

Variation of Heartwood Proportion and Wood Colour from Fast Grown 5-Year-Old Teak

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Abstract

The heartwood percentage and wood colour of fast plantation grown teak destined for harvest at 5 years of age were characterized using automatic image processing 'ImageJ' routines and CieLab's colour system with the following coefficients: L for lightness, a* for redness, and b* for yellowness. Analyses were conducted on material from different dry and wet sites. Comparison with 6-year-old plantation from a dry site was conducted to study differences arising in older trees. Analyses of variation of those properties between and within different tree diameter classes were also conducted. The results showed that brightness, redness, and yellowness values of 5-year-old teak trees were 60.7, 10.7 and 23.1, respectively. Tree clone had a more dominant effect on wood colour and heartwood proportion than site, thus if specific colour preferences are needed of plantation trees, clone selection is important. The drier site produced larger proportions of heartwood in trees, as well as a more attractive figure. The trees produced heartwood proportions of 20% and 14% from the dry and wet sites respectively. On average, these 5-year-old teak trees already produced 18% heartwood. Faster tree growth (larger diameter) appeared to have produced significantly larger heartwood proportions. Radially, the palest colour (the highest L but the lowest a*b* parameters) occurred in an area between heartwood and sapwood indicating the presence of a transition zone in all the tree samples.

Keywords: extractives, super teak, clone, young teak, wet and dry sites, Indonesia.

Introduction

In Indonesia, there has been an effort to cultivate fast grown plantation teak with the aim to harvest it within 5 years-'super teak'. However Saranpaa (2003) and Thulasidas *et al.* (2006) indicated that timber from shorter rotations brings a lower price on timber markets as it is generally believed to exhibit a lower quality. While intensive timber production may induce changes to the anatomical and technical properties of the wood colour, density, durability, and mechanical properties, potentially this may affect the suitability of using such timber for high quality products (Saranpaa 2003). To test this assertion, an investigation was undertaken of the wood properties to determine the possible utilization potential of the very fast grown teak.

One of the wood properties highly regarded for panelling and furniture is the wood figure (Nocetti *et al.* 2011) which is characterized by the presence of a rich wood-colour and the presence of a coloured heartwood. Teak is highly regarded for its wood colour and this is considered as an important aspect for its marketing (Nocetti *et al.* 2011). Consequently, it is the attractive figure that is one of the major reasons why this species is widely planted commercially (Moya and Marin 2011).

In addition to the effect on figure, wood colour might be useful as an indirect indicator of the level of resistance to insect and fungi attack (Gierlinger *et al.* 2004; Lukmandaru and Takahashi 2008). Wood colour also tends to reflect the chemical make-up of the heartwood (Lukmandaru *et al.*

2009) but to a lesser extent the sapwood. Similarly a study on larch heartwood by Gierlinger *et al.* (2004) revealed that the amount of polyphenols turned out to be strongly correlated with the reddishness (a*) of larch heartwood and this provided an indirect correlation between the red hue and brown rot decay resistance. Furthermore, they proposed that colour characterization to predict decay resistance of the wood might be beneficial in tree breeding programs for optimization of timber utilization.

Nocetti *et al.* (2011) reported that wood colour was possibly affected by environmental influences. Combination of dry climate and fertile site tended to produce more yellowish-brown colour (higher yellowness (b*) parameter which corresponds to the blue yellow axis) of the heartwood. In their study, climate was considered as the first-order contributor for explaining wood colour variation.

Furthermore, according to Trockenbrodt and Jouse (1999), proportion of heartwood become an important criterion influencing the wood quality and potential utilization of young plantation teak. Moya and Marin (2011) mentioned that this property is a very important characteristic of teakwood. According to Pinto *et al.* (2004), heartwood proportion varies between and within species. It is influenced by growth rate, stand type, individual tree characteristics, site conditions and genotype (Pinto *et al.* 2004), as well as by tree clone (Moya and Marin 2011). However, according to Bouslimi *et al.* (2013) only limited tree growth information is available on within-tree heartwood proportion, and site effects.

