Journal of Tropical Forest Science 27(3): 351–356 (2015)

SONIC AND ULTRASONIC WAVES IN AGARWOOD TREES (*AQUILARIA MICROCARPA*) INOCULATED WITH *FUSARIUM SOLANI*

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Received January 2014

KARLINASARI L, INDAHSUARY N, KUSUMO HT, SANTOSO E, TURJAMAN M & NANDIKA D. 2015. Sonic and ultrasonic waves in agarwood trees (*Aquilaria microcarpa*) inoculated with *Fusarium solani*. Agarwood or gaharu is a valuable non-timber forest product that has unique aroma and is widely used in many cultures and industries. It develops as a result of fungal infection, injury and non-pathological processes in several genera of trees from the family Thymelaeaceae, including *Aquilaria*. The presence of agarwood can be determined using non-destructive sound waves to evaluate the internal condition of *A. microcarpa* trees. The aim of this study was to compare the velocity of sound between 'stress' or sonic waves and ultrasonic waves travelling through the trunk of standing *A. microcarpa* trees inoculated with *Fusarium solani*. The ultrasonic wave velocities (Vusn) were found to be 29.5% higher than sonic wave velocities (Vsn). Statistical analysis showed no significant difference in velocity in relation to height of measured tree section. Vsn and Vusn values were found to be approximately 700 and 900 m s^{-1} respectively for trees that contained agarwood. Non-destructive sound wave testing is, therefore, a feasible method to detect the presence of agarwood.

Keywords: Gaharu, non-destructive testing, sonic velocity, ultrasonic velocity, standing tree, aloeswood

INTRODUCTION

Agarwood or aloeswood, commonly known as gaharu, is a non-timber forest product of high value. Agarwood has unique aroma and is traditionally used in many cultures to provide tranquillity, healing and spiritual cleansing. Buddhists, Hindus and Muslims have used agarwood in spiritual ceremonies and the essential oil from agarwood is used in medicine, perfume and soap. The high demand for agarwood has resulted in its high market value.

Agarwood is a resinous material produced by some tree species as a result of fungal infection, injury or non-pathological processes that lead to physiological and chemical changes to the wood. Several genera of trees from the family Thymelaeaceae can produce agarwood, including *Aquilaria* and *Gyrinops. Aquilaria* spp. are considered one of the highest quality sources (Schmidt 2011). Agarwood is largely native to South-East Asia (Indonesia and Malaysia) and is also found across east India and southern China (Liu et al. 2013). The high value of agarwood has led to it being over harvested, resulting in some genera, notably *Aquilaria*, being added to the IUCN Red List of Threatened Species (World Conservation Monitoring Centre 1998) and remaining in the Convention on International Trade in Endangered Species of Wild Fauna and Flora since 2004 (CITES 2004). Efforts have been made to preserve agarwood resource and increase its supply through artificial cultivation. Agarwood can be induced in *Aqulilaria* spp. through inoculation with pathogens (Liu et al. 2013, Nor Azah et al. 2013) such as *Fusarium* spp. fungi (Sitepu et al. 2011).

Common methods for collecting agarwood include direct harvesting and indiscriminate felling in natural forests and among cultivated trees using visual assessment and experience of agarwood collectors. Agarwood can be found in the trunk and other parts of the tree such as

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branches. The colour and fragrance of agarwood indicate its presence. The darker the wood, the higher is the agarwood content. Agarwood is collected mainly in the form of wood and then traded as lumps, chips and powder.

