Physical and Mechanical Properties of 10-Year Old Superior and Conventional Teak Planted in Randublatung Central Java Indonesia

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Abstract

Tree breeding program has been conducted in Indonesia in order to produce more productive teak trees. Recently, from this program, superior clones (clone source) of teak have been selected for the establishment of the wider plantations. These clones show a good performance on growth characteristics such as stem diameter and tree height. However, it is important to evaluate wood quality of selected superior teak. Physical (heartwood percentage, wood color, basic density, and shrinkage per 1% change in moisture content) and mechanical (static bending strength and compressive strength) properties were investigated for 10-year old of two sources type of teak (superior and conventional) planted in Randublatung, Central Java, Indonesia. There was not significant different between superior and conventional teak was found in all physical and mechanical properties of both teak wood, suggesting that wood properties of both teak are similar at the same age. All trees are in juvenile phase as show by increasing of basic density from pith to bark. Basic density has positively correlation with all mechanical properties measured. It can be said that basic density can be used to estimate mechanical properties.

Keywords: conventional teak, mechanical properties, physical properties, superior teak

Abstrak

Program pemuliaan pohon telah dilakukan di Indonesia untuk meningkatkan produktivitas hutan jati. Program ini telah menghasilkan bibit unggul dengan perbanyakan vegetative (klon) dan telah digunakan sebagai materi pembangunan hutan tanaman jati di banyak lokasi. Karakteristik pohon jati dari klon ini menunjukkan pertumbuhan diameter dan tinggi yang sangat baik. Akan tetapi, sifat-sifat kayu dari pohon jati ini juga penting untuk diketahui. Oleh karena itu, penelitian ini bertujuan untuk mengkaji sifat fisis (pesentase teras, warna kayu, kerapatan dasar, dan perubahan dimensi per 1% perubahan kadar air) and mekanis (kekuatan lengkung statis dan kekuatan tekan) pohon jati umur 10 tahun yang berasal dari 2 tipe sumber benih (superior dan konvensional) yang ditanam di Randublatung, Jawa Tengah, Indonesia. Dari hasil penelitian menunjukkan bahwa sifat fisis dan mekanis kayu jati superior (klon) dan jati konvensional (biji) tidak berbeda secara nyata. Hal ini menunjukkan bahwa, pada umur yang sama jati superior dan konvensional memiliki sifat yang sama. Variasi pada arah radial dari kerapatan dasar adalah naik dari hati ke kulit. Dari hasil ini, diperkirakan bahwa kayu jati tersebut masih dalam fase juvenil. Selanjutnya, kerapatan dasar berkorelasi positif terhadap semua sifat mekanis yang diukur. Hal ini menunjukkan bahwa sifat mekanis dapat diduga melalui kerapatan dasar.

Kata kunci: jati unggul, jati konvensional, sifat fisis, sifat mekanis

Introduction

Teak (*Tectona grandis* L.f.) is an important commercial plantation species, and its demand is increasing in Indonesia. In contrast, the total teak wood production is decreasing because of declining teak wood resources and the plantation productivity (Hidayati *et al.*

2014). Therefore, tree breeding program has been conducted by Indonesian State Forest Enterprise (Perhutani) since 1981 to produce more productive teak trees (Suseno 2000). Recently, from this program, superior clones (clone source) of teak, which is called Jati Plus Perhutani (JPP), have been selected for the establishment of the wider plantations. These clones show good performance on growth characteristics such as stem diameter and tree height.

It is important to evaluate wood quality of selected superior teak. Wood quality is determined by wood properties such as anatomical, physical, and mechanical properties which are very important for the end use of the wood. Furthermore, heartwood percentage is also important factor due to its relationships with natural durability of the wood.