Teak in this study has been planted in Indonesia since 2007 (first harvesting started in 2012) in many areas which can be classified into wet and dry sites. The objectives of the study were to investigate heartwood proportion and wood colour of the 5-year-old teak planted on different sites at radial and axial variations. The effect of tree clone was also considered to see to what extent those properties are influenced by the genetic sources and the environment. As the variation in the stem diameter of the trees at the same age is quite large, the effect of growth rate (tree growth) on wood colour and heartwood proportion was also considered.

Materials and Methods

Materials Preparation

Eighteen trees ranging from small, medium and large diameter stems from 5-year-old fast grown Jati Utama Nasional (JUN) teak plantation forests in Bogor, West Java, Indonesia, and Magetan, East Java, Indonesia (Table 1), were selected and felled for wood colour and heartwood percentage measurements. For comparison, 6-year-old trees from dry site (Magetan) were also cut down. Three discs at five centimetres thickness were taken from bottom, middle and at the top (stem diameter minimum 7 cm) of each tree. In addition, specimens were taken from sawn boards

between the bottom and middle sections to observe the colour variation in the longitudinal direction (along the length of boards). Seven boards were selected as replicates from each of the sites and for each tree diameter class. In total 60 discs and 42 boards were prepared for measurement.

Site Information

Climate data were collected from the Meteorology, Climatology and Geophysics Agency at Darmaga Station, Bogor, West Java (representing Site 1-wet site) and Karangploso Station, Malang, East Java (representing Site 2-dry site) from 2007 to 2013 (during the course of tree growth at the plantations). The climate data covered average temperature, average humidity, and rain fall, number of rain days, air pressure, and wind velocity.

Physical and chemical soil properties were obtained from the primary data collection at both sites. Three soil sub samples were gathered from 0-30 cm depth and quartered to obtain single 0.5 kg samples for soil testing at the Soil Research Centre, Ministry of Agriculture, Bogor, and Lab. of Soil Science and Natural Resource, Faculty of Agriculture, Bogor Agricultural University, Bogor. A summary of climate and soil properties data is presented in Table 2.

Table 1. Selected tree samples***

No	Tree code	Diameter [cm]	Height* [m]	Clone**	Tree code	Diameter [cm]	Height* [m]	Clone**
Site 1 (West Java)				Site 2 (East Java)				
Class Diameter 1: large (>26 cm)								
1	SA22	30.25	16.00	A	K198	29.3	10.5	B
2	AC18	31.4	18.20	B	S12	29.3	12	C
3	AC23	32.2	13.60	A	S101	28.7	9.2	C
Class Diameter 2: medium (17-25 cm)								
1	S 50	20.7	11.50	-	S108	21.5	8.5	-
2	S 74	21.3	9.10	-	S153	24.2	6.5	-
3	S 105	22.9	11.40	-	S78	24.5	8.65	-
Class Diameter 3: small (10-16 cm)								
1	S 89	14.3	9.65	-	S27	14.3	6.4	-
2	S 53	11.9	8.90	-	S2	16.6	6.7	-
3	S 120	14.6	10.10	-	S10	16.2	5.8	-
6-year old trees								
1					M73	27.7	10	
2					Y56	27.4	12	

*Economic height: height of stem at the top with minimum diameter of 7 cm

**In this study, DNA testing to check the tree clone was conducted only on wood from the large diameter classes

***Damayanti *et al.* (2019)

Colour and Heartwood Measurements

Colour Measurement. CR10 Tristimulus colourimeter (Konika Minolta®) with 8 mm aperture at the point measurement was used for measuring the colour coefficients of the sapwood, transition and heartwood zones

from cross sections of disc samples, and also from the sapwood and heartwood zones of the sawn boards.

Three replicate measurements were conducted at different locations from each zone. All colour measurements were made using standard illumination conditions: D65 and 10 degrees observer (HunterLab 2012). Small circular areas were marked on the faces of test specimens to ensure that

repeatable measurements were performed at the same location. The colour coefficients L a*b* were measured and used to represent wood colour of each sample. All measurement points were treated as target (absolute measurements).

