

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 extractive 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 findings, 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 disk 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 100°C. 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 temperature was $575 \pm 25^\circ\text{C}$ 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 significantly 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 properties 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

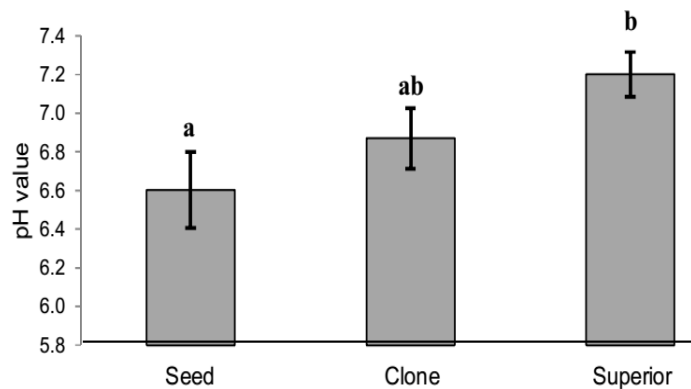


Figure 2. pH value of teakwood by seed source. Average of 4 trees (superior teak) and 3 trees (seed and clone), with the standard deviation error bar. The same letters are not statistically different at $P < 0.05$ by Duncan's test.

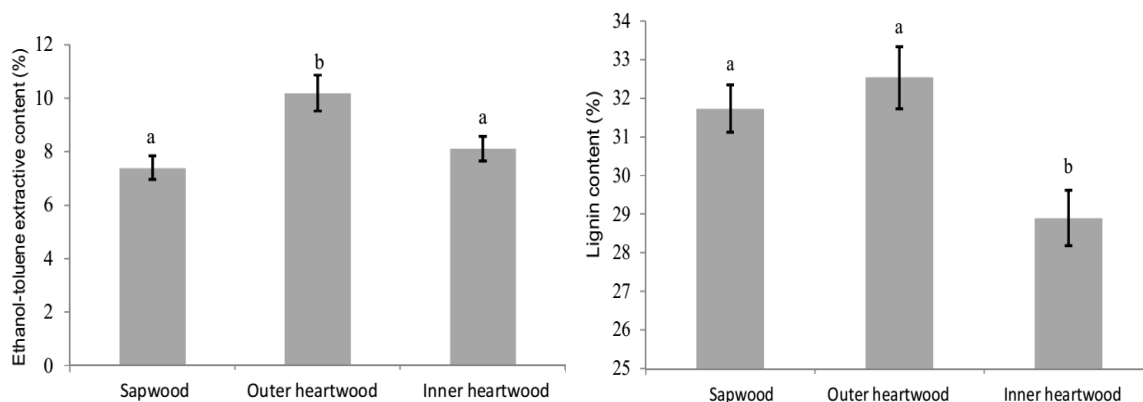


Figure 3. Ethanol-toluene extractive (left) and lignin content (right) of teakwood by seed source and radial position. Average of 4 trees (superior teak) and 3 trees (seed and clone), with the standard deviation error bar. The same letters on the same graphic are not statistically different at $P < 0.05$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