The color of wood is one of the criteria of wood to assess its suitability for certain end-use, such as furniture and decorative veneers (Thulasidas *et al*. 2006). Research about wood properties of teak has been conducted by many researchers in the world by destructive and non-destructive evaluation (Kedharnath *et al*. 1963, Indira & Bhat 1998, Bhat *et al.* 2001, Cordero & Kanninen 2003, Bhat & Priya 2004, Moya & Marin 2011, Hidayati *et al.* 2013a, 2013b, Hidayati *et al.* 2014). Furthermore, many researchers also conducted the research about heartwood percentage and wood color of teak (Cordero & Kanninen 2003; Kokutse *et al*. 2006, Thulasidas *et al*. 2006, Lukmandaru *et al*. 2009, Moya & Berrocal 2010, Moya & Marin 2011). However, researches about wood properties of clone sources are limited in Indonesia (Wahyudi & Arifien 2005, Krisdianto & Sumarni 2006, Basri & Wahyudi 2013, Wahyudi *et al.* 2014a,b).

The objectives of this study were to clarify the heartwood percentage, wood color, physical properties, and mechanical properties of 10-year-old of clone source and conventional teak (seed source) planted in Randublatung, Central Java. The differences between two sources type, radial variation of basic density, and relationship between basic density and mechanical properties measure were also investigated. The information of these result are important for the plantation management and silvicultural practices.

Material and Methods

Sample preparation

Three trees of clone source and two trees of seed source from Perum Perhutani plantation located in Randublatung, Central Java, Indonesia (7^{o}05'S, 111^{o}30'E) were used in this present study. The environmental condition of site was as follow; average temperature of 27.5 ^{o}C; annual precipitation of 1650 mm/year; relative humidity of 72%, altitude of 140 meter above sea level., soil of homous margalitic, loamy sand. The mean diameter of clone and seed source was 19.4 and 16.3 cm, respectively. From these trees, only the bottom part was used for determining physical properties [heartwood percentage, wood color, basic density, and shrinkage per 1% change in moisture content (radial, tangential, and longitudinal)] and mechanical properties (Modulus of Rupture, MOR and Modulus of Elasticity, MOE) and compressive strength (parallel and perpendicular to grain).

Heartwood percentage and wood color properties

Heartwood percentage was measured on 5-cm-thick disks cut from 30 cm above the ground. Total diameters of disks, heartwood diameter, bark thickness, height of disk were measured. Heartwood percentage was calculated using formula proposed by Wahyudi and Arifien (2005).

For measuring wood color (heartwood and sapwood), air-dried wood meal were prepared. Color of wood meal was measured using a colorimeter (NF333, Nippon Denshoku). The CIELAB (L*, a*, b*) system was employed to evaluate heartwood and sapwood colors. The value of L*, a*, and b* indicate psychometric lightness, a color parameter on the red/green axis, and a color parameter on the yellow/blue axis, respectively.

Physical properties

Basic density (BD) was measured on 10-cm-thick disks cut from 30 cm above the ground. Radial strips (2 cm in width, 2 cm in thickness, and length depend on tree diameter) were prepare from each disk. The radial variations of basic density were determined at 2 cm intervals from pith to bark. Small blocks were obtained from two opposite sides with respect to the pith of the disk. Basic density was calculated as the ratio of oven-dry weight to green volume as determined by the water displacement method.

A total of 25 specimens of clone and 12 specimens of conventional teak were prepared from the disk cut from 30 cm above the ground. The specimens were placed in the laboratory until air-dried condition. The radial, tangential, and longitudinal dimensions of the specimens under air- and oven-dried conditions were measured by digital caliper. Shrinkage in the radial, tangential, and longitudinal directions per 1% change in moisture content was calculated according to Istikowati *et al.* (2012).

Mechanical properties

Air-dried specimens for MOR and MOE tests (2 x 2 x 30) cm^3, compressive tests parallel and perpendicular to the grain (2 x 2 x 6) cm^3 were obtained from air-dried radial-sawn board cut from logs at 40 cm above the ground at 2-cm intervals. The procedure of the testing was according to British Standard (BS. 373:1957). The total specimens were 30 and 18 for clone and seed source respectively. MOR, MOE tests and compressive tests were conducted using a Universal Testing Machine (Instron 3369) with load speed of 0.25 cm min^{-1} and 0.06 mm min^{-1}, respectively. MOR, MOE, compressive strength (parallel and perpendicular to grain) were calculated by using software (Bluehill 3, Instron).

Data analysis

T-test analysis was conducted to determine the significant differences between clone and seed source of all physical and mechanical properties measured. Simple correlation was also conducted for determining correlation between basic density and all mechanical properties measured using Excel 2003.

