Acoustic Properties of *Syzygium* sp., *Dialium* sp., *Gymnostoma* sp., and *Sindora* sp. Wood

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Acoustic properties such as specific dynamic Young's modulus (E_d/γ), internal friction (Q^{-1}), and acoustic conversion efficiency (ACE) of wood are important properties frequently examined using free-free flexural vibration. This study determined the suitability for making musical instrument soundboards and frameboards from four tropical wood species; namely *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora*. The results show that (E_d/γ), (Q^{-1}), and ACE were in the range of 20.0 to 28.9 GPa, 0.0031 to 0.0085, and 3.41×10^7 to 10.83×10^7, respectively. Based on the results, *Syzygium* was preferred for making the frameboard of violins and guitars. The outer sapwood (outer part) of *Syzygium* was the most suitable for making frameboard by considering the lowest ACE and highest Q^{-1}. Based on E_d/γ, the inner sapwood (middle part) in *Dialium* was the most suitable for making soundboard, but based on Q^{-1} and ACE, heartwood (inner part) was the most preferred for making soundboard. *Gymnostoma* was also preferred for making soundboard of violins and guitars (inner sapwood) because it yields the highest mean value of Q^{-1} and ACE. Considering ACE and Q^{-1}, the outer sapwood in *Sindora* was the best for making frameboard. When considering E_d/γ and Q^{-1}, the heartwood is the most suitable for making the frameboard of violins and guitars.

Keywords: Acoustic properties; Tropical wood species; Syzygium; Dialium; Gymnostoma; Sindora

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INTRODUCTION

There is great opportunity to explore the acoustic properties of various wood species for manufacturing high quality musical instruments, since wood is found in numerous tropical forests in Malaysia. Even though tropical rainforests have enormous resources of timber (especially in Borneo), where the major timber consumers are housing developers, wood fabricators, and furniture manufacturers, research on tropical wood for musical instruments is still lacking. Musical instruments are manufactured from wood due to its unique acoustic properties, even though there are other various materials currently available. However, up to this point, experienced manufacturers have determined the suitability of tropical wood for making musical instruments mainly based on trial and error. Therefore, although there are a lot of other wood species available in Malaysia, the tropical wood species that have been selected by experienced manufacturers in making musical instruments are very limited, such as *Intsia palembanica* (Merbau) and *Artocarpus champeden* Spreng. (Cempedak) (Chong 2000). The importance of this study is to employ a scientifically based approach in determining the acoustic properties of wood rather than trial and error.

Suitable wood for manufacturing musical instruments can be scientifically determined by the acoustic properties. So far, only a few tropical wood species have been used, such as *Dialium* and *Agathis borneensis* (Yasuda *et al*. 1993; Obataya *et al*. 1996; Matsunaga *et al.* 1996; Chong 2000; Kubojima *et al*. 2000; Chang *et al.* 2000).

Acoustic properties such as specific dynamic Young's modulus (E/γ), internal friction Q^{-1}), and acoustic conversion efficiency (ACE) of wood are important properties frequently examined by researchers. ACE is related to the ratio of acoustic energy radiated from the musical instrument to the energy given to the instrument. A high ACE is required for an excellent soundboard. Generally, wood with a higher value of E_d/γ and lower Q^{-1} is suitable for soundboards; thus, wood having a lower value of $Q^{-1}/(E_d/\gamma)$ is suitable for musical instruments. Vibration technique is one of the non-destructive evaluation techniques used as an alternative method for measuring the acoustic properties of wood.

Full-grown trees were used as the source of wood for this work. By using the whole tree, a serious producer of musical instruments can be assured that the variation from heartwood and sapwood is acceptable. These particular species are not being used by the major timber consumers such as the housing developers, wood fabricators, and furniture manufacturers, but they are found growing easily in the tropical forest. Research on these species for musical instruments is still lacking because musical instrument in Malaysia are very limited to *Intsia palembanica* (Merbau) and *Artocarpus champeden* Spreng. (Cempedak). As far as the authors have been able to determine, there is no historical use of these woods and no record on any prior use of any of this species in the musical field. The objectives of this study are to determine acoustic properties including E_d/γ, Q^{-1}, and ACE of four selected low density tropical wood species namely *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora* from tropical forests in Borneo and determine their suitability for making acoustic instruments like violin and guitar.