According to HunterLab (2012) procedure, the CIELab colour system estimates the wood colour coefficients using three coordinates: L for lightness represents the position on

the black–white axis (L = 0 for black, L = 100 for white), a* for the chroma value, this defines the position on the red–green axis (+100 indicates red shades, -100 indicates green shades), and b* for chroma value and defines the position of the yellow–blue axis (+100 indicates yellow shades, -100 indicates blue shades). Measurements were conducted at room temperature.

Table 2. Summary of climate data and soil properties of plantation sites from 2007 to 2013 at Bogor (Site 1) and Magetan (Site 2)

Climate/Soil Properties	Unit	Site 1 (Wet)	Site 2 (Dry)
Location		Bogor (West Java)	Magetan (East Java)
Elevation	m.a.s.l	157	110
East longitude		106°51'	111°24'
South latitude		6°35'	7°44'
Average temperature	°C	25.8 (25.5-26)	26.9 (26.6-27.1)
Average humidity	%	82.8 (81-85)	76.5 (74-81)
Average annual rainfall	mm	3667 (2845-4051)	2330 (1739-3749)
Number of dry months	Months	0	3
Average number of rain days	Days	23.3	15.6
Wind velocity	Km/Hour	3.3	11-18
Average air pressure	Millibar	989.3	1011.6
Mean tree diameter	cm	22	23
Mean tree height	m	12	8
Ca	Me/100g	13.78	39.63
Mg	Me/100g	2.23	4.76
K	Me/100g	0.54	3.30
ECEC	Me/100g	17.17	19.25
Fe	%	3.38	3.29
Al	%	6.3	5.1
Mn	ppm	1621	950
Cu	ppm	29	50
Zn	ppm	66	156
P (Bray 1*)	ppm	14.80	13.20
Rough Silicate	%	74.68	59.94
pH of H ₂ O		5.90	7
Soil texture		14% sand, 20% dust, 65% loam	46% sand, 32% dust, 22% loam

Ca calcium, Mg magnesium, K potassium, ECEC Effective Cation Exchange Capacity, Fe iron, Al aluminium, Mn manganese, Cu copper, Zn zinc, P phosphorus

Me/100g=meg+/100g=meg/100g= Mili-equivalent of Hydrogen per 100 g of dry soil (SI cmol+/kg)

*Bray method: Used for the determination of available Phosphorus content in the soil (Sawyer and Mallarino 1999).

Heartwood Measurement. To minimize the human decision making, automatic image processing was used to determine heartwood percentage using ImageJ® freeware routines (Mekhtiev and Torgovnikov 2004). A digital camera was employed to capture images from each sanded disc. An outline of the steps for calculating the heartwood percentage

is presented in Figure 1. Total disc area was determined by thresholding B/W images of disks. The heartwood area was conveniently further thresholded due to grey level differences from the background wood to provide proportions of heartwood from each disk.



Figure 1. Automatic image processing procedure using ImageJ® to determine heartwood percentage from digital images of disk sections

Data Analysis

Tests to determine if the data were normally distributed were conducted using Saphiro-Wilk W test (Statistica®). Differences between 5- and 6-year-old teak (age differences) and between sites (different teak plantations) were carried out by using Mann-Whitney U-test (Statistica®). Furthermore, variation among different clones, different tree diameter classes and different axial and radial positions were analysed using Kruskal-Wallis ANOVA test (Statistica®). These non-parametric tests were used since the data were not normally distributed.

Results and Discussion

Wood Colour and Heartwood Proportion of 5-year-old Fast Grown Teak

In general, the brightness (L) of 5-year-old teak trees from both plantations was 60.7, and the redness (a*) and yellowness (b*) values were 10.7 and 23.1, respectively. Tests were further conducted to analyse the difference between 5- and 6-year-old JUN teak trees (Table 3). As the 6-year-old teak was only available from the dry site, the comparison was carried out between 5- and 6-year-old teak trees at this site. The older plantation produced significantly lower L and b* and higher a* values.

