FIELD NOTE

Basic wood properties of Borneo ironwood (*Eusideroxylon zwageri*) planted in Sarawak, Malaysia

Haruna Aiso-Sanada¹,², Ikumi Nezu³, Futoshi Ishiguri³*, Aina Nadia Najwa Binti Mohamad Jaffar⁴, Douglas Bungan Anak Ambun⁴, Mugunthan Perumal⁴, Mohd Effendi Wasli⁴, Tatsuhiro Ohkubo³ and Hisashi Abe¹

¹ Department of Wood Properties and Processing, Forestry and Forest Products Research Institute, Tsukuba 305-8687, Japan
² Research Fellow of Japan Society for the Promotion of Science
³ School of Agriculture, Utsunomiya University, Utsunomiya 321-8505, Japan
⁴ Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
* Corresponding author: ishiguri@cc.utsunomiya-u.ac.jp

Received: June 8, 2019  Accepted: December 6, 2019

ABSTRACT  The aim of this study is to obtain the basic wood properties of planted Borneo ironwood (*Eusideroxylon zwageri*) from a plantation established about 80 years ago. Stem diameter at 1.3 m above the ground, tree height, and stress-wave velocity (SWV) of stem were measured on 36 planted *E. zwageri* trees. Later, core samples were collected from four trees whose measurements represented the average stem diameter of all the measured trees. Using the core samples, the moisture content (MC), basic density (BD), and compressive strength parallel to grain (CS) were measured. Dynamic Young’s modulus for longitudinal direction at green condition (*E*) was also calculated from SWV. There was no significant relationship between growth characteristics and SWV. Mean values of MC, BD, CS, and *E* were 37.2 %, 0.86 g/cm³, 64.3 MPa, and 18.47 GPa, respectively. Significant differences among individual trees were found in MC, BD, and CS. In addition, radial variations were almost constant from bark side to pith side. The results indicate that longitudinal *E* is independent from growth characteristics, and that the *E. zwageri* wood tested in this study has uniform BD and CS in the radial direction.

Key words: Borneo ironwood, compressive strength, basic density, dynamic Young’s modulus

INTRODUCTION

*Eusideroxylon zwageri* Teijsm. & Binnend., known as belian in Malaysia, ulin in Indonesia, and Borneo ironwood in English, is in the Lauraceae family. This evergreen tree species is distributed in Eastern and Southern Sumatra, Bangka, Belitung, Borneo, and the Sulu archipelago and Palawan (Soerianegara and Lemmens 1993). Although *E. zwageri* trees grow very slowly, this species is known as one of the heaviest and most durable timbers in South-East Asia (Soerianegara and Lemmens 1993; United States Department of Agriculture Forest Service 2010). Due to these natures, *E. zwageri* wood is commonly utilized for marine work, boatbuilding, heavy construction, and roofing shingles (Soerianegara and Lemmens 1993; United States Department of Agriculture Forest Service 2010).

For effective wood utilization, the physical and mechanical properties of the wood must be known. Data of physical and mechanical properties can usually be obtained from published literature; however, wood properties generally vary within a tree (in radial and longitudinal directions) and among trees (Panshin and de Zeeuw 1970). In the case of the tropical fast-growing planted species *Acacia* spp., wood fiber length and wood density increase from pith to bark sides (Kim et al. 2011; Nugroho et al. 2012). Makino et al. (2012) pointed out that in *Acacia mangium*, the compressive strength parallel to grain also increased from pith to bark. In *E. zwageri* wood, physical and mechanical properties such as wood density, shrinkage, modulus of elasticity, and modulus of rupture have been listed in literature (Soerianegara and Lemmens 1993; United States Department of Agriculture Forest Service 2010), whereas the radial variations of wood properties in *E. zwageri* are not fully investigated, especially in the case of planted trees.

This study was carried out to obtain the basic information on physical and mechanical properties of wood from planted *E. zwageri* trees in relation to growth characteristics. With collected core samples from bark to pith sides, we also investigated the radial variations of the wood...
properties of *E. zwageri*.

**MATERIALS AND METHODS**

In this study, *Eusideroxylon zwageri* trees grown in the Landeh Nature Reserve, Sarawak, Malaysia (01°24′58″N, 110°18′32″E; altitude: ca. 30 m above sea level; topography: flat) were investigated. The Landeh Nature Reserve was established in 1936, and both *E. zwageri* and *Shorea macrophylla* seedlings were planted at the site. *Eusideroxylon zwageri* trees were linearly planted in a Southeast to Northwest direction, and *S. macrophylla* trees were vertically planted against the line of *E. zwageri* trees (Fig. 1). The spacing of *E. zwageri* trees was 8 m between lines, and 5 m between trees in a line (Fig. 1). In this study, a total of 36 trees from five lines (6, 9, 9, 7, and 5 trees, respectively, from each line) were selected to measure growth characteristics and wood properties.

