axis, the shear stress on RT plane (τ_{RT}) is obtained as

$$\tau_{RT} = \frac{F_R \cos 31^0}{A} \quad \text{.......} \quad (2)$$

whereas the shear strain (γ_{RT}) can be derived by the following relation:

$$\gamma_{RT} = 2\varepsilon_{45} - \varepsilon_T - \varepsilon_R \quad \text{.......} \quad (3)$$

where ε_R and ε_T are normal strains in the radial and tangential direction of the specimens, respectively and ε_{45} is the normal strain in the 45° inclined direction with respect to R direction. The shear modulus (G_{RT}) was determined from the incremental relationship between the shear stress ($\Delta\tau_{RT}$) and strain ($\Delta\gamma_{RT}$) within the linear elastic region as: $G_{RT} = \frac{\Delta\tau_{RT}}{\Delta\gamma_{RT}}$.

Compressive tests were also undertaken to determine modulus of elasticity in longitudinal (E_L), radial (E_R) and tangential (E_T) directions and Poisson's ratios in all planes. Similar to those used in shear tests of the specimen of 40 mm × 40 mm × 40 mm. Strain gauges were placed in main axes L, R and T of the specimen to record strains and to determine modulus along all principle axes and Poisson ratios in all mutual principle planes as shown in Figure 4.

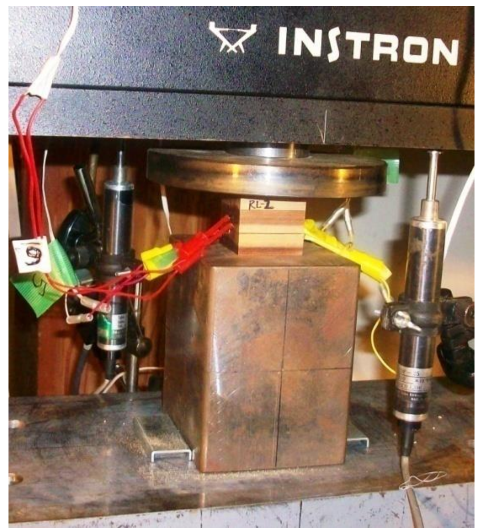


Figure 4. Setting up compression test in RL plane

Young's modulus (E_L, E_R and E_T) were calculated based on the incremental relationship between the compressive stress (Δσ) and strain (Δε) within the linear elastic region as

$$E_i = \frac{\Delta\sigma_i}{\Delta\varepsilon_i}, i = L, R, T \quad \text{.......} \quad (4)$$

The relationships between strains in mutual principle directions were used to obtain Poisson's ratios (ν_{LR}, ν_{LT}, ν_{RT}, ν_{RL}; ν_{TL} and ν_{TR}) as expressed below.

$$\nu_{LR} = \left|\frac{\varepsilon_R}{\varepsilon_L}\right| \quad \text{.......} \quad (5)$$

$$\nu_{RL} = \left|\frac{\varepsilon_L}{\varepsilon_R}\right|; \quad \text{.......} \quad (6)$$

$$\nu_{LT} = \left|\frac{\varepsilon_T}{\varepsilon_L}\right|; \quad \text{.......(1).......} \quad (7)$$

$$\nu_{TL} = \left|\frac{\varepsilon_L}{\varepsilon_T}\right|; \quad \text{.......} \quad (8)$$

$$\nu_{RT} = \left|\frac{\varepsilon_T}{\varepsilon_R}\right|; \quad \text{.......(2).......} \quad (9)$$

$$\nu_{TR} = \left|\frac{\varepsilon_R}{\varepsilon_T}\right| \quad \text{.......} \quad (10)$$

Results and Discussion

Density and Moisture Content

Summarised results of density measurements and moisture content of all specimens are presented in Figures 5 and 6.

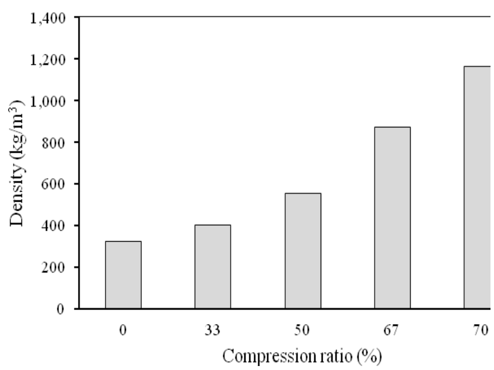


Figure 5. Density of moisture-dependent swelling specimens corresponding to compression ratios with initial MC=6%

Figure 5 shows the relationships between the density of compressed wood with various initial MCs and the compression ratios. The density increases with the increase of the compression ratio, as expected. The average improvement on density with increasing CR were 25%, 75%, 175% and 261% corresponding to CRs of 33%, 50%, 67% and 70% respectively, in comparison to the control specimen.

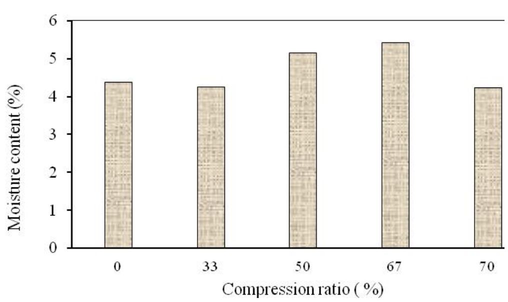


Figure 6. Moisture content of specimens at target MC=6%

Figure 6 shows the actual moisture content corresponding to the compression ratio. In general, the actual moisture was less than the target moisture content due to the manufacturing process of compressed wood in high temperature which leds to evaporation. Compressed wood moisture content is slightly higher than targeted moisture content of 6% with increasing of compression ratio. Compressed wood with 50%, 67% and 70% compression ratio reached actual moisture content of 5.2%, 5.4% and 4.2%, which is lower than targeted moisture content of 6%, respectively.

Mechanical Properties

Table 1 shows shear modulus obtained from Eqs. (4), which also indicated the relationship between the shear modulus and the compression ratio of compressed wood samples tested. It could be seen that the dependence of shear modulus on different compression ratios. The value of G_{RT} increases with increase on the CR due to densification occurring in the radial direction, whereas that of G_{LR} decreases until 50% of CR then increases slightly to 67% of CR and finally steeply increase to 70% of CR. However, G_{LT} decreases initially and then it is in the up-trend to the final 70% of CR. The great changes in percentage were recorded from G_{RT} and G_{LT}.

Table 1. The average of shear modulus

CR (%)	G_{LR}	G_{LT}	G_{RT}
	MPa	MPa	MPa
0	972	784	31
33	300	669	122
50	178	787	170
67	208	1208	256
70	1590	5717	878

Table 2 shows the CR-dependent modulus of elasticity of compressed wood with 12% moisture content in R, L, T directions based on the compression tests. The value of E_L increases greatly with the increase of compression ratio. The highest value of modulus of elasticity was approaching to 33 GPa in the L direction for the CW with 70% CR and 12% moisture content. The value of E_T increases significantly by increasing compression ratio and the maximum value is 3000 MPa at 70% CR. However, the values of E_R of the compressed wood corresponding to CRs of 33, 50 and 67% are lower than that of non-densified wood, with an exception case for 70% of CW. This is due to some fractures of wood cell during densification process. Normally, the fractures along the fibre direction are distributed around mid-thickness of the radial plane (Yoshihara and Tsunematsu 2007b).

Table 2. Modulus of elasticity in the L, R, T directions with various CRs

CR	E_L	E_R	E_T
(%)	MPa	MPa	MPa
0	8017	753	275
33	19864	338	1592
50	27028	354	2267
67	28415	523	2347
70	32858	3111	5061

The ratios between transversal and axial strains on various planes, which are commonly known as 'Poisson's ratio' were obtained. In general, the values of Poisson's ratios decreased with the increase of compression ratio in comparison, except for ν_{LR} and ν_{TL} related to CR=67%. However, the values of Poisson's ratio increased from 67% CR to 70% CR except those recorded in RT and TR planes were decreased. The high values of Poisson's ratio occur on LT plane at 33% CR and 50% of CR on LT plane, i.e. 0.67 and 0.51 respectively. In timber specimen it is likely to produce Poisson's ratio more than 0.5 due to excessive strain in transversal direction.(Anshari, *et.al*. 2011).

Conclusions

In term of density, the increase of CR from 33%, 50%, 67%, and 70% the corresponding densities were increased by 25%, 75%, 175% and 261% respectively, in comparison to the average initial density of the normal wood of 322 kg/m^3.

Shear modulus in LT plane showed significant improvement by increasing compression ratio from 33% to 70%, whereas on the LR plane the shear modulus showed the inverse tendency up to 67% CR. Young's modulus in L and T direction increased significantly with the rise of compression ratio or density. The highest values of E_L and E_T were recorded about 33 GPa and 5 GPa respectively for CW with 70% CR. For Poisson ratios, the values on the RL, TL, RT and TR planes varies significantly, but those on the LR and LT planes changed moderately.

Moisture-dependent dimensional changes behaviour in the R, T direction and material properties were obtained to be implemented in the finite element modelling to carry out structural analysis of timber joints and other structures using compressed wood fasteners.

Acknowledgments

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References

Anshari, B., Guan, Z.W., Kitamori, A, Jung, K., Hassel B.I., Komatsu, K., 2011, Mechanical and moisture-dependent swelling properties of compressed Japanese cedar, Construction and Building Materials, 25(2011):1718-1725.

Dwianto, W., Norirnoto, M., Morooka, T.,Tanaka, F., Inoue, M., and Liu, Y., 1998. Radial compression of sugi wood *(Cryptomeria japonica D. Don).* European Journal of Wood and Wood Products, 56(6): 403-411.

Hassel, B.I., Berard, P., Moden, CS., and Berglund, LA., 2009. The single cube apparatus for shear testing - Full-field strain data and finite element analysis of wood in transverse shear. Composites Science and Technology 69(7-8): 877-882

Heger, F., Groux, M., Girardet, F., Wezbacher, C., Rapp, AO., and Navi, P., 2004. Mechanical and Durability Performance of THM-Densified Wood. Workshop COST Action E22' Environmental Optimization of Wood Protection: 1-10.

Jung, K., Kitamori, A., and Komatsu, K., 2008. Evaluation on structural performance of compressed wood as shear dowel. Holzforschung 62(4): 461-467.

Kitamori, A., Jung, K., Mori, T., and Komatsu, K., 2010. Mechanical properties of compressed wood in accordance with the compression ratio. Mokuzai Gakkaishi 56(2): 67-78.

Kutnar, A., Kamke, FA., and Sernek, M., 2008. The mechanical properties of densified VTC wood relevant for structural composites. European Journal of Wood and Wood Products 66(6): 439-446.

Yoshihara, H. and Tsunematsu, S. 2007a. Bending and shear properties of compressed Sitka spruce. Wood Science and Technology 41(2): 117-131.

Yoshihara, H. and Tsunematsu, S., 2007b. Elastic properties of compressed wood Spruce with respect to its section obtained under various compression ratio. Forest Product Journal: 98-100.

Zhou, Y., Fushitani, M., Sato, K. and Ozawa, M., 2000. Bending creep behaviour of hot pressed wood under cyclic moisture change cnditions. Journal of Wood Science 46: 423-430.

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Chemical Properties of 15-year-old Teak (*Tectona grandis* L.f) from Different Seed Sources

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Abstract

Fifteen year-old teak wood samples planted in Ciamis FMU (Perhutani Enterprise) were evaluated for their chemical properties. Three seed sources such as conventional seed, clone, and superior wood and radial positions namely sapwood, outer heartwood, and inner heartwood were the observed factors. The specimens were taken from the bottom parts of their sources. Completely randomized design was used. Cell wall components were analyzed by various gravimetric methods. Analysis of variance and Duncan's test were performed for data analysis. The results showed that no significant difference in the quantity of cell wall components (cellulose, hemicellulose, and lignin), extractives (ethanol-toluene and hot-water solubles), ash, and silica content among the seed sources. Superior teakwood or Jati Plus Perhutani, which has the highest growth rate (2.1~3.6 cm/year) among others, showed a comparative higher average pH values (7.08~7.38) and solubility in 1% NaOH (17.22~17.83%) than other sources. Radial factors significantly affected ethanol-toluene extractive and lignin content. The ethanol-toluene extractive had the highest content (9.30~11.54%) at the outer part of heartwood while lignin content was the lowest (28.12~30.10%) in the inner part. The result indicated some good characteristics of young teak trees compared to the mature ones in relation to wood processing.

Keywords : growth-rate, superior teak wood, Jati Plus Perhutani, clone

Introduction

Teak (*Tectona grandis* L.f) is a popular and major tree species distributed in Indonesia, especially Java island. Its timber has high strength and durability, as well as a beautiful grain widely used in furnitures, sawntimbers, and handicrafts. Due to its desirable quality, a shortage of teak wood emerged (Purwanta *et al.* 2015), and consequently the forest managements were forced to look for alternative techniques to increase their quantity. Selected programs by Perhutani Enterprise (state-owned company) were focused on growth-rate and site adaptability of teak trees. Therefore, the vegetative propagation of teak and the establishment of clonal forest has resulted to superior clones of teak (Na'iem 2000), also known as Jati Plus Perhutani (JPP). These clones showed desirable characteristics, including the comparatively high values in stem diameter and tree height.

Although tree selection gave an increased volume of log production per hectare, many other physical and chemical wood properties were also important in wood processing. The variations in the basic properties of wood could contribute to reducing negative impacts on the wood processing. Tree variation studies of chemical properties have been limited in superior teak wood until recently, compared to physic-mechanical properties (Basri and Wahyudi 2012; Wahyudi *et al.* 2014; Hidayati *et al.* 2015; 2016). The influence of tree growth-rate in chemistry of teak wood was previously reported to affect extracive content (Lukmandaru 2010). In addition, it gave various trends on other species (Shmulsky and Jones 2011; Humar *et al.* 2008; Kang *et al*. 2004; Miranda and Pereira 2002; Taylor *et al.* 2003). In the present research, the variations of chemical characteristics from pith to bark were studied in 15-year-old trees from three seed sources under same growth conditions and management practices. The variation in chemical properties of woods in relation to growth-rates, as well as the comparison with the results from earlier foundings, were also discussed.

Materials and Methods

Plant Materials

Specimens representing different seed sources at the Ciamis Forest Management Unit site were selected from 15-year-old trees. The locations were RPH Gadung, BKPH Banjar Utara, 43 (superior seed specimens) and 44 compartments (clone specimens). The soil topography was almost flat. These seed sources were superior, cloned, and conventional. Superior teak was the best cloned and commercially named JPP teak (vegetative propagation). Cloned teak had an average diameter at the test site (vegetative propagation) while conventional teak were taken directly from seeds (generative propagation).

