Effect of Clone and Sites for Wood Properties of Fast Grown Teak and Determination of The Best Clone for Next Cultivation in Teak Plantation Industries

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Abstract. Cloning copies all of the characteristics of an individual, not just the optimal characteristics, and thus the clonal plantations have a vital role in increasing forest productivity. Determination of the surviving clone with the best properties in all plantation sites may assure uniformity in wood properties. Determination of the surviving clone with the best properties in all plantation sites may assure uniformity in wood properties. The more uniform the wood properties, the higher price the industries are willing to pay. This study aimed to investigate wood properties variation within and between selected clones at two different plantations of super teak, in order to investigate the effect of genetic or environment on wood properties and to determine the best clone for subsequent cultivation based on the wood properties. Research was conducted on three clones of 5-year old fast grown teak at two locations. The results showed that genetic factor more influenced the uniformity of wood color. Furthermore, site effect was more dominant on wood density, wood hardness, and radial unit shrinkage, while MOE, fibre length, and 'crystallinity' were affected by genetic effect. Effect of clone was not clear on radial and tangential shrinkage, tangential unit shrinkage and MOR. In the case of fast grown teak, Clone B can be recommended for future plantation at both sites.

1. Introduction

Teak (Tectona grandis Linn. f) is a popular and highly desirable timber for furniture, flooring, construction building, poles, boat making and appearance grade veneer. Recent data shows that globally, the demand of plantation teak increased 47% by volume and 58% by value for the period of 2010 - 2012 [1]. Mature teak is mostly harvested at the age of approximately 80 years [2]. The rotation age of established plantation forests from India and Indonesia is 50 to 80 years [3]. As a result of high demand, this long rotation has caused the price of teak wood to increase significantly due to a limited supply. Consequently, timber industries that rely on teak as a source of raw material face difficulties with the continuity of stock supply [4].
This situation has prompted the silviculturists to investigate various methods which would allow establishing shorter rotation stands and a faster growth of teak. One of the methods already developed is through vegetative cultivation, such as tissue culture, bud grafting and shoot cutting. As a result, the rotation age can decrease from 50 - 80 years to 20 - 40 years [5]. The new concept of fast growth with high productivity management of teak plantations is widely developed in the world, and it now becomes a general trend [6].

In Indonesia, many types of growing regimes of fast growing teak have been widely cultivated. The combination of breeding technology and intensive silviculture treatment has enabled teak timber producers to harvest the tree at a very young age, for example as early as 5 years. Timber communities call this timber “super teak”.

The super teak was planted from several selected mother trees (clone). Clonal plantations have a vital role in increasing forest productivity [7]. Individual selection based on higher growth rate of clones may accede to the use of younger-age trees and consequently reducing the plantation harvesting cycle [8].

Cloning copies all of the characteristics of an individual, not just the optimal characteristics [9]. Furthermore, it is not possible to select only one trait for a specific site if the clone is already proven to survive and provide the desired wood properties. Thus, looking for groups of clones with similar characteristics that can be planted in small areas with specific site conditions is desired [9].

Determination of the surviving clone with the best properties in all plantation sites may assure uniformity in wood properties. The more uniform the wood properties are, the higher price the industries are willing to pay [10]. The first section of this paper reports on the investigation of the wood properties variation within and between selected clones at two different plantations of super teak, in order to determine the effect of genetic or environment on wood properties. The second section of this study aimed to determine the best clone for subsequent cultivation based on the wood properties investigated: wood colour, heartwood proportion, density, shrinkage, unit shrinkage, hardness, bending properties (modulus of elasticity (MOE) and modulus of rupture (MOR)), fibre length, micro fibril angle (MFA), and degree of crystallinity.

2. Materials and methods

2.1. Materials

Six trees from large diameter stems (diameter > 26 cm) of 5-year old super teak plantation forests in Bogor, West Java, Indonesia, and Magetan, East Java in Indonesia were selected and felled. Trees SA22 and AC23 were from Clone A; both trees were planted in the wet site (Bogor). Furthermore, trees AC18 and 198 were originated from Clone B and were planted at different sites (Tree AC18 in the wet site while tree 198 in the dry site). Trees 12 and 101 were from Clone B; both trees were planted in the dry site (Magetan). Evaluation within clone was carried out at the same plantation sites (Clone A in the wet site and Clone C in the dry site), and at different plantations (Clone B planted at wet and dry sites).

