Study of Provenance and Site Variability on Calorific Value and Other Fuel Properties of Teak Stem

Asri Prasaningtyas and Joko Sulistyo

Abstract

Currently Perum Perhutani has conducted efforts to improve the productivity of teak forest by provenance trial. However, only a few studies have so far considered the variation of these main fuel properties of wood under the influence of external factors such as location and provenance. On the other side, the huge amount of waste was regularly generated from primary and secondary wood processings. Therefore, in this research, the calorific value and other fuel properties were investigated and related to provenance and growth site. This research used the stem wood and bark of five provenances (1 to 5) of teaks that were planted at three sites of Perhutani stand (Bojonegoro, Ngawi, Ciamis). The fuel characterisctics of bark were only evaluated at Ciamis site. Compared to bark, wood generally had lower values in ash content, volatile matter content, and density, but had higher values in fixed carbon content, calorific value, and Fuelwood Value Index levels. The caloric values of teak wood and bark were 4,191~4,520 cal/g and 3,545~3,939 cal/g, respectively. Provenance and site interaction had significant effect to the ash content, density, and calorific value in wood. The samples from Ciamis site (code Ft) had the highest level in calorific value. However, the relation between calorific value and density is not clear in this experiment. With regard to bark, provenance 3 (Ft) showed the best energy properties.

Keywords: wood waste, fuelwood, fixed carbon, ash content, heating value

Introduction

Teak is one of the most important timber species and categorized as fancy wood to produce multiple end-uses from handicrafts to heavy construction. In Indonesia, the teak plantations are mostly managed by the state-owned company, Perum Perhutani. Not only does Perum Perhutani manage the plantations, but it also has wooden industries to produce sawn woods, plywoods, and other wood-based panels. Consequently, the logging and wooden industrial wastes have been generated in considerable amounts. Those wastes are utilized for heat and electricity production in those wooden factories and are donated to communities around the forest.

Biomass has been proved as useful and cost-effective alternative renewable energy source in its various forms. The logging residues of final felling operations primariliy include tops, branches, and twigs that have been allowed to remain at the site, whereas the industrial wastes are mainly in the form of slab and sawdust. Along with wood parts, bark wastes are also found in huge numbers. Debarking these logs would be impractical due to their small size. The bark portion in the teak stem was varied depending on site or tree age. The percentage of bark of Indonesian teak reached 25% (Lukmandaru *et al.* 2010), whereas that of Indian teak reached 43% (Tewari *et al.* 2013) although the measurement method was different between the two. Hence, it is necesary to estimate the contribution of the wastes by exploring their fuel properties. However, literature on energy characteristics for teak is available in scanty numbers because this timber is not intended to be used as a commercial fuel. The study reported here serves to fill that gap. It is important to understand the physical and chemical nature of feedstock. The calorific value is the most important characteristic for comparing the effectiveness of any fuel. Any variations in the calorific value between species or in tree parts indicate differences in their chemical and physical compositions.

The quality of teak timber could be improved by intensive management. The potential for managing teak in different sites and under different situations is well documented. Provenance trials to evaluate growth performance, stem form, and productivity in teak trees have been conducted. This trial is the first step in a genetic improvement programme component of plantation establishment. Selection for desirable wood properties, however, was not much emphasized. The effect of site and provenance on the basic properties of teak wood has been investigated in Indonesian teak (Lukmandaru 2012; Hidayati *et al.* 2013) and teak grown overseas (Kjaer *et al.* 1999; Varghese *et al.* 2000; Bhat and Priya 2004; Bhat *et al.* 2005). Significant differences in several parameters were observed among provenances and sites. It is hypothesised that ecological differences between regions of provenance of teak have led to differences in energy properties.

The main aim of this study was to analyse variation in the calorific value and other fuel characteristics of teak stem from main resource bases, depending on the growth-site and provenance. This work used three different sites (Bojonegoro, Ciamis, and Ngawi Forest Management Unit) and five provenances. The information gathered will be useful for further research on the tree improvement aspects of teak with reference to energy properties and to bring out their potential utility for future afforestation programmes. In addition, the best performing provenances can be used for bioenergy production.