Sample Preparation

Ten sound trees from superior teaks (4 trees, diameter of 32~55 cm, tree diameter growth rate of 2.1~3.6 cm/year), seeds (3 trees, diameter of 25~28 cm, tree diameter growth rate of 1.6~1.8 cm/year), and clones (3 trees, diameter of 25~28 cm, tree diameter growth rate of 1.6~1.8 cm/year) were harvested on October 21, 2015. The tissues at the bottom part (30 cm above the ground) were taken and the wood specimens were obtained as a cross-sectional disk (Figure 1) from each sample tree (5 cm in thickness). The radial direction of the disc was further divided into three parts as follows: sapwood (0.5 cm from bark-sapwood border), outer heartwood (0.5 cm from sapwood-heartwood border), and inner heartwood (0.5 cm from the pith). The wood specimens were then taken by drilling in cardinal directions (east-north) and were mixed. Furthermore, the drilled woods were separately grounded into powder and sieve-screened (to pass a 40~60 mesh sieve) for chemical properties determinations.

Chemical Properties

Chemical values for the replicated samples were obtained using various gravimetric methods. The extractive content was determined by successive Soxhlet extraction of about 3 g of each sample using ethanol-toluene (2:1, v/v) Extractions were made in 250-ml Soxhlets with 150 ml of solvent for 6 h and followed by hot-water in a water bath for 3 h. The extracts of ethanol-toluene were concentrated in a rotary evaporator, dried in an oven 1 h at 100C. The percentage of extractives was determined gravimetrically in relation to initial dry mass, according to ASTM D1107 – 96 (2002). The hot-water solubility (HWS) was determined according to ASTM D 1110 –80 (2002). Separately, the solubility in 1% NaOH was measured after dissolving the wood powder (2 g) in a water bath (ASTM D 1109-84 2002).

After determination of extractive content, the carbohydrate (holocellulose) fraction of wood was isolated by removing the lignin from extractive-free wood using the acid chlorite method Browning (1967). For determination of alpha-cellulose in wood, NaOH (17.5%) was applied to holocellulose, dissolving hemicelluloses. Hemicellulose content was determined by the difference between holocellulose and alpha-cellulose content. Klason lignin was determined by hydrolysing the carbohydrates with 72% sulphuric acid TAPPI, T222 - os 78 (1992).

Measurement of ash content and acid insoluble ash content (silica) was conducted according to the ASTM D-1102-2002 and TAPPI T244 om-88 standard method, respectively. The ashing tempereature was 575 $\pm$ 25°C for 3 h in a muffle furnace. Measurement of pH value was conducted by submerging wood powder (1 g per part) in distilled water (20 ml), then the pH of the filtrate was measured with a pH meter (OAKTON). Three measurements were made for each part.

Statistical Analysis

Analysis of variance (ANOVA) was utilized to determine the significant differences that existed among the variables (seed source and radial position) examined. Statistical differences were established at the 0.05 level. A Duncan test for multiple comparisons was used to show which group means differed, then the data were calculated by using SPSS-Win 16.0.

Figure 1. Cross-section of 15-year-old teak tree samples. Left-right : seed (tree diameter growth rate of 1.6~1.8 cm/year), clone (tree diameter growth rate of 1.6~1.8 cm/year), and superior teakwood (tree diameter growth rate of 2.1~3.6 cm/year).

Results and Discussion

Effect of Seed Sources and Radial Position

The measurement of chemical properties of the woods were summarized in Table 1. Based on ANOVA (Table 2), the seed sources factor significantly affected the pH values and interacted with radial position factor to affect the solubility in 1% NaOH. Superior teak, which showed the fastest growth-rate, had the highest pH value and signifcantly differed from those of seed origin (Figure 2). Furthermore, 1% NaOH solubility of superior teak wood tended to give higher values than those of the seed origin (Table 1).

Theoretically, pH values were influenced by phenolic extractives, inorganic contents, acetic acid, and acetyl groups from hemicelluloses (Fengel and Wegener 1989; Rowell *et al.* 2005). The 1% NaOH solubility dissolves some low molecular sugars (Browning 1967). Thus, this trend indicated that seed sources or growth-rate of trees would affect the composition of extractives, inorganic materials, or hemicelluloses. Previously, the growth-rate factors affected only ethanol-toluene extractive content but not its components in matured teak wood (Lukmandaru 2010). This finding suggest that the extractive content of young wood did have a connection with seed source and growth-rates. In the earlier reports, the effect of growth-rate on extractive content did not show similar response in various species (Wilkes 1984; Taylor *et al.* 2003; Kang *et al.* 2004; Humar *et al.* 2008).

Radial position significantly affected extractives and lignin content (Table 2). The Duncan test showed the outer heartwood had the highest level of extractives (Figure 3) while the inner part had the lowest level of lignin content (Figure 3). The high content of extractives at the outer part of heartwood were also observed in mature and young teak (Lukmandaru and Takahashi 2008; Lukmandaru *et al.* 2016). The low value of lignin content in the inner part of heartwood did not correspond with both the previous study on mature teak (Miranda *et al.* 2011) and young teak from the community forest (Lukmandaru *et al.* 2016) As a result, no systematic differences were found in their radial direction. Thus, the different pattern might be associated with the juvenility in the inner part of heartwood.

Table 1. Chemical porperties of teak wood from different seed sources. Average of three replications (seed and clone specimens) and four replications (superior specimen). The same letters on the same row are not statistically different at $P < 0.05$ by Duncan's test.

	Sapwood			Outer heartwood			Inner heartwood			References		
	Seed	Clone	Superior	Seed	Clone	Superior	Seed	Clone	Superior	11-20 years[1]	41-50 years[2]	61-70 years[3]
Ethanol-toluene extractive (%) [b]	7.02	7.02	7.91	9.30	11.54	9.74	8.26	7.91	8.18	6.17-7.40	6.62~16.24	8.48(3.88)
Hot-water solubility (%) [b]	2.00	2.96	2.42	2.06	2.21	2.21	2.27	1.89	2.02	4.19-5.25	0.28~4.10	4.30(0.63)
Solubility in 1% NaOH (%) [b]	12.38ab	16.93c	17.49c	13.47bc	17.41c	17.83c	11.65a	16.12bc	17.22c	16.96-17.95	-	16.94(0.46)
Holocellulose (%) [a]	76.12	76.88	77.14	76.37	75.01	75.93	76.79	76.14	77.47	77.09-78.48	63.83-76.63	77.46(0.93)
α-cellulose (%) [a]	49.29	48.74	47.64	47.19	47.17	47.54	48.36	47.07	47.61	48.34-50.26	40.80-53.80	49.36(1.83)
Hemicellulose (%) [a]	26.87	28.14	29.50	29.18	27.85	28.39	28.43	29.07	29.86	28.22-28.75	-	28.09(0.90)
Lignin (%) [a]	31.91	32.04	31.25	32.46	32.70	32.45	30.10	28.50	28.12	31.47-33.52	29.94-33.78	33.52(1.03)
Ash (%) [b]	0.90	1.39	1.18	0.90	0.93	0.94	0.80	0.83	0.86	0.81-1.52	0.85-3.74	1.59(0.32)
Silica (%) [b]	0.28	0.42	0.50	0.39	0.35	0.36	0.19	0.29	0.55	-	-	-
pH value	6.95	6.97	7.15	6.46	6.98	7.08	6.39	6.66	7.38	-	-	-

Remark : a = percentage of free-extractive meal; b = percentage of oven-dry weight meal.
Sources : [1] teak wood from community forest (Lukmandaru *et al*. 2016); [2] teak wood from Perhutani plantation (Lukmandaru 2010); [3] teak wood from from Perhutani plantation (Lukmandaru *et al*. 2016)

Table 2. Analysis of variance of seed source and radial direction in chemical properties of teakwood

Source of variation	df	Mean square									
		Extractives	HWS	1% NaOH	Holocellulose	α-cellulose	Hemicellulose	Lignin	Ash	Silica	pH value
Sources (A)	2	1.156	0.136	71.294**	1.806	1.315	3.63	2.051	0.079	0.094	0.943*
Radial position (B)	2	20.641**	0.435	10.437	3.19	4.013	2.305	35.732*	0.28	0.007	0.131
A x B	4	2.012	0.346	25.804**	1.05	1.252	2.749	1.122	0.055	0.037	0.189
Error	21	3.131	0.634	5.581	4.011	5.538	5.549	6.147	0.153	0.029	0.241

Remark : ET = ethanol-toluene extractive content, HWS: hot-water solubility, ** = significant at the 1% level; * = significant at the 5% level

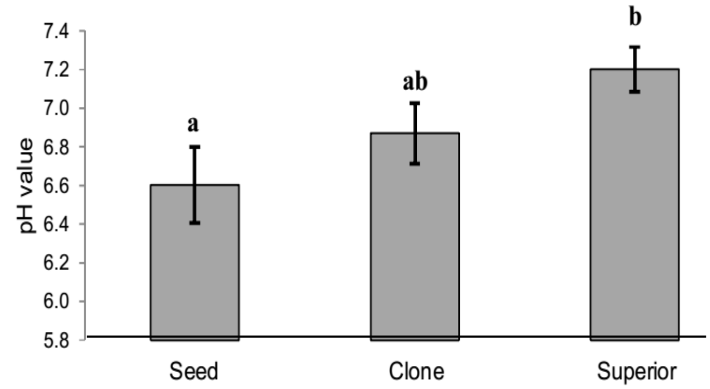

Figure 2. pH value of teakwood by seed source. Average of 4 trees (suprerior teak) and 3 trees (seed and clone), with the standard deviation error bar. The same letters are not statistically different at $P < 0.05$ by Duncan's test.

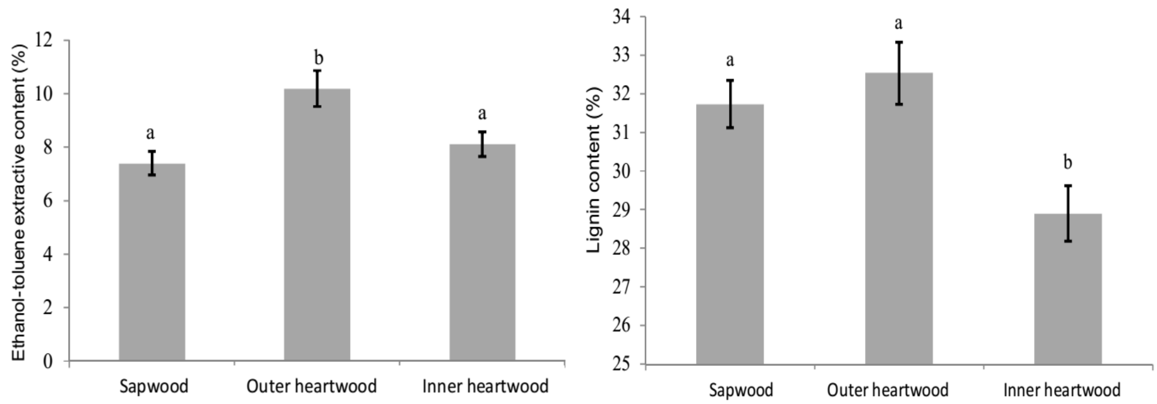

Figure 3. Ethanol-toluene extractive (left) and lignin content (right) of teakwood by seed source and radial position. Average of 4 trees (suprerior teak) and 3 trees (seed and clone), with the standard deviation error bar. The same letters on the same graphic are not statistically different at $P < 0.05$ by Duncan's test.

Comparison with Conventional Teak Woods

The comparison of 15-year-old and other teak woods from previous works were described in Table 1. Unfortunately, the samples with different ages at the same site were not taken for comparison purposes. With regard to cell wall components (cellulose, hemicellulose, and lignin), the value range calculated in this experiment were found to be similar with those of young and mature teak wood from varied sites (Lukmandaru 2010; Lukmandaru *et al.* 2016). Technically, the cell wall components were associated with mechanical properties (Fengel and Wegener 1989; Pereira *et al.* 2003; Curling *et al.* 2002). Therefore, regardless of the basic density, those woods from three different seed sources would be expected to behave similarly and also to show inconsiderable differences in the strength properties of the matured woods.

The comparatively high content of extractives in outer heartwood region was observed. This indicates a more intense heartwood formation which is characterized by polyphenols increase in heartwood and decrease sugars in sapwood (Hillis 1987; Niamké *et al.* 2011).This radial distribution pattern corresponds to the schemes reported on teak wood at various ages (Lukmandaru and Takahashi 2008). It has been reported that the wood regions near pith and sapwood were much less resistant to termites and fungal attack than the outer heartwood (Bhat and Florence 2003; Bhat *et al*. 2005; Kokutse *et al.* 2006; Lukmandaru and Takahashi 2008). This might suggest a different content of toxic compounds among the regions in this young stage.

The presence of low-weight molecular sugars in hot-water soluble extracts would reduce the natural durability of teak wood on the contrary to the toxic components in the ethanol-toluene extracts (Windeisen *et al*. 2003; Lukmandaru 2013). It showed that the amount of extractives and HWS from the samples of 15-year-old trees were similar or lower than the matured woods. It should be noted that the composition and amount of toxic components affected more of the natural durability than the amount of extractive content in teak wood (Haupt *et al.* 2003;

Thulasidas and Bhat 2007; Lukmandaru and Takahashi 2009). Therefore, it could not be concluded that those young woods would posses low natural durability before conducting several bioassay tests. From the wood adhesion point of view, the low levels of extractives is certainly an advantage (Kanazawa *et al.* 1978; Sakuno and Moredo 1998).

Mineral deposits might cause difficulties during the machining and coating process. The average range of ash content of 15-year-old samples generally were lowered than the matured trees observed by Lukmandaru (2010) and Lukmandaru *et al*. (2016). This indicated that the age of trees along with their sites of plantation, might have a connection with the ash content. Silica, which was one of the inorganic components, had an average content values ranged 0.15 to 0.55%, while its major recorded values were 0.4% (Martawijaya *et al.* 1981). The high silica contents which was above 0.3% in the wood, dulled cutting instruments considerably (Shmulsky dan Jones 2011). Although the ash contents were not so high compared to the high silica content in samples such as 15-year-old wood. This made woodworking undesirable from the starting point.

The average range of pH value in this study (6.39~7.38) showed greater significant values than previous researches on young and mature teak woods (Windeisen *et al.* 2003; Lukmandaru 2012). It is assumed that the inorganic composition of the wood may affect the pH value, particularly the high content of calcium, potassium, and magnesium due environmental conditions (Fengel and Wegener 1989). Therefore, it should be verified further for their inorganic elements both in the wood and top soil. It was observed that low pH value hastened the hardening of urea formaldehyde resin during hot-press treatment (Maloney 1993). Wood coating process was discovered to be pH sensitive. As a result, low pH values increased the risk of accelerated corrosion of metals, and negatively impacted machinery and tools in wood processing (Adamopoulos *et al.* 2007). While low pH values tended to prevent crystallization in wood-cement compatibility (Hachmi and Moslemi 1990). Therefore, the pH values toward neutral range in the tested samples would be suitable for certain wood processing.