Result and Discussion

Heartwood percentage and wood color

The statistical values of heartwood percentage are listed in Table 1. The mean value of heartwood percentage from clone source and seed source teak was 45.2 and 28.5%, respectively. Krisdianto and Sumarni (2006) reported that heartwood percentage was 39.6 and 20.3% of 7-year old clone and seed source planted in East Kalimantan. On the other hand, heartwood percentage of

9-year old superior teak (JPP) planted in Central Java was 25% (Basri & Wahyudi 2012). In addition, heartwood percentage of 3-year old clone and seed source planted in Semarang, Central Java were 29.81 and 25%, respectively (Wahyudi & Arifien 2005). They also reported that heartwood percentage of 8-year-old conventional teak planted at the same place was 58.23%.

This result of the heartwood percentage is consistent with the result of previous study by Krisdianto and Sumarni (2006). Furthermore, heartwood percentage of clone source was higher than seed source but no significant difference was found between clone and seed source. Wahyudi and Arifien (2005) reported that heartwood percentage was not significant different between 3-year-old clone and seed source. On the other hand, heartwood percentage was significantly different between clone and seed source, which was clone source, has higher heartwood percentage than seed source (Krisdianto & Sumarni 2006). Our result of the differences of heartwood percentage of clone and seed source was similar to this previous result (Wahyudi & Arifien 2005). However, based on this result, it is suggesting that clone source has high possibility to have higher heartwood percentage.

Table 1 also shows the statistical value of the wood color of the two different sources type. No significant difference was found between L*, a*, and b* value of heartwood and sapwood for clone and seed sources. Moya and Berrocal (2010) reported that the mean values of L*, a*, and b* at the heartwood form 7- to 15-year old teak trees planted in Costa Rica were 58.2, 10.4, and 25.9, respectively. At the sapwood, L*, a*, and b* were 73.8, 5.8, and 25.2, respectively. The values of L*, a*, and b* at the inner heartwood of 32-year old teak from Randublatung were 54.2, 6.3, and 23.5, respectively (Lukmandaru *et al*. 2009). At the same age, previously report showed that L*, a*, and b* of the sapwood were 70.1, 3.8, and 26.4, respectively. Our result of the wood color (L*, a*, and b*) of heartwood and sapwood were lower than these previous reports (Lukmandaru *et al*. 2009, Moya & Berrocal 2010).

Physical and mechanical properties

Table 2 shows physical and mechanical properties of clone and seed sources. The mean value of basic density was 0.47 and 0.48 g cm^{-3} for clone and seed sources, respectively. Basri and Wahyudi (2012) reported that specific gravity of superior teak (JPP) from Central Java at 5-, 7-, and 9-year old were 0.46, 0.49, and 0.51. Specific gravity of 3-year old from clone source planted in Semarang was 0.43-0.64 (Wahyudi & Arifien 2005). Wahyudi *et al.* (2014a) also reported that specific gravity of 4- and 5-year old superior teak planted in West Java was 0.35 and 0.45, respectively. Wenneng *et al.* (2014) found that basic density of 10-, 15-, 20-, and 25-year old teak (source is unknown) planted in Laos was 0.53, 0.52, 0.53, 0.50 g cm^{-3}. Specific gravity of 8-year old of seed source planted in Semarang was 0.47 – 0.70 (Wahyudi & Arifien 2005). Furthermore, basic density of 10-year old teak planted in Solomon island was 0.54 g cm^{-3} (Anonim, 2011).

In the present study, mean value of basic density of clone and seed source is lower than previous results at the same age and around (Basri & Wahyudi 2012, Wenneng *et al.* 2014, Wahyudi & Arifien, 2005). However, the value is higher than the result of the younger age of the previous results (Basri & Wahyudi 2012, Wahyudi & Arifien 2005, Wahyudi *et al.* 2014a). Therefore, it can be said that basic density of wood will increase with the increasing of the three age.