Table 3. Average colour parameters of 5- and 6-year-old JUN trees (Dry site)

Colour Parameter	Mean and Standard Error				P value
	5 years (N=251)		6 years (N=33)		
L	60.4	0.5	55.5	0.8	0.00**
a*	11.1	0.2	13.1	1.3	0.00**
b*	23.8	0.2	23.2	0.4	0.014*

*= Significant at $\alpha < 0.05$; **= Significant at $\alpha < 0.01$ according to Mann-Whitney U test

Table 4. Colour of teak planted in Indonesia and India

Age (years)	Annual Rainfall (mm)	Colour Parameter			Authors
		L	a*	b*	
5	1739-3749	60.4	11.1	23.8	This study
5	2845-4051	61.0	10.11	22.15	This study
6	1739-3749	55.5	13.1	23.2	This study
8	1400-1800	65.2	4.3	23.8	Lukmandaru and Takahashi (2008)
30	1700-2500	65.7	4.8	25.48	Lukmandaru and Takahashi (2008)
35	2500-3500	52.3	6.35	21.1	Thulasidas <i>et al.</i> (2006)
35	1500-2300	54.0	6.37	23.4	Thulasidas <i>et al.</i> (2006)
35	2500-3000	56.4	6.8	23.4	Thulasidas <i>et al.</i> (2006)
51	1300-2000	60	5.5	24.25	Lukmandaru and Takahashi (2008)

Table 5. Heartwood proportion of plantation teak grown in Indonesia and Malaysia

Ages (years)	Teak		Authors	Location
	Fast Grown	Teak grown from seed		
3	29.81% (bottom)	25% (bottom)	Wahyudi and Arifien (2005)	Central Java, Indonesia
	16% (stem 2.5-4.8 cm)		Trockenbrodt and Jouse (1999)	Malaysia
4	16.5-63% (stem diameter 5.8-10.9 cm)		Trockenbrodt and Jouse (1999)	
5	22.61 % (average from the base, middle and top part of trees)	20.31%	Sumarni <i>et al.</i> (2008)	South Sumatera, Indonesia
	25-65% (stem diameter 6.9-11.4 cm)		Trockenbrodt and Jouse (1999)	Malaysia
	18%		Wahyudi <i>et al.</i> (2014)	West Java, Indonesia
	21%		Damayanti (2010)	Tegal, Central Java, Indonesia
	20% (average stem diameter 23 cm)		This study	Magetan, East Java, Indonesia
	14% (average stem diameter 22 cm)		This study	Bogor, West Java, Indonesia
6	44.31%		Anisah and Siswamartana (2005)	Ciamis, West Java, Indonesia
	20.12%			Ngawi, East Java, Indonesia
	23% (average stem diameter 27.5 cm)		This study	Magetan, East Java, Indonesia
7	39.6%	20.3%	Krisdianto and Sumarni (2006); Krisdianto (2008)	Penajam, East Kalimantan, Indonesia
8		58.23% (bottom) 46.30% (middle)	Wahyudi and Arifien (2005)	Central Java, Indonesia

The brightness indices of the 5- and 6-year-old teak from this study were lower than that for the 8-year-old trees planted in Gunungkidul, Jogjakarta. The annual rainfall from the Gunung Kidul area is much lower than the dry site's annual amount. The average L value for 8-year old teak was 65.2 (Lukmandaru and Takahashi 2008). It showed that even in older wood, the very dry environment potentially produced lighter coloured wood. Older teak trees from Kerala, India, aged 35 years planted under rather similar climate conditions to this study produced darker coloured timber with a similar yellowness index (Thulasidas *et al.* 2006). Summary of wood colour of 5- and 6-year-old JUN teak and comparison with older age teak is presented in Table 4.

Gierlinger *et al.* (2004) stated that old trees from natural stands had higher a^* values than young trees from the same provenance grown in plantations. However, in this current study, the redness value was almost twice as high as that from older teak. Possibly this was because there are differences between genetic or environmental factors such

as soil fertility and climatic conditions (Moya and Marin 2011). It is proposed that measurements of colour from different aged plantations grown at the same location should be conducted to study trends in wood colour due to age differences.