Non-destructive technology helps in determining the internal condition of standing trees. Visual assessment and non-destructive technology based on sound propagation techniques have been used successfully in evaluating trees (Yamamoto et al. 1998, Chuang & Wang 2001, Ahmad et al. 2012). The speed of sound as it passes through a tree is a common evaluation parameter (Pellerin & Ross 2002) because it correlates well with wood properties. The speed of sound or velocity can be affected by grain angles, knots, advanced decay or deterioration as well as microstructural characteristics, chemical composition, moisture content and direction of wave propagation (i.e. longitudinal, radial or tangential). For evaluating standing trees, the speed at which a wave travels across the diameter of the trunk (i.e. the radial measurement direction) is a good indicator of the presence of decay and other deterioration within the trunk (Ross 1999). The use of non-destructive methods based on sound waves combined with field experience in agarwood harvesting could help facilitate accurate tree felling. The aim of this study was to compare the speed of sound between stress waves and ultrasonic waves travelling across the trunks of standing *Aquilaria microcarpa* trees inoculated with *Fusarium solani.*

MATERIALS AND METHODS

Aquilaria microcarpa trees were planted in 1998 at a forest area with specific purposes under the Forestry Research and Development Agency (FORDA) management, Carita Beach, Banten (6° 8′ to 6° 14′ S and 105° 50′ to 105° 55′ E). Thirty-five trees with diameter of at least 15 cm were randomly selected and inoculated with *F. solani* (FORDA-CC 00509). Holes, 3 mm in diameter, were drilled into each tree to a depth that was 1/3 the diameter of the stem at the point of drilling on the tree trunk. The holes were spaced 15 cm vertically and 5 cm horizontally. Each hole was inoculated with 1 mL of *F. solani* liquid using manual injection. Radial measurements were made at three heights (20, 130 and 200 cm from the ground) as shown in Figure 1.

Three years after inoculation, acoustic-based technology was used to evaluate the presence of agarwood. A sonic measurement system used four to six sensors and were evenly placed around

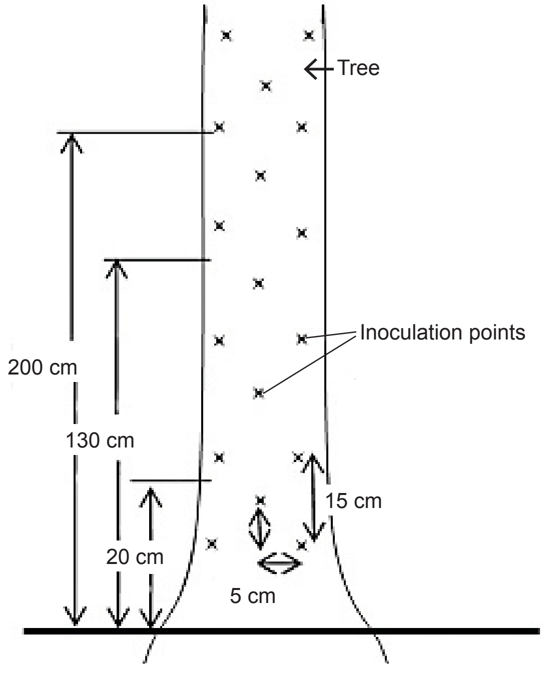

Figure 1 Experimental set-up for sound wave testing

the trunk in a horizontal plane. The sensors were magnetically attached to a nail that was tapped into the bark and sapwood. Sonic wave velocity transmission data were collected by sequentially tapping each nail using electronic hammer. A complete data was obtained through this measurement process and the average values of sonic wave velocity were calculated. Ultrasonic wave velocities were calculated by a tool that emitted ultrasonic waves from a transmitting transducer to a receiving transducer. The radial directions used were north–south and east–west, and three ultrasonic velocity readings were collected for each radial direction. The average ultrasonic wave velocities were calculated for each orientation of the radial measurements. A sonic tomograph and an ultrasonic device were used for generating sonic and ultrasonic waves respectively (Figure 2).

Wood density and moisture content for each tree were determined by sampling the wood in green condition. Core samples were extracted using an increment borer, 5 mm in diameter, at 5–10 cm below diameter at breast height. The samples were sealed in aluminium foil and transported to the laboratory. Wood density was determined based on the ratio of weight of the sample to its volume. Moisture content was determined in accordance with the gravimetric method.