Materials and Methods

Field Sampling

The stem samples were taken at different sites (Bojonegoro, Ngawi, and Ciamis Forestry Management Units), whereas five provenances (code 1 to 5) planted in each site were observed. The stem samples were procured from slab wastes of a sawmill in each site. The slab wastes were randomly selected for each provenance. The codes of the provenaces are presented in Table 1. From the slab, wood and bark samples were then separated by hand. The fuel properties of the bark that were determined were only those of samples from Ciamis. The fuel properties of each part, which was obtained at different weights by sawing, were determined. The 2 g of specimens were for moisture content, density, ash content, volatile matter content tests, while 1 g of specimen was for calorific value test.

Table 1. Codes for observed provenaces in three sites

Provenance	Bojonegoro (D)	Ngawi (E)	Ciamis (F)
1	D9	E47	Fi
2	D11	E149	Fk
3	D16	E502	Fp
4	D18	E52	Fr
5	D20	E4	Ft

Laboratory Methods

Densities of dried samples (ca. 2 g) were determined by water displacement volume method (ASTM D 2395-02). An air dried sample (1 g) was burned in an oxygen bomb calorimeter (Parr Instrument Company Inc, no. 1341 3403 series) for determining the calorific value.

Moisture content of sample (2 g) was determined after oven-drying (ASTM D 4442-92). The ash content and volatile matter content (2 g dry basis) were determined using ASTM D5142. Fixed carbon content (FCC %) was calculated from the equation:

FCC (%) = 100 - (% Ash content + % Volatile matter content) ………………………………………..................(1)

Fuelwood value index (FVI) was based on the properties of calorific value, wood density, and ash content (Purohit and Nautiyal 1987):

Fuelwood Value Index (FVI) = Calorific Value (kJ/g) × Wood density (g/cm^3) / Ash content (g/g) ....(2)

Statistical Analysis

Analyses of variance (ANOVA) were performed for evaluating site and interaction on wood samples. For the bark part, the differences among provenances were analysed using one-way ANOVA models. A Tukey's test was used to show which groups were significantly different. All data were analyzed using SPSS 18 for Window.

Results and Discussion

Fuel Properties of Wood

Generally, woody biomass is a renewable fuel because the amount of carbon dioxide resulting from burning is equal to that absorbed during the tree growth. The understanding of fuel properties, i.e., calorific value, ash content, volatile content, fixed carbon content, ultimate carbon, and hydrogen, is very important for utilization of any material as fuel. An ideal fuelwood species should have high calorific value, high wood density, and low ash content. The measurement of proxymate analysis is described in Table 2. The moisture content in the wood was in the narrow range (11~12%), indicating homogenous condition in the field. Ash content was widely varied (0.43~1.87%) and still in the range reported by the previous study (Lukmandaru 2011) on teak grown in Randublatung stand (0.7~3.0%). The ranges of volatile matter and fixed carbon contents were 78.4~83.9% and 15.5~21.7%, respectively. For comparison, the values of volatile matter and fixed carbon contents on teak wood (4 years) from Nigeria were 74.7% and 16.6%, respectively (Chow and Lucas 1988).

The data of density, calorific value, and FVI are presented in Table 3. The density range obtained here was 0.55~0.69 g/cm^3. Previously, the density of teak wood from community forest in Gunungkidul, Yogyakarta, was 0.50~0.67 g/cm^3 (Marsoem *et al.* 2014) while the density of teak wood from Perhutani stand (clonal, 12 years) was 0.51~0.52 g/cm^3 (Hidayati *et al.* 2014). Furthermore, the specific gravity of the wood was 0.62~0.75 (Martawijaya *et al*. 2005). The wide variation was also found in calorific value (4,191~4,520 cal/g). Those levels are lower than those of Martawijaya *et al.* (2005) (5,081 cal/g) and teak grown in Nigeria (4,580 cal/g) (Chow and Lucas 1988). Studies on local commercial species for fuel (Matheson 1990; Cahyono *et al.* 2008) showed the calorific value of 4.197 cal/g for lamtoro (*Leucaena leucocephala*), 4,168 cal/g for gamal (*Gliricidia maculata*), and 3,329~3,514 cal/g for kaliandra (*Caliandra calothyrsus*).

