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DRILLING RESISTANCE METHOD TO EVALUATE DENSITY AND HARDNESS PROPERTIES OF RESINOUS WOOD OF AGARWOOD (*AQUILARIA MALACCENSIS*)

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ABSTRACT

Gaharu or agarwood is produced by certain trees in response to fungal infections and wounds. The response is a pathological process that alters the physiological and chemical compounds produced in tree wood, yielding a fragrant resinous material. We investigated the density and hardness properties of agarwood using the drilling resistance method in 25 disks of *Aquilaria malaccensis* that had previously been inoculated with *Fusarium solani*. A micro drilling technique was applied in two directions across the diameter of the disks to measure resistance, starting in the part containing agarwood. In addition, hardness properties were determined based on the Janka test and density was measured based on the gravimetric method. We found that hardness properties varied greatly in disks containing agarwood. A low correlation was found between the amplitude of resistance and hardness and density, indicating that other variables beyond density are also involved in the changes of wood properties in agarwood. A strong correlation was observed between hardness and wood density.

KEYWORDS: Resinous wood, fungal attack, nondestructive testing, microdrilling resistance, included phloem.

INTRODUCTION

Agarwood or gaharu, also known as oud, is produced as a result of fungal infection in certain trees, mainly *Aquilarias* pp. and *Gyrinops* spp. from family *Thymelaceae*. It occurs in the trunk, branches, and roots of the trees following natural or artificial inoculation which induces the production of a fragrant resin in wood. The intensity of the fragrance determines the quality of the resultant agarwood (Turjaman et al. 2016). The main chemical compounds in agarwood are aromatic terpenes, with sesquiterpenes as the primary active compounds, and chromones, which are responsible for the fragrance when agarwood is burnt (Naef 2011, Jong et al. 2014). The resin associated with agarwood formation is the result of the tree defense reactionin areas around the point of fungal invasion. This process can be induced by artificial inoculation of *Fusarium solani* to form agarwood in *Aquilaria malaccensis* (Mohamed et al. 2010, Turjaman et al. 2016, Karlinasari et al. 2015, 2016).

Because agarwood formation causes changes in physiological and chemical compounds in wood, it could potentially alter the wood properties. In particular, fungal attack may weaken the wood because fungi commonly degrade cell walls during the early stage of attack (Schwarze et al. 1995). In agarwood trees, *endophytic* fungi are involved in agarwood formation. *Endophytes* are microorganisms that establish a symbiotic relationship with host plants and do not cause harm to it; in fact, the host benefits from enzymes secreted by the *endophytes* (Mohamed et al. 2010, Turjaman et al. 2016). The color of the wood also reveals aga rwood formation. Dark brown indicates the presence of agarwood, while white or another light color indicates normal wood.

The drill resistance method is categorized as a nondestructive method for measuring wood density as well as diagnosing the internal condition and detecting defects (Isik and Li 2003, Creed et al. 2004, Kahl et al. 2009, Lin et al. 2016, İçel and Güler 2016). This method uses a thin drilling needle to penetrate the wood. In general, sound wood has high resistance to drill dealing because it is dense, hard in texture, and difficult to penetrate. Meanwhile, the lower density of severely decayed wood translates to a softer texture, which in turn means reduced drilling resistance. No reports have been made on the use of the drilling resistance method to evaluate the presence of agarwood (*Aquilaria malaccensis*) in relation to density and hardness properties.

MATERIALS AND METHODS

Five *A. malaccensis* trees (approximately 11 years old) that had been wounded and artificially inoculated with *F. solani* (strain FORDA-CC00500) 30 months prior were chosen for this experimentation. The trees were located in a community forest in Prabumulih district, South Sumatra province, Indonesia. Five 25 cm thick disk sections were cut from each felled treat different tree heights (20–70, 70–120, 120–170, 170–220, and 220–270 cm above the ground). The disks were then dried until achieving an air-dry condition. In total, 25 disks were used in this study. The moisture content (MC) of each disk was measured with a moisture meter. Micro-drilling testing using Resistograph was conducted to determine the torque resistance change when a was needle drilled into the wood, and this information was used to evaluate wood properties (Fig. 1).