As shown in Table 5, average heartwood proportion from both sites measured from the base to the top part of 5-year-old JUN teak in this study was 18% (average diameter of the discs was 17 cm). This result was similar to the heartwood proportion of 17% for the same teak planted in West Java, Indonesia (Wahyudi *et al.* 2014). Six-year-old JUN teak in this study produced a larger proportion of heartwood (23%) even though it was not statistically significant compared to 5-year-old JUN teak ($p = 0.22$). These values were far lower than the 76-year old teak whose heartwood proportion reached 84% (Wahyudi 2000; Wahyudi and Arifien 2005). An outline of these heartwood proportions of plantation teak of different ages and sites is presented in Table 5 and the appearance of the heartwood of 5-year-old fast grown teak is presented in Figure 2.



Figure 2. Heartwood of 5-year-old fast grown teak from dry site (left) and wet site (right)

Wood Colour and Heartwood Proportion of Wood from Wet and Dry Sites

Differences were observed between wet and dry sites as reflected by different a^* and b^* coefficients. Even though the L value was higher (the timber was lighter) from the wetter site, there was little influence upon L. In contrast to the wetter site, more distinct figure was observed from the

wood from the drier site due to higher redness (a^*) and yellowness (b^*). This result is in agreement with Nocetti *et al.* (2011) who noted that a dry and fertile site produced more yellow heartwood colour. Besides having drier climate, according to the ECEC (Effective Cation Exchange Capacity) value, Site 2 also has a higher ECEC value and more fertile soil than Site 1. Colour of the teak heartwood from the wet and dry sites is presented in Figure 3.



Figure 3. Appearance of the wood colour of teak wood grown from a wet site (left) and a dry site (right)

Furthermore, the result from this study is also in line with Thulasidas *et al.* (2006) findings for 35 year old teak planted on different wet and dry sites. Their studies revealed that while no significant differences were observed in brightness and reddishness, yellowness of wood from wet sites was less than that from the dry sites; this was proposed to act as a limiting factor for timber prices.

Bhat (1999) in Moya and Calvo-Alvarado (2012) identified two broad wood colour groups from contrasting geographic regions in Asia. They suggested that a uniform golden yellow to brown colour is typical of one group wood from tropical wet climates along the coast, and the second

group is represented by a darker colour of the wood from tropical dry climates from central areas. While the L coefficient was not statistically significant in this study, the results are in agreement with the proposed groupings.

It is still unclear which environmental factor is responsible for elucidating wood colour variation, but according to Moya and Calvo-Alvarado (2012), wood from drier climates produces darker wood colour. Slower growth due to dry seasons will create a larger stem diameter (Thulasidas and Bhat 2007), which is in line with the current study (Table 2) although in this study this difference was not significant ($p = 0.89$). The length of dry season and deficit in

soil water reduce the tree growth (shown by significantly shorter trees from the dry site, Table 2) during this period, and induces the heartwood formation (Kokutse *et al.* 2010). Gierlinger *et al.* (2004) and Moya and Calvo-Alvarado (2012) suggested that extractives will be formed at different rates in the heartwood of trees from drier climates than those from humid climates. These are possibly the reasons why heartwood proportion of wood from wet and dry sites were statistically significant in this study. The humidity at the wet site was also higher than that from the dry site (Table 2). In keeping with this, the wood produced from the drier site in this study had a larger proportion of heartwood (20%) than wetter site (14%) as seen in Figure 2.

Gierlinger *et al.* 2004; Kokutse *et al.* 2010; Lukmandaru and Takahashi 2008 suggested that the higher dynamics of heartwood's formation in trees from drier sites produce higher extractives content leading to the formation of a darker and redder wood colour. On the other hand Moya and Calvo-Alvarado (2012) indicated that less extractive material will be produced during the growth of trees in growth-favourable environmental conditions (wet sites) because reserve material is used for other needs of the tree rather than for the formation of extractives and heartwood, so the timber will be less dark.

When termite resistance is considered, Lukmandaru and Takahashi (2008) claimed that the wood is more resistant when it is darker and redder. This was based on the moderate correlation between wood brightness and redness and the survival rate in the first week after exposure. However, these authors believe that the relationship between the termite resistance and colour is complex because it is known that the colour of wood tends to be related to the quantity and types of wood extractives. Other studies have attempted to relate wood durability to wood colour (Gierlinger *et al.* 2004), but they may or may not be appropriate for modelling the durability of fast grown teak. Based on studies of old teak (Lukmandaru and Takahashi 2008), the durability of fast grown material has yet to be assessed and potentially it is worthy of further study.