By ANOVA, no significant factor affected the proxymate data in moisture, fixed carbon, and volatile matter contents (Table 3). Provenance × site interaction was significant ($p < 0.05$) for ash content, density, and calorific value. This interaction was manifested in the Ciamis site having smaller values for ash content for several provenances, whereas the highest value was observed in samples from Bojonegoro site. The highest density level (0.69 g/cm^3) was found in samples of Bojonegoro (D18). The highest calorific value (4,520 cal/g) was observed in Ciamis site (Ft). The site and provenance effects, as a single factor, significantly affected FVI, the highest value of which was measured in Ciamis (20.9) and provenance 2 (17.8) (Figure 1).

The provenance indicates various locations that are distinct from each other either geographically or in eco-agri systems. In an earlier report, significant effect of 21 provenances (13 locals and 8 from outside Indonesia) was observed on physical properties measured by non-destructive evaluation (Hidayati *et al.* 2013). Furthermore, variation in heartwood proportion, calcium, and silica contents was measured among the provenances in teak wood from Puerto Rico (Kjaer *et al.* 1999). The effect of provenance on anatomical properties was also observed by Bhat and Priya in Indian teakwood (2004). In this study, the variabilility in ash content, density, and calorific value among provenances led to conclusion that geographic variation may influence the wood properties. Because all trees were growing under similar environmental conditions, the observed differences among provenances may partly be due to genetical variation.

Table 2. Proxymate analysis of teak wood waste (average of three replications).

Sites/provenances	Moisture content (%)	Ash content (%)	Volatile matter content (%)	Fixed carbon content (%)
Bojonegoro				
D9	11.7	1.68 c	80.8	17.5
D11	12.2	0.87 ab	81.3	17.8
D16	11.8	1.61 c	80.5	17.9
D18	12.0	1.13 b	82.2	16.7
D20	12.4	1.87 c	80.7	17.4
Average	12.02 (0.28)	1.43 (0.41)	81.1 (0.68)	17.46 (0.47)
Ngawi				
E47	11.8	1.05 b	81.3	17.6
E149	11.5	0.67 a	78.4	20.9
E502	11.8	1.27 b	80.0	18.7
E52	11.5	0.86 ab	80.6	18.6
E4	12.0	1.08 b	82.1	16.9
Average	11.72 (0.21)	0.98 (0.22)	80.48 (1.40)	18.54 (1.51)
Ciamis				
Fi	12.2	0.62 a	79.8	19.6
Fk	11.6	0.48 a	80.8	18.8
Fp	12.5	0.43 a	77.9	21.7
Fr	12.0	0.84 ab	79.6	19.6
Ft	12.0	0.60 a	83.9	15.5
Average	12.06 (0.32)	0.59 (0.15)	80.4 (2.21)	19.04 (2.25)

Remarks: The same letters on the same column are not statistically different at $P < 0.05$ by Tukey's test.

Table 3. Density, calorific value, and fuel value index of teak wood waste (average of three replications) T

Sites/provenances	Density (g/cm^3)	Calorific value (cal/g)	Fuel value index
Bojonegoro			
D9	0.55ab	4211 d	6.4
D11	0.58b	4243 de	12.2
D16	0.60b	4397 e	7.0
D18	0.69c	4343 de	11.8
D20	0.64b	4239 d	6.1
Average	0.61 (0.05)	4286.6 (79.4)	8.7 (3.03) g
Ngawi			
E47	0.63b	4210 d	10.8
E149	0.56ab	4237 de	15.6
E502	0.62b	4254 de	10.6
E52	0.59b	4274 de	12.8
E4	0.52a	4379 e	8.9
Average	0.58 (0.04)	4270.8 (64.8)	11.74 (2.56) g
Ciamis			
Fi	0.67bc	4388 e	19.8
Fk	0.65bc	4320 e	25.5
Fp	0.56ab	4191 d	25.3
Fr	0.59b	4379 e	12.9
Ft	0.66bc	4520 f	21.1
Average	0.62(0.04)	4359.6 (119.2)	20.9(5.14) h

Remarks: The same letters on the same column are not statistically different at $P < 0.05$ by Tukey's test.