EXPERIMENTAL

Materials

The specimens were cut from heartwood and sapwood of four wood species. *Sindora* sp. (vernacular name Sepetir applied in Malaysia) is from the Leguminosae family. It grows in the district of Borneo, Malaysia, and has a brown to light brown appearance. It is normally used in light construction, plywood, and furniture. *Syzygium* sp. (vernacular name, Ubah) is from the Myrtaceae family. It grows in Borneo, Malaysia, and has a dark grey to red brown appearance. It is normally used in beams, joists, rafters, and medium heavy structures. *Gymnostoma* spp. (*Gymnostoma nobile*) (vernacular name, Rhu) is from the Casuarinaceae family. It grows in Borneo and has a dark brown to red brown appearance. It is normally used in firewood and charcoal. *Dialium* spp. (vernacular name, Keranji) is from the *Leguminosae* family. It grows in Borneo and has a light to yellow brown appearance. It is normally used in pilings, doors, and window frames. Wood samples of *Syzygium* sp., *Dialium* sp., *Gymostoma* sp., and *Sindora* sp. with diameter at breast height (DBH) were at 46.8, 41.0, 45.0 and 76 cm, respectively. Test samples were from three radial positions namely heartwood, inner sapwood and outer sapwood (Fig. 1). Heartwood samples were 3 cm from the pith to avoid the inclusion of juvenile wood.

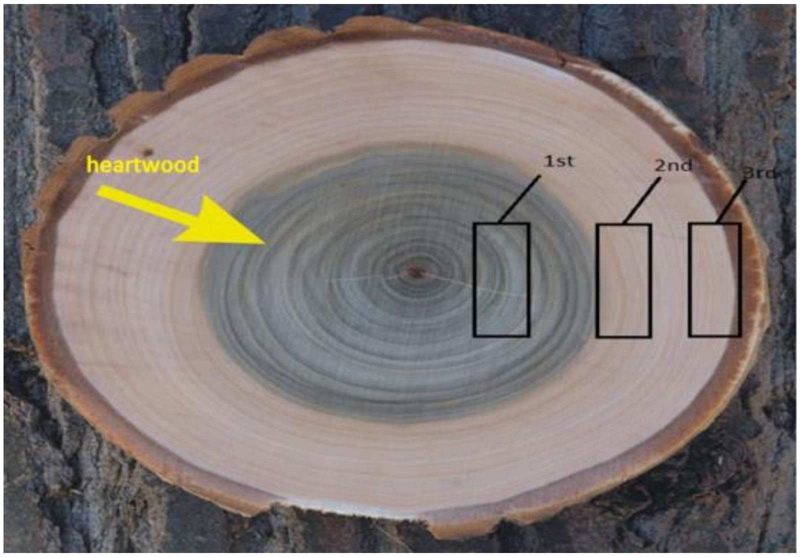

Fig. 1. Heartwood (1st), inner sapwood (2nd) and outer sapwood (3rd) of *Dialium* spp. (vernacular name, Keranji)

Methods

The four species of wood specimens were machined and divided into heartwood, inner sapwood, and outer sapwood (Fig. 1). Each section was machined into dimensions of 340 mm (L) x 20 mm (T) x 10 mm (R) for free-free vibration test. Each section provided 20 specimens of each species for the tests. All specimens were oven-dried to reduce the moisture content and were stored at ambient temperature at 25 °C and 60% relatively humidity for one month prior to testing.