| Tree code | Diameter (cm) | Height* (m) | Clone*** | Tree code | Diameter (cm) | Height* (m) | Clone*** |
|-----------|---------------|-------------|----------|-----------|---------------|-------------|----------|
|           |               |             |          |           |               |             |          |

Table 1. Tree selection used in the study.
| Site 1 (West Java) | Site 2 (East Java) |
|-------------------|-------------------|
| SA22              | 30.25             | A | 198 | 29.3 | 10.5 | B |
| AC18              | 31.4              | B | 12  | 29.3 | 12   | C |
| AC23              | 32.2              | A | 101 | 28.7 | 9.2  | C |

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

2.2. Methods

2.2.1. Wood properties measurement and analysis. The wood properties investigated were wood colour, heartwood proportion, density, shrinkage, unit shrinkage, hardness, bending properties (MOE and MOR), fibre length, MFA, and degree of crystallinity.

2.2.1.1. Colour and heartwood measurement. Three, five centimetre thick discs were taken from the bottom, middle, and top of each tree. In addition to colour measurement, specimens were also taken from sawn boards between the bottom and middle sections to observe the colour variation from the tangential faces (along the length of boards).

2.2.1.1.1. Colour measurement. A “CR10” Tristimulus colourimeter (Konika Minolta®) with an 8 mm aperture at the point measurement was used for measuring the colour coefficients of the sapwood, transition-wood 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 [11]. 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).

2.2.1.1.2. Heartwood measurement. To minimize the human error, automatic image processing was used to determine heartwood percentage using ImageJ® freeware routines [12]. A digital camera was employed to capture images from each sanded disc. Total disc area was determined by thresholding black/white (B/W) images of disc. The heartwood area was conveniently further threshold due to grey level differences from the background wood to provide proportions of heartwood from each disc.

2.2.1.2. Density, shrinkage and unit shrinkage. The discs (seven discs from each tree) were used for shrinkage, density, crystallinity, and hardness measurements. Shrinkage samples, measuring 25 mm (radial) x 25 mm (tangential) x 100 mm (longitudinal) were prepared from each disc aiming to preserve true radial and tangential directionality [13]. Specimen’s radial position was also denoted as heartwood (HW), transition-wood (TZ) and sapwood (SW) accordingly. Six replications for each zone (depend on disc/stem diameter) were used. The procedures used for determining densities and shrinkage properties were carried out largely according to Kingston and Risdon [13].

The shrinkage properties in this paper refer to shrinkage and unit shrinkage. Shrinkage occurs when bound water is removed from the cell walls in a condition below the fibre saturation point (FSP) [14]–[16]. The magnitude of wood shrinkage is often used as a guide for anticipated stability in service
It influences the behavior of the timber during seasoning and affects the target size of sawn green timber [16].

Wood shrinks or swells in three principal directions: longitudinal, radial and tangential. In normal wood, longitudinal shrinkage is one or two orders of magnitude less than transverse shrinkage, and tangential shrinkage is usually 1.5 to 2.5 times higher than radial shrinkage [18]. Some researchers have used the ratio of tangential to radial (T/R) as a descriptor of dimensional stability of wood [19]–[22]. Reportedly the T/R ratio for wood ranges from 1.40 to more than 2, and the wood best suited for uses is one with a low T/R ratio [23].

However, Brown et al. [24] indicate that the T/R ratio might be more or less independent of structure, and that it tends to be related to anisotropy [22]. Kingston and Risdon [13] recommend the use of unit shrinkage, as a good indicator of the potential for the timber to move in service. Kingston and Risdon [13] derived the unit shrinkages from the ratio of the difference in shrinkage between 12% and 5% EMC over the change in moisture content.

The standard procedure for determining moisture content of timber was applied according to AS/NZS 1080.1: 2012 “Timber – Methods of test – Moisture Content” which prescribes that the end point condition is reached when the weight change is less than 0.2% of the previous determination. The radial and tangential dimensions were measured using digital calliper (Mitutoyo®) with 0.001 mm accuracy. The tangential and radial measurements were taken at three equidistant points along each sample in the middle of the faces. Three measurements for each dimension were averaged for each test specimen. The lengths of the test specimens were measured with digital vernier calliper (Mitutoyo®) with 0.01 mm accuracy.