Table 4. Site and provenance analysis of variance in fuel properties and density of teak wood waste

Source of variations	df	Mean square						
		MC	AC	VMC	FCC	Density	CV	FVI
Site (A)	2	0.17	0.38**	9.178	10.9	0.001	2136.7	51.5*
Provenance (B)	4	0.51	2.65**	2.205	9.3	0.008*	33536.1*	606.9**
A x B	8	0.25	0.19*	6.209	5.8	0.010**	26329.9*	2.2
Error	30	0.23	0.08	5.385	5.7	0.001	8719.3	17.0

Remarks: df = degree of freedom, MC = moisture content, AC= ash content, VMC = volatile matter content, FCC = fixed carbon content, CV = calorific value, FVI = fuel value index. ** Significant at the 1% level (one-way analysis of variance); * significant at the 5% level (one-way analysis of variance)

Calorific value of plants is defined as the amount of heat energy released during combustion of plant tissue. The calorific value is mainly affected by elemental composition, moisture content, and quantity of ash produced (Kumar *et al.* 2011). The higher the moisture content is, the less efficient the wood becomes as a fuel since the net calorific value for heating is reduced. After felling, green wood starts to lose moisture quickly at first as it loses free water and then at a slower rate, it loses bound water (Shmulsky and Jones 2011). The moisture content gradually approaches an equilibrium state that fluctuates with temperature and relative humidity as discovered in this study (11~12%). The small variation in moisture content values showed the homogenity of the slabwood samples. Thus, it is not very important as there is no significant difference among the factors.

The highest calorific value in Ciamis site (Ft) need attention in terms of fuel purpose. This tendency is supported by comparatively low ash content levels in Ciamis site. It is known that the fuel quality reduces with the amount of ash present in the biomass. When wood is used as a fuel, the accumulation of ash will interfere with combustion and reduce the efficiency of the furnace. On the other hand, density is one of the important parameters that directly affect the quality of a fuel. The species having higher density are preferred as fuel because of the high-energy content per unit volume and their slow burning property. Previous study showed positive correlation between density and calorific value (Munalula and Menicken 2009; Chin *et al.* 2013). This pattern was not observed in this study as the highest values was measured in Bojonegoro site (D18). The reasons for the dissimilarities were probably due to differences in the chemical composition of the wood, particularly in relation to the polysaccharide fraction and lignin. The higher value of the heat of combustion of lignin, compared with polysaccharides, results from the higher ratio of carbon to hydrogen in that substance (Shmulsky and Jones 2011). In addition, high fixed carbon content adds to high-energy value of plant material. However, by ANOVA, it is discovered that this variation also does not have significance. Variations of cell wall composition indicated in this experiment might be also related to the differences of growing site (soil type, annual rainfall, and temperature).

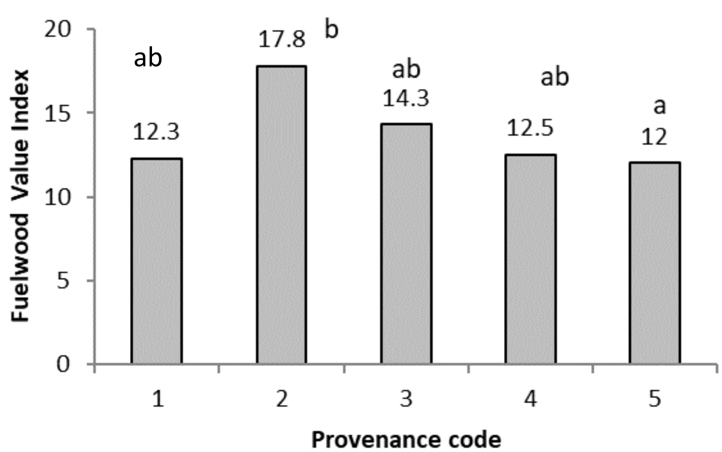

Figure 1. Fuelwood value index of teak wood waste (average of three replications). The same letters are not statistically different at $P < 0.05$ by Tukey's test.

Fuel Properties of Bark

It is essential to achieve maximum utilization of all above-ground portions of each harvested tree, including the bark. Therefore, a detailed analysis of biomass with high feasibility and abundant availability is a crucial step in producing biomass fuel as a commercial fuel. Due to differences in chemical structure, bark and wood showed huge differences in fuel characteristics. Compared to the wood, bark generally had higher values in ash content, volatile matter content, and density, but had lower fixed carbon content, calorific value, and FVI (Table 4). Based on calorific value and FVI, it was found that bark was less effective as fuel than wood.