Fig. 1: Microdrilling resistance testing using Resistographâ.

The diameter of the needle shaft was 3 mm, the flat tip was 3 mm wide, and the needle had a maximum length of 45 cm. The drill is an automatically adapted rotation speed mechanism (Rinn et al. 1996). Resistographâ recorded the drilling torque while penetrating the cross section of the wood at a constant speed (ca. 1000rpm). The resistance value is expressed as a percentage, which serves as a relative measure of power consumption when the needle penetrates the wood found as percentage of amplitude. Readings were taken in two different drilling line directions for each disk. The drilling line started from the area denoting the existence of agarwood as shown by dark-brown color (Fig. 2).

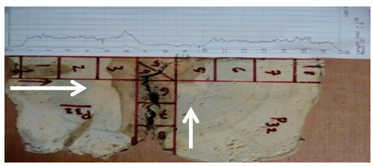

Fig. 2: Drilling line from Resistographâ on wood disk.

A hardness test was conducted on each disk, with an area of indentation (2 × 2 cm) on the cross-section face radially following the line of drilling resistance testing (Fig. 3).

Fig. 3: Hardness testing on a 2 × 2 cm area of the disk.

The testing procedure given in ASTM D143 - 2005 using universal testing machine (UTM) Instron machine type 3369 with a standard 1.13 cm diameter steel ball mounted on the crosshead. A threshold was set to automatically record the "maximum load" as a function of the depth of penetration of the steel ball into the wood as specified in ASTM D143. After Resistograph measurements and hardness testing, samples for density measurements were cut from the disks as 2 × 2× 2 cm blocks, avoiding the areas with indentation from the hardness testing. The size and weight of the sample blocks were measured to evaluate the MC and wood density based on the gravimetric method.

Statistical analysis was conducted to determine the influenced of different tree heights of disk, and relationship between amplitude and wood density as well as hardness properties.

RESULTS AND DISCUSSION

The resinous wood indicating agarwood formation in inoculated trees was identified by its dark-brown color when the bark was removed. This wood produced a unique aroma when it was burnt. The average density value of the *A. malaccensis* wood was 0.29 $g \cdot cm^{-3}$ in the air-dry condition (MC=16.65%). The average amplitude was 7.59%, and the average hardness was 146.08 $kg \cdot cm^{-2}$ (Tab. 1). Statistical analysis found no significant difference (a = 5%) between disks based on their height above the ground. This finding is in agreement with previous studies (Putri et al. 2017, Karlinasari et al. 2008) reporting that the vertical position on the trunk did not significantly affect the physical and mechanical properties of wood.

Tab. 1: Moisture content (MC), density, amplitude, and hardness of inoculated trees of Aquilaria malaccensis.

Disk section based on height above the ground (cm)	MC (%)	Density ($g \cdot cm^{-3}$)	Amplitude (%)	Hardness ($g \cdot cm^{-2}$)
H20-70	16.50	0.30	7.53	135.23
H70-120	16.42	0.28	8.03	142.50
H120-170	17.32	0.31	7.34	148.08
H170-220	16.89	0.28	7.53	142.54
H220-270	16.15	0.29	7.90	156.23
Average	16.65	0.29	7.59	146.08
SD	1.50	0.02	1.30	31.66
CV (%)	8.99	7.66	17.14	21.67

The resistography drill through the entire diameter of the disk allowed evaluating the wood characteristics in a detail radially, while the destructive testing yielded information about hardness and density. For the drilling resistance technique, the total energy consumed in penetrating the sample is closely related to the characteristics of the material (Couto et al. 2013, İçel and Güler 2016). A resistogram appears as a succession of peaks and troughs in relation to the ability of the drill to penetrate material. As shown in Fig. 3, the resistogram showed that the trough corresponds to the dark-brown area, the color of which indicated resin deposit.

