Physical and Mechanical Properties of Four Varieties of Ironwood

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Abstract

Bulian or ironwood (*Eusideroxylon zwageri* Teijsm. & Binn.) belongs to the family of Lauraceae. The most valuable characteristic of ironwood is very durable and an excellent physical and mechanical properties. Four varieties of ironwood namely *exilis, grandis, ovoidus* and *zwageri* had been identified based on morphological characteristics and genetic marker. It has never been determined that there is a correlation between mechanical properties of wood and the varieties. Four logs samples were collected from Senami forest, Jambi, Indonesia. The Physical and mechanical property test was referred to British Standard (BS) 375-57, including moisture content, density, shrinkage, bending strength. Some parameters of physical and mechanical properties were not significantly different among investigated logs. These were dry air moisture content, tangential shrinkage green to oven dry, green hardness and green compression parallel to grain. Other parameters were significantly different among investigated logs. The cluster analysis based on physical and mechanical properties shows that *zwageri* and *ovoidus* formed one cluster with a higher degree of similarity than another cluster, which was formed by *grandis* and *exilis*. This dendrogram is synchronized with the dendrogram which was formed based on other morphological structures of ironwood.

Keywords: ironwood, physical and mechanical properties, senami forest, varieties

Introduction

Bulian or ironwood (*Eusideroxylon zwageri* Teijsm. & Binn.), synonymous with *Bihania borneensis* Meissner and *Eusideroxylon lauriflora* Auct., belongs to the family of Lauraceae, tribus of Cryptocaryeae and subtribus of Eusideroxylineae (Kostermans 1957). Ironwood is one of the most important construction woods in Indonesia. The wood is used for making furniture, window and door frames, harbors, heavy construction, roofs, bridges, railway sleepers, marine pilling, boat construction, fence posts, heavy duty industrial flooring, shingles and vehicle body work.

Oldfield *et al.* (1998) showed that ironwood is included in the list of threatened tree species. Its decline was first noted in 1955. Population reduction caused by overexploitation and shifting agriculture has been noted in the following regions: Kalimantan, Sumatra, Sabah, Sarawak and the Philippines. Its regeneration in logged forests is limited. So far, the species has only been planted on a small scale because the supply of seeds and seedlings is inadequate. Based on the IUCN red list of threatened species, *E. zwageri's* category and criteria are *VU A1cd+2cd.* This means that ironwood is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future (IUCN 2014).

The most valuable characteristic of ironwood is that it is not vulnerable to termites and other ubiquitous tropical wood-eating insects and fungi. For this reason, the wood is in great demand for construction throughout Indonesia (Peluso 1992). Martawijaya *et al.* (1989) explained that the physical characteristics of ironwood are excellent. Class of strength is one, durability class is one, and it is very hard, with a specific gravity of 0.88-1.19. Additionally, Wong *et al.* (1996) explained that ironwood is found to be very resistant to fungi in a fungal decay test. Sampling of ironwood heartwood poles in Sarawak revealed only surface biodeterioration after 20 years in ground-contact. Furthermore, although the wood is impermeable to preservatives, it can be used in severe decay hazard environments (soil burial).

Ironwood belongs to the heaviest wood species. Its volumetric swelling and swelling anisotropy are almost 15% and 1.73, respectively. The moisture content of green wood amounts to 44.16%. Bending strength is 17744.9 kg cm^{-2}, the crushing strength comes to 867.3 kg cm^{-2} and the impact bending to 0.92 kg cm^{-2}. The results of mechanical testing confirm the suitability of ironwood as construction timber (Scharai-Rad & Sulistyobudi 1985).

Almost the same averages of modulus of elasticity were reported by some studies. Scharai-Rad and Sulistyobudi (1985) reported the value of modulus elasticity is about 196939 kg cm^{-2}, Martawijaya *et al.* (1989) reported it ranges from 174000 to 184000 kg cm^{-2}, and Kostermans *et al.* (1994) reported its value ranges from 177550 to 184690 kg cm^{-2}. Wood density was reported to vary between 0.88 and 1.19 g cm^{-3} (Martawijaya *et al.* 1989) and (0.83-) 0.88 (-1.19) g cm^{-3} (Kostermans *et al.* 1994).

Furthermore, Martawijaya *et al.* (1989) wrote that physical and mechanical properties of ironwood are as follows: radial and tangential shrinkage from green to oven dry are 4.2 and 8.3%, green and air dry modulus of elasticity are 174000 and 184000 kg cm^{-2}, green and air dry compression parallel to grain are 665 and 734 kg cm^{-2}, green end hardness is 973 kg cm^{-2}; and green and air dry tensile strength parallel to grain are 48.2 and 26.7 kg cm^{-2}. Kostermans *et al.* (1994) reported that compression parallel to grain is 683.7-816.3 kg cm^{-2} and compression perpendicular to grain is 178.6 kg cm^{-2}. The rate of shrinkage from green to oven dry is rather high: 4.2-4.3% radial and 7.5-8.3% tangential. Ironwood dries slowly, although the moisture content of green wood is comparatively low (about 38%).