The comparatively low calorific value in bark could be related to the low value of fixed carbon content and high value of ash and volatile matter contents even though the density is higher compared to the wood. A biomass having low ash content is considered better feedstock. The bark of all evergreen hardwood species usually presents significantly higher ash content than the wood. Majority of ash in a tree is concentrated in the bark tissues because of its importance to physiological functions. Extractives content has positive effect on calorific value of a biomass (Kataki and Konwer 2001). Unlike wood, bark contains suberin and polyphenols, more extractives, and less polysaccharides (Fengel and Wegener 1984). In addition, volatile content is inversely proportional to fixed carbon content and a biofuel rich in fixed carbon (low content in volatiles) will burn slowly. During the combustion process, when the biomass is heated, the volatiles escape first and burn in gaseous state, leaving behind the fixed carbon as char, which burns later in solid state.

By using one-way ANOVA involving only one site (Ciamis) at a time (Table 5), it was known that provenance was significant for any other variable tested ($p < 0.05$). This variability might reflect adaptive responses to geographic variation and environmental conditions. Fp gave the highest significant values in density (0.85 g/cm^3), calorific value (3,939 cal/g), FVI (3.64), and fixed carbon content (18.0%), and the lowest value in ash content (3.84%) and volatile matter content (78.1%). It is noticed that the highest density value of bark was also found in the same provenance (Fp) and this pattern is not found in wood. This implies that calorific value in bark is more related to other characteristics and more predictable than that of the wood. Unfortunately, the evaluation has been conducted only on Ciamis site. It would be interesting to find the trend in bark that is related to the site and to compare it with the wood. Future works should be conducted on more sites as well as to estimate the actual contribution of both wood and barks as fuel.

Table 5. Fuel properties and density of bark waste from Ciamis site (average of three replications).

Provenance	Moisture content (%)	Ash content (%)	VMC (%)	FCC (%)	Density (g/cm^3)	Calorific value (g/cm^3)	Fuel Value Index
Fi	12.4 a	5.30 e	79.0 h	15.7 kl	0.84 n	3813 pq	2.53 s
Fk	12.7 ab	5.87 ef	79.2 h	15.0 jk	0.83 mn	3756 o	2.23 rs
Fp	13.4 b	3.84 d	78.1 h	18.0 l	0.85 n	3939 q	3.64 t
Fr	12.5 a	7.19 g	80.1 i	12.8 j	0.77 m	3545 o	1.59 r
Ft	12.4 a	6.50 ef	79.5 hi	14.0 jk	0.81 mn	3619 o	1.91 r
Average	12.68(0.42)	5.74(1.27)	79.18(0.73)	15.1(1.95)	0.82(0.03)	3734.4(156.2)	2.38(0.78)
Sign.	0.01*	<0.01**	0.01*	<0.01**	0.01*	0.01*	0.03*

Remarks : VMC = volatile matter content, FCC = fixed carbon content,. ** Significant at the 1% level (one-way analysis of variance); * significant at the 5% level (one-way analysis of variance). The same letters on the same column are not statistically different at $P < 0.05$ by Tukey's test.

Conclusions

The effect of provenance and site on fuel properties of teak wood and bark has been studied. The ranges of caloric value in wood and bark were 4,191-4,520 cal/g and 3,545-3,939 cal/g. Significant interaction between those factors was found in ash content, density, and calorific value. Based on the calorific value and ash content, provenance 5 in Ciamis site (code Ft) was found to be the most promising fuel source. There was no particular trend observed betwen density and calorific value. Provenance effect was also found in FVI and the highest value was observed in provenance 2. Characterization on bark showed that provenance factor significantly affected all tested parameters. It is measured that provenance 3 (Fp) had the best fuel properties for the bark part.

Acknowledgements

The authors thank to Perum Perhutani for providing the slab samples and Dr. Ganis Lukmandaru for revising the manuscript.

References

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

Bhat, K.M., P.B. Priya. 2004. Influence of provenance variation on wood properties of teak from the Western Ghat region in India. IAWA Journal 25(3):273–282.

Cahyono, T.D.; Z. Coto, F. Febrianto. 2008. Analisis nilai kalor dan kelayakan ekonomis kayu sebagai bahan bakar substitusi batu bara di pabrik semen. Forum Pascasarjana 31(2):105-116.

Chin, K.L.; P.S. H'ng; E.W. Chai; B.T. Tey; M.J. Chin; M.T. Paridah; A.C. Luqman; M. Maminski. 2013. Fuel characteristics of solid biofuel derived from oil palm biomass and fast growing timber species in Malaysia. Bioenergy Research 6:75–82.