Test specimen weights were made to an accuracy of 0.001 g. The densities measured were basic density (oven dry mass / green volume), air dry density (mass at 12% MC / volume at 12% MC before and after steam reconditioning) and oven dry density (mass at 0% MC / volume at 0% MC) [13]. Shrinkage values from green to 12% MC, 5% MC and 0% were expressed as a percentage of green dimensions. Unit shrinkages were calculated by dividing the difference in the shrinkage of the specimens at the nominal 12% and 5% EMC by the difference in the equilibrated moisture content for each individual specimen.

2.2.1.3. Hardness. The specimens used were the same as the density and shrinkage specimens (2.2.1.2), but, the opposite side of each disc was used for hardness measurement. The hardness was determined using an Instron® universal strength testing machine according to the Australian Standards for mechanically testing small clear specimens of timber [25]. Wood specimens were tested in the radial (R hardness), tangential (T hardness) and longitudinal (end hardness) grain directions. The reason for testing all wood faces was to ensure a more representative value of each specimen [26], and to enable radial and tangential hardness to be tabulated as side hardness for ready comparison with data for other species. Before and after testing, the weight and dimensions of each specimen were measured for the determination of wood density and moisture content.

2.2.1.4. Bending properties. Specimens for bending tests were taken from bottom (Log 1), middle (Log 2), and top part (Log 3) of the trees, and grouped into heartwood, transition-wood and sapwood zones. Three replicates were used for each axial and radial position. 20 x 20 x 300 mm specimens were prepared for bending tests employing an Instron® universal strength testing machine according to the Australian Standards procedure for mechanically testing small clear specimens of timber [25].
The loading rate was 1.0 mm per-minute and the specimens were loaded on the radial face. Before and after testing, the weight and dimensions of each specimen were measured for determination of wood density and moisture content.

2.2.1.5. Fibre length. Three, five-centimeter thick discs were taken from bottom, middle and at the top (stem diameter minimum 7 cm) of each tree, and separated into three zones along the radial direction: heartwood, transition-wood zone and sapwood. Specimens were chipped before maceration. The maceration process was carried out according to the Franklin method described in Tesoro [27]. The samples were heated slowly at 40 – 60 °C in the mixture of Acetic Acid and Hydrogen Peroxide (H2O2) at a ratio of 1 : 1 in a boiling water bath. The heating process took about 12 hours to produce milky white to almost transparent whips, these being adequately macerated for a satisfactory separation of cells. The separated cells were washed with water to remove residual acid and H2O2, and stained with Safranin.

The fibres were randomized by using a method described by Assoc. Prof Jugo Ilic. A plastic petri dish (the diameter slightly larger than the length of a slide) was perforated with one mm holes 1 cm apart all over the bottom, was loaded with a clean glass slide, and placed in a container filled with water up to the bottom of the petri dish. Slurry of fibres then were added into petri dish and topped up with water, and then stirred gently to randomize the fibres. The water was released gradually from the larger container until the water level was lower than the bottom of the glass slide. Slides with randomized exposed fibres were covered with glycerol or permanent mount in a few cases for further reference. The length of 25-fibres was measured for each zone: heartwood, transition-wood and sapwood.

2.2.1.6. Microfibril Angle (MFA) and Degree of Crystallinity. Specimens for the crystallinity measurement were end-matched with the density and shrinkage specimens. The samples were 50 mm (tangential direction) x 15 mm (longitudinal direction) x 30 - 40 µm (radial direction). The crystallinity and its quantifiers were measured using X-Ray Diffraction (XRD) (Shimadzu®). The X-ray beam was powered with a 40kV, 30mA source and scans made in the range from 0 - 40 degrees at a scan speed of 2 degrees per minute.

The degree of crystallinity (DC) was calculated as the ratio between the crystalline and total non-crystalline and amorphous regions. The dimension of crystallites (CW-width and CL-length) was determined using the Scherrer formula [28] for diffraction intensities (002) and (040), usually in the angular range from 20 to 24 degrees and from 32 to 37 degrees, respectively [29]. Cellulose lattice spacing (d) was calculated using Bragg Equation [29]. The number of crystallite planes for each of the diffraction intensities was calculated by dividing the crystallite dimension with the crystallite lattice spacing (d).

Micro fibril angle (MFA) was determined from the (002) reflection plane, and calculated by using Cave’s method. The T parameter was calculated according to Stuart and Evans [30] by manually drawing tangents to the sides of plots of the diffraction arcs.