Close relationships existed in the regression model between amplitude and wood density (coefficient determination $R^2 > 0.60$) in previous research on trees in a breeding program (Isik and Li 2003, Couto et al. 2010), lumber (Alves et al. 2013, İçel and Güler 2016), and coarse woody debris (Kahl et al. 2009). However, our analysis of the linear regression model for agarwood found low correlations between amplitude and wood density ($R^2 = 0.25$) and between amplitude and hardness ($R^2 = 0.24$) (Figs. 4 and 5).

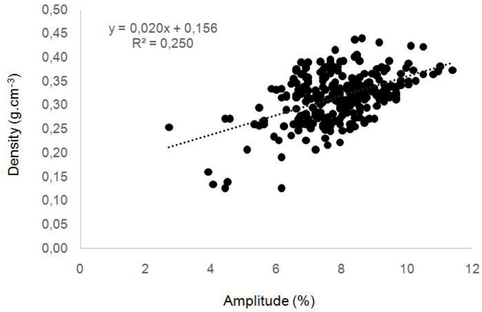

Fig. 4: Scatter plot between amplitude and wood density.

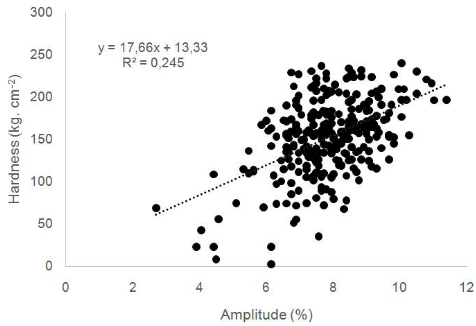

Fig. 5: Scatter plot between amplitude and hardness properties.

This outcome is presumably due to other variables that have some degree of influence on the drilling properties for agarwood, such as juvenile wood, chemical components, and unique cell characteristics. The resinous wood that forms agarwood is a product of pathology (i.e., a defense mechanism against fungal infection), and it is found in wounded woody tissues rather than in normal tissues (Qi 1995). At a nearly stage of attack, it probably also involves the wet conditions that foster fungal growth. Therefore, a softer are a reveals the site of fungal activity. At an advanced stage of attack, the agarwood resins have formed, causing the are a containing the agarwood to be denser, harder, and altered in color. When this area is burned, it emitsa strong, fragrant scent. The main chemical compoundsin agarwood area complex mixture of sesquiterpenes and chromones with other simple volatile aromatic compounds, which contribute to the pleasing odor of agarwood (Naef 2011). A unique anatomical characteristic of the genus Aquilaria is the existence of included phloem, which is related to resin deposition (Tabata et al. 2003, Mohamed et al. 2013, Rasool and Mohamed 2016, Lin et al. 2016). The characteristics of included phloem differ between juvenile and mature wood (Mohamed et al. 2013).

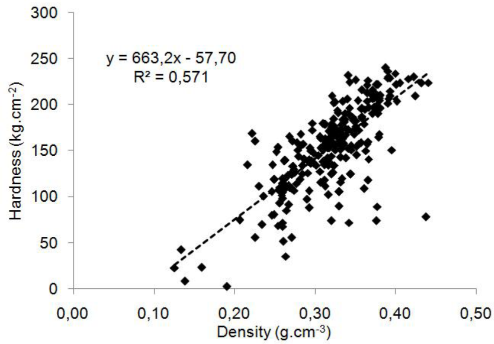

Fig. 6: Scatter plot between wood density and harness properties.

Moderate correlation was found between wood density and hardness properties of resinous wood of agarwood with a coefficient determination (R^2) of 0.57 (Fig. 6). Wood density as well as specific gravity generally has a good correlation with wood strength. They also reflects the presence of gums, resins, and extractives (Kretschmann 2010).

CONCLUSIONS

Based on the results from this study, only a slight relationship exists between amplitude tested by microdrilling resistance and wood density as well as wood hardness. Therefore, in evaluating wood properties of the resinous wood of agarwood in *A. malaccensis* using drilling resistance, not only should wood density be considered but also other variables to improve the coefficient determination in the relationship.

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