Table 1 Statistical values of heartwood percentage and wood color of teak from two sources type

Properties	Source				Significant between two sources type
	Clone (n=3)		Seed (n=2)		
	Mean	SD	Mean	SD	
Heartwood percentage	45.2	9.1	28.5	7.6	ns
Wood color					
Heartwood					
L*	46.7	6.3	45.3	5.3	ns
a*	10.5	0.7	10.3	0.9	ns
b*	19.1	1	18.9	2	ns
Sapwood					
L*	56.8	3	59.2	3.1	ns
a*	6.9	0.8	8.4	0.8	ns
b*	11.6	1.9	15.5	2.4	ns

Note : n = number of sample tree, SD = standard deviation, ns = no significance.

Table 2 Mean values of physical properties and mechanical properties of teak from two sources type

Properties	Source				Significant between two source types
	Clone (n=3)		Seed (n=2)		
	Mean	SD	Mean	SD	
Physical properties					
Basic density (g cm^{-3})	0.47	0.02	0.48	0.03	ns
RS per 1% change in MC (%)	0.13	0.03	0.10	0.01	ns
TS per 1% change in MC (%)	0.24	0.04	0.21	0.01	ns
LS per 1% change in MC (%)	0.04	0.02	0.04	0.01	ns
Mechanical properties					
Static bending strength					
MOR (kg cm^{-2})	805	66	889	23	ns
MOE (x 1000 kg cm^{-2})	92	8	109	14	ns
Compressive strength parallel to grain (kg cm^{-2})	406	34	441	6	ns
Compressive strength perpendicular to grain (kg cm^{-2})	202	11	239	31	ns

Note : RS = radial shrinkage, TS = tangential shrinkage, LS = longitudinal shrinkage, MC = moisture content, n = number of sample tree, SD = standard deviation, ns = no significance.

The statistical analysis using t-test shows that basic density was not significant difference between two source types of teak (Table 2). Wahyudi and Arifien (2005) reported that at 3-year old, clone and seed source has similar value of density. Our result of differences of basic density between clone and seed source are consistent with the previous results (Wahyudi & Arifien 2005). Furthermore, Figure 1 shows the radial variation of clone and seed source. The radial variation of basic density of both sources type were increase from pith to bark. Hidayati *et al.* (2014) reported that basic density of 12-year old teak clones were gradually increased from pith to bark. On the other hand, basic density varied relatively little from pith to bark (Bhat *et al*. 2001). Our result of radial variation of basic density is consistent with the result reported by Hidayati *et al*. (2014).

Based on this result, it is suggesting that these woods are still in juvenile phase. Hidayati *et al*. (2014) reported that xylem maturation process in teak is depending on age rather than diameter growth. Furthermore, Bhat *et al.* (2001) reported that the maturity of teak begins at approximately 15-25 year.

The mean value of radial, tangential, and longitudinal shrinkages per 1% change in Moisture content are shown in Table 2. The mean value of radial, tangential, and longitudinal shrinkage were 0.13 and 0.10, 0.24 and 0.21, and 0.04 and 0.04 for clone and seed source, respectively. On the other hardwood species in Indonesia, the mean values of radial shrinkage of Terap, Medang, and Balik Angin were 0.15, 0.26, and 0.17, respectively. The mean value of tangential shrinkage was 0.24, 0.31, and 0.22 for Terap, Medang, and Balik Angin (Istikowati *et al*. 2014). In addition, the basic density of Terap and Balik Angin was lower and Medang was higher than our results in Table 2. Furthermore, no significant difference was found between clone and seed source for radial, tangential, and longitudinal shrinkages (Table 2). Based on this result, it is suggesting that dimensional stability between clone and seed source is similar at the same age.