Conclusions

This study investigated the effect of seed source and radial position variation in the chemical properties of genetically improved and conventional 15-year-old teak samples. The cell wall components, extractives, and ash contents were not responsive to those factors. Superior teak wood samples had significantly higher pH and solubility in 1% NaOH levels compared to seed samples. Radial factors strongly influenced extractives and lignin content. As expected, the 15-year-old samples in this experiment tended to give similar or lower amount of extractives and ash contents than those of matured samples in the previous works. Other characteristics were the comparatively high pH values and silica content observed in the tested samples. As there were no considerable differences in the levels of cell wall components, it was assumed that fast-growing teak such as superior wood would meet the expectation in term of strength properties. Therefore, they could be utilized for proper production in certain wood products and reduced the risk of metal corrosions due to a comparatively high pH value.

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References

American Society for Testing and Materials. 2002. Annual Book of ASTM Standards. ASTM International, Philadelphia, PA, USA.

Adamopoulos, S., E. Voulgaridis, C. Passialis. 2005. Variation of Certain Chemical Properties within the Stemwood of Black Locust (*Robinia pseudoacacia* L.). Holz als Roh- und Werkstoff 63: 327–333.

Basri, E.; I. Wahyudi. 2012. Sifat Dasar Kayu Jati Plus Perhutani dari Berbagai Umur dan Kaitannya dengan Sifat dan Kualitas Pengeringan. Jurnal Penelitian Hasil Hutan 31:93-102.

Bhat K.M.; E.J.M. Florence 2003. Natural decay resistance of juvenile teak wood grown in high input plantations. Holzforschung. 57 : 453–455.

Bhat, K.M.; P.K. Thulasidas; E.J.M. Florence; K. Jayaraman. 2005. Wood durability of home-garden teak against brown-rot and white-rot fungi. Trees 19 : 654–660.

Browning, B.L.. 1967: Methods of Wood Chemistry Vol. II. Interscience Publisher,A Division of John Wiley and Sons, Inc. New York.

Curling, S.F.; C.A. Clausen, J.E. Winandy. 2002. Relationships between Mechanical Properties, Weight Loss, and Chemical Composition of Wood During Incipient Brown-Rot Decay. Forest Product Journal 52, 34-39.

Fengel, D.; G. Wegner. 1989. Kayu : Kimia, Ultrastruktur, Reaksi-Reaksi. Gadjah Mada University Press (terjemahan). Yogyakarta.

Hachmi, A.; A.A. Moslemi. 1990. Effect of Wood pH and Buffering Capacity on Wood-cement Compatibility. Holzforschung 44:425-430.

Hidayati, F.; J. Sulistyo; 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 dan Teknologi Kayu Tropis 13(1): 11-21.

Hidayati, F., I.T. Fajrin, M.R. Ridho, W.D. Nugroho, S.N. Marsoem, M. Na'iem. 2016. Sifat Fisika dan Mekanika Kayu Jati Unggul “Mega” dan Kayu Jati Konvensional yang Ditanam di Hutan Pendidikan Wanagama, Gunung Kidul , Yogyakarta. Jurnal Ilmu Kehutanan 10(2):98-107.

Haupt, M., H. Leithoff, D.Meier, J. Puls, H.G. Richter, O. Faix. 2003. Heartwood Extractives and Natural Durability of Plantation-Grown Teakwood (*Tectona grandis* L.) – a case study. Holz als Roh- und Werkstoff 61:473-474.

Hillis, W.E. 1987. Heartwood and tree exudates. Springer. New York.

Humar, M., B. Fabicic, M. Zupancic, F. Pohleven, P. Oven. 2008. Influence of Xylem Growth Ring Width and Wood Density on Durability of Oak Heartwood. International Biodeterioration & Biodegradation 62: 368-371

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 Resin Urea Adhesive. Mokuzai gakkaishi 24:55-59.

Kang, K.Y.; S.Y. Zhang, S.D. Mansfield. 2004. The Effect of Initial Spacing on Wood Density, Fiber and Pulp Properties in Jack Pine (*Pinus banksiana* Lamb). Holzforschung 58:455-463.

Kokutse, A.D.; A. Stokes; H. Bailleres; K. Kokou; C. Baudasse 2006. Decay resistance of Togolese teak (*Tectona grandis* L.) heartwood and relationship with colour. Trees. 20 : 219-223.

Lukmandaru, G. 2010. Sifat Kimia Kayu Jati (*Tectona grandis*) pada Laju Pertumbuhan Berbeda. Jurnal Ilmu dan Teknologi Kayu Tropis 8(2): 188-196

Lukmandaru G. 2012. Sifat Kelarutan dalam Air, Keasaman dan Kapasitas Penyangga pada Kayu Jati. Prosiding Seminar Nasional MAPEKI XIV, Yogyakarta. p. 875-882.

Lukmandaru G. 2013. Antifungal Activities of Certain Components of Teak Wood Extractives. Jurnal Ilmu dan Teknologi Kayu Tropis 11 (1) : 11-18.

Lukmandaru, G.; A.R. Mohammad, P. Wargono, V.E. Prasetyo. 2016. Studi Mutu Kayu Jati di Hutan Rakyat Gunungkidul. Jurnal Ilmu Kehutanan 10(2): 108-118.

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

Lukmandaru, G.; K. Takahashi. 2009. Radial Distribution of Quinones in Plantation Teak (*Tectona grandis* L.f.). Annals of Forest Science 66(6) :605p1-9.

Maloney, T.M. 1993. Modern Particleboard and Dry-process Fiberboard Manufacturing (update edition). Miller Freeman, San Fransisco.

Martawijaya, A., I. Kartasujana., K. Kadir., S.A. Prawira. 1981. Atlas Kayu Indonesia. Pusat Penelitian dan Pengembangan Hasil Hutan. Bogor. p.42-47

Miranda, I.; H. Pereira 2002. The variation of chemical composition and pulping yield with age and growth factors in young *Eucalyptus globulus*. Wood and Fiber Science 34:140-145.

Miranda, I.; V. Sousa, H. Pereira. 2011. Wood Properties of Teak (*Tectona grandis*) from a Mature Unmanaged Stand in East Timor. Journal Wood Science 57(3):171–178.

Na’iem, M., 2000. Variasi Genetik pada Spesies Pohon Hutan. Training Course on Basic Forest Genetic. Kerjasama Indonesia Forest Seed Project dan Fakultas Kehutanan Universitas Gadjah Mada, Yogyakarta.

Niamké, B.; N. Amusant; J.P. Charpentier; G. Chaix; Y. Baissac; N. Boutahar; A.A. Adima; S. Kati-Coulibaly; C. Jay-Allemand. 2011: Relationships between biochemical attributes (non-structural carbohydrates and phenolics) and natural durability against fungi in dry teak wood (*Tectona grandis* L.). Annals Forest Science 68: 201-211.

Pereira, H.; J. Graca, J. C. Rodrigues. 2003. Wood Chemistry in Relation to Quality. In : Wood Quality and Its Biological Basic. Barnet, R. J.; G. Jerominidis (editor). Blackwell Publishing Ltd. USA.

Purwanta, S., P. Sumantoro, H.D. Setyaningrum, C. Saparinto. 2015. Budi Daya dan Bisnis Kayu Jati. Penebar Swadaya. Jakarta.

Rowell, R.M., R. Pettersen, J.S. Han, J.S. Rowell, M.A. Tshabalala. 2005. Cell Wall Chemistry. In: Rowell, R.M. (Ed), Handbook of Wood Chemistry and Wood Composites. CRC Press,Corporate Blvd., Boca Raton, Florida

Sakuno, T.; C. Moredo. 1998. Bonding Properties of Some Tropical Woods after Solvent Extraction. Proceeding of the Second International Wood Science Seminar. Serpong, Indonesia. p.183-189.

Shmulsky, R.; Jones, P.D. 2011. Forest Products and Wood Science: An Introduction, Sixth Edition. John Wiley & Sons, Inc.

Taylor, M.T.; B.L. Gartner, J.J. Morrell. 2003. Co-incident Variations in Growth Rate and Heartwood Extractive Concentration in Douglas-Fir. Forest Ecology and Management 186: 257-260

Technical Association for the Pulp and Paper Industries. 1992. TAPPI Test Method T 222 os-74. TAPPI Press. Atlanta

Thulasidas, P.K.; K.M. Bhat. 2007. Chemical extractive compounds determining the brown-rot decay resistance of teak wood. Holz als Roh-und Werkstoff 65:121-124.

Wahyudi, I.; T. Priadi, I.S. Rahayu. 2014. Karakteristik dan Sifat-Sifat Dasar Kayu Jati Unggul Umur 4 dan 5

tahun Asal Jawa Barat. Jurnal Ilmu Pertanian Indonesia 19:50-56.
Windeisen, E.; A. Klassen, G. Wegener. 2003. On the Chemical Characterisation of Plantation Teakwood from Panama. Holzs als Roh-und Werkstoff 61(6): 416-418.
Wilkes, J. 1984. The Influence of Rate of Growth on the Density and Heartwood Extractives Content of Eucalypt Species. Wood Scence and Technology18:113-120.

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Fuelwood Characteristics of Five Species Grown in Merauke Forest

Nunik Sri Wahyuni and Joko Sulistyo

Abstract

Papua has a large area of production forests, such as in Merauke. These forests provide great benefits for the pulp and wooden industries, which generate a large amount of biomass waste. Therefore, this study aimed to investigate the proximate analysis, specific gravity, calorific value, and Fuelwood Value Index (FVI) of wood and bark of five species, namely *Acacia mangium* Willd*, Acacia crassicarpa* A. Cunn*, Eucalyptus pellita* F. Muell*, Melaleuca viridiflora* Sol. Ex Gaertn*,* and *Lophostemon suaveolens* Sol. Ex Gaertn*.* The calorific value ranged from 4,066 to 5,435 cal/g, while the FVI values ranged from 4.04 to 76.41. The highest calorific value was observed in the bark of *Melaleuca viridiflora,* while the highest fuelwood value index was observed in *Eucalyptus pellita* wood. Furthermore, the calorific value of wood was higher compared to the bark in all species. There was no significant correlation between specific gravity, calorific or FVI value. It is noticed that a strong correlation (r = -0.92*) was observed between the calorific value and volatile matter in the bark. Based on the proximate analysis results, only the moisture content level was significantly correlated with the calorific value of wood or bark.

Keywords: green energy, proxymate analysis, waste biomass, fabaceae, specific gravity

Introduction

Wood is a commonly used source of energy due to its several advantages, both economically and environmentally. Firewood is very sustainable and is cheaper compared to fossil fuels, meanwhile, Indonesia has numerous tropical forests that provide great potential as a source of energy. One area with potential for biomass production is the Papua Province, with a forest area covers 25.1 million ha (Badan Pusat Statistik 2014).

Merauke is one of the forest areas in Papua with high biodiversity for the wooden and pulp industries. Several species grown in this forest include *Acacia mangium* Willd*, Acacia crassicarpa* A. Cunn*, Eucalyptus pellita* F. Muell*, Melaleuca viridiflora* Sol. Ex Gaertn*, and Lophostemon suaveolens* Sol. Ex Gaertn. The wood products commonly manufactured in Papua island include plywood, sawn wood, veneer, and molding/dowel. Furthermore, the wooden and pulp industries generate wastes from the processing or logging stages, meanwhile the presence of a large proportion of bark from trees produces unutilized wastes.

The calorific value and fuelwood value index (FVI) are important indicators to compare the effectiveness of woods in producing energy. Besides, the calorific value of *A. mangium, A. crassicarpa, E. pellita*, and *M. viridiflora* wood has been previously measured (Yantasath *et al.* 1993; Doran and Turnbull 1998; Dombro 2010), but data on proximate analysis and FVI are limited, while the energy properties of bark have also been less explored. Therefore, this study aimed to investigate wood and bark from Merauke forest as a source of energy. In addition, it also examined the relationship between energy and the related basic properties of wood.

Materials and Methods

Wood Preparation

The wood samples were obtained from one tree for each species in the forest area of PT Selaras Inti Semesta (Medco Groups), Papua, Merauke. For each tree, the discs were sawn at the bottom part while the wood and bark were separated. Furthermore, the samples were taken randomly in the form of wood powder and pieces to test the chemical and energy properties. Measurements of wood properties were performed in three replications.

Specific Gravity and Calorific Value Determination

The specific gravity was measured using the water displacement method with ASTM D 2395-02, while the calorific value was measured using an oxygen bomb calorimeter (Parr InstrumentInc., no. 1341 seri 3403) device referred to ASTM 5865-04.

Proximate Analysis

This test includes moisture content by oven method (ASTM D 4442-92), ash content by dry-ashing method (ASTM D1102-84), volatile matter content (ASTM D3175-02), and fixed carbon content (ASTM D3172).

Fuelwood Value Index

The fuelwood value index (FVI) was based on the properties of calorific value (kJ/g), wood density (g/cm^3), and ash (%) (Purohit and Nautiyal 1987) with the formula (FVI) = (Calorific Value ×Wood density)/Ash content.

Statistical Analysis

The relationships between the independent variables were analyzed using Pearson's correlation analysis. All statistical calculations were performed with SPSS-Win 12.0.

Results and Discussion

The specific gravity results are presented in Figure 1. The highest values were observed in *Lophostemon suaveolens* wood (0.87), while the value in acacia woods was relatively low compared to the other three species (>0.75). Furthermore, there was a significant difference between the specific gravity values of the wood and bark for each species, meanwhile, the specific gravity levels for the two acacia species (family Fabaceae) were greater in the bark compared to the other three species (family Myrtaceae). The high specific gravity value in the bark is presumably caused by the compression of dead bark cells and the formation of thick-walled phellem cells.

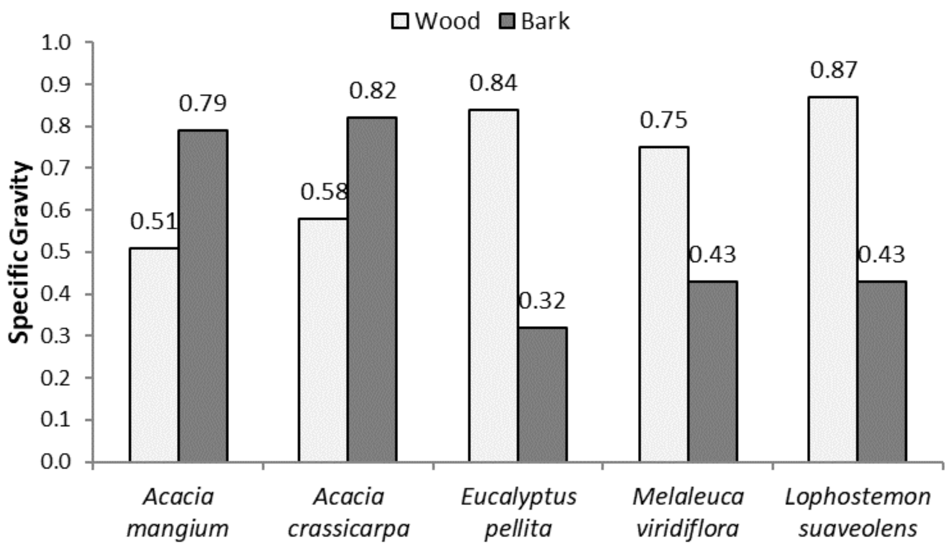

Figure 1. Specific gravity of five tree species growing in Merauke forest (mean of three replications)

Table 1. Proximate analysis of five tree species growing in Merauke forest (mean of three replications)

Species/Part	Moisture content (%)	Ash content (%)	Volatile matters (%)	Fixed carbon (%)
Acacia mangium				
Wood	16.6	0.23	85.64	14.12
Bark	17.3	2.57	79.38	18.04
Acacia crassicarpa				
Wood	13.2	0.24	82.75	17.00
Bark	16.7	1.04	81.81	17.15
Eucalyptus pellita				
Wood	15.5	0.20	83.88	15.92
Bark	16.5	0.28	79.48	20.23
Melaleuca viridiflora				
Wood	16.2	0.46	84.09	15.45
Bark	14.5	1.44	75.57	22.98
Lophostemon suaveolens				
Wood	15.5	0.58	83.97	15.44
Bark	17.0	1.77	79.70	18.52

In general, an ideal raw material for energy needs to have low moisture, ash, volatile matter, and high fixed carbon content. The proximate analysis results are presented in Table 1. The moisture content obtained ranged between the air-dry content (13-18%), while the ash content was higher in the bark (Fengel and Wegener 1984) except for *Eucalyptus pellita*. Furthermore, the volatile matter content was higher in the wood compared to fixed carbon. The lowest ash content value was found in *Eucalyptus pellita wood* (0.20%), meanwhile, there was no significant difference in the volatile matter and fixed carbon contents of wood and bark in *Acacia crassicarpa*. The highest fixed carbon level was observed in the bark of *Melaleuca viridiflora* (22.98%), while the lowest volatile matter concentration was also obtained in the same species (75.57%).