For 36 *E. zwageri* trees, stem diameter at 1.3 m above the ground, tree height, and stress-wave velocity (SWV) of stem were measured following the methods previously described by Ishiguri et al. (2012). In brief, stress-wave propagation time between start and stop sensors (0.5 and 1.5 m above the ground, respectively) was measured using a commercial handheld stress-wave timer (Fakopp Micro-second Timer, Fakopp Enterprise, Hungary) and a small hammer. The SWV was calculated by dividing the distance between two sensors by the stress-wave propagation time.

Based on the data of stem diameter, four trees with similar mean stem diameters (referred to as trees A, B, C, and D) to the average of the 36 trees were selected for core samples. Four core samples (5 mm in diameter) from the bark side were collected from each of the trees via core bore (5.15 mm in diameter, Haglöf, Sweden) with a Smartsocket for Φ 5 mm cores (MKS-19, Techno Forest, Japan) and an impact drill (TW-1001D, Makita, Japan). Due to the high wood density of *E. zwageri*, the core samples could not reach the pith. Thus, they were collected from the bark side to as close as possible to the pith side, resulting in core samples of varying lengths.

Moisture content (MC), basic density (BD), and compressive strength parallel to grain at green condition (CS) were measured using collected core samples. One core sample from each tree was cut into 1 cm intervals, and then weight and volume at green condition were measured. Volume was measured using the water displacement method. After weight and volume measurement, core samples were kept in the oven (105 ± 3°C) overnight and then measured for oven-dry weight. The MC and BD were calculated as follows:

\[
MC (\%) = \frac{(W_g - W_o)}{W_o} \times 100
\]

\[
BD (g/cm^3) = \frac{W_o}{V_g}
\]

where \( W_g \) = weight at green condition, \( W_o \) = oven-dry weight, and \( V_g \) = volume at green condition.

Using another core sample from each tree, the CS was measured using a strength-testing machine for core samples (Fractometer II, IML) according to Ishiguri et al. (2012). Since the CS measurements in the standard 5 mm samples exceeded the range of CS values found in the strength-testing machine, each core sample was cut to 2.5 mm thickness. Then, the specimens were tested in the strength-testing machine, where load was slowly applied in the longitudinal direction of the specimen. CS value was calculated by doubling the measured values.

Using values of SWV (km/s) and density at green condition (\( \rho = \frac{W_g}{V_g}, \) kg/m\(^3\)), dynamic Young’s modulus for longitudinal direction at green condition (\( E \)) was calculated using the following formula (Nanami et al. 1993):

\[
E \text{ (GPa)} = (\text{SWV} \times 1000)^2 \times \rho.
\]

To clarify the among-tree variations of the wood properties, a one-way analysis of variance (ANOVA) was applied. The ANOVA test was conducted using R software (R Core Team 2018).
RESULTS

The mean stem diameter, tree height, and SWV of the 36 trees was 20.6 cm, 16.5 m, and 4.11 km/s, respectively (Table 1). As shown in Fig. 2, a significant relationship between stem diameter and tree height was found ($r = 0.549^{**}$), whereas SWV showed no significant correlations to stem diameter ($r = -0.308^{ns}$) or tree height ($r = -0.240^{ns}$). Among the trees from which core samples were collected, stem diameter, tree height, and SWV ranged from 20.4 to 23.8 cm, from 14.1 to 19.5 m, and from 3.63 to 4.17 km/s, respectively (Table 1).

Mean values of MC, BD, CS, and $E$ of trees A to D were 37.2%, 0.86 g/cm$^3$, 64.3 MPa, and 18.47 GPa, respectively (Table 2). Significant differences among individual trees were found in MC, BD, and CS (Table 2). Radial variations of MC, BD, and CS in relation to relative distance from pith were almost constant from pith to bark sides (Fig. 3). As shown in Fig. 3, values of MC, BD and CS in heartwood were almost the same as those in sapwood.

DISCUSSION

Growth characteristics and wood properties of planted $E. zwageri$ were investigated in Sarawak, Malaysia. Based on the results, SWV was independent of growth characteristics, suggesting that the $E$ of $E. zwageri$ is not influenced by growth characteristics. In addition, it is indicated that $E. zwageri$ can produce wood with uniformly high BD from bark side to pith side.