2.2.2. Wood properties variation within clone. Variation within a clone was assessed by comparing the wood properties of different trees originated from the same clone.
2.2.3. **Wood properties between clones.** Variation between clones was assessed by comparing different clones planted at the same site: Clone A and Clone B at the wet site, then Clone B and Clone C at the dry site. Both variations within clone and between clones were tested using independent t-test if the data were normally distributed and Mann-Whitney U Test if the data were not normally distributed. The distribution of wood properties data was tested according to Saphiro-Wilk’s W test (Statistica®).

2.2.4. **Determination of the best clone.** For the determination of the best clone, wood properties of each clone were averaged and tabulated. Assessments were then conducted based on the best wood properties (compared to mature teak). Clone with the closest wood properties compared to mature teak was each allocated one point. The points for each clone then were added, and the clone with the highest score was selected as the preferred clone.

3. Results and discussion

3.1. Variation of wood properties within and between clones

3.1.1. Wood colour and heartwood proportion. In this study, super teak trees from the same clone planted on the same site exhibited similar colour coefficients, except for the yellowness index for trees at the wet site. Furthermore, if the same clone was planted on different sites, Clone B exhibited similar a* and b* coefficients. Error! Reference source not found. shows the variation of the colour index within clone planted at same and different sites. The result is also in good agreement with the report from Gierlinger [31] that the wood colour of trees from the same provenance grown on different sites is similar. And this is consistent with the result of a study by Moya and Marin [9], showing that heartwood colour is significantly dependent on clone type.

| Variables | Clone A (Wet Site) | Clone B (Wet and Dry Sites) | Clone C (Dry Site) |
|-----------|-------------------|-----------------------------|-------------------|
|           | SA22              | AC23                        | AC18              | 198 | P Value | 12 | 101 | P Value |
| L         | 61.2              | 63.4                        | NS                | 61.5 | 56.9     | 0.02* | 62.6 | 61.1 | NS      |
| a (+)     | 9.2               | 9.7                         | NS                | 10.5 | 11.0     | NS    | 10.1 | 11.4 | NS      |
| b (+)     | 19.3              | 21.5                        | 0.00**            | 22.2 | 21.8     | NS    | 24.0 | 25.1 | NS      |

*=Significant at α=<0.05; **= Significant at α=<0.01 according to independent t-test or Mann-Whitney U test; SA22, AC23, AC18, 198, 12 and 101 are tree codes; SA22 and AC 23 from Clone A; AC18 and 198 from Clone B; and tree no 12 and 101 are from Clone C

Table 3. Color variation between clones of super teak.

| Variables | Wet Site | Dry Site |
|-----------|----------|----------|
|           | Clone A  | Clone B  | P Value | Clone B  | Clone C  | P Value |
| L         | 62.4     | 61.5     | NS      | 56.9     | 61.7     | 0.02*   |
| a (+)     | 9.5      | 10.5     | NS      | 11.0     | 10.9     | NS      |
| b (+)     | 20.5     | 22.2     | 0.00*   | 21.8     | 24.6     | 0.00*   |

*=Significant at α=<0.05; **= Significant at α=<0.01 according to independent t-test or Mann-Whitney U test
This study revealed that trees from different clones planted at the wet site resulted in different $b^*$ and exhibited different $L$ and $b^*$ values when planted at the dry site. Table 33 shows the variation of the colour index between different clones planted at the same sites. These results support the finding by Gierlinger [31] who observed that Larch (Larix spp.) trees from different provenances planted on the same site showed different colour characteristics.

The colour characteristics especially lightness and yellowness of wood from different clones were evident even if the clones were planted on the same site. This study showed that the effect of clone was greater on wood colour than the effect of site. This result is in line with Moya and Marin [9]. Thus, it is suggested that if specific colour preference is needed of plantation trees, clone selection is important.

Unfortunately, the analysis of variance of heartwood proportion from clones could not be applied as there were only three to six discs from each clone. This is in line with the colour properties by Moya and Marin [9] reported that the heartwood proportion from young teak was more influenced by clone than site.

3.1.2. Density, shrinkage, unit shrinkage and mechanical properties

Table 44 shows variations within clone of oven dry density, shrinkage, unit shrinkage and mechanical properties of super teak. Trees from the same Clone A and Clone B planted at a same site generally showed similar wood density (see density of shrinkage and mechanical specimens in Table 4) when planted at the wet site (Clone A), but different wood densities when planted at the dry site (Clone B). However, when a same clone planted at different wet and dry sites (Clone B), the density was consistently and significantly different. According to Saranpää [32], the basic density was under a strong genetic control. However in this study, site effects were more dominant than genetic effects, and this result was in good agreement with Zobel and Buijtenen [33] who reported that the inheritance of wood density in teak was rather weak. Indira and Bhat [34] also reported that site had a great influence on wood density.