The energy properties of the five species were measured in the form of calorific value (Figure 2) and FVI (Figure 3). To use wood as fuels, both parameters are required in high amounts. The highest calorific value was found in the bark of *Melaleuca viridiflora* (5,435 cal/g), while the highest FVI value was observed in *Eucalyptus pellita* (76.41). Furthermore, the bark's calorific value was greater than the wood in *Acacia mangium, Eucalyptus pellita*, and *Melaleuca viridiflora*. There was no huge difference in calorific value between bark and wood in *Eucalyptus pellita* and *Lophostemon suaveolens*. Meanwhile, the calorific value of wood varies with the value of the bark due to the different properties of both parts (Shmulsky and Jones 2011). Regarding the chemical properties, the bark has a higher lignin and ash content compared to wood (White 1987; Fuwape 1991). Variations between the species indicate the presence of other factors aside from these parameters. Therefore, a chemical analysis of the wood and bark is necessary for a detailed explanation.

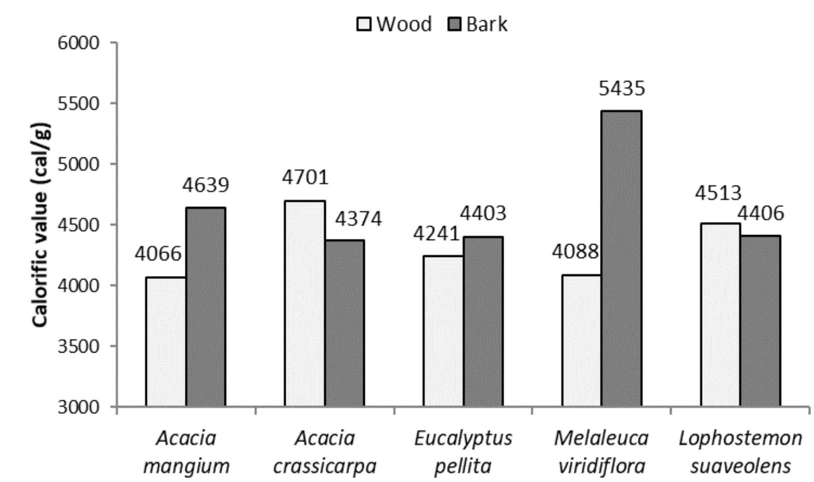

Figure 2. Calorific value of five tree species growing in Merauke forest (mean of three replications)

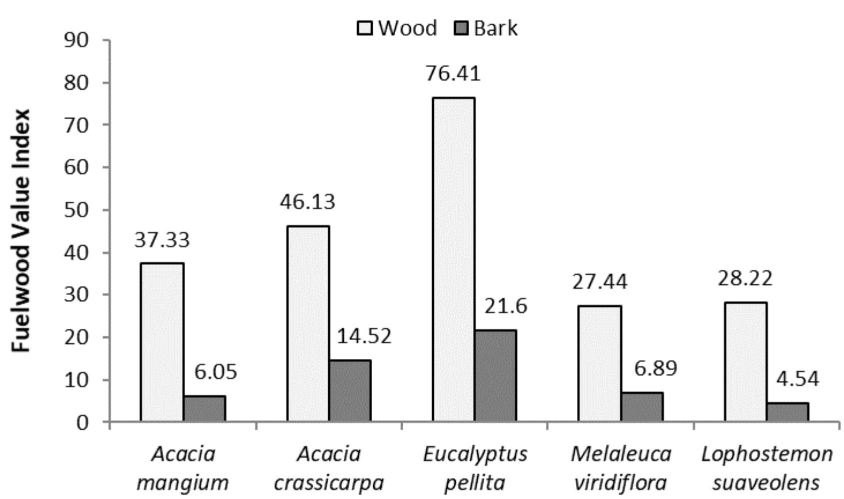

Figure 3. Fuelwood value index of five tree species growing in Merauke forest (mean of three replications)

The FVI value is linearly related to the density and calorific value but inversely to the ash content. The value was relatively higher in wood compared to the bark for all species, while the highest difference in FVI values between wood (76.41) and bark (21.6) was observed in *Eucalyptus pellita*. Furthermore, the relatively low calorific value (4,241 cal/g), low ash content (0.20%), and high specific gravity (0.84) altogether caused the high FVI values obtained in *Eucalyptus pellita* wood. A previous study showed that woods with an FVI value of at least 10 is suitable as firewood (Kataki and Konwer 2002). This implies that wood is better used as fuel compared to bark.

The degree of relationship between the parameters was evaluated by Pearson's correlation (Table 2?). The results of the correlation between proximate values and energy properties when the two parts were combined together showed that the calorific value is strongly correlated with volatile matter (*r* = -0.80**) and fixed carbon (*r* = 0.80), while FVI was negatively correlated with ash content (*r* = -0.73) and volatile matter (*r* = 0.65*). In contrast, when the two parts were separated, there was no significant correlation between the proximate values and the FVI. Furthermore, the calorific value was strongly negatively correlated with the moisture contents in both parts, while a strong correlation (*r* = -0.92*) was also observed between the calorific value and volatile matter in the bark.

Table 2. Pearson's correlation coefficients between energy properties and basic wood properties of five tree species growing in Merauke forest

Parts	Calorific value	Fuelwood Value Index
Wood - Bark		
Specific gravity	-0.27	0.32
Moisture content	-0.50	-0.41
Ash content	0.42	-0.73*
Volatile matters	-0.80**	0.65*
Fixed carbon	0.80**	-0.53
Wood		
Specific gravity	0.07	0.16
Moisture content	-0.90*	-0.22
Ash content	0.10	-0.72
Volatile matters	-0.79	-0.21
Fixed carbon	0.77	0.33
Bark		
Specific gravity	-0.20	-0.21
Moisture content	-0.88*	0.05
Ash content	0.19	-0.87
Volatile matters	-0.92*	0.35
Fixed carbon	0.83	-0.02

The calorific value value was linearly proportional to fixed carbon and specific gravity but inversely related to the ash content and volatile matter. This relationship was also observed in previous studies (Jenkins *et al.* 1998; Patabang 2011). However, this trend was not observed, especially when the two parts were separated. The small number and the limited variations in values between the species are thought to have influenced this result. Furthermore, the moisture content levels were consistently negatively correlated with the calorific value, therefore, the dryer the wood, the higher the calorific value (Munalula and Meincken 2009). A similar trend was also observed in FVI. There was no significant correlation between specific gravity and calorific value or FVI, indicating that differences in moisture content and chemical properties such as lignin, extractives, and inorganic materials (White 1987; Fuwape 1991) among species or between bark and wood had a greater impact. In addition, the correlation between specific gravity and calorific value was not strong as expected due to the varying specific gravity and calorific value values between trees which potentially leads to a negative correlation (Montes 2011).

Conclusions

Wood and bark showed considerable differences and varied by species as indicated by the specific gravity values. Based on the proximate analysis, the lowest value of ash content was found in *Eucalyptus pellita* wood while the highest value for fixed carbon and the lowest value in the volatile matter was found in the bark of *Melaleuca viridiflora*. Furthermore, the highest calorific value was observed in the bark of *Melaleuca viridiflora,* while the highest fuelwood value index was observed in *Eucalyptus pellita* wood. In general, the fuelwood value index in wood were greater compared to the bark for all species. The moisture content was found to be significantly negatively correlated with the calorific value of the bark or wood. Based on the results, there was no significant correlation between specific gravity, calorific value, or fuelwood value index of the five tree species studied. In summary, *Eucalyptus pellita* wood should be considered to be the most appropriate biomaterial for energy purpose.

References

American Society for Testing and Material. 2006a. *Annual Book of ASTM Standard. Volume 04.10 Wood*. Easton ,MD. USA.

American Society for Testing and Material.2006b. *Annual Book of ASTM Standard. Volume 05.06 Gaseous Fuels; Coal and Cake*. Easton, MD. USA.

Badan Pusat Statistik. 2014. Buku Rekalkulasi Penutupan Lahan Indonesia. Kementerian Lingkungan Hidup dan Kehutanan.

Dombro, D. B. 2010. *Eucalyptus pellita :* Amazonia Reforestation's Red Mahogany. Palneta Verde Reforestacion S.A. Colombia.

Doran, J. C.; J. W. Turnbull. 1998. Plants Resources of South-East Asia.

Fuwape, J. A. 1991. Effect of extractives on heating value of *Gmelina arborea*. Journal of Tropical Forest Science 4(4):281-28.

Fengel, D.; G. Wegener 1984. Kayu: Kimia, ultrastruktur, reaksi-reaksi. Prawirohatmodjo S, editor. Sastrohamidjojo H, penerjemah. Gadjah Mada University Press, Jogjakarta.

Jenkins, B.M.L.; L. Baxter; T.R.J. Miles. 1998. Combustion properties of biomass. Fuel Processing Technology 54: 17-46.

Kataki, R.; D. Konwer. 2002. Fuelwood characteristics of indigenous tree species of North-East India. Biomass and Bioenergy 22: 433-473.

Montes, C. S.; D.A.D. Silva; R.A. Garcia; G.I.B.D. Muniz; J.C. Weber. 2011. Calorific value of *Prosopis africana* and *Balanites aegyptiaca* wood: Relationship with tree growth, wood density and rainfall gradiens in The West African Sahel. Biomass and Bioenergy 35: 346 - 353.

Munalula, F.; M. Meincken. 2009. An evaluation of South African fuelwood with regards to calorific value and environmental impact. Biomass and Bioenergy 33 : 415 – 420.

Patabang, D. 2011. Studi karakteristik briket arang kulit buah kakao. Jurnal Mekanikal 2(1): 23-31.

Purohit, A.N.; A.R. Nautiyal 1987. Fuelwood value index of Indian mountain tree species. The International Tree Crops Journal 4:177-182.

Shmulsky. R.; P.D. Jones. 2011. Forest Products and Wood Science: An Introduction, Sixth Edition. John Wiley & Sons, Inc.

White, R.E. 1987. Effect of lignin content and extractives on the higher heating value of wood. Wood and Fiber Science 19(4): 446-452

Yantasath, K., S.; Anusontpornperm; T. Utistham; W. Soontornrangson; S. Watanatham. 1993. Acacia for fuelwood and charcoal. Acacia for Rural, Industrial, and Environmental Development. Proceeding of the Second Meeting of the Consultative Group For Research and Development of Acacia (COGREDA), Editor K. Awang, dan D. A. Taylor. Udorn Thani. pp 144-150.

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Analysis on Chemical Components of Woods to Predict Ethanol Production Values

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Abstract

This paper deals with analysis on chemical components of woods to predict ethanol production values. The aim is expected to give a reliable value of ethanol production, eliminating the effort needed to directly measure this ethanol production from each wood species. Since the data of wood chemical components is widely available, this result will be valuable in determining a potential use of a wood species as bio-ethanol feedstock. Saccharification and fermentation processes by enzymatic hydrolysis were applied for xylems derived from 49 branch trees of Cibodas, 32 branch trees of Purwodadi, and 19 branch trees of Bali Botanical Gardens in Indonesia. Three major wood components were analysed, i.e. cellulose, hemicellulose, and lignin. The results show varied relationships between ethanol production and chemical components of wood. The content of cellulose in wood was not exactly related to its ethanol production. This trend was also occurred for the relationship between hemicellulose and ethanol production. However, lignin content in woods gave an expected trend where the less lignin content, the higher the ethanol production. Furthermore, the ratios of cellulose-hemicelluloses and cellulose-lignin have been quantified. The result showed that the celullose-lignin ratio can potentially be used to predict the value of ethanol production which is expressed by linear regression $y = 0.0616x + 0.8341$; where $R^2 = 0.4127$, x = ethanol production and y = cellulose-lignin ratio. *Gymnostoma sumatranum* with cellulose content of 43.8% and lignin content of 24.1% (celullose-lignin ratio of 1.8) has actual ethanol production of 12.1 mg/100mg wood meal, compared to 15.7 mg/100 mg wood meal resulted from above equation. Therefore, by using its cellulose-lignin ratio, the woods having high ethanol production can be screened from literatures.

Keywords: enzymatic hydrolysis, chemical components, ethanol production, celullose-lignin ratio.

Introduction

Tropical countries are the most productive places in producing tree biomass and an enormous amount of plants. These places experience abundant rain and no winter climate at any time during the year, generating various kinds of trees as natural resources. Many valuable tree plants have been found in Indonesian forests. In addition to native trees, many tropical trees were also collected from all over the world and planted in Indonesian Botanical Gardens, i.e. Cibodas, Purwodadi and Bali.

Recently, raw materials for bioethanol production are still dominated by food plants (generation I), such as corn, sugar-cane, cassava, etc. This condition will cause conflict of interest as it competes with food supply, causing increasing price of foods. This situation becomes worse as environmental issue such as global warming has been predicted to threaten world food supply. Furthermore, the availability of these raw materials is not guaranteed. Generally, even the total amount of starch and sucrose production of the world (1.5×10^9 tonnes/year) that can be converted into bioethanol can only fulfil at the most of 8×10^{11} L/year, while the demand for world fuel is 1.2×10^{12} L/year (Hayashi 2009). Therefore, alternative sources of raw materials other than food crops are needed, which is the non-food lignocellulosic materials (generation II).