As for tropical tree species with slower-growing characteristics, it has been reported that the SWV of standing trees is 3.83-4.10 km/s for $Shorea acuminatissima$ at age thirty-five (Ishiguri et al. 2012), and 3.22 km/s for $Tectona grandis$ at age twenty-four (Hidayati et al. 2013), respectively. In both species, stem diameter growth did not negatively affect the SWV (Ishiguri et al. 2012; Hidayati et al. 2013). The SWV obtained in this study was higher than that of $T. grandis$ and similar to that of $S. acuminatissima$ (Table 1). No relationships were found between growth characteristics and SWV (Fig. 2), indicating that SWV and growth characteristics of $E. zwageri$ are independent of each other. Since $E$ can be calculated by using the values of SWV and density at green condition, the relationship

Table 1. Mean ± standard deviation values of growth characteristics and stress-wave velocity of $E. zwageri$ tested in this study.

| Property   | Mean ($n_1 = 36$) | Code for trees collected core samples | Mean ($n_2 = 4$) |
|------------|------------------|--------------------------------------|------------------|
| DBH (cm)   | 20.6 ± 7.8       | A 22.8, B 23.8, C 20.8, D 20.4      | 22.0 ± 1.6       |
| TH (m)     | 16.5 ± 5.7       | A 18.7, B 14.1, C 19.5, D 15.7      | 17.0 ± 2.5       |
| SWV (km/s) | 4.11 ± 0.25      | A 4.17, B 4.08, C 3.83, D 3.63      | 3.93 ± 0.25      |

Note: $n_1$, number of individual trees in the plot; $n_2$, number of individual trees with collected core samples; DBH, stem diameter at 1.3 m above the ground; TH, tree height; SWV, stress-wave velocity.
between growth characteristics and SWV in this study suggest that E in E. zwageri may be independent from growth characteristics.

It is known that E. zwageri wood has some of the highest physical and mechanical properties amongst硬材 (Wood Technology Division and Forest Products Chemistry Division 1974; Soerianegara and Lemmens 1993; United States Department of Agriculture Forest Service 2010). Wood density and CS at 38 % moisture content in this species were found to be 1.30 g/cm$^3$ and 80 MPa, respectively (Soerianegara and Lemmens 1993). Similar results were reported on the green conditions of this species from the United States Department of Agriculture Forest Service (2010), with 0.89 g/cm$^3$ for BD and 79.9 MPa for CS, respectively. In this study, similar or relatively lower values of BD and CS at green condition (MC $\geq$ 37.2 %, Table 2) were obtained compared to those in previous reports. In addition, these properties showed significant differences among individual trees (Table 2), even though trees A to D had similar diameter. Our results suggest that physical and mechanical properties may vary among individual trees in E. zwageri. On the other hand, values of E in E. zwageri trees ranged from 15.88 to 20.63 GPa (Table 2). Although the measurement method and moisture content of the specimens differed, the E obtained in this study might be within range of those in other tropical hardwood species, such as Acacia meransii (17.2 GPa), Eucalyptus spp. (12.7 to 21.5 GPa), and T. grandis (15.1 GPa) (MC $\geq$ 12 %, Ilic 2003).

Wood properties such as wall thickness and microfibril angle of the S$_2$ layer in wood fibers generally vary in the radial direction (Panshin and de Zeeuw 1970; Kim et al. 2011; Makino et al. 2012; Nugroho et al. 2012; Ishiguri et al. 2012, 2016; Palermo et al. 2014). However, in some species, especially tropical hardwoods such as Dysisoxylon mollissimum and S. acuminatissima, the values are constant from pith to

---

Table 2. Mean ± standard deviation values of moisture content, basic density, compressive strength parallel to grain at green condition, and dynamic Young’s modulus at green condition in the sampled E. zwageri trees.

| Property                  | Sampled tree code | Mean ($n=4$) |
|---------------------------|-------------------|--------------|
|                           | A                 | B            | C            | D            |
| MC (%)                    | 37.5 ± 4.1        | 39.8 ± 3.8   | 37.2 ± 3.3   | 34.3 ± 2.0   | 37.2 ± 2.3$^*$ |
| BD (g/cm$^3$)             | 0.86 ± 0.03       | 0.83 ± 0.03  | 0.87 ± 0.04  | 0.90 ± 0.03  | 0.86 ± 0.03$^*$ |
| CS (MPa)                  | 67.1 ± 7.5        | 73.8 ± 11.0  | 61.8 ± 7.8   | 54.4 ± 4.1   | 64.3 ± 8.2$^*$ |
| E (GPa)                   | 20.63             | 19.32        | 18.04        | 15.88        | 18.47 ± 2.0 |

Note: $n$, number of individual trees; MC, moisture content at green condition; BD, basic density; CS, compressive strength parallel to grain at green condition; E: dynamic Young’s modulus for longitudinal direction at green condition; * significance at the 5 % level by ANOVA test; ** significance among trees at the 1 % level by ANOVA test.