Statistical analysis of single factors was performed to determine the influence of height on the trunk (i.e. 20, 130 and 150 cm) for both sonic and ultrasonic wave velocities. Descriptive statistics and analysis of comparison of means (t-tests) were conducted to compare the results of sonic and ultrasonic velocities. Values were significant at the 0.05 confidence level.

Three *A. microcarpa* trees (no. 17, 19 and 32) were felled to verify their internal condition. All logs were transported to FORDA in Bogor. The appearance of the logs and cross-sections of the trees was photographed using digital camera.

RESULTS AND DISCUSSION

Ultrasonic wave velocities (Vusn) were approximately 29.5% higher than the sonic wave velocities (Vsn) (Figure 3). Analysis of variance (ANOVA) indicated no significant difference for Vsn or Vusn with respect to height (Table 1). This might be due to the induction treatments, which were applied evenly around the trunk from bottom to top including branches.

The average values of radial Vsn and Vusn were 729 and 950 m s^{-1} respectively, with coefficient of variation (CV) values lower than 10% (Table 2). The t-test revealed significant difference in the average velocities between sonic and ultrasonic waves (Table 3). Ultrasonic wave velocity were found to be close to sonic velocity in Japanese cedar plantation trees (Chuang & Wang 2001).

The ranges for Vsn were 529 to 807 and for Vusn, 807 to 1203 m s^{-1} respectively (Table 2). This indicates that most of the trees had already

(a) (b)

Figure 2 (a) Sonic or stress wave and (b) ultrasonic wave testing methods applied on an *Aquilaria* tree

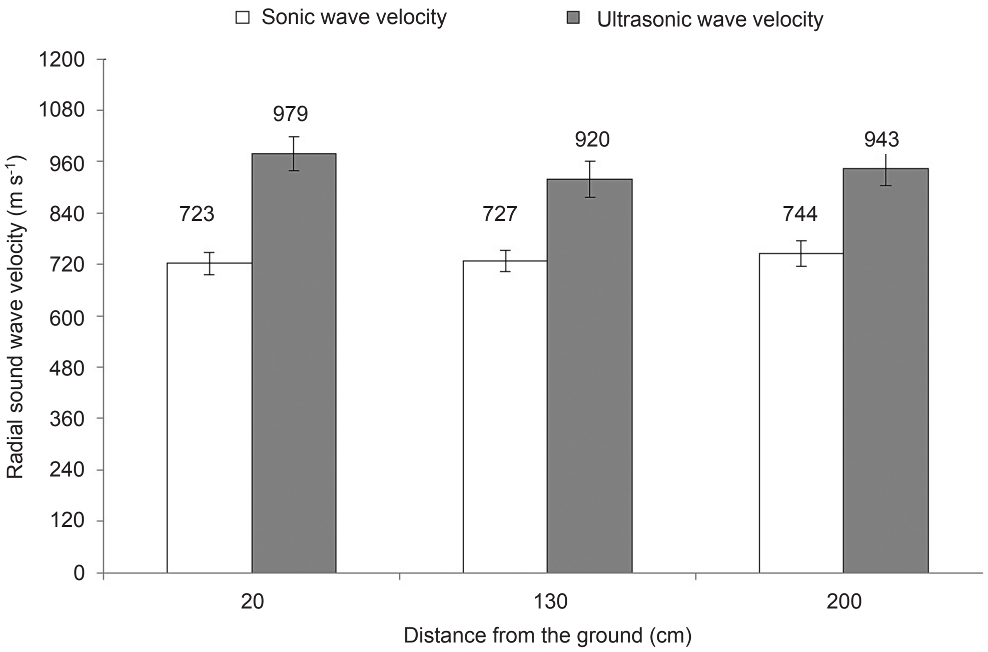

Figure 3 Radial sound wave velocities for both sonic and ultrasonic testing at different heights of the trunk

Table 1 Analyses of variance of the influence of height on sonic and ultrasonic velocities

