On the Propagation of *Ganoderma boninense* Infection of Basal Stem Rot in Oil Palm With the Aid of Acoustics Computed Assisted Tomography

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ABSTRACT *Ganoderma boninense* (GB), a causal agent of basal stem rot (BSR) disease, remains as a threat in oil palm plantation as it caused a considerable amount of yield losses especially in South East Asia. Studies related to spread and transmission of the disease through roots and airborne have been reported by researchers but, knowledge on the propagation inside the oil palm however are still very limited. This paper is a hypothesis on the infection propagation of GB in oil palm with the help of acoustics computed tomography system. Three different characteristics of oil palm which consist of healthy, asymptomatic and severely infected palm were selected and tested using an acoustic device for tomogram image construction. Result of the acoustics tomography image from each samples obtained from the experiment have revealed the possibility of infection propagation in oil palm stem. Hypothesis of *Ganoderma boninense* infection mechanisms are outlined and concluded.

KEYWORDS: Acoustic tomography; Basal Stem Rot; Detection; Oil palm; *Ganoderma boninense*
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INTRODUCTION

Acoustics tomography has been known and paid attention by researchers since it was initially introduced. It was commonly used for *in-situ* inspection of trees, logs, lumber, poles and wood based-composites since 1986 (Andres *et al.*, 2013). Mostly, tomography method uses the principle of measurement of stress-wave transmission that based on time of flight (TOF) data. Since stress wave is correlated with the stiffness of specimen (Wang *et al.*, 2001), it is able to predict the elastic properties of a specimen. By applying this concept with some combination of image processing techniques, two-dimensional (2D) internal cross section characteristics of tree trunk can be obtained. The principle of acoustics computed assisted tomography (ACAT) consist of the standard algorithm of image processing which is the filtered convolution backprojection or filtered backprojection (Stark et *al.*, 1981). This method was used to improve the blurry image of cross-sectional imaging from the primary method which is the conventional backprojection so that clearer image of cross-sectional image can be produced.

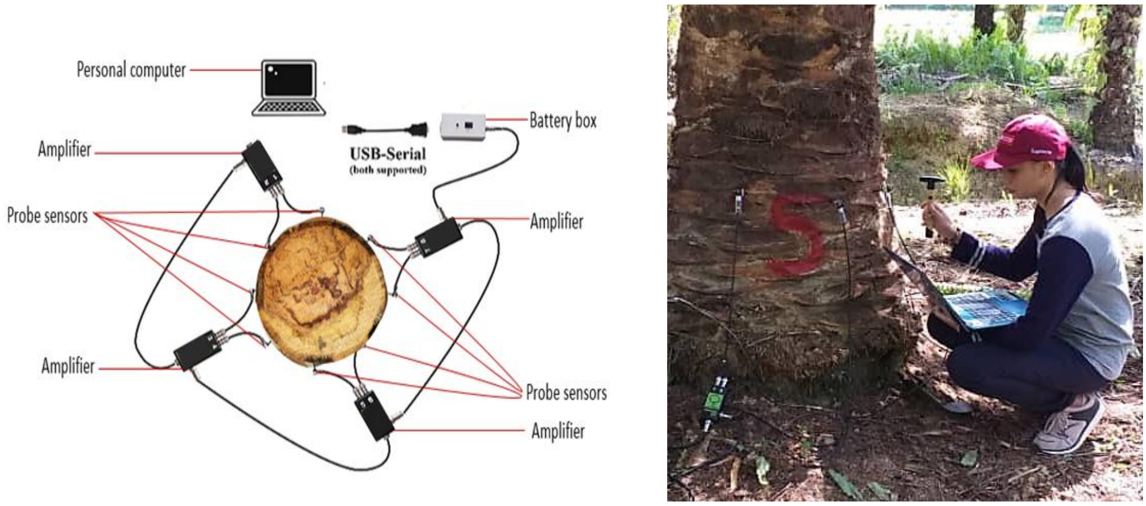
The structural anatomy of oil palm trunk consists of vascular bundles and parenchyma cells unlike hardwood and softwood. There are three main parts of oil palm trunk namely peripheral region, central region and inner region. Peripheral region consist of highly compact vascular bundle thus provides mechanical support to the oil palm. Meanwhile, the central region has less compact distribution of vascular bundles and become more scattered towards the inner region of the oil palm trunk (Sulaiman *et al.*, 2012). Therefore, the elastic property of the inner region is lower compared to the central region, and the outer trunk which is the peripheral region has the highest elasticity. Generally, elasticity is proportional with the hardness characteristics where the inner region is the softest and the peripheral region is the hardest. Therefore, it is expected that for healthy palm trees, acoustic waves will travel slower in the inner region compared to the speed in the peripheral region.

Based on this information, this paper aims to propose a hypothesis on the *Ganoderma boninense* (GB) infection propagation where the infectious GB mycelia from the root of the palm tree will eventually propagate outside of the trunk to produce fruiting bodies. This hypothesis is explained based on the anatomy of the oil palm trunk with the aid of ACAT result.