Wood Colour and Heartwood Proportion between and within Clones

Clone factor significantly affected heartwood colour (Moya and Marin 2011). In this study, trees from the same clone planted on the same site produced the same colour coefficients. Furthermore, the same clone if planted on different sites consistently produced the same a^* and b^* coefficients. Gierlinger *et al.* (2004) stated that the wood colour of the same provenance grown on different sites is similar. However in this study, the L coefficient was different as darker coloured wood was produced from the drier site. The extreme difference in annual rainfall between both sites had an influence on the L coefficients even if the trees originated from the same clone.

Moreover, in this study, it was shown that trees from different clones planted at the same location resulted in different L and b^* values. This is supported by Gierlinger *et al.* (2004) who observed that in Larch (*Larix* spp.) trees of different provenances planted on the same site showed different colour characteristics. Consequently, the different clones of teak in this study may have originated from different provenances.

From this section it can be summarized that the colour characteristics of wood from different clones may still appear even if they are planted on a same site. This study showed that clone had a greater influence on the wood colour than site. Thus, it is suggested that if specific colour preferences are needed of plantation trees, clone selection is important (Damayanti *et al.* 2019).

Analysis of variance of heartwood proportion in clones could not be applied as there were only three to six discs from each clone. Table 6 shows the heartwood proportions of the same clone planted at the same site (green rows), different clone planted at the same sites (yellow rows), and the same clone planted on different sites (blue rows). Generally, variation among the clones showed that same clone planted at the same site produced a similar amount of heartwood; also different clone planted at the same site produced different amounts of heartwood, while the same clone planted on different sites exhibited similar heartwood proportions (and consistently, drier sites produced larger heartwood proportions). Similar to that of wood colour, the result showed that the heartwood proportion from young teak was more influenced by clone than site. The result is in good agreement with Moya and Marin (2011).

Table 6. Proportion of heartwood from 5-year-old fast grown teak clones

Clones	Sites	Heartwood Proportion (%)
A	Wet	12
A	Wet	25
C	Dry	19
C	Dry	21
A	Wet	18
B	Wet	28
B	Dry	32
C	Dry	20
B	Wet	28
B	Dry	32

Effect of Tree Size on Wood Colour and Heartwood Proportion

Additional observations were conducted to assess the wood colour variation among different tree diameter classes. The analysis was conducted because a large variation was observed between tree diameters of trees of the same age.

In this study, wood colour characteristics were different among different tree diameter classes. In contrast with the small diameter class, the largest diameter class exhibited the lowest L and the highest a^*b^* coefficients.

Wood colour affecting the figure of wood in teak exhibited an inverse relationship between L and a*b* coordinates, lightness, redness, and yellowness, respectively. Hence, faster grown trees produced more attractive wood colour, showing a nicer figure.

Because there is a site effect on heartwood proportion, an analysis was also conducted for each of the sites. On the wet site, the faster tree growth produced larger diameter trees which had significantly larger heartwood proportions ($p = 0.02$), viz 13%, 9% and 21% for small, medium and the large diameter classes respectively. While, faster growth resulted consistently in the production of a larger proportion of heartwood from the drier site, this was not significant statistically ($p = 0.33$). The proportion of heartwood produced from small, medium and large trees was 16%, 20% and 24% respectively, and this is in line with the results for radiata pine obtained by Harris (1954) in Cown *et al.* (1991) who stated that dominant trees with deep root systems and an adequate water supply would tend to form greater amounts of heartwood.

Wood Colour Variations within Trees

Strong patterns of colour were evident from wood along the tree radius from trees from both sites. Even though the trees are still young, they exhibited clear colour variations from the sapwood, transition zone and the

heartwood. Colour coefficients along the axial and radial positions of 5-year-old teak are shown in Table 7.