Velocity	Source of variation	Sum of squares	df	Mean of square	F	p value
Sonic	Between group	9225.81	2	4612.91	0.7513	0.474 ns
	Within group	626255.25	102	6139.76		
	Total	635481.06	104			
Ultrasonic	Between group	62555.69	2	31277.85	2.0521	0.134 ns
	Within group	1554678	102	15241.94		
	Total	1617234	104			

ns = Not significant at the 0.05 confidence level

Table 2 Physical characteristics of agarwood trees

Parameter	Moisture content (%)	Density (g cm^{-3})	Vsn (m s^{-1})	Vusn (m s^{-1})
Mean	52.77	0.76	729	950
Standard deviation	10.04	0.11	60.4	92.7
Coeffiecient of variation (%)	19.03	15.11	8.3	9.8
Minimum	28.00	0.52	529	801
Maximum	70.19	1.11	807	1203

n = 35, Vsn = sonic velocity, Vusn = ultrasonic velocity become decayed or deteriorated. A study (Yamamoto et al. 1998) to detect heart rot in a plantation of *Acacia mangium* showed that stress wave values or sonic velocities of sound trees possessed radial stress wave velocities of 928 to 1259 m s^{-1}, while trees with interior decay had much lower values (357 to 876 m s^{-1}). Ultrasonic velocity values in healthy living trees of an urban hardwood species were more than 1000 m s^{-1}, less than the values found in trees after dieback, wilting of the crown, open trunk wounds and other abnormalities including attack by pathogenic organisms (Karlinasari et al. 2011). Preference radial stress wave velocity values for healthy standing trees of certain hardwood species were found to be more than 900 m s^{-1} (Wang et al. 2004). Radial ultrasonic speed values measured on two axes were found to be more than 1200 m s^{-1} for healthy trees of hardwood temperate species (Sandoz et al. 2000). A preliminary research done by Dani (2010) on a limited number of individual *Aquilaria* spp. trees found that living trees that had been inoculated 1 year earlier had Vusn values of approximately 1000 m s^{-1}, with wood density of 0.72 g cm^{-3}.

Visual inspection and single-path sound (sonic and ultrasonic) wave tests have been found to correctly identify a general problem in the tree but without specificity (Wang & Allison 2008, Indahsuary et al. 2014). The trees assessed in this study were predicted to contain more or less the same quality of agarwood because the trees had been artificially inoculated. Visual assessment for the presence of white spots served to identify fungal attack that led to the formation of aloes. The verification from felled tree in Figure 4 shows a tree in which aloes have formed, seen as dark-coloured spot in the xylem (Figure 4a). Figure 4b shows the tree in cross-section, with a line gap providing visual proof of fungal attack.

CONCLUSIONS

The study showed the potential of non-destructive testing using sound wave to assess the presence

Table 3 Statistical comparison (t-test) for equality of means analyses between sonic and ultrasonic velocities

Parameter	Sound velocity
	Significance (two-tailed)
Equal variances assumed	0.000*
Equal variances not assumed	0.000*

* Significant at the 0.05 confidence level

(a) (b)

Figure 4 (a) Stem and (b) cross-section of an agarwood *Aquilaria* tree of agarwood in *A. microcarpa* trees. Testing was based on velocity values of sound travelling across the tree trunk. Statistical analysis showed no significant difference in the velocities at different heights of the trunks. The Vsn and Vusn values were approximately 700 and 900 m s^{-1} respectively for trees containing agarwood or aloeswood.

ACKNOWLEDGEMENTS

The authors thank the Osaka Gas Foundation of International Cultural Exchange Research Grant for year 2012–2013 and the Directorate of Higher Education, Ministry of Education and Culture, Republic of Indonesia under 'Higher Education Research Grant of IPB' schemes for year 2013 (contract no. 265/IT3.41.2/L2/SPK/2013) for financial support. The authors are also grateful to L Graham of Kalimantan Forest Carbon Partnership for proofreading the manuscript.

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