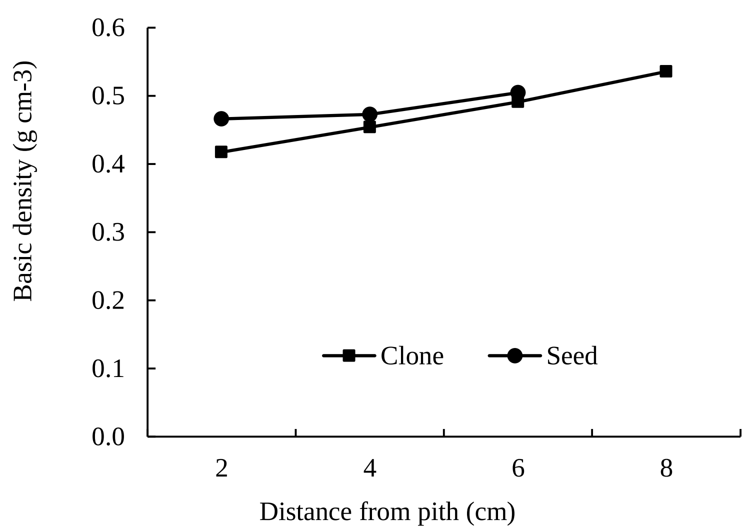
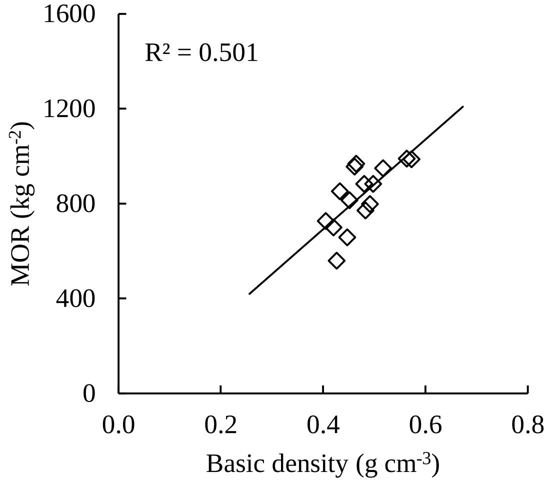


Figure 1 Radial variation of the basic density form two different sources type.

Table 2 also shows the result of mechanical properties. The mean value of static bending strength of MOR was 805 and 889 kg cm^{-2} for clone and seed source, respectively. MOE was 92,000 and 109,000 kg cm^{-2} for clone and seed source respectively. MOR and MOE of 10-year-old teak at base part planted in Solomon Island were 1,080 and 118,000 kg cm^{-2}, respectively (Anonim, 2011). Wahyudi and Arifien (2005) reported that MOR and MOE of 8-year-old of conventional teak at the base part planted in Semarang were about 970 and 73,000 kg cm^{-2}. On the other hand, at 3-year-old of clone and seed source planted in the same place, MOR was about 780 and 720 kg cm^{-2}, respectively, whereas for MOE was 62,000 and 42,000 kg cm^{-2} (Wahyudi & Arifien 2005). Furthermore, MOR was 654 and 782 kg cm^{-2} for 4- and 5- year-old of teak planted in West Java. At the same ages, MOE was 77.995 and 80,653 kg cm^{-2}, respectively (Wahyudi *et al.* 2014a).



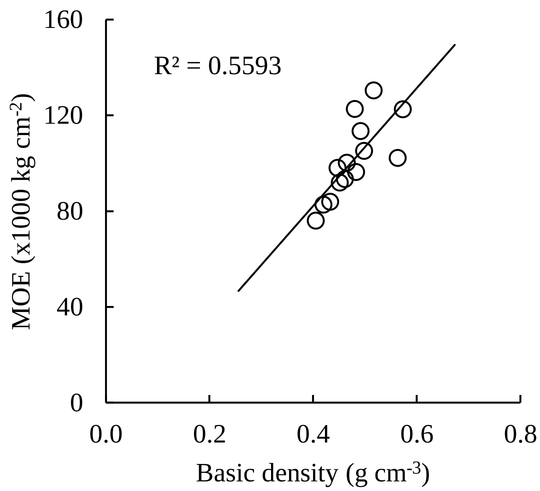
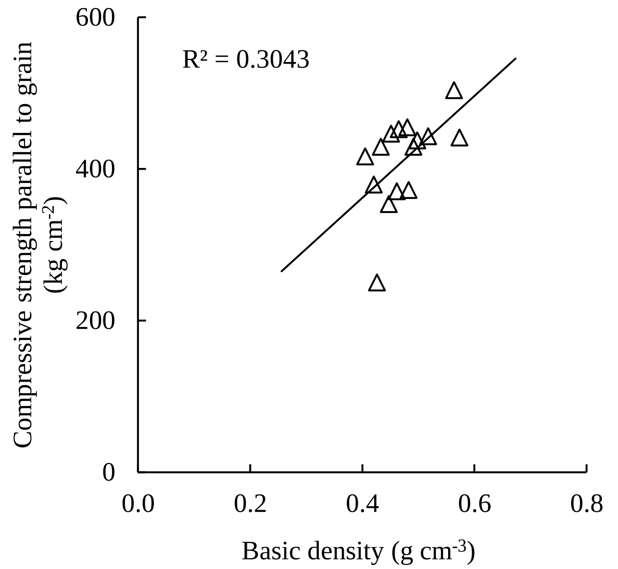


Figure 2 Relationships between basic density and MOR and MOE of teak.