Different patterns are observed for the shrinkage and unit shrinkage variations within clone. In general, trees from the same clone planted at the same and different sites exhibited similar shrinkages. Thus, genetic effect seemed to be more dominant for shrinkage than the site effect. Unfortunately except for longitudinal shrinkage in softwoods, published information is difficult to find on the effect of genetics on transverse wood shrinkage.

In unit shrinkage, trees from the same clone planted at the wet site (Clone A) showed similar radial unit shrinkage but different tangential unit shrinkage. Furthermore, when planted at dry site (Clone C) and at different sites (Clone B), different results in radial unit shrinkage but similar tangential unit shrinkage were obtained. For radial unit shrinkage, site effect was more dominant, but in tangential unit shrinkage, genetic effect was more dominant.

Hardness showed slightly different patterns than density. At the wet site, trees from the same clone exhibited little difference in wood hardness. However, when planted on the dry site, even trees from the same clone showed consistently different wood hardness. Furthermore, when trees from the same clone were planted at different sites, they showed similar side hardness but different end-grain hardness. Only end-grain hardness followed the pattern in the density. Hence in this study, no clear variation within clone on side-hardness was observed.
Table 4. Within clones variation of density, shrinkage and mechanical properties of super teak.

| Variables                        | Clone A (Wet Site) | Clone B (Wet and Dry Sites) | Clone C (Dry Site) |
|----------------------------------|-------------------|-----------------------------|-------------------|
|                                  | SA22 AC23 P Value | AC18 198 P Value            | 12 101 P Value    |
| Oven dry density (kg m⁻³)        | 483 479 NS        | 470 514 0.00*               | 476 514 0.00*     |
| Shrinkage from green to 0% MC (%)|                   |                             |                   |
| Radial                           | 2.8 3.0 NS        | 2.9 2.9 NS                  | 2.9 3.2 NS        |
| Tangential                       | 4.4 5.0 0.03*     | 5.1 5.1 NS                  | 5.3 5.4 NS        |
| Unit Shrinkage                   |                   |                             |                   |
| Radial                           | 0.13 0.14 NS      | 0.13 0.15 0.00*             | 0.15 0.17 0.02*   |
| Tangential                       | 0.19 0.22 0.05*   | 0.21 0.22 NS                | 0.21 0.23 NS      |
| Hardness (N)                     |                   |                             |                   |
| Air dry density (kg m⁻³)         | 535 518 NS        | 502 541 0.00**              | 500 540 0.00**    |
| Radial                           | 3132 2922 NS      | 2963 3314 NS                | 2785 3298 0.00**  |
| Tangential                       | 3529 3443 NS      | 3415 3554 NS                | 2843 3350 0.00**  |
| End-grain                        | 4323 4024 NS      | 3839 4440 0.00**            | 4137 4704 0.00**  |
| MOE & MOR                        |                   |                             |                   |
| Air dry density (kg m⁻³)         | 574 500 0.00*     | 518 578 0.00*               | 537 558 NS        |
| MOE (GPa)                        | 8.5 7.9 NS        | 7.4 7.8 NS                  | 7.4 9.0 NS        |
| MOR (MPa)                        | 64.6 47.3 0.01*   | 47.9 49.3 NS                | 57.6 60.9 0.00*   |

*=Significant at ρ=0.05; **= Significant at ρ=0.01 according to independent t-test or Mann-Whitney U test; SA22, AC23, AC18, 198, 12 and 101 are tree codes; SA22 and AC 23 from Clone A; AC18 and 198 from Clone B; and tree no 12 and 101 are from Clone C.

The same pattern was observed for the variation of MOE within clones. Trees from the same clone planted at same and different sites exhibited similar MOE values, thus, clone effect was more dominant than the site effect. For MOR, trees from the same clone planted at the same site exhibited different values, but when planted at different sites showed similar values. Thus, it is not clear whether genetic effect or site effect had greater effect on MOR.