Wood-derived lignocellulosic biomass is a good solution as an alternative raw material for bioethanol that should be developed. Wood has several advantages such as having high cellulosic content (≥80% holocellulose). In spite of that, wood can be planted in marginal land, unlike agriculture crops (Kaida *et al*. 2009a). Mixing of 85% wood-based bioethanol with fossil fuel can reduce 65% carbon emission, while mixing of starch-based bioethanol with fossil fuel can only reduce it for 17~23% (Watanabe 2008). Bioethanol raw material from wood does not need spacious storage unlike other lignocellulosic materials. Wood can also be cultivated as Industrial Timber Plantation to more ensure material supply. Cellulose produced from this industrial forest can reach up to 5.0×10^9 tonnes/year that can be converted into 2.6×10^{12} L of bioethanol (Hayashi 2009). Wood plantation on Industrial Timber Plantation area suits Kyoto Protocol since these planted trees can increase carbon stock on earth which eventually will reduce green-house gasses in the atmosphere.

Plant-derived fuel will be one potential solution as an alternative energy source because abundant production of biomass in Indonesia. Therefore, continuity of plant-derived fuel is more guaranteed than that of fossil fuel. Indonesia has various wood species that strengthen its position as world producer for bioethanol in the future by exploring potential wood species.

The main problem on bioethanol production from lignocellulosic biomass, especially wood is the characteristic of plant cell wall which make it difficult for enzymatic hydrolysis. This drawback limits its utilization and cause uneconomical ethanol production from cellulose. Hayashi (2009) mentioned that wood is highly resistant to enzymatic degradation which inhibits its degradation into fermented sugar. Therefore, easy accessibility for both saccharification and fermentation is also included as the most important factors in the conversion of wood into bioethanol.

Research on uncomplicated hydrolysis process and conversion of a wood species to become bioethanol is still uncommon so that big opportunity is widely opened to seek and explore these wood species. Recent studies revealed that sengon xylem consists of soft walls which are easily hydrolysable with commercial cellulase preparations. On the other hand, mangium xylem consists of hard walls which are less hydrolysable than those of sengon, although lignin content is lower for mangium than sengon (Kaida *et al*. 2009a). Genetically loosened walls increased the level of saccharification from 30% to 60% in the case of sengon and from 10% to 15% in the case of mangium (Kaida *et al*. 2009a). It is required to know the variety of saccharification level in the fast-growing tropical trees, in which sengon is the fastest growing tree species in Indonesia. Enzymatic saccharification was employed in this study because the hydrolysis is much more environmentally friendly than other processes such as acid hydrolysis.

Wood is mainly comprised of cellulose, hemicelluloses and lignin in which the crystalline bundles of cellulose are embedded in a covalently linked matrix of hemicellulose and lignin (Ingram and Doran 1995). The cellulose and hemicellulose fractions that comprise about two-thirds to three-quarters of lignocellulosic materials can be hydrolysed enzymatically to release the sugars that in turn can be converted into ethanol. Nevertheless, cellulose is considered as the most important ethanol source since it can be broken down into glucose that is further fermented into ethanol. Unlike cellulose, hemicellulose releases two forms of sugars, the pentoses and hexoses, where the pentoses are not readily fermented to ethanol, making the cellulose the only preferable component for hydrolysis. The condition of close association of the three major wood components resulted in many researches on effective pre-treatment process to disrupt this association with the main goal is to increase the enzyme accessibility in order to facilitate the digestibility of cellulose (Alvira *et al*. 2010; El-Zawawy *et al*. 2011). Therefore, the chemical components of certain materials are understandable to be the major consideration in choosing the most suitable feedstock for bioethanol.

The aim of this study was (1) to screen and to assess the xylems of Indonesian Botanical Garden trees for saccharification in order to be used in bioethanol production, (2) study on the relationship of wood chemical components and their ethanol production, (3) proposed that celullose-lignin ratio can be used to predict the value of ethanol production.

Materials and Methods

Wood Sample Preparation

Branch of trees from Cibodas (49 branch trees), Purwodadi (32 branch trees), and Bali (19 branch trees) Botanical Gardens were cut out at the height of 2 to 3 m above the ground. Their barks were peeled and their xylems were dried in an oven at 70°C. The xylem was then milled to a powder using a ball mill at a speed of 15 rps for 30 min. The powder was used as a xylem preparation for saccharification alone or in combination with fermentation.

Cell Wall Analysis

Xylem preparation was ground in liquid nitrogen and the resulting fine powder was successively extracted 4 times with water and 24% KOH containing 0.1% $NaBH_4$. The insoluble wall residue (cellulose fraction) was washed twice with water. The amount of cellulose was determined by measuring the acid-insoluble residue: the samples were extracted with acetic/nitric reagent (80% acetic acid/concentrated nitric acid, 10:1) in a boiling water bath for 30 min (Updegraff 1969) and the resulting insoluble material was washed in water and freeze-dried. Total sugar in each fraction was determined by phenol-sulfuric acid method (Dubois *et al*. 1956). Lignin content was determined by the Klason method (Chiang and Funaoka 1990).

Enzymatic Hydrolysis

Fifty mg of each xylem preparation was impregnated with water, autoclaved at 120°C for 3 min, and washed once with water by centrifugation. A commercial cellulase preparation (Accelerase, Palo Alto, USA) derived from *Trichoderma viride* was used to digest the xylem. The enzyme preparation contained endocellulases, exocellulases (CBHI and CBHII), xyloglucanase, xylanase, galactanase and polygalacturonase. Enzymatic hydrolysis of the xylem preparation was performed in 1 ml of 50 mM sodium acetate buffer, pH 4.8, containing 0.02% Tween 20 and 0.4 fpu (filter paper units) of a cellulase preparation (2.0 mg). The mixture was incubated at 45°C in a rotary shaker set at 75 rpm. About 100 µl of the supernatant was collected at 48 h of hydrolysis and used for sugar analysis. The sugar released was estimated as reducing sugar by the Nelson-Somogyi method (Somogyi 1952). Furthermore, free sugars released were directly analyzed according to their alditol acetates using gas chromatography (Hayashi 1989).

Ethanol Production

The mixtures from previous enzymatic hydrolysis were inoculated with a seed culture of *Saccharomyces cerevisiae* (SH1089) and yeast nutrients (4 mg $(NH_4)_2HPO_4$, 0.2 mg $MgSO_4/7H_2O$ and 8 mg yeast extract). The mixtures were incubated at 37°C in a rotary shaker set at 100 rpm. About 100 µl of the supernatant was collected after 48 h fermentation and used for ethanol analysis. The ethanol formed was measured by gas chromatography on a Supelcowax-10 column (0.53 mm i.d. × 15 m; Supelco, Bellefonte, PA, USA) at 50°C using an Agilent gas chromatograph. Butanol was used as an internal standard.

Results and Discussion

Composition of Xylem and Enzymatic Saccharification

Cibodas Botanical Garden Woods. Appendix 1 shows the amounts of celluloses varied between 24.3% (*Pterospermum javanicum*) and 60.0% (*Araucaria glauca*). Hemicelluloses varied between 3.3% (*Agathis borneensis*) and 18.5% (*Firmiana malayana*). Lignin contents varied between 22.2% (*Casuarina junghuhniana*) and 39.6% (*Michelia montana*).

Previous results showed the levels of enzymatic saccharification varied among xylems from the 49 wood species. At 48 h, the xylem of *G. sumatranum* released 42.5 mg of sugars/100 mg wood meal (Kaida *et al*. 2011) while poplar xylem released only 30.3 mg/100 mg wood meal (Kaida *et al*. 2009b). The higher incidence of cellulose hydrolysis was also observed in *A. microsperma* (37.1 mg/100mg wood meal) which was higher than in poplar (Kaida *et al*. 2011). *Araucaria glauca* has the highest cellulose content (60%) while its sugar released was only 17.1 mg/100mg wood meal. Therefore, the levels of enzymatic saccharification were regardless of the cellulose content (Dwianto *et al*. 2011).

Purwodadi Botanical Garden Woods. Appendix 2 shows the amounts of celluloses varied between 34.7% (*Diospyros celebica*) and 54.8% (*Acacia catechu*). Hemicelluloses varied between 8.0% (*Alstonia scholaris*) and 26.9% (*Pterocymbium javanicum*). Lignin contents varied between 23.3% (*A. catechu*) and 36.9% (*Syzygium polyanthum*).

Previous results showed the levels of enzymatic saccarification varied among xylems from the 32 trees. At 48 h, the highest level of saccharification was obtained from the xylem of *F. malayana*, which had released 36.9 mg of sugars/100 mg wood meal (Sakata *et al*. 2012), while sengon only released 29 mg of sugars/100 mg wood meal (Kaida *et al*. 2009a). The higher incidence of cellulose hydrolysis was also observed in *P. indicus* (34.0 mg/100mg wood meal) which was higher than in sengon (Sakata *et al*. 2012).

A. catechu has the highest cellulose content while its sugars released was only 28.4 mg/100 mg wood meal (Sakata *et al*. 2012). Therefore, the levels of enzymatic saccharification was regardless of the cellulose content (Dwianto *et al*. 2011). The amount of hemicellulose in xylems varied between 8.0 to 26.9%, in which xyloglucan content varied between 0 to 0.1425%. *Alstonia scholaris* has the lowest hemicellulose content while its sugar released was only 12.6 mg/100 mg wood meal (Sakata *et al*. 2012). Therefore, the levels of enzymatic saccharification was regardless of the hemicellulose content (Dwianto *et al*. 2011). Although xyloglucanase activity improved the total hydrolysis of lignocelluloses (Benko *et al*. 2008), there was no correlation between ethanol production and xyloglucan content. Lignin is known to be a recalcitrant compound in cellulose hydrolysis (Chen and Dixon 2007). The data shows the correlation between the high level of enzymatic saccharification and the low lignin content, but it does not happen all the time. *A. catechu* also has the lowest lignin content but its sugar released was only 28.4 mg/100mg wood meal. Therefore, the levels of enzymatic saccharification were regardless of the lignin content (Dwianto *et al*. 2011).

Bali Botanical Garden Trees. Appendix 3 shows that the amounts of cellulose varied between 35.9% (*Mimusops elengi*) and 51.2% (*Tabernaemontana macrocarpa*). Hemicelluloses varied between 5.7% (*Podocarpus neriifolius*) and 22.4% (*Flacourtia rukam*). Lignin contents varied between 23.2% (*Toona sureni*) and 39.1% (*Calophyllum soulattri*).

Previous results showed the levels of enzymatic saccharification varied among xylems from the 19 wood species. At 48 h, the highest level of saccharification was obtained from the xylem of *A. scholaris* which released 38.0 mg sugars/100 mg wood meal (Kaida *et al*. 2012), while sengon only released 29.0 mg sugars/100 mg wood meal (Kaida *et al*. 2009a). Higher levels of cellulose hydrolysis when compared to that of sengon were also observed in *F. rukam* (36.9 mg/100mg wood meal), *S. rarak* (34.9 mg/100mg wood meal) and *F. padana* (30.3 mg/100mg wood meal).

T. macrocarpa has the highest cellulose content while its sugar-released was only 24.8 mg/100 mg wood meal (Kaida *et al*. 2012). From this condition, it can be said that the level of sugar released was not directly related to cellulose content (Dwianto *et al*. 2011). The amount of hemicellulose in xylems varied between 5.7 to 22.4%, in which xyloglucan contents varied between 0 to 0.0877%. *P. neriifolius* has the lowest hemicellulose content yet its sugar-released was only 26.6 mg/100 mg wood meal (Kaida *et al*. 2012). This result showed that lower level of hemicellulose can not ensure that higher sugar released could be obtained (Dwianto *et al*. 2011). Although xyloglucanase activity improved the total hydrolysis of lignocelluloses (Benko *et al*. 2008), there was no correlation between ethanol production and xyloglucan content. Lignin is known to be a recalcitrant compound in celullose hydrolysis (Chen and Dixon 2007). The data shown the correlation between the high yield of enzymatic saccharification and the low lignin content, but this condition was not a must. *T. sureni* has the lowest lignin content (23.2%) but its sugar-released was only 23.0 mg/100mg wood meal. Therefore, the yield of enzymatic saccharification was also not directly related to lignin content (Dwianto *et al*. 2011).

Relationships between Chemical Components of Wood and their Ethanol Production

The results from Appendix 1 to 3 were then plotted on the graphs of chemical components of wood against ethanol production as shown in Figure 1. Analysis of relationship between chemical components and ethanol production of all wood samples tested revealed various patterns of cellulose, hemicellulose and lignin content. Cellulose and hemicellulose contents demonstrated weak correlation with ethanol production. Correlation between lignin content and ethanol production was more pronounced, were the lower the lignin content of wood samples, the higher the ethanol production. The complexity of wood structure and high lignin content were estimated to be the major cause that inhibits contact between cellulose and the enzyme in saccharification process. We assumed that lignin was the primary obstacle to releasing sugar in several wood samples tested. The wood with lower lignin content will give higher cellulosic ethanol production which ultimately will reduce the processing cost. This statement goes along with some previous researches (Jørgensen *et al*. 2007; Taherzadeh and Karimi 2008; Yamashita *et al*. 2010) saying that removal of lignin can effectively increase cellulose hydrolysis, in other words result in higher sugar release. The structure of lignin -which is made up of cross-linked network polymers gives the plant structural support and im-permeability resistance against microbial attack and oxidative stress which limits the accessibility of enzymes to cellulose and the rate of hydrolysis by acting as a shield, preventing the digestible parts of the substrate from being hydrolyzed (Yamashita *et al*. 2010).

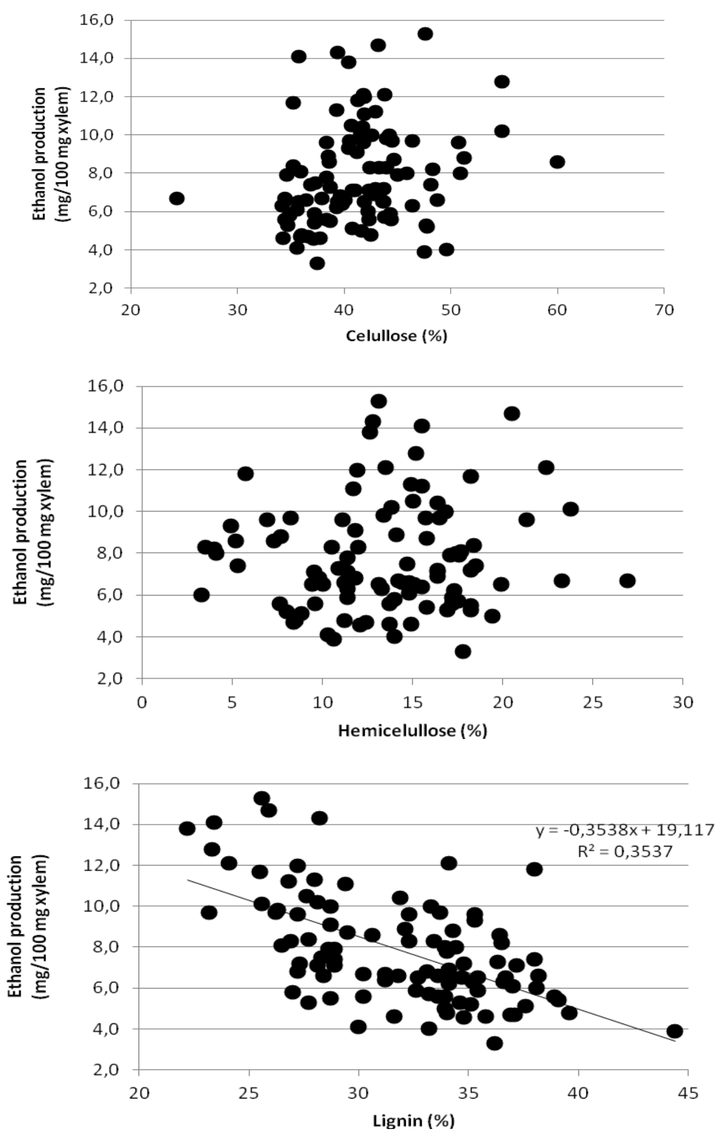

Figure 1. Relationships between major chemical components of wood and their ethanol production (Dwianto *et al*. 2012).