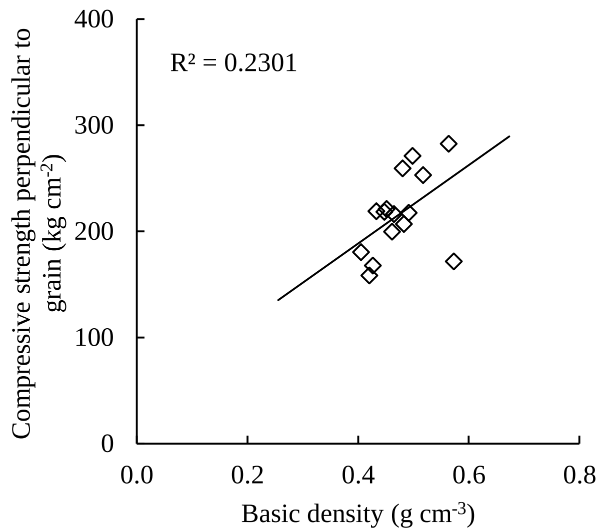


Figure 3 Relationships between basic density and compressive strength of teak.

In the present study, MOE and MOR values especially for conventional teak was slightly lower than previous results at the same age (Anonim 2011). However, the values were higher than previous results at the younger age of teak trees (Wahyudi & Arifien 2005, Wahyudi *et al.* 2014a). Therefore, similar to basic density, MOE and MOR of static bending strength will increase with the increasing of tree age. Furthermore, compressive strength parallel to grain and compressive strength perpendicular to grain were also determined in this present study (Table 2). The mean value of compressive strength parallel to grain was 406 and 441 kg cm^{-2} for clone and seed source, respectively. In addition, the mean value of compressive strength perpendicular to grain was 202 and 239 kg cm^{-2} for clone and seed source. The information of compressive strength for the young teak is very limited. No significant difference was found between clone and seed source for all mechanical properties (Table 2). Wahyudi and Arifien (2005) reported that MOE and MOR were not different between clone and seed source which was in agreement with this results. Based on this result, it can be said that mechanical properties is not differ between clone and seed source at the same age.

Relationship between basic density and mechanical properties

Figure 2 and 3 show the relationships between basic density and mechanical properties. Basic density was positively significant correlation with all mechanical properties measured. Thulasidas and Bhat (2012) reported that MOR, MOE, and compressive strength parallel to grain has significant positive correlation with air-dried density in teak planted in Kerala, India. Other researchers reported that basic density has positively significant correlation with compressive strength parallel to grain in teak clones planted in Indonesia (Hidayati *et al.* 2014). Similar result was also found in other hardwood species in Indonesia (Makino *et al*. 2012, Istikowati *et al*. 2014). In the present study, result of the relationship between basic density and mechanical properties was in agreement with these previous studies (Thulasidas & Bhat 2012, Hidayati *et al.* 2014, Makino *et al*. 2012, Istikowati *et al*. 2014). Therefore, based on this result, it can be concluded that mechanical properties can be predicted by basic density.

Conclusion

No significant difference between two sources type of teak seed was found in heartwood percentage, wood color, and all physical and mechanical properties measured. It is suggesting that wood properties are similar between clone and seed source at the same age. This result shows the promising future of utilization of clone as source of superior teak. Plantation management and silvicultural practices should be concerning to produce more productive teak forest without decreasing the quality of wood. However, further research is required to clarify this result. Furthermore, radial variation of basic density was increase from pith to bark, indicating that this wood is still in juvenile phase. As basic density was significantly correlation to all mechanical properties. It can be said that basic density can be used to estimate mechanical properties.

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