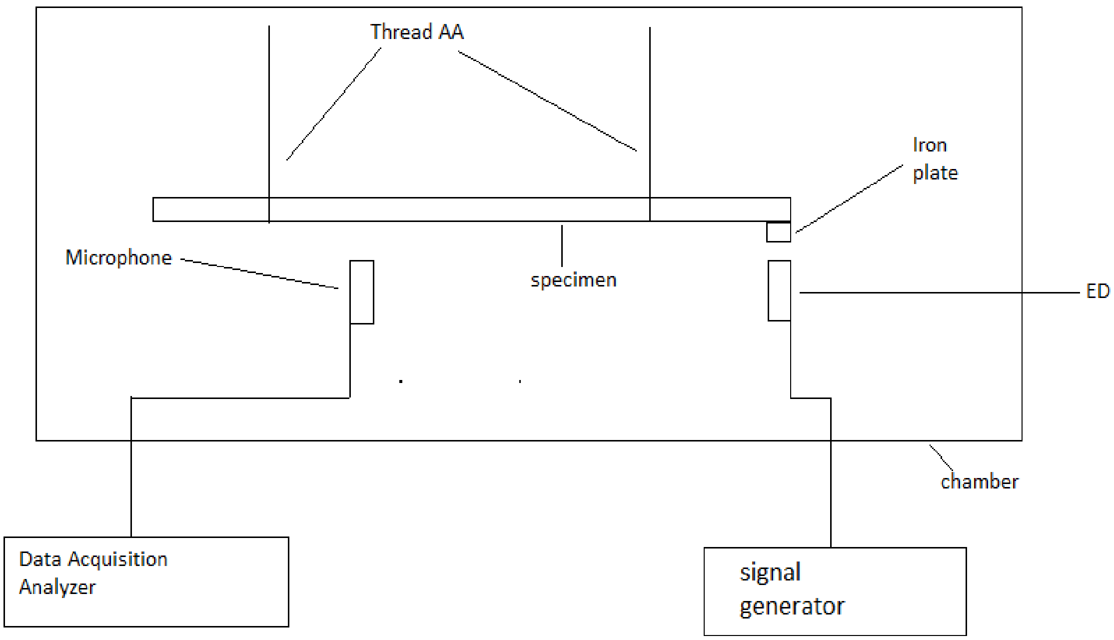

Fig. 2. Schematic diagram of free-free flexural system

Figure 2 shows a schematic diagram of free-free flexural system (Sedik *et al*. 2010). The specimen was held with a thread according to the first mode of vibration. The specimen with iron plate bonded at one end was set facing the electromagnetic driver, and a microphone was placed at the centre below the specimen. The frequency was varied from 1 Hz to 1000 Hz to achieve a resonant or natural frequency. The dynamic Young's Modulus (E) was calculated from the resonant frequency using Eq. 1,

$$E_d = \frac{4\pi^2\ f^2 l^4 A\rho}{I(m_n)^4} \tag{1}$$

where $I = \frac{bd^3}{12}$, d is beam depth, b is beam width, l is beam length, f is natural frequency of the specimen, n is mode of vibration, ρ is density, A is cross sectional area, and $m_1 = 4.73$.

The internal friction, Q^{-1}, was calculated from the resonant, lower, and upper frequencies (Eq. 2). The upper frequency f_2 and lower frequency f_1 were obtained by reducing the amplitude to 0.5 (6.02 dB) below the amplitude of the resonant frequency f_0,

$$Q^{-1} = \tan(\delta) \tag{2}$$

where $\delta = \pi\Delta f/f_0\sqrt{3}$, $\Delta f = f_2 - f_1$

The acoustic converting efficiency (ACE), was evaluated by using Eq. 3,

$$ACE = \frac{\sqrt{Ed/\gamma}}{\gamma\tan\delta} \tag{3}$$

where specific gravity (γ) in the air dry state was determined using Eqs. 4,

$$\text{Specific gravity } (\gamma) = m/m_w \tag{4}$$

and where m is the oven dry mass of sample (volume of sample at air dry state) and m_w is the mass of displaced water.

RESULTS AND DISCUSSION

Three major properties, namely specific dynamic Young's Modulus (E_d/γ), internal friction (Q^{-1}), and acoustic conversion efficiency (ACE) based on the frequency of the different species of wood, were compared which are shown in Figs. 3, 4, and 5, respectively. ACE is related to the ratio of acoustic energy radiated from the musical instrument to the energy given to the instrument. Generally, wood with higher value of E_d/γ and lower Q^{-1} is suitable for soundboards (Yano *et al*. 1992, 1995). A high ACE is required for an excellent soundboard; thus, wood having a lower value of $Q^{-1}/(E_d/\gamma)$ is suitable for musical instruments.

Based on Table 1 and Figs. 3 through 5, the mean E_d/γ, Q^{-1}, and ACE of each wood species were in the range 20.0 to 28.9 GPa, 0.0031 to 0.0085, and 3.41×10^7 to 10.83×10^7, respectively. *Syzygium* yielded the lowest mean acoustic properties in terms of E_d/γ and ACE and the highest Q^{-1}. In comparison with previous studies (Yano *et al*. 1992; Yano *et al*. 1995), the present study clearly showed that *Syzygium* is preferred for making frameboard of guitars and violins. The outer sapwood, the outermost sapwood, was the most suitable sample for making frameboard by considering the lowest ACE and highest Q^{-1} among the three samples (Yano *et al*. 1995).

Dialium spp. was preferred for making soundboard of violins and guitars due to the highest mean value of ACE and E_d/γ and lowest mean value of Q^{-1}. Based on the value of E_d/γ, the inner sapwood was most suitable for making soundboard, but based on the value of Q^{-1} and ACE, the outer sapwood was most preferred for making soundboard because of its lowest Q^{-1} and highest ACE in *Dialium* spp. (heartwood to sapwood) (Sedik *et al.* 2010).