Since we expect woods with higher cellulose content should produce higher ethanol production, this research confirmed that any wood should be investigated individually to see its suitability for bioethanol production. It might occur that even though the wood has high level of cellulose, the composition of its other chemical components such as hemicellulose and lignin may act as inhibitors in the conversion of its cellulose into reducing sugar that will be further converted into ethanol. However, even though this study shows lignin is the main factor affecting the ethanol production and the same result is also obtained by many other studies stated above, other study shows that improving the surface area accessible to cellulase is a more important factor for achieving a high sugar yield (Rollin *et al*. 2011). Since the cellulose, hemicellulose and lignin are present in various amounts in different parts of the plant and form the structural framework of the plant cell wall which depends on plant species, age and growth conditions (Jørgensen *et al*. 2007), their contribution on the amount of ethanol production is not just in the matter of their quantity on plants, especially woods, but also on how they are distributed and growth condition involved. It is also mentioned by Chandra *et al*. (2007) that the chemical, physical and morphological characteristics of the heterogeneous lignocellulosic substrates influenced the effectiveness of enzymatic hydrolysis.

Analysis on Chemical Components of Woods to Predict Ethanol Production Values

A previous study on the relationship between chemical components of woods and their ethanol production showed varied relationships between ethanol production and chemical components of woods (Dwianto *et al*. 2012). The content of cellulose in wood did not exactly relate to its ethanol production. This trend also occurred for the relationship between hemicelluloses and ethanol production. However, lignin content in woods gave an expected trend where the less lignin content, the higher the ethanol can be obtained. The study concluded that high cellulose content of wood is not the only indicator of its high ability to result in high ethanol production. The complexity of wood structure makes it necessary to always examine the other two components, hemicelluloses and lignin where lignin seems to be the most prominent component affecting the ethanol production.

On the other hand, ratio of wood component seems to be acceptable to use in determining the potential use of wood as bioethanol feedstock. It is due to the assumption that wood with high cellulose content and low lignin and hemicellulose content will generally produce more ethanol than the opposite. However, an exact value of the way these components affect ethanol production is still not known. Therefore, this study was undertaken to get a closer approach to quantify this issue. The scattered graphs of around 100 wood species showing their celullose-hemicellulose ratio against ethanol production is shown in Figure 2 and the graph of celullose-lignin ratio against ethanol production is shown in Figure 3.

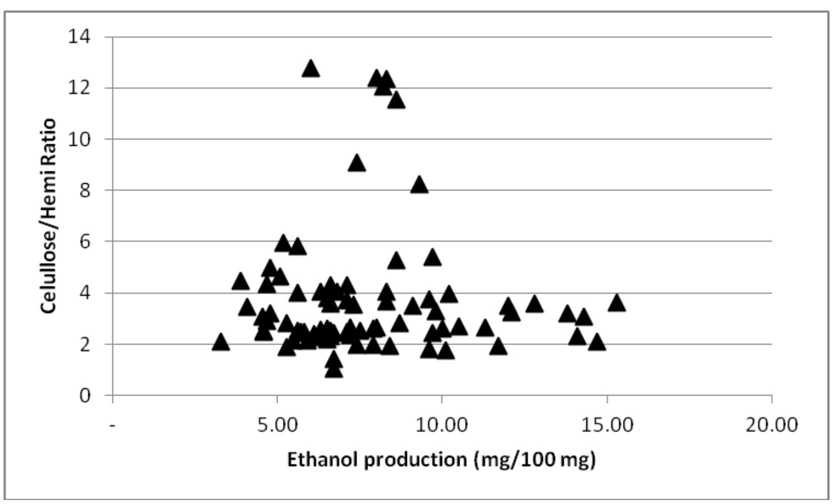

Figure 2. Relationship between celullose-hemicellulose ratio and ethanol production.

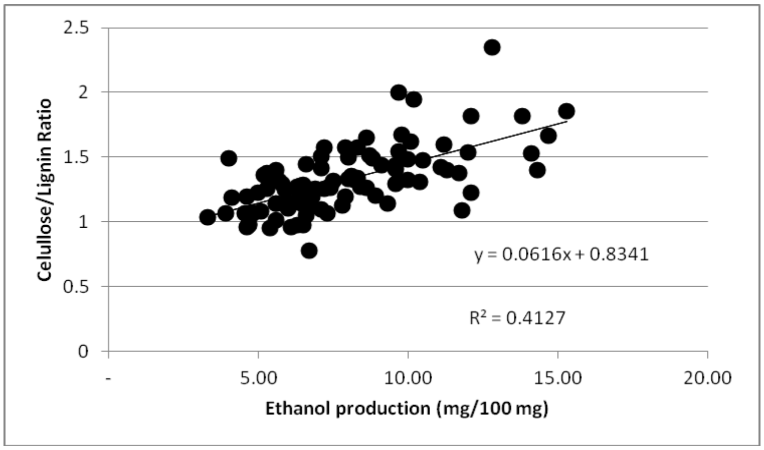

Figure 3. Relationship between celullose-lignin ratio and ethanol production.

Analysis of relationship between celullose-hemicellulose ratio and ethanol production of all wood samples tested revealed broad patterns. Celullose-hemicellulose ratio demonstrated weak correlation with ethanol production. However, correlation between celullose-lignin ratio and ethanol production was more pronounce where the higher celullose-lignin ratio of wood samples, the higher amount of ethanol can be produced. Celullose-lignin ratio is expressed by linear regression y = 0.0616x + 0.8341; where R^2 = 0.4127, x = ethanol production and y = cellulose-lignin ratio. This result justifies that wood with lignin content that is much lower than its cellulose content will strongly produce higher ethanol production. Kaida *et al*. (2011) reported that *Gymnostoma sumatranum* has the higher ethanol production among other Indonesian botanical gardens' wood species. *G. sumatranum* with cellulose content of 43.8% and lignin content of 24.1% (cellulose-lignin ratio of 1.8) has actual ethanol production of 12.1 mg/100 mg wood meal, compared to 15.7 mg/100 mg wood meal resulted from above equation. The coefficient determination actually is not high (R^2 = 0.4127). Other factors outside the chemical composition to affect the equation were probably density and anatomical features of the woods. However, the two factors were not observed on these results.

By using its cellulose-lignin ratio, we could select the woods potentially having high ethanol production from literatures. Some major and minor timbers from literatures (Soerianegara *et al*. 1994; Lemmens *et al*. 1995) having celullose-lignin ratio more than 3.0 are *Parishia paucijuga, Sterculia macrophylla, Pterocymbium sp., Artocarpus lanceifolius, Lithocarpus sp., Swintonia sp*., and *Sterculia ceramica*.

However, since the cellulose, hemicelluloses and lignin are present in various amounts in the different parts of the plant and form the structural framework of plant cell wall depending on plant species, age and growth conditions (Jørgensen *et al*. 2007), their contribution on the amount of ethanol production is not just in the matter of their quantity on plants, especially woods, but also on how they are distributed and growth condition involved. It is also mentioned by Chandra *et al*. (2007) that the chemical, physical and morphological characteristics of the heterogeneous lignocellulosic substrates influenced the effectiveness of enzymatic hydrolysis. Even though each wood species has to be investigated thoroughly to see its potential for bioethanol feedstock, still this equation using cellulose-lignin ratio can be used as an alternative option to save time and effort in screening the remarkable number of wood species.

Conclusion

High cellulose content of wood is not the only indicator of its high ability to produce high ethanol production. The complexity of wood structure makes it necessary to always examine the other two components, hemicellulose and lignin where lignin seems to be the most prominent component that affects the ethanol production. Celullose-lignin ratio can be used to predict the value of ethanol production which is expressed by linear regression y = 0.0616x + 0.8341; where R^2 = 0.4127. This regression also confirms that wood with lignin that is much lower than its cellulose content will strongly produce higher ethanol production. Therefore, by using its cellulose-lignin ratio, woods having high ethanol production can be selected from literatures. Still, further analysis is needed to confirm this result.

References

Alvira P, Tomás-Pejó E, Ballesteros M, Negro MJ. 2010. Pretreatment Technologies for An Efficient Bioethanol Production Process Based on Enzymatic Hydrolysis: A Review. Bioresource Technology 101: 4851-4861.

Benko Z, Siika-Aho M, Viisa V, Reczey K. 2008. Evaluation of the Role of Xyloglucanase in the Enzymatic Hydrolysis of Lignocellulosic Substrates. Enzeme. Microb Technol. 43: 109-114.

Chandra RP, Bura R, Mabee WE, Berlin A, Pan X, Saddler JN. 2007. Substrate Pretreatment: The Key to Effective Enzymatic Hydrolysis of Lignocellulosics. Biofuels.

Chen F, Dixon RA. 2007. Lignin Modification Improves Fermentable Sugar Yield for Biofuel Production. Nature Biotechnology 25(7): 759-761.

Chiang VL, Funaoka M. 1990. The Dissolution and Condensation Reactions of Guaiacyl and Syringyl Units in Residual Lignin during Kraft Delignification of Sweetgum. Holzforschung 44(2): 147-155.

Dwianto W, Fitria, Wahyuni I, Adi DS, Hartati S, Kaida R, Hayashi T. Relationships between Chemical Components of Wood and Its Sugar Released. 2011. Proceeding of the International Conference on Sustainable Future for Human Security, Kyoto University, Kyoto, Japan, p. 449-452.

Dwianto W, Fitria, Wahyuni I, Adi DS, Hartati S, Kaida R, Hayashi T. 2012. Relationships between Chemical Components of Wood and their Ethanol Production. Proceedings of the Second Korea-Indonesia Workshop and International Symposium on Bioenergy from Biomass, Puspiptek-Serpong, p. 87-90.

Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith. F. 1956. Colorimetric Method for Determination of Sugars and Related Substances. Anal. Chem. 28: 350-356.

El-Zawawy WK, Ibrahim MM, Abdel-Fattah YR, Soliman NA, Mahmoud, MM. 2011. Acid and Enzyme Hydrolysis to Convert Pretreated Lignocellulosic Materials into Glucose for Ethanol Production. Carbohydrate Polymers 84: 865-871.

Hayashi T. 1989. Measuring β-glucan Deposition in Plant Cell Walls. In: Linskens HF, Jackson JF, editors. Modern Methods of Plant Analysis: Plant Fibers. Berlin: Springer-Verlag Berlin, pp. 138-160.

Hayashi T. 2009. Case Study on Bioethanol Production in Riau. The Third Humanosphere Science School, Pekanbaru, Indonesia.

Ingram LO, Doran JB. 1995. Conversion of Cellulosesic Materials to Ethanol. Fems Microbiology Reviews 16: 235-241.

Jørgensen H, Kristensen JB, Felby C. 2007. Enzymatic Conversion of Lignocellulose into Fermentable Sugars: Challenges and Opportunities. Biofuels, Bioproducts and Biorefining 1: 119-134.

Kaida R, Kaku T, Baba K, Oyadomari M, Watanabe T, Hartati S, Sudarmonowati E, Hayashi T. 2009a. Enzymatic Saccharification and Ethanol Production of *Acacia mangium* and *Paraserianthes falcataria* Wood, and *Elaesis guineensis* Trunk. J. Wood Sci. 55: 381-386.

Kaida R, Kaku T, Baba K, Oyadomari M, Watanabe T, Nishida K, Kanaya T, Shani Z, Shoseyov O, Hayashi T. 2009b. Loosening Xyloglucan Accelerates the Enzymatic Degradation of Cellulose in Wood. Molecular Plant 2(5): 904-909.

Kaida R, Sakata M, Tokue M, Taji T, Sakata Y, Hayashi T, Sukara E, Suprapedi, Adi DS, Dwianto W. 2011. Enzymatic Saccharification and Ethanol Production of Xylems from Cibodas Botanical Garden Trees. Prosiding Seminar Nasional Kimia Terapan Indonesia, Serpong, p. 118-121.

Kaida R, Tokue M, Sakata M, Taji T, Sakata Y, Hayashi T, Kusumah SS, Darmawan T, Adi DS, Dwianto W. 2012. Enzymatic Saccharification and Ethanol Production of Xylems from Ekakarya Bali Botanical Garden Trees. Indonesian Polymer Journal 15 (2): 52-56.

Rollin JA, Zhu ZG, Sathitsuksanoh N, Zhang YHP. 2011. Increasing Cellulose Accessibility Is More Important than Removing Lignin: A Comparison of Cellulose Solvent-based Lignocellulose Fractionation and Soaking in Aqueous Ammonia. Biotechnology and Bioengineering 108: 22-30.

Sakata M, Tokue M, Kaida R, Taji T, Sakata Y, Hayashi T, Narko D, Fitria, Adi DS, Dwianto W. 2012. Enzymatic Saccharification and Ethanol Production of Xylems from Purwodadi Botanical Garden Trees. Wood Research Journal 3 (2): 117-120.

Somogyi M. 1952. Notes on Sugar Determination. J. Biol. Chem. 195: 19-23.

Taherzadeh MJ, Karimi K. 2008. Pretreatment of Lignocellulosic Wastes to Improve Ethanol and Biogas Production: A Review. Int. J. Mol. Sci. 9: 1621-1651.

Updegraff DM. 1969. Semimicro Determination of Cellulose in Biological Materials. Anal. Chem. 32: 420-424.

Watanabe T. Biomass Conversion. 2008. The First Humanosphere Science School, Cibinong, Indonesia.

Yamashita Y, Sasaki C, Nakamura Y. 2010. Effective Enzyme Saccharification and Ethanol Production from Japanese Cedar using Various Pretreatment Methods. Journal of Bioscience and Bioengineering 110: 79-86.

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Appendix 1. Chemical components and ethanol production of Cibodas Botanical Garden's woods.