---

Fig. 3. Radial variations from bark to pith sides in moisture content, basic density, and compressive strength parallel to grain of E. zwageri. Moisture content and compressive strength parallel to grain were measured at green condition. Circles, squares, triangles, and diamonds indicate tree A, tree B, tree C, and tree D, respectively. Open and filled symbols indicate sapwood and heartwood, respectively.
bark sides (Ishiguri et al. 2012, 2016). In E. zwageri with stem diameters of around 60 cm, radial variation of BD showed constant values from the relative position of 30 to 40% (ca. 18 to 24 cm) distance from pith, but gradually decreased after 40% (Wood Technology Division and Forest Products Chemistry Division 1974). In the present study, we used the sample trees with stem diameter (with bark) of less than 24 cm (Table 3) and found that MC, BD and CS values were almost stable from bark side to pith side (Fig. 3). These facts indicate that E. zwageri might have stable wood properties in the radial direction from the pith side to certain positions around 24 cm from the pith.

CONCLUSION

This study aimed to clarify the basic wood properties of E. zwageri planted in Sarawak, Malaysia. The following results were obtained:

1. No significant relationships were found among growth characteristics and SWV, suggesting that longitudinal Young’s modulus is independent of growth characteristics.

2. Mean values of MC, BD, and CS were, respectively, 37.2%, 0.86 g/cm³, and 64.3 MPa. Significant differences among trees were found in all properties, indicating that physical and mechanical properties varied among individual trees in E. zwageri.

3. Radial variations of MC, BD, and CS were almost constant from pith to bark sides. Based on the results of this study and those of a previous report, E. zwageri with stem diameters around 50 cm may produce wood with stable qualities in the radial direction.

ACKNOWLEDGEMENTS

The authors would like to thank the Director of Forest, Sarawak Forest Department, Sarawak, Malaysia, and Dr. Akira Kagawa, Department of Wood Properties and Processing, Forestry and Forest Products Research Institute, Tsukuba, Japan, for the support in collecting the core samples.

REFERENCE

Hidayati F, Ishiguri F, Iizuka K, Nordin MN, Makein K, Ishiguri F, Aiso H, Hirano M, Yahya R, Wahyudi I, Ohshima J, Iizuka K, Yokota S. 2016. Effects of radial growth rate on anatomical characteristics and wood properties of 10-year-old D. mollissimum trees planted in Bengkulu, Indonesia. Tropics 25: 23–31.

Kim NT, Matsumura J, Oda K. 2011. Effect of growing site on the fundamental wood properties of natural hybrid clones of Acacia in Vietnam. Journal of Wood Science 57: 87–93.

Makino K, Ishiguri F, Wahyudi I, Takashima Y, Iizuka K, Yokota S, Yoshizawa N. 2012. Wood properties of young Acacia mangium trees planted in Indonesia. Forest Products Journal 62 (2): 102–106.

Nanami N, Nakamura N, Arima T, Okuma M. 1993. Measuring the properties of standing trees with stress waves III. Evaluating the properties of standing trees for some forest stands. Mokuzai Gakkaishi 39: 903–909 (In Japanese with English summary).

Nugroho WD, Marsoem SN, Yasue K, Fujiwara T, Nakajima T, Hayakawa M, Nakaba S, Yamagishi Y, Jin HO, Kubo T, Funada R. 2012. Radial variations in the anatomical characteristics and density of the wood of Acacia mangium of five different provenances in Indonesia. Journal of Wood Science 58: 185–194.

Palermo GP de M, Latorraca JV de F, de Carvalho AM, Calonego FW, Severo ETD. 2014. Anatomical properties of Eucalyptus grandis wood and transition age between the juvenile and mature woods. European Journal of Wood and Wood Products 73: 775–780.

Panshin AJ, de Zeeuw C. 1970. Variability of wood within a species. In: Textbook of wood technology volume 1: structure, identification, uses, and properties of the commercial woods of the United States and Canada. McGraw-Hill Book Company, New York, St. Louis, San Francisco, Düsseldorf, London, Mexico, Panama, Sydney, Toronto. 237–275.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Soerianegara I, Lemmens RHMJ. 1993. Plant resources of southeast Asia No 5 (1): Timber trees: Major commercial timbers. Prosea, Bogor.

United States Department of Agriculture Forest Service. 2010. Wood Technical Fact Sheet: Eusideroxylon zwageri https://www.fpl.fs.fed.us/documents/TechSheets/Chudnoff/SEAsian_Oceanic/htmlDocs_SEAsian/Eusideroxylonzwageri.html (cited June 3, 2019).

Wood Technology Division and Forest Products Chemistry Division. 1974. The properties of tropical woods 19: studies on the utilization of ten species from Kalimantan and New Guinea. Bulletin of the Government Forest Experimental Station 262: 59–163 (In Japanese).