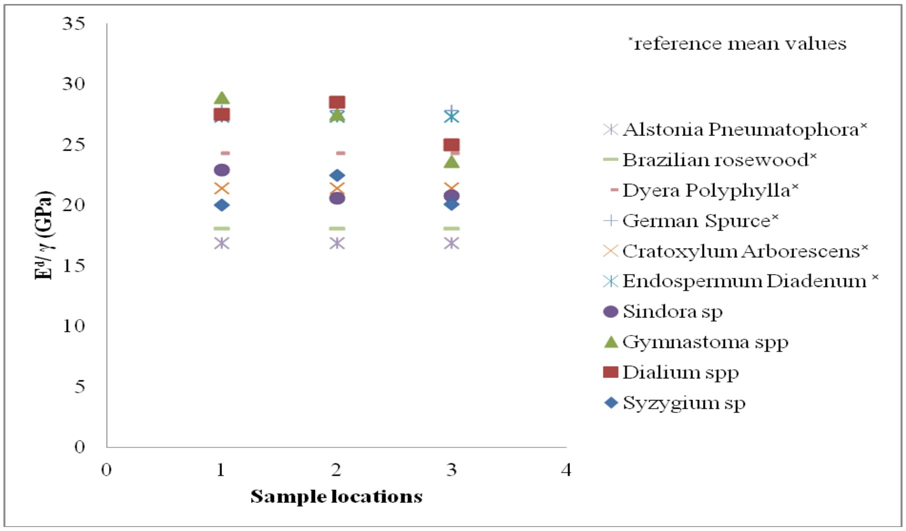

Fig. 3. Mean specific dynamic Young's Modulus (E_d/γ) from three samples (heartwood to sapwood) for *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora* wood log and comparisons to wood species for manufacturing soundboard and frameboard

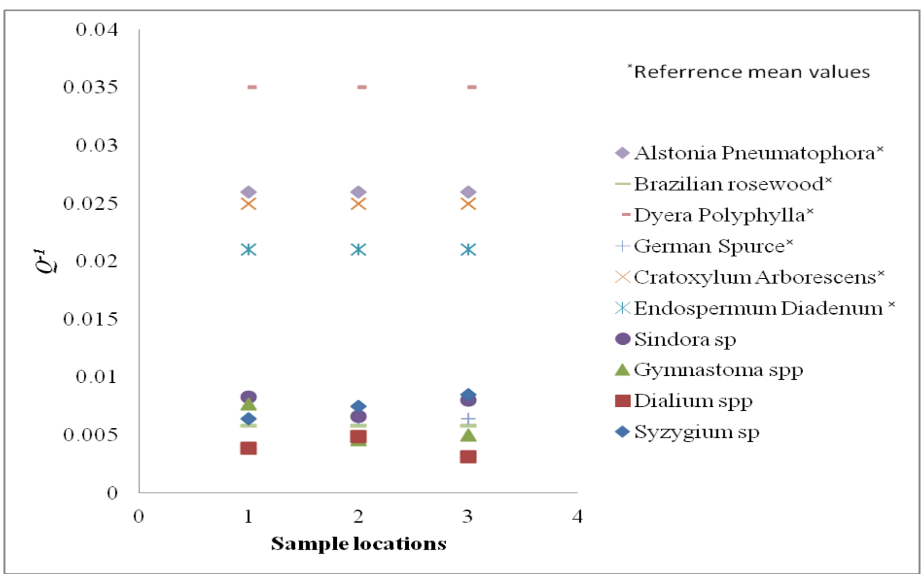

Fig. 4. Mean internal friction (Q^{-1}) from three samples (heartwood to sapwood) for *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora* wood log and comparisons to wood species for manufacturing soundboard and frameboard