Four varieties of ironwood namely *exilis, grandis, ovoidus* and *zwageri* had been identified based on morphological characteristics and genetic marker (Irawan 2005, Irawan *et al.* 2015). It has never been determined that there is a correlation between mechanical wood properties and other botanical characteristics (Koopman & Verhoef 1938). However, some researchers found that some important physical properties are moisture content, radial shrinkage, tangential shrinkage, and density have been reported to be influenced by genetic factors (Cave & Walker 1994, Ying *et al.* 1994).

Materials and Methods

Sample collection and methods

Sample logs were collected from Senami forest, Jambi, Indonesia. Four logs of *E. zwageri* were used as samples for mechanical property tests. The size of the logs was 25 cm dbh. They were cut at 100 cm above soil surface with length of 100 cm. The sample logs were recognized as representing four varieties of ironwood namely - *exilis, ovoidus,* *zwageri* and *grandis*- were used to explain wood properties of investigated logs. The samples were investigated at the Laboratory of Forest Product Technology at Bogor Agriculture University, Indonesia.

From each log one set sample was taken which consisted of five unit samples for physical and mechanical property investigation. The size was (5x5x55-70) cm^3. The Physical and mechanical property test was referred to British Standard (BS) 375-57. Water content was measured by Gravimetry method. The sample size was (1x2x2) cm^3. The samples were weighed and dried in an oven at a temperature of (103±2) °C until they reached constant weight. Water content was calculated by the formula: {(first weight-constant weight)/constant weight} x 100%.

Density was measured by the standard method in which density is the comparison of the constant weight of wood to its green volume. The green volume was calculated based on the principle of Archimides. Sample size was (1x2x2) cm^3. Shrinkage tests were conducted using sample sizes of (5x5x0.6) cm^3 for tangential shrinkage and (2x2x2) cm^3 for radial shrinkage. The shrinkage was measured from green condition to air dry and oven dry.

Bending strength and modulus of elasticity were tested using an AMSLER universal testing machine with a capacity of 6000 kg. The sample size was (2x2x24) cm^3. The samples were pressured centrally until they were destroyed. Tensile strength parallel to grain and compression parallel to grain were tested using the same machine until the samples were destroyed These sample sizes were (2x2x6) cm^3 and (2x2x7.12) cm^3. Side hardness was measured by pressing a steel ball into the sample. The maximum load required to embed the ball to one-half its diameter is the value of side hardness.

Parameters and statistical analysis

Macroscopic features which were observed were wood color, wood texture, wood fibers, and wood hardness. In addition to those four parameters, investigation was also conducted to determine vessel elements, including vessel distribution, size and frequency; rays, including type, size and frequency; type of axial parenchyma; tree rings; and color differentiation between early wood and late wood. Microscopic features investigated included proportion of rays, proportion of fibers, proportion of parenchyma, and proportion of vessels.

The following parameters of physical and mechanical properties of sample logs were investigated: green and dry air moisture content (%); radial shrinkage of green to oven dry (%); radial shrinkage of green to air dry (%); tangential shrinkage of green to oven dry (%); tangential shrinkage of green to air dry (%); density (g cm^{-3}); green and air dry hardness (kg cm^{-2}); green and air dry modulus of elasticity (MOE) (kg cm^{-2}); green and air dry bending strength (MOR) (kg cm^{-2}); green and air dry tensile strength parallel to grain (kg cm^{-2}) green and air dry compression parallel to grain (kg cm^{-2}). Data were analyzed using analysis of variance, Duncan multiple range test, and discriminant analysis and clustering, which was performed using UPGMA cluster analysis. The software package used was Number Cruncher Statistical System (NCSS) (Hintze 2001).

Results and Discussion

Results

Some parameters of physical and mechanical properties were not significantly different among logs. These were dry air moisture content, tangential shrinkage green to oven dry, green hardness and green compression parallel to grain. Other parameters were significantly different among logs. For green moisture content, *exilis* was not different from *ovoidus* but it was different from *zwageri* and *grandis*, while both *zwageri* and *grandis* were significantly different from one another. The same performance can also be found on green to air dry radial shrinkage (Table 1).

Green to oven dry radial shrinkage was the parameter that shows the clearest differentiation among logs. The investigated logs were significantly different from one another. Green to air dry tangential shrinkage and dry air MOR show that *exilis* was significantly different from *ovoidus*, *zwageri* and *grandis* while among the last three logs there was no significant difference. Density of *exilis* was not significantly different from the other three investigated logs. *Ovoidus* and *zwageri* were also not significantly different from each other; however, they were significantly different from *grandis* variety.