Wood species	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ethanol production (mg/100 mg wood meal)
Gymnostoma sumatranum	43.8	13.5	24.1	12.1
Adenanthera microsperma	35.7	15.5	23.4	14.1
Casuarina junghuhniana	40.4	12.6	22.2	13.8
Tabernaemontana macrocarpa	44.5	8.2	33.7	9.7
Flacourtia rukam	37.3	14.7	28.3	7.5
Taxus sumatrana	48.3	4.0	36.5	8.2
Pinus merkusii	40.4	4.9	35.3	9.3
Garcinia parvifolia	40.7	15.0	27.6	10.5
Mangifera odorata	35.2	18.2	25.5	11.7
G. beccarii	35.2	18.4	27.7	8.4
Araucaria cunninghamii	50.9	4.1	33.9	8.0
Agathis becarii	43.3	3.5	32.3	8.3
Lithocarpus indutus	44.0	13.4	26.3	9.8
Artocarpus heterophllus	41.9	11.9	27.2	12.0
Ficus padana	34.6	17.6	28.9	7.9
Acer laurinum	39.3	14.9	28.0	11.3
Platea latifolia	39.6	9.8	33.1	6.8
Bischofia javanica	41.8	11.1	32.3	9.6
Weinmannia blumei	42.3	11.4	28.1	7.1
Actinodaphne glomerate	41.2	11.8	28.7	9.1
Symplocos acuminata	36.4	14.4	31.8	6.6
Persea rimosa	34.4	13.7	33.9	5.6
Lithocarpus pseudomoluccus	42.4	10.5	26.9	8.3
Ostodes paniculate	34.4	14.2	30.2	6.7
Rauvolfia javanica	37.1	12.1	34.8	4.5
Toona sureni	38.7	18.2	28.7	5.4
Firmiana malayana	36.9	18.5	28.9	7.4
Araucaria var. Glauca	60.0	5.2	36.4	8.6
Sloanea sigun	34.9	14.0	27.0	5.8
Lithocarpus rotundatus	38.7	10.9	36.3	7.3
Litsea firma	39.4	15.1	34.7	6.5
Decaspermum fruticosum	34.5	14.8	28.4	6.6
Podocarpus neriifolius	48.1	5.3	38.0	7.4
Neonauclea obtusa	35.7	9.4	36.7	6.5
Lithocarpus pallidus	34.3	13.7	35.8	4.6
Michelia champaca	40.1	11.2	38.2	6.6
Manglietia glauca	40.8	8.8	37.6	5.1
Neonauclea lanceolate	36.6	8.4	37.1	4.7
Manglietia calophylla	44.4	7.6	38.9	5.6
Mastixia trichotoma	35.6	14.8	37.0	6.1
Alstonia scholaris	38.6	7.3	30.6	8.6
Macaranga rhizinoides	40.8	9.5	37.2	7.1
Acmena acuminatissima	36.0	11.2	34.0	4.8
Michelia montana	42.5	8.5	39.6	4.8
Syzygium polyanthum	34.2	13.3	35.2	6.3
Agathis borneensis	42.2	3.3	38.1	6.0
Persea excelsa	37.7	14.9	31.6	4.6
Pterospermum javanicum	24.3	23.3	31.2	6.7
Radermachera gigantea	35.6	10.3	30.0	4.1

Appendix 2. Chemical components and ethanol production of Purwodadi Botanical Garden's woods.

Wood species	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ethanol production (mg/100 mg wood meal)
Firmiana malayana	43.2	20.5	25.9	14.7
Pterocarpusa indicus	47.6	13.1	25.6	15.3
Sapindus rarak	39.4	12.8	28.2	14.3
Hibiscus macrophyllus	40.5	16.5	26.2	9.7
Acacia catechu	54.8	15.2	23.3	12.8
Canarium aspermum	44.2	16.8	33.3	10.0
Schizolobium amazonicum	54.8	13.8	28.1	10.2
Parkia timoriana	44.7	15.8	29.5	8.7
Melia azedarach	44.0	12.0	33.4	8.3
Albizia procera	41.5	23.8	25.6	10.1
Leucaena leucocephalla	42.9	18.2	27.3	7.2
Enterolobium cyclocarpum	45.9	17.4	34.4	8.0
Dalbergia latifolia	45.0	17.1	28.6	7.9
Mimusops elengii	38.3	21.3	27.2	9.6
Lagerstromia loudonii	48.7	11.3	33.6	6.6
Pterocymbium javanicum	37.9	26.9	34.0	6.7
Swietenia mahagoni	43.7	16.4	34.8	7.2
Artocarpus heterophyllus	42.3	17.2	30.2	5.6
Homalium tomentosum	39.3	17.3	34.1	6.2
Flacourtia rukam	41.0	16.4	28.9	7.1
Guioa diplopetala	-	11.8	27.2	6.8
Anthocephalus cinensis	46.4	11.4	36.6	6.3
Albizia lebbekoides	43.7	19.9	34.0	6.5
Cananga odorata	43.8	17.5	33.2	5.7
Alstonia scholaris	47.8	8.0	35.1	5.2
Lagerstroemia speciosa	47.7	16.9	34.6	5.3
Diospyros celebica	34.7	18.2	27.7	5.3
Wrightia tomentosa	38.3	9.6	33.6	5.6
Michelia alba	37.2	17.2	32.6	5.9
Tectona grandis	47.5	10.6	44.4	3.9
Syzygium polyanthum	35.9	12.4	36.9	4.7
Bischofia javanica	37.5	17.8	36.2	3.3

Appendix 3. Chemical components and ethanol production of Bali Botanical Garden's woods.

Wood species	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ethanol production (mg/100 mg wood meal)
Alstonia scholaris	42.9	15.5	26.8	11.2
Flacourtia rukam	41.8	22.4	34.1	12.1
Sapindus rarak	41.9	11.7	29.4	11.1
Ficus padana	42.6	16.8	28.7	10.0
Podocarpus neriifolius	41.3	5.7	38.0	11.8
Pometia pinnata	38.5	14.1	32.1	8.9
Tabernaemontana macrocarpa	51.2	7.7	34.3	8.8
Toona sureni	46.4	15.7	23.2	9.7
Araucaria cunninghamii	50.7	6.9	35.3	9.6
Artocarpus heterophyllus	41.7	16.4	31.9	10.4
Mimusops elengii	35.9	17.7	26.5	8.1
Guioa diplopetala	42.8	16.4	34.1	6.9
Firmiana malayana	41.6	19.4	33.9	5.0
Syzygium polyanthum	41.9	10.0	32.7	6.5
Michelia champaca	43.6	13.1	35.4	6.5
Bischofia javanica	38.3	11.4	34.0	7.8
Hibiscus tiliaceus	39.8	15.5	31.2	6.4
Decaspermum fruticosum	44.3	11.4	35.4	5.9
Calophyllum soulattri	37.2	15.8	39.1	5.4
Pterospermum javanicum	49.6	14.0	33.2	4.0

The Natural Durability and Drying Properties of Ganitri Wood (*Elaeocarpus sphaericus* Schum)

Trisna Priadi and Arizal Sani

Abstract

Ganitri (*Elaeocarpus sphaericus* Schum.) is a fast-growing species that was majority planted in community-based forets in Java. This research aimed to evaluate the natural durability and drying properties of ganitri wood, hence the best uses of the wood can be achieved. The wood durability was tested in laboratory and field scales based on SNI 7207:2014 and ASTM D 1758-02 standards respectively, while the wood treatibilty evaluation used soaking method with 5% borax preservative. The wood drying property was assessed through oven drying at 100°C temperature based on Terazawa method. The resistance of the wood against subterranean termites *Coptotermes curvignathus* is classified as durability class IV. Ganitri wood was very easy to be preserved with the cold soaking method. Boron retention in ganitri was 22.87 kg.m^{-3}, while its penetration was 27.80 mm or 94.24%. Ganitri had rather poor drying properties, which was prone to surface check. The proper drying for ganitri wood was suggested using initial and final temperatures 53°C and 83°C, respectively, while the initial and final relative humidity were 85% and 30%.

Keywords: drying, durability, fungi, ganitri wood, preservation, termite.

Introduction

The use of fast-growing wood species from community forests tends to increase. Meanwhile, optimal wood utilization requires a good understanding of wood properties. Many wood species from community forests are used as materials for buildings, furniture and other products. Ganitri is a fast-growing species that has been widely cultivated in several community forests in Java (Rohandi and Gunawan 2014). Ganitri (*Elaeocarpus sphaericus* Schum) is a tropical plant that grows and spreads from India, Nepal, Sri Lanka, Burma, Malaysia, and Indonesia. In Indonesia, ganitri trees can be found in the islands of Sumatra, Java, Kalimantan, Bali, Sulawesi and Nusa Tenggara. Ganitri can grow well from the coast to 1200 meters above sea level (Zuhud *et al.* 2013).

The seeds of ganitri are generally harvested and are well known as one of the non-wood forest products. Moreover, the wood of ganitri can be used as carpentry and building materials (Rohandi and Gunawan 2014). Ganitri wood has yellow heartwood and white sapwood, smooth texture, with straight and interlocked grain. The air-dry density of ganitri wood is 0.35 and is classified in strength class IV. The wood can be used as light construction, wooden tools, furniture, plywood, and panel products (Prihatini 2020). Furthermore, ganitri wood is easily preserved by the soaking method for up to 3 days so that the retention and penetration of boric acid equivalent (BAE) 10% met the requirements of the Indonesian National Standard (SNI) (Suhaendah and Siarudin 2015).

Some basic properties of ganitri wood have been studied as described above. However, there is insufficient scientific information on the natural durability and drying properties of ganitri wood, which are very important for proper processing and utilization to produce high-quality wood products. Therefore, the objective of this study was to evaluate the natural durability and drying properties of ganitri wood. Wood durability will determine the service life of wood products. Low durability wood will require preservation to protect from biodeterioration.

Materials and Methods

Natural Durability

The natural durability of ganitri wood (*Elaeocarpus sphaericus* Schum) against subterranean termites was tested in a laboratory scale based on SNI 7207:2014 standard (BSN 2014). Wood samples with the size of 2.5 cm x 2.5 cm x 0.5 cm were oven-dried at a temperature of 60 ± 2°C for 48 hours to get the dry weight of the wood samples before testing (W_1).

A total of 200 grams of sterile sand was put into a test bottle, followed by adding 30 ml of distilled water to regulate the water content of the sand. Then 200 subterranean termites (*Coptotermes curvignathus* Holmgren) from the worker caste were placed into the bottle. Furthermore, the test bottles were sealed using aluminum foil with some tiny holes for air circulation and kept in the dark for 4 weeks. For comparison in this study, jackfruit (*Artocarpus heterophyllus*) and sengon (*Falcataria moluccana*) woods represent durability class II and class IV wood, respectively. After four weeks of test, the wood samples were cleaned and then oven-dried at a temperature of 60 ± 2°C for 48 hours to get wood sample weight after testing (W_2) and to calculate the weight loss of wood sample (Equation 1). The durability classifications against subterranean termites attack referred to the Indonesian National Standard 7207-2014 (Table 1).

$$WL = \frac{W_1 - W_2}{W_1} x100 \quad (1)$$

where:
WL = Weight loss of wood sample (%)
W1 = Wood weight before the test (g)
W2 = Wood weight after the test (g)

Table 1. Durability classification of wood against subterranean termites

Class	Durability	Weight Loss (%)
I	Very Durable	< 3.52
II	Durable	3.52~7.50
III	Moderate	7.51~10.95
IV	Poor	10.96~18.95
V	Very poor	> 18.95

Source: BSN 2014

Field test of wood durability based on ASTM D 1758-02. The size of the wood samples were 45.7 cm × 2 cm × 2 cm. The samples were oven-dried at 60°C for 48 hours before the test to determine the initial weight (W_1). After that, the 2/3 sample length were buried in the ground at Arboretum, Faculty of Forestry and Environment, IPB University. The inter-sample graves spacing was 30 cm within rows and 60 cm between rows. After 3 months of exposure, the sample woods were cleaned and oven dried again at 60°C for 48 hours to gain the final weight (W2) to calculate the wood weight loss. The wood damages due to termites and fungi were visually graded based on the criteria in Table 2 and Table 3.

Table 2. The assessment criteria of wood durability from termites attack

Durability Grades	Attacks
10	No attack; only 1~2 bites of termites
9	Attack ≤ 3% across the sample
8	3% < attack ≤ 10% across the sample
7	10% < attack ≤ 30% across the sample
6	30% < attack ≤ 50% across the sample
4	50% < attack ≤ 70% across the sample
0	Damage > 70% across the sample

Source: ASTM D 1758-02

Table 3. The assessment criteria of wood durability from fungal attack

Durability Grades	Attacks
10	No attack; only little fungal attack
9	Attack ≤ 3% across the sample
8	3% < attack ≤ 10% across the sample
7	10% < attack ≤ 30% across the sample
6	30% < attack ≤ 50% across the sample
4	50% < attack ≤ 70% across the sample
0	Damage > 70% across the sample

Source: ASTM D 1758-02

Preservative Treatability

The preservative treatability test used wood samples at the size of 10 cm × 6 cm × 6 cm. The samples were air-dried to get the moisture content below 16%. Both ends of wood samples were coated with paraffin then weighed before treatment (W0). Then the wood samples were soaked in borax solution at a concentration of 5% for 48 hours. After preservation, the samples were weighed (W1) to determine the retention of borax in the samples using Equation 2.

$$R = \frac{W_1 - W_0}{V} \times C \quad (2)$$

where:
R = Retention (kg.m^{-3})
W_0 = Wood weight before preservation (kg)
W_1 = Wood weight after preservation (kg)
V = Wood volume (m^3)
C = Concentration of preservative solution (%)

The wood samples were air-dried and cut into two pieces in the middle of the sample. The sample cross-sections were sprayed with reagent A and B sequentially to determine boron penetration. Reagent A consisted of 10 g of turmeric powder in 100 ml of alcohol, while reagent B contained 80 ml of alcohol and 20 ml of hydrochloric acid, which was saturated with salicylic acid. The color change to red indicated the presence of boron in the wood. Penetration measurements were performed in 2 ways. The penetration depth was directly measured at the penetrated cross-section from four sides and then averaged (Equation 3). The second penetration was calculated as the penetration percentage from the total cross-section area (Equation 4). The penetrated area was drawn on transparent plastic and overplayed on millimeter block paper for measuring the areas.

$$\overline{X} = \frac{X_1 + X_2 + X_3 + X_4}{4} \quad (3)$$

$$\overline{X} = \frac{A_p}{A_T} x100 \quad (4)$$

where:
$\overline{X}$ = Penetration (mm or %)
$X_{1,2,3,4}$ = Penetration from four sides of sample
A_p = Penetrated area (mm^2)
A_t = Total cross section area (mm^2)

Drying Properties

The drying properties test of wood is based on Terazawa (1965) method. Wood sample size was 20 cm × 10 cm × 2.5 cm at fresh conditions (moisture content > 30%) with 12 replication. The samples were dried at 100°C up to a constant oven-dried weight. Observation of defects (checks) was done every three hours. Deformation and internal check were evaluated at the end of drying. The samples were also weighed regularly. All the defects were measured and scored. The most severe defect score was used to determine the minimum and maximum temperatures and relative humidity for drying the wood (Table 4).