In the wet site, redness and yellowness index significantly decreased at different axial positions along the tree. The highest a* and b* coefficient was observed at the bottom of the trees, and became paler with increasing tree height. In the dry site, a more uniform colour was exhibited axially. This means that between the bottom, middle and top part of the trees, the L, a* and b* values were similar. According to Moya and Calvo-Alvarado (2012), this more uniform colour within trees produced from the dry site has met one of desired industrial goals for improving the uniformity of wood colour. However, for teak, colour variation of the wood is more visually appealing, but if uniformity is required it can be rendered by staining. Studies on colour variability in the axial direction have not previously been reported.

In the radial direction, the transition zone showed higher L values than the sapwood. On the other hand, redness (a*) was least in the transition zone, and highest in heartwood. The transition zone also had the lowest yellowness (b*), while sapwood had the highest. Redness dominated the heartwood, and yellowness dominated the sapwood. Gierlinger *et al.* (2004) proposed that different colour characteristics between the heartwood and sapwood are probably due to the oxidation and polymerization of phenolic components during and after heartwood formation.

Table 7. Average Axial and radial colour coefficients of 5-year-old teak trees

Colour Parameters	Axial (mean)			P value	Radial (mean)			P value
	Bottom	Middle	Top		Sapwood	Transition	Heartwood	
Wet Site								
L	60.1	61.5	61.8	0.61	65.1	67.1	52.4	0.00**
a*	10.9	9.6	9.6	0.04*	9.0	8.1	12.7	0.00**
b*	23.2	21.1	21.9	0.01**	23.4	20.5	21.9	0.00**
Dry Site								
L	61.0	59.2	61.1	0.61	64.0	66.5	53.1	0.00**
a*	10.8	11.6	11.0	0.33	10.1	8.9	13.6	0.00**
b*	23.9	23.7	24.0	0.59	24.4	22.7	24.0	0.00**

*=Significant at $\alpha < 0.05$; **= Significant at $\alpha < 0.01$ according to Mann-Whitney U test

Consistently, transition zones had the palest colour (the highest L and the lowest a* and b*). This result is consistent with the transition zone definition proposed by Hillis (1987) as the narrow and pale-coloured zone surrounding heartwood. This relatively white zone devoid of colour from of the transition zone is also due, in part, to that wood having a lower moisture content as can be seen in Figure 4.

The phenomenon of transition zone in teak wood was also observed by Barnacle and Ampong (1974) in teak planted in Ejura, Ghana. They experienced preservative penetration problems associated with poor ingress of

treatment chemicals in relatively wide zones of transition zone in 15 cm diameter fence posts from 12-15-year-old unpruned plantation grown teak. Some posts also showed alternating penetrated and non-penetrated bands in the heartwood. Furthermore, Norton (2012) observed full outer sapwood penetration and virtually no penetration in the heartwood with vacuum pressure impregnation using copper based preservative (CCA and Copper Naphthenate) in six specimens of six and a half year old teak trees planted in tropical north Queensland, Australia. In this case, the transition zone which was apparent in three of six samples was also not penetrated.

In the light of the report from Thulasidas *et al.* (2006), there appears to be a need for further study if improved durability of young plantation grown teak is required since timber from young plantations generally tends to have lower

natural durability. The presence of refractory transition zones appears to present additional difficulties for adequate penetration of preservatives similar to that of the heartwood.



Figure 4. Transition zone (arrows) as it appears in cross sections of all logs cut from 5-year old fast grown teak trees

Conclusions

Colour characteristics of the same clone planted at the same or different sites, appeared to produce a uniform colour. Only the lightness intensity (L value) was influenced in wood from very different wet and dry sites. Type of clone had the most dominant effect on wood colour rather than site. Similar to colour, clone had a more dominant effect on the proportion of heartwood than site, and the drier site produced a larger proportion of heartwood. The transition zone was observed along the radius and was shown by measurement to have the palest colour area surrounding the heartwood. This zone also had the highest L and the lowest a^* and b^* values. More attractive figure was observed from trees planted on drier sites than wetter ones as measured by higher redness (a^*), yellowness (b^*) and lower lightness values (L).

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