To clarify the effect of clone or site on the wood properties, variations between different clones planted at the same site were then studied. The results are shown in Table 5. In general, trees from different clones planted at the same site exhibited similar wood density. This result confirms the above finding that the site effect was more dominant than the genetic effect for wood density.
Table 5. Variation of density, shrinkage, and mechanical properties between clones.

| Variables                          | Wet Site | Dry Site |
|------------------------------------|----------|----------|
|                                    | Clone A  | Clone B  | P Value | Clone B | Clone C | P Value |
| Oven dry density                   | 515      | 503      | NS      | 514     | 497     | 0.05*   |
| Shrinkage from green to 0% MC      |          |          |         |         |         |         |
| Radial                            | 2.9      | 2.9      | NS      | 2.9     | 3.1     | NS      |
| Tangential                         | 4.7      | 5.1      | NS      | 5.1     | 5.3     | NS      |
| Unit Shrinkage                     |          |          |         |         |         |         |
| Radial                            | 0.13     | 0.13     | NS      | 0.15    | 0.16    | NS      |
| Tangential                         | 0.20     | 0.21     | NS      | 0.22    | 0.23    | NS      |
| Hardness (N)                       |          |          |         |         |         |         |
| Air dry density (kg m\(^{-3}\))    | 525      | 502      | 0.00*   | 541     | 518     | 0.01*   |
| Radial                            | 3009     | 2963     | NS      | 3314    | 3018    | NS      |
| Tangential                         | 3478     | 3415     | NS      | 3554    | 3073    | 0.00*   |
| End-grain                          | 4148     | 3839     | NS      | 4440    | 4395    | NS      |
| MOE & MOR                          |          |          |         |         |         |         |
| Air dry density (kg m\(^{-3}\))    | 8.2      | 7.4      | NS      | 7.8     | 8.3     | NS      |
| MOE (GPa)                          | 56.6     | 47.9     | NS      | 49.3    | 59.5    | 0.03*   |
| MOR (MPa)                          | 540      | 518      | NS      | 578     | 549     | 0.01*   |

* = Significant at α=<0.05 according to independent t-test or Mann-Whitney U test

For the shrinkage properties (shrinkage and unit shrinkage), the results in Table 5 show that trees from different clones planted at the same site exhibited consistently similar shrinkage and unit shrinkage values. The previous results in Table 4 show that clone effect is more dominant than site effect for radial and tangential wood shrinkage and the tangential unit shrinkage, but site effect is more dominant on radial unit shrinkage. The results in Table 5 are not as expected because it appeared that site effect is consistently more dominant on shrinkage properties. Consequently, it is not clear which factor had more dominant effect on shrinkage and tangential unit shrinkage.
Wood hardness of trees from different clones planted at the same site exhibited generally similar hardness values. From the above result no clear pattern of variation within clone is observed, and it can be concluded that in line with wood density, the site effect is greater on wood hardness than the genetic effect.

Trees from different clones planted at the wet site showed similar MOE, but when planted at the dry site, the trees exhibited different MOE values. The previous conclusion that MOE was more influenced by genetic effect than by site effect is confirmed by the result from the dry site. Similar variation of MOE is observed with MOR. The above result shows that neither the effect of clone nor site is observed for MOR. This can be seen from

Table 55.

3.1.3. Fibre length. The results presented in Table 6 show that in general, the same clone planted at the same or different site exhibited similar fibre length. Considering fibre length effect due to genetics seemed to be greater than the effect of site is indicated in Table 7; different clones planted at same site exhibit different fibre length values.

| Cell Length (µm) | Clone A (Wet Site) | Clone B (Wet and Dry Sites) | Clone C (Dry Site) | P Value | P Value | P Value |
|-----------------|---------------------|----------------------------|---------------------|---------|---------|---------|
| Fibre           | SA22                | AC23                       | AC18 198            | 12      | 101     |         |
|                 | 1391                | 1303                       | 0.00**              | 1320    | 1317    | NS      |
|                 |                     |                            |                     | 1314    | 1315    | NS      |

**= Significant at α=<0.01 according to independent t-test or Mann-Whitney U test; SA22, AC23, AC18, 198, 12 and 101 are tree codes; SA22 and AC 23 from Clone A; AC18 and 198 from Clone B; and tree no 12 and 101 are from Clone C

Table 7. Between clones variation of fibre and vessel length of super teak.

| Cell Length (µm) | Wet Site | Dry Site |
|-----------------|----------|----------|
| Fibre           | 1347     | 1320     | 0.02*    | 1317    | 1314    | NS       |

*=Significant at α=<0.05 according to independent t-test or Mann-Whitney U test
3.1.4. Ultrastructure ‘crystallinity’. In general, trees from the same clone planted at the same or different sites exhibited similar ‘crystallinity’, as indicated in Table 8. The result shows that clone effect is more dominant than factor site. Furthermore, when trees from different clone planted at same site, it also showed similar ‘crystallinity’ characteristics (Table 9).