Table 4. Temperatures (T) and relative humidity (RH) in the initial and final drying (Terazawa 1965)

Defects	T (°C) and RH (%)	Defect Score						
		1	2	3	4	5	6	7
Surface check	Initial T	70	65	55	55	53	50	45
	Initial RH	75	78	82	83	85	90	90
	Final T	95	90	85	83	82	81	79
	Final RH	29	29	27	30	30	28	28
Deformation	Initial T	70	66	58	54	50	49	47
	Initial RH	75	75	78	81	81	85	89
	Final T	95	88	83	80	77	75	70
	Final RH	29	29	25	27	28	27	27
Internal Check	Initial T	70	55	50	49	48	45	
	Initial RH	75	81	81	85	85	89	
	Final T	95	83	77	73	71	70	
	Fnal RH	29	27	25	27	27	27	

Data Analyses

The durability, treatability and drying properties data of wood were analyzed descriptively. The effect of wood species on wood durability and treatability was analyzed using variance analysis (ANAVA) with a completely randomized experimental design and further Duncan multiple range tests when the ANAVA showed a significant effect at 95% confidence interval.

Results and Discussion

The Natural Durability of Ganitri Wood

Based on four months of laboratory testing, ganitri wood was attacked by subterranean termites, as well as jackfruit and sengon woods. The weight loss of woods due to termites' attacks is shown in Figure 1.

Figure 1 shows that the weight loss of ganitri wood was slightly lower than sengon but much higher than jackfruit samples, which indicated that ganitri wood is more durable than wood sengon but less durable than jackfruit wood. Pandit and Kurniawan (2008) stated that the natural durability of wood sengon is classified into durable class IV~V, so sengon is prone to subterranean termites. Febrianto *et al.* (2013) stated that the natural durability of jackfruit from the termites belonged to class II, which means that the wood is resistant to the termites. According to Morimoto *et al.* (2006), *A. heterophyllus* wood contained artocarpin that had a fatal effect against *Reticulitermes speratus* termites. In addition, Saiin (2017) reported that jackfruit wood extractives contained morine substance. It was alleged that this extractive substance was unfavorable to termites. Syafi'i (2001) also stated that extractive substances could cause woods to have high natural durability.

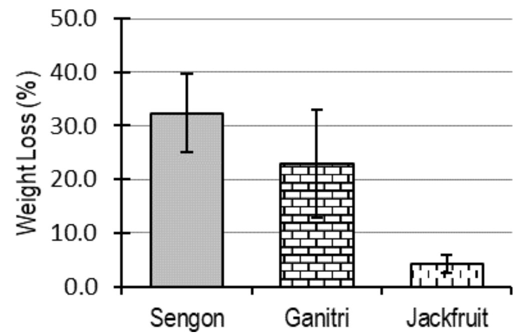

Figure 1. Weight loss of wood samples due to subterranean termites attack

The analysis of variance revealed that the wood species significantly affected the weight loss of the sample at a 95% confidence interval. In this lab experiment, the Duncan test showed that the weight loss of ganitri wood was not significantly different from that of sengon wood, but it was significantly higher than that of jackfruit wood. The higher the wood weight loss value, the lower wood durability from subterranean termites attack. Therefore, the resistance of sengon and ganitri woods against subterranean termites was relatively similar (class IV), but less resistant than that of jackfruit wood.

The durability field test shows that wood damage was mostly caused by subterranean termites' attacks, particularly *Macrotermes gilvus* (Figure 2). Besides, there were also some fungal attacks. Heavy damage occurred in ganitri and sengon woods due to termite attacks, while less damage occurred in jackfruit wood (Figure 3). The weight loss of ganitri wood was 86.4%, while in sengon and jackfruit woods were 64.4% and 0.7%, respectively.

Figure 2. Subterranean termites (*Macrotermes gilvus*) were found on tested samples

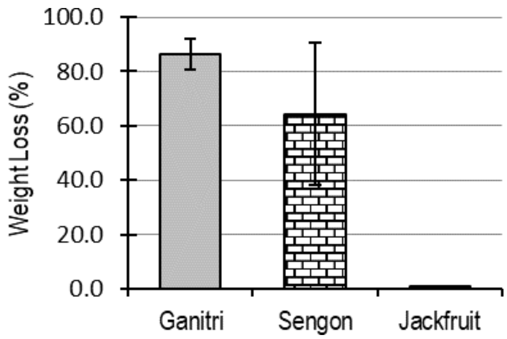

Figure 3. Weight loss of sample woods in the field test.

Figure 3 shows that the weight loss in the field test of ganitri wood was higher than that of sengon and jackfruit woods. This means that ganitri wood was less durable from biodeterioration in ground contact test than sengon and jackfruit woods. The ANAVA analysis revealed that wood species significantly affected the weight loss of wood samples at a 95% confidence interval. Moreover, the Duncan test resulted that the weight loss of ganitri wood was significantly higher than jackfruit wood but was not significantly different from that of sengon wood.

The visual grading of defects generally showed similar results to the weight loss variable. Ganitri wood had the lowest grade (Table 5), which indicated the lowest durability against termite and fungi. Jackfruit wood was more durable than sengon wood. In the field ground contact test, the sample woods were influenced by daily wet (rain) and dry that support the biodeterioration process by termites and fungi. Nuriyatin *et al.* (2003) reported that the characteristics of different woods affect the behavior of termites when they contact or bite the wood as a nutrient source. Wood containing toxic extractive substances can prevent termite and fungal attacks. Termites will choose the most favorable wood for their food. This visual grading also showed that termite attack was more severe than fungal attack.

Table 5. Durability grade of woods from subterranean termites and fungi in the field test

Wood Samples	Durability Grade against Termites	Durability Grade against Fungi
Ganitri	4	7
Sengon	6	9
Jackfruit	10	10

Comparing the durability in lab and field tests shows that ganitri wood was more prone to biodeterioration in the field than that of sengon. However, in lab tests, ganitri wood was more resistant to termite than sengon wood. It reveals that when ganitri wood is influenced by environmental wetting and attack by fungi, it is more favorable to termite attack.

The Preservative Treatability

The retention of borax preservative in ganitri wood was 22.9 kg.m^{-3}, while the preservative penetration was 27.8 mm (Table 6). Both retention and penetration of preservatives in this research fulfilled Indonesian National Standard (SNI 03-5010.1-1999). According to this SNI standard, preservative retention for indoor and outdoor are 8.0 kg.m^{-3} and 11.0 kg.m^{-3}, respectively, while the penetration must be more than 5 mm (BSN 1999).

The penetration of borax preservative into ganitri wood was about 94.2% (Table 6). It revealed that based on the classification of IUFRO in Smith and Tamblyn (1970), the treatability of ganitri wood was easy. Therefore ganitri wood can be preserved with borax preservative by soaking method for 48 hours.

Table 6. Preservative treatability of ganitri wood

Testing Variables	Testing Values	Standar Values	Notes
Retention (kg.m^{-3})	22.9	8 (indoor) 11 (outdoor)	SNI 03-5010.1-1999 SNI 03-5010.1-1999
Penetration (mm)	27.8	5	SNI 03-5010.1-1999
Penetration (%)	94.2	> 90 (easy)	IUFRO method (Smith and Tamblyn 1970)

The Drying Properties

The drying test results in that ganitri wood had fairly poor drying properties (Table 7). This wood was prone to surface check with a score of 5. The surface check mainly occurred at the beginning of the drying process when the moisture content of wood is still high. According to Yamashita *et al.* (2013), a wood surface check is generally caused by dimensional changes that are not the same in all wood parts. The surface of wood dries up faster, but the wood inside is still saturated with water. Checks generally occur on parenchyma rays in the wood because they are the weakest part of the wood structure. According to Rasmussen (1961), surface checks frequently occur in the rays, resin canals, and mineral layers. The way to avoid this defect is by providing high air humidity at the beginning of the drying process, and the temperature should not be too high (Walker 2007).

Table 7. Drying defects evaluation of ganitri wood

Surface Checks		Internal Checks		Deformation		Max. Score	Drying Prop.
max	min	max	min	max	min		
5	1	1	1	1	1	5	Fairly Poor

The worst defect that occurred in ganitri wood was surface checks with a score of 5 (Table 7). Therefore it suggested drying temperature was 53~82°C, while the relative humidity (RH) was 85%~30% (Table 8).

Table 8. The drying temperatures and relative humidity (RH) for ganitri wood

Wood	Temperatures (˚C)		RH (%)	
	Initial	Final	Initial	Final
Ganitri	53	82	85	30

Conclusions

The durability of ganitri wood from subterranean termite is about the same as sengon wood, class IV. Ganitri wood can be easily preserved with borax preservatives. Its retention was 22.9 kg.m^{-3}, while the penetration was 27.8 mm or 94.2%. The drying property of ganitri wood is fairly bad. The suggested drying for this wood is using temperature 53~82 °C and relative humidity 85~30%.

References

[ASTM] American Society for Testing and Materials. 2002. Test Method of Evaluating Wood Preservatives by Field Test with Stakes. ASTM D 1758-02.

[BSN] Badan Standardisasi Nasional.1999. Pengawetan Kayu untuk Perumahan dan Gedung. SNI 03-5010.1-1999

[BSN] Badan Standardisasi Nasional. 2014. Uji Ketahanan Kayu Terhadap Organisme Perusak Kayu. SNI 7207-2014.

Febrianto, F.; Pranata, A.Z.; Arinana; Gumilang, A. 2013. Keawetan alami sembilan jenis kayu dari kampus dramaga Institut Pertanian Bogor terhadap serangan rayap. *JITKT*. 11 (1): 19-28.

Morimoto, M.; Ohta, Y.; Ihara, T.; Arima, K.; Fukumoto, H.; Chavasiri, W.; Komai, K. 2006. Insect antifeedants in Thailand plant extracts against the common cutworm, *Spodoptera litura*, and a subterranean termite, *Reticulitermes speratus*. *Jpn. J. Environ. Entomol. Zool*. 17(1):1-7. https://www.jstage.jst.go.jp/article/jjeez/17/1/17_1/_article/-char/ja/

Nuriyatin, N.; Apriyanto, E.; Satriya, N.; Saprinurdin. 2003. Ketahanan lima jenis kayu berdasarkan posisi kayu di pohon terhadap serangan rayap. *JIPI.* 5 (2): 77-82.

Prihatini, E.; Maddu, A.; Rahayu, I. S.; Kurniati, M. 2020. Sifat Dasar Kayu Ganitri (*Elaeocarpus sphaericus* (Gaertn.) K. Schum.) dari Sukabumi dan Potensi Penggunaannya**.** *Jurnal Ilmu Kehutanan*. 14(1): 109-118.

https://doi.org/10.22146/jik.57480.

Rasmussen, E.F. 1961. *Dry Kiln Operator's Manual*. The US. Departement of Agricultural. Agric.

Rohandi, A.; Gunawan. 2014. Sebaran Populasi dan Potensi Tanaman Ganitri (*Elaeocarpus ganitrus* Roxb) di Jawa Tengah. Jurnal Ilmu Kehutanan. 8(1):25-33.

Saiin, C. 2017. Isolation of morin from the wood of Thai *Artocarpus heterophyllus*. Asian Journal of Natural & Applied Sciences. 6(4): 85-89.Smith, D.N.R.; Tamblyn, N. 1970. Proposed Scheme for An International Standard Test for The Resistance of Timbers to Impregnation With Preservatives. New Zealand (AU): Forest Product Research Laboratory. https://doi.org/10.22146/jik.8550.

Suhaendah, E.; Siarudin, M. *2015.* Pengawetan Kayu Ganitri dan Mahoni melalui Rendaman Dingin dengan Bahan Pengawet Boric Acid Equivalent. Jurnal Ilmu dan Teknologi Kayu Tropis. Journal of Tropical Wood Science and technology. 13(2):185-192. https://doi.org/10.51850/jitkt.v13i2.34

Syafi'i, W. 2001. Eksplorasi dan Identifikasi Komponen Bio-Aktif Beberapa Jenis Kayu Tropis dan Kemungkinan Pemanfaatannya Sebagai Bahan Pengawet Kayu Alami. Bogor (ID). Institut Pertanian BogorTerazawa, S.1965. An easy method for the determination of the wood drying schedule. Wood Industry. Wood Technological Association of Japan. 20 (5): 216-226.

Pandit, I.K.N.; Kurniawan, D. 2008. Anatomi Kayu: Struktur Kayu, Kayu sebagai Bahan Baku dan Ciri Diagnostik Kayu Perdagangan Indonesia. Bogor (ID). Institut Pertanian Bogor

Walker, J.C.F. 2006. Primary Wood Processing: Principles and Practice 2nd ed. London (GB): Springer.

Yamashita, K.; Hirakawa, Y.; Saito, S.; Nakatani, H.; Ikeda, M.; Ohta, M. 2013. Effect of cross-sectional dimensions on bow and surface checking of *sugi* (*Cryptomeria japonica*) boxed-heart square timber dried by conventional kiln drying. *J Jap Wood Res Soc*. 60 (1): 1-11.

Zuhud, E.A.M.; Siswoyo, E.; Sandra, E.; Hikmat, A.; Adhiyanto, E. 2013. Buku Acuan Umum Tumbuhan Obat Indonesia Jilid VII. Jakarta (ID): Dian Rakyat.

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WOOD RESEARCH Journal

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Name and complete address of Authors
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4.Other rules:

4.1. Names of wood are followed by Botanical Name.
4.2. Values between are written using this symbol (⍰), e.g. 3.75 ⍰ 8.92%.
4.3. Editors could modify Figures without changing their substantial meaning.
4.4. References are arranged from A to Z.
4.5. References in text are written as this example: (Palomar *et al.* 1990; Arancon 1997).
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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[c]	4.5 ± 0.8[a]	0.29 ± 0.13[a]
27	88.5 ± 9.3[a]	4.8 ± 0.9[a]	0.40 ± 0.12[a]
29	75.0 ± 11.1[b]	3.8 ± 0.6[a]	0.30 ± 0.07[a]

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.

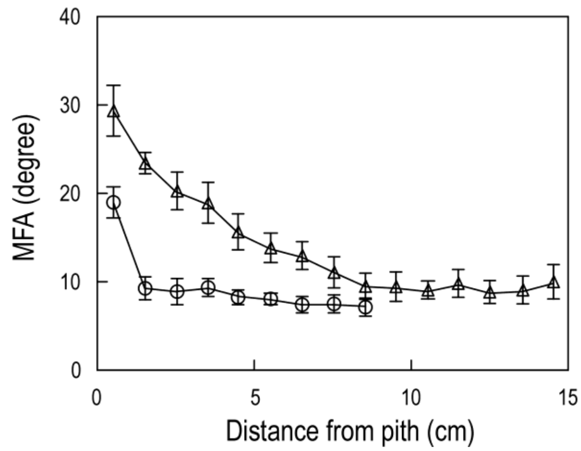

Figure 3. Radial variation of microfibril angle of the S2 layer in tracheid. Open circle, *Agathis* sp.; open triangle, *Pinus insularis*; Bars indicate the standard deviation. (Source: Ishiguri *et al* 2010)

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