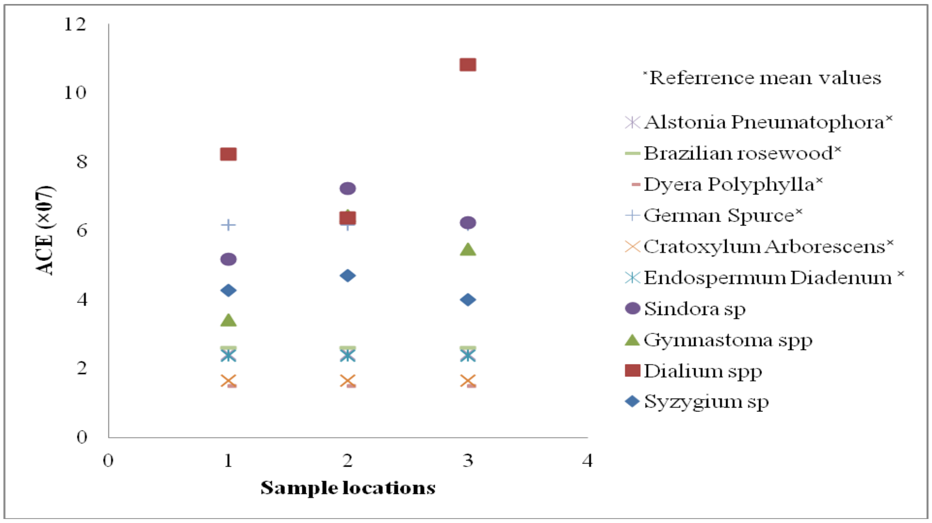

Fig. 5. Mean acoustic converting efficiency (ACE) from three samples (heartwood to sapwood) for *Syzygium*, *Dialium*, *Gymnostoma*, and *Sindora* wood log and comparisons to wood species for manufacturing soundboard and frameboard

Based on the mean value of the acoustic properties, *Gymnostoma* is also preferred for making soundboard for violins and guitars. Considering the mean value of acoustic properties between the three samples, the inner sapwood might be the best sample for making soundboards due to the highest mean value of Q^{-1} and ACE, even though the mean value of E_d/γ did not yield the highest result among the three samples. Based on the mean value of E_d/γ and Q^{-1} and comparison between the previous study, *Sindora* was preferred for making frameboard for violins and guitars even though the mean value of ACE was quite high compared to the three others species (Yano *et al.* 1992, 1995). Considering the mean value of ACE and Q^{-1}, the heartwood is the best sample for making frameboard. When considering the mean value of E_d/γ and Q^{-1}, the outer sapwood was the most suitable for making frameboard for violins and guitars.

Table 1. Mean Acoustic Properties (Obtained from Free-Free Flexural Vibration) of Received Wood Species Studied and Wood Species Suggestion for Manufacturing Soundboard and Frame Board

Species	Category	γ	E_d/γ (GPa)	Q^{-1}	ACE (×10^7)
Syzygium (ubah)	1st	0.523	20.0	0.0064	4.27
	2nd	0.433	22.2	0.0075	4.69
	3rd	0.419	20.1	0.0085	3.99
Dialium (keranji)	1st	0.517	27.5	0.0039	8.23
	2nd	0.537	28.5	0.0049	6.36
	3rd	0.468	25.0	0.0031	10.83
Gymnastoma (rhu)	1st	0.652	28.9	0.0077	3.41
	2nd	0.563	27.5	0.0046	6.43
	3rd	0.560	23.6	0.0050	5.47
Sindora (sepetir)	1st	0.361	22.9	0.0083	5.18
	2nd	0.306	20.6	0.0066	7.23
	3rd	0.295	20.8	0.0080	6.24

CONCLUSIONS

1. The suitability for the three samples for each species of wood for manufacturing soundboard and frameboard was evaluated and compared with the value of wood species for manufacturing soundboard and frameboard for musical instrument such as guitars and violins.
2. The mean values of specific dynamic Young's Modulus (E_d/γ), internal friction (Q^{-1}), and acoustic converting efficiency (ACE) of each wood species were in the ranges of 20.0 to 28.9 GPa, 0.0031 to 0.0085, and 3.41×10^7 to 10.83×10^7, respectively.
3. Based on the evaluation, *Syzygium* was preferred for making frameboard for guitars and violins. The outermost sapwood of the *Syzygium*, was the most suitable sample for making frame board by considering the lowest ACE and highest Q^{-1}.
4. *Dialium* is preferred for making soundboard for violins and guitars because of the highest mean value of ACE and E_d/γ. Based on the value of E_d/γ, the inner sapwood was the most suitable for making soundboard. Based on the value of Q^{-1} and ACE, the outer sapwood was the most preferred for making soundboard since it yield the lowest Q^{-1} and highest ACE amongst the three samples in *Dialium*.
5. *Gymnostoma* was also preferred for making soundboard for violins and guitars. The inner sapwood might be the best sample for making soundboard due to the highest mean value of Q^{-1} and ACE amongst the three samples.

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