Table 8. Variation of wood ‘crystallinity’ within clone.

| Variables                | Clone A (Wet Site) | Clone B (Wet and Dry Sites) | Clone C (Dry Site) |
|--------------------------|--------------------|------------------------------|--------------------|
|                          | SA22  AC23 P Value | AC18 198 P Value            | 12 101 P Value     |
| MFA (°)                  | 18.2   15.8 0.02*   | 15.5   15.0 NS              | 14.0   16.3 NS     |
| DC (%)                   | 37.2   46.1 0.00**  | 42.9   45.7 NS              | 42.5   45.3 NS     |
| Crystallite Width (nm)   | 3.7    3.6 NS      | 3.5    3.6 NS               | 3.5    3.4 NS      |
| d002                     | 0.39   0.39 NS     | 0.39   0.39 NS              | 0.39   0.39 NS     |
| N002                     | 9.3    9.2 NS      | 9.0    9.1 NS               | 8.9    8.7 NS      |
| Crystallite Length (nm)  | 27.3   24.8 NS     | 29.1   28.1 NS              | 32.1   26.8 NS     |
| d040                     | 0.25   0.25 NS     | 0.25   0.25 NS              | 0.24   0.26 NS     |
| N040                     | 109.4  99.5 NS     | 117.1  111.9 NS             | 132.7  104.1 NS    |

*=Significant at α=<0.05; **= Significant at α=<0.01 according to independent t-test or Mann-Whitney U test; SA22, AC23, AC18, 198, 12 and 101 are tree codes; SA22 and AC 23 from Clone A; AC18 and 198 from Clone B; and tree no 12 and 101 are from Clone C; d = crystallite lattice spacing; N = number of crystallite planes.

Table 9. Variation of wood ‘crystallinity’ between clones.

| Variables                | Wet Site                      | Dry Site                      |
|--------------------------|-------------------------------|-------------------------------|
|                          | Clone A | Clone B | P Value | Clone B | Clone C | P Value |
| MFA (°)                  | 17.1    | 15.5    | 0.05*   | 15.0    | 15.3    | NS      |
| DC (%)                   | 41.5    | 42.9    | NS      | 45.7    | 44.2    | NS      |
| Crystallite Width (nm)   | 3.6     | 3.5     | NS      | 3.6     | 3.4     | NS      |
| d002                     | 0.39    | 0.39 NS | NS      | 0.39    | 0.39 NS | NS      |
| N002                     | 9.3     | 9.0     | NS      | 9.1     | 8.8     | NS      |
| Crystallite Length (nm)  | 26.1    | 29.1    | NS      | 28.1    | 28.8    | NS      |
| d040                     | 0.25    | 0.25 NS | NS      | 0.25    | 0.25 NS | NS      |
| N040                     | 104.6   | 117.1   | NS      | 111.9   | 115.0   | NS      |

Note: P values were obtained by using independent t-test or Mann-Whitney U test; SA22 and AC 23 from Clone A; AC18 and 198 from Clone B; and tree no 12 and 101 are from Clone C; d = crystallite lattice spacing; N = number of crystallite planes.
### 3.2. Determination of the "best" clone based on the wood properties

Table 10 presents the results of the assessment of the variation of wood properties examined to determine within clone effects of trees planted at Bogor and Magetan. The wood properties were assessed on the basis of their similarity of super teak to that of approximately 80-year old mature teak as described in Indonesian Wood Atlas [35] and other relevant literature.