For green hardness, there was no difference among investigated logs, but they were significantly different from each other for air dry hardness. The difference was shown by two groups, where *exilis* and *ovoidus* were not significantly different and neither were *zwageri* and *grandis*. However, both two groups were significantly different from each other. Green MOE, green MOR and dry compression parallel to grain show the same performance among investigated logs. The significantly different were only *zwageri* and *exilis*. The difference was shown by two groups for air dry MOE, where *exilis* and *zwageri* were not significantly different and neither were *ovoidus* and *grandis*. However, both two groups were significantly different from each other (Table 2).

Green tensile strength parallel to grain shows complicated differentiation. *Exilis* and *ovoidus* were not significantly different and neither were *exilis* and *zwageri* or *ovoidus* and *grandis*. However, *ovoidus* was significantly different from *zwageri* and *zwageri* was significantly different from *grandis*. For air dry tensile strength parallel to grain, *exilis* was significantly different from the other three investigated logs, as was *ovoidus*. However, *zwageri* and *grandis* were not significantly different from each other (Table 3).

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The cluster analysis based on physical and mechanical properties shows that *zwageri* and *ovoidus* formed one cluster with a higher degree of similarity than another cluster, which was formed by *grandis* and *exilis* (Figure 1). This dendrogram is synchronized with the dendrogram which was formed based on other morphological structures of ironwood (Irawan 2005).

Table 1 Moisture content and shrinkage of four different investigated logs of ironwood

Investigated logs	Green moisture content, %	Dry air moisture content, %	Green to oven dry radial shrinkage, %	Green to air dry radial shrinkage,%	Green to oven dry tangential shrinkage, %	Green to air dry tangential shrinkage,%
Exilis	39 a	14,4 a	5,68 a	1,46 a	7,26 a	1,84 a
Ovoidus	36 ab	15,2 a	4,93 b	1,15 ab	8,03 a	2,74 b
Zwageri	34 b	14,9 a	4,32 c	1,00 b	8,85 a	2,88 b
Grandis	43 c	14,8 a	6,86 d	1,90 c	8,35 a	2,73 b

Note: The mean values that are followed by the same letters are not significantly different based on 5% of Duncan multiple range test.

Table 2 Density and MOE of four different investigated logs of ironwood

Investigated logs	Densities, g cm^{-3}	Green hardness, kg cm^{-2}	Air dry hardnes, kg cm^{-2}	Green MOEs, kg cm^{-2}	Air dry MOEs, kg cm^{-2}	Green MORs, kg cm^{-2}
Exilis	0,87 ab	541 a	638 a	154665,8 a	170806,4 a	1491,28 a
Ovoidus	0,90 b	535 a	583 a	137729,5 ab	135461,7 b	1575,73 ab
Zwageri	0,91 b	610 a	785 b	123209,5 b	173173,7 a	1797,66 b
Grandis	0,82 a	595 a	783 b	133651,6 ab	121141,6 b	1576,02 ab

Note: The mean values that are followed by the same letters are not significantly different based on 5% of Duncan multiple range test.

Table 3 MOR, tensile, and compression strength of four different investigated logs of ironwood

Investigated logs	Dry air MORs, kg cm^{-2}	Green tensile strengths parallel to grain, kg cm^{-2}	Air dry tensile strengths parallel to grain, kg cm^{-2}	Green compressions parallel to grain, kg cm^{-2}	Dry air compressions parallel to grain, kg cm^{-2}
Exilis	1573,87a	37,07 ab	35,64 a	658,60 a	694,74 a
Ovoidus	1838,44 b	41,30 bc	44,98 b	722,58 a	760,15 ab
Zwageri	2012,43 b	33,27 a	41,04 c	670,22 a	777,16 b
Grandis	1834,67 b	42,42 c	41,40 c	628,22 a	727,39 ab

Note: The mean values that are followed by the same letters are not significantly different based on 5% of Duncan multiple range test.

Discussion

Physical and mechanical properties of ironwood obtained by this study show the same properties as did the study by Scharai-Rad and Sulistyobudi (1985). Even some properties such as green moisture content, dry air MOR, and air dry compression parallel to grain strongly support that the wood sample used in both cases was *grandis* variety. Those physical and mechanical properties also obtained more or less the same results as results provided by Martawijaya *et al.* (1989) and Kostermans *et al.* (1994).