Chow P.; E.B. Lucas. 1988. Fuel characteristics of selected four-year-old trees in Nigeria. Wood and Fiber Science 20(4):431-437.

Fengel, D.; G. Wegener. 1984. Wood: Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin.

Hidayati, F.; F.; Ishiguri, K. Lizuka, K. Makino, Y. Takashima, S. Danarto, W.W. Winarni, D. Irawati, M. Na'iem, S. Yokota. 2013. Variation in tree growth characteristics, stress-wave velocity, and Pilodyn penetration of 24-year-old teak (*Tectona grandis*) trees originating in 21 seed provenances planted in Indonesia. Journal of Wood Science 59:512–516.

Hidayati, F.; F. Ishiguri, K. Lizuka, K. Makino, S.N. Marsoem, S. Yokota. 2014. Among-clone variations of anatomical characteristics and wood properties in *Tectona grandis* planted in Indonesia. Wood and Fiber Science 46(3):385–393.

Kataki, R.; D. Konwer. 2001. Fuelwood characteristics of some indigenous woody species of Northeast India. Biomass Bioenergy 20:17–23.

Kjaer, E. D.; S. Kajornsrichon, E. B. Lauridsen. 1999. Heartwood, calcium, and silica content in five provenances of teak (*Tectona grandis* L.). Silvae Genetica 48(1):1-3.

Kumar, R.; K.K. Pandey; N. Chandrashekar; S. Mohan. 2011. Study of age and height wise variability on calorific value and other fuel properties of Eucalyptus hybrid, *Acacia auriculaeformis*, and *Casuarina equisetifolia*. Biomass and Bioenergy 35: 1339-1344.

Lukmandaru, G.; V.E. Prasetyo, J. Sulistyo, S.N. Marsoem. 2010. Sifat pertumbuhan kayu jati dari hutan rakyat Gunungkidul. Prosiding Seminar "Hutan Kerakyatan Mengatasi Perubahan Iklim", Jogja, pp. 79-86.

Lukmandaru, G. 2011. Komponen kimia kayu jati dengan pertumbuhan eksentris. Jurnal Ilmu Kehutanan 5(1):21-29.

Lukmandaru, G. 2012. Chemotaxonomic study in the heartwood in the heartwood of Javanese teak – analysis of quinones and other related components. Wood Research Journal 3(1):30-35.

Marsoem, S.N.; V.E.Prasetyo; J. Sulistyo; Sudaryono; G. Lukmandaru. 2014. Studi mutu kayu jati di hutan rakyat Gunungkidul. III. Sifat fisika kayu. Jurnal Ilmu Kehutanan 8(2):75-88.

Martawijaya, A.; I. Kartasujana, K. Kadir, Y.I. Mandang. 2005. Atlas Kayu Indonesia Jilid I. Badan Penelitian dan Pengembangan Kehutanan Bogor.

Matheson, A.C. 1990. Breeding strategies for MPTs, Calliandra at CATIE. In: Glover N. & Adams, N. (Editors): Tree improvement of multipurpose species. Forestry/Fuelwood Research and Development (F/FRED) Project, Winrock International, Arlington & Nitrogen Fixing Tree Association, Waimanalo, United States, Multipurpose tree species network Technical Series No 2. pp.87

Munalula, F.; M. Meincken. 2009. An evaluation of South African fuelwood with regards to calorific value and environmental impact. Biomass and Bioenergy 33:425-420.

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.

Tewari, V.P.; K.M. Mariswamy. 2013. Heartwood, sapwood and bark content of teak trees grown in Karnataka, India
Journal of Forestry Research 24(4): 721-725.

Varghese, M.; A. Nicodemus, P.K. Ramteke, Z. Anbazhagi, S.S.R. Bennet, K. Subramanian. 2000. Variation in growth, and wood traits among nine population of teak in Peninsular India. Silvae Geneticae 49:1-5.

Asri Prasaningtyas and Joko Sulistyo*

Department of Forest Products Technology, Faculty of Forestry, Universitas Gadjah Mada,
Jl. Agro No. 1, Bulaksumur, Yogyakarta, Indonesia
Tel. : +62-274-6491428 ,
Fax. : +62-274-550541
**Email* : jsulistyo@ugm.ac.id