**Table 10.** Summary of the average wood properties of super teak for scoring for best clone based on the similarity with mature teak

| Variables | Clone A (Wet Site) | Clone B (Wet and Dry Sites) | Clone C (Dry Site) | Mature Teak |
|-----------|-------------------|-----------------------------|--------------------|-------------|
|           | Mean   | STD  | COV  | Mean   | STD  | COV  | Mean   | STD  | COV  |
| Height    | 15*    | 2    | 11   | 14     | 5     | 38   | 11     | 2     | 19 |
| Diameter  | 31*    | 1    | 4    | 30     | 1     | 5    | 29     | 0.4   | 1  |
| **Colour** [36] | | | |
| L         | 62*    | 9    | 14   | 59     | 10    | 16   | 62*    | 6     | 9  |
| a*        | 9      | 3    | 30   | 11*    | 3     | 31   | 11*    | 3     | 26 |
| b*        | 21     | 2    | 11   | 22     | 2     | 10   | 25*    | 2     | 9  |
| Heartwood % | 18    | 10   | 56   | 30*    | 6     | 20   | 20     | 15    | 75 |
| **Density and shrinkage** |
| Shrinkage from green to 0% MC [3] | | | | | |
| Radial    | 2.9*   | 0.4  | 13   | 2.9*   | 0.4   | 14   | 3.1    | 0.5   | 16 |
| Tangential | 4.7*  | 0.9  | 19   | 5.1    | 0.8   | 16   | 5.3    | 0.9   | 18 |
| **Unit Shrinkage** (no reference was found; the best unit shrinkage was selected as the lowest value) | | | | | |
| Radial    | 0.13*  | 0.03 | 19   | 0.15   | 0.03  | 17   | 0.16   | 0.03  | 18 |
| Tangential | 0.20* | 0.04 | 22   | 0.22   | 0.04  | 16   | 0.23   | 0.05  | 21 |
| **Density (kg m\(^{-3}\)) [3]** |
| Air dry (corrected) | 515   | 21   | 4    | 532*   | 39    | 7    | 528    | 36    | 7  |
| Oven dry  | 481    | 20   | 4    | 500*   | 37    | 7    | 497    | 35    | 7  |
| **Hardness (N) [35]** |
| Side Hardness | 3244  | 678  | 21   | 3278*  | 531   | 16   | 3046   | 417   | 14 |
| End Hardness | 4148  | 588  | 14   | 4124   | 632   | 15   | 4395*  | 563   | 13 |
| **Stiffness and bending** [3] |
| MOE (GPa)  | 8      | 2    | 22   | 8      | 1     | 20   | 8      | 2     | 20 |
| MOR (MPa)  | 57     | 21   | 37   | 49     | 19    | 38   | 60     | 15    | 25 |
| **Cell Dimensions (µm) [35]** |
| Fibre length | 1347* | 143  | 11   | 1319   | 119   | 9    | 1314   | 111   | 8  |
| “Crystallinity” [36] |
| MFA (°)    | 17     | 3    | 15   | 15*    | 2     | 16   | 15*    | 4     | 24 |
| DC (%)     | 41     | 8    | 19   | 44*    | 7     | 15   | 44*    | 7     | 17 |
| Total score | 8     |     | 8    | 7      |       |      |        |       |    |

* indicates a score of one when the wood properties of a clone was closest to mature teak’s property (the best clone was chosen with the highest score based on wood properties)
The results showed that Clone A planted at the wet site exhibits eight points when the assessments were combined between the assessment on the wood properties and the tree size. Consequently, the score for Clone A is six when wood properties only were included.

The score of Clone C is seven; here the score of seven is based on the assessments on wood properties only because the tree size (height and diameter) of trees when planted at the dry site were lower than those Clone A because trees from Clone C were all planted under less favourable conditions than trees from Clone A. Hence, if the assessment is based on wood properties only, Clone C exhibits ‘better’ wood properties than Clone A. However, the score attributed to Clone C may have been affected by site effect because some wood properties such as hardness is more influenced by site effect (section 3.3.1 Variation of wood properties within and between clones). Accordingly, the scores seven obtained in Clone C possibly are achieved not only because of clone effect itself but also because they were planted at drier environment, for example wood hardness was 18% higher at the dry site compared to the wet site.

Clone B which attained a score of eight appeared to have the highest wood properties compared to the other clones. The tree sizes are also comparable to the trees from Clone A planted at the wet site. From the result, it has been proven that even though planted at different sites, Clone B still exhibits comparable wood properties. Based on the score and validity of the evaluation, it would appear that Clone B can be suggested for planting at both sites for next cultivation.

4. Conclusions

A uniform wood colour was observed in trees from the same clone irrespective of growing site. Site effect is more dominant on wood density, wood hardness and radial unit shrinkage, while MOE, fibre length, and ‘crystallinity’ were affected by genetic effect. Effect of clone type was not clear on radial and tangential shrinkage, tangential unit shrinkage and MOR. For the best clone, Clone B can be recommended for future replanting at both sites.

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