Results of moisture content measurement supported indigenous knowledge. Local people believed that *exilis* is the heaviest variety due to high moisture content. The moisture content of *exilis* is 39%, which is a little lower compared to *grandis* but is higher than those of *ovoidus* and *zwageri*. Those results are also in agreement with Scharai-Rad & Sulistyobudi (1985). They found that the moisture content of ironwood was 44.16%, which is close to *grandis* (43%).

The difference in radial shrinkage of wood among ironwood varieties is more pronounced compared to their tangential shrinkage. The trend of differentiation among ironwood varieties on radial shrinkage and moisture content is parallel to each other. The highest values belong to *grandis* and the lowest belong to *zwageri*. The values of green to oven radial shrinkage are a little bit higher than those provided by Martawijya *et al.* (1989) and Kostermans *et al.* (1994). However, the interval values of green to oven dry tangential shrinkage are quite similar.

The density results obtained by this study are lower than those reported by Scharai-Rad and Sulistyobudi (1985). The reason is the different stem size from which samples were taken. Lower density values provided by this study are due to the small size of stems from which samples were taken. The size of the stems was about 25 cm, which is still very young for ironwood since the harvestable trees must reach a diameter of 60 cm. However, they are still in the density interval which was obtained by Martawijaya *et al.* (1989), Dahms (1981, 1982), and Kostermans *et al.* (1994).These differences in wood density are meaningful since density has moderate to high heritability in many species (Zobel 1961, Stonecypher & Zobel 1966, Zobel & Talbert 1984, Zobel & Jett 1995, Rozenberg & Cahalan 1997). They also proved that wood density, however, is not significantly correlated with annual growth rate (ring width) in either juvenile wood or mature wood, although a weakly negative correlation tends to strengthen in mature wood (Koga & Zhang 2002). The only species groups in which density is closely related to growth rate are the ring and semi-ring-porous hardwoods. In these species the density and hardness tend to increase as the growth rate increases (Wilson & White 1986, Dinwoodie 2000, Bowyer *et al.* 2003).

Scharai-Rad and Sulistyobudi (1985) explained that the high density of ironwood is due to extremely thick fiber walls and relatively low proportion of vessels. However, this explanation is not fully correct. *Zwageri* is the variety which has the highest density but it has fiber wall thickness of just 8.45 μ and vessel proportion of 11.50% while *grandis* variety, which has the lowest density, has thicker fiber wall thickness (11.20 μ) and lower vessel proportion (8.00%). This is understandable since wood density is not a simple characteristic. As described by many literatures, density is affected by the cell wall thickness, the cell diameter, the earlywood to latewood ratio and the chemical content of the wood (Cave & Walker 1994, Bowyer *et al.* 2003).

The hardness results obtained by this study are lower than those obtained by Martawijya *et al.* (1989) and Kostermans *et al.* (1994). Lower hardness values are possibly due to the young age of stems from which samples were taken. However, *zwageri* variety has the highest values for both green and air dry hardness, which are close to both former literatures.

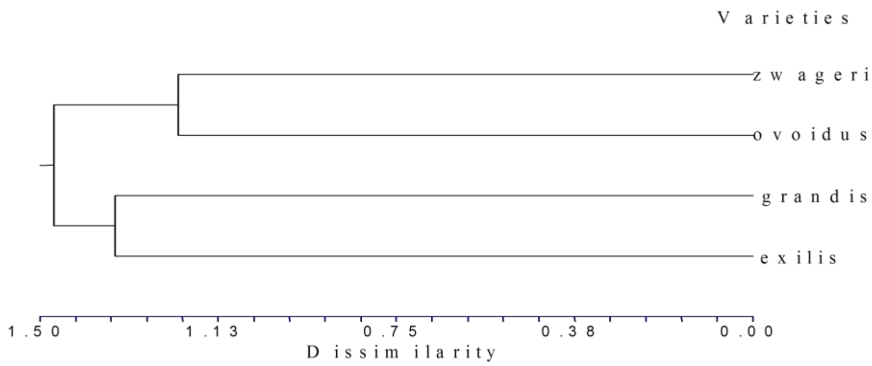

Figure 1 Physical and mechanical properties among investigated logs of ironwood varieties revealed by cluster analysis (UPGMA) based on distance type of Euclidean and scale type of standard deviation (Hintze 2001).

Green and air dry MOE results obtained by Martwaijaya *et al.* (1989) had higher values as did green tensile strength parallel to grain, compared to the results of this study. Dry tensile strength parallel to grain and MOR in green condition obtained opposite results (Kostermans *et al.* 1994). However, the differences between these results are not really pronounced.

Conclusion

Physical and mechanical properties of ironwood are significantly different among investigated logs. Z*wageri* and *ovoidus* varieties formed one cluster with a higher degree of similarity than another cluster, which was formed by *grandis* and *exilis*. This dendrogram is synchronized with the dendrogram which was formed based on other morphological structures of ironwood.

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