METHODOLOGY

As previously mentioned, the purpose of this paper is to propose a hypothesis on how *Ganoderma boninense* (GB) infects palm trees for the basal stem rot (BSR) disease with the aid of acoustics computed assisted tomography (ACAT). It is a common knowledge that the BSR disease is the result of the infection from GB mycelia that originated from the palm root (Rees *et al.*, 2009). In order to formulate the hypothesis, 12 palm tree samples for each level of infection (total of 36 samples) were selected namely healthy, asymptomatic and severely infected. Healthy oil palms were identified as tree with no yellowish to pale leaves and no skirting fronds; asymptomatic for yellowish to pale leaves with skirting and/or unopened spears, whereas severely infected by *Ganoderma boninense* are characterised as trees with yellowish to pale leaves with skirting and/or unopened spears, but most importantly the presence of fruiting body and/or lesion of *Ganoderma boninense* can be seen at the trunk base. Sample selections were advised and suggested by personals of the plantation, Kam Cheong Plantation Sdn. Bhd., Sandakan where the investigation was performed.

The ACAT system used in this paper consists of eight sensors that are interfaced to a laptop computer as shown in Figure 1(a). The sensors are in the form of a long stainless steel embeded with piezoelectric material. Each sensor were fixed through the bark into oil palm trunk by using rubber hammer with equal spacing around the tree circumferential of oil palm tree. Prior to that, all oil palm tree (OPT) samples with an altitude of one meter above the ground were marked and the leftover fronds around that height were cleaned using a chain-saw to ensure good contact between sensors and palm trunk. With the sensors were hammered correctly into the palm trunk, their heads were gently tapped one at a time on the centre using steel hammer with uniform strength to generate the readouts data (Figure 1(b)). Readouts data which were the time of flight of sound that propagate from one sensor to another were collected automatically by the measurement system. The time flights were converted into velocity using back projection lagorithm and were then fed into the tomography software for image construction of tree trunk circumferential at the sensors level.



(a) ACAT system connection and setup (b) Tapping each sensor to get time flight data

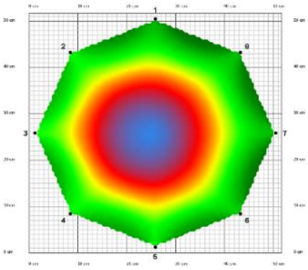
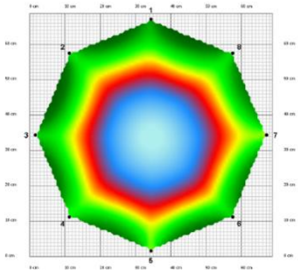
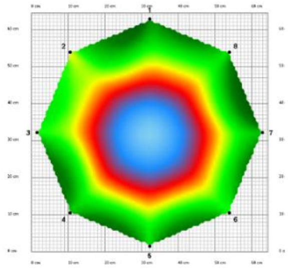
Figure 1. The acoustics computed assisted tomography (ACAT) system full set up and installation.

RESULTS AND DISCUSSION

Cross Sectional Tomography of the Oil Palm Trees

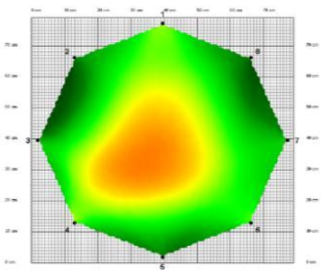
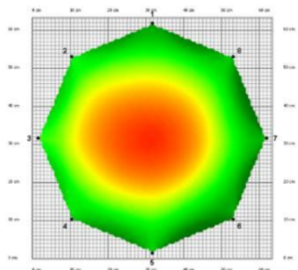
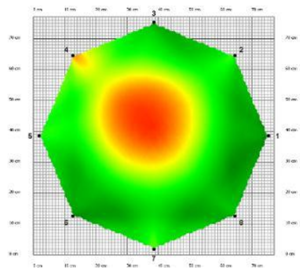
Figure in Table 1 shows the tomography image and the corresponding cross sectional view for three healthy oil palm tree samples. These three pairs of images represent all other 12 samples of healthy tree as they were generally similar. It can be seen that the tomography image is in circular form that consists of three almost perfect symmetric rings: ocean blue region with acoustics wave speed between 465 to 533 m/s at the center, yellow-reddish ring with wave speed 554 to 603 m/s in the middle and outer green ring that represent wave speed between 604 to 1401 m/s. Detail examination shows that wave speed gradually increased from the inner region to the outer tree trunk. This implies that the cross sectional hardness of a healthy palm tree gradually increased from the inner to outer region where the inner region is the softerst region. This agrees with the anatomical cross section of a palm reported by Killmann & Lim (1987) where the cross section of the tree was divided into three parts: Cortex made the outer region, peripheral in between and central zone at the center. Sectional oil palm trunk density is directly related to the number and thickening of the vascular bundles, and that these increase radially from the core to the trunk periphery (Killmann & Lim, 1987; Killmann & Wong, 1988) which is propotional to the hardness of the region (Fathi, 2014). This was further confirmed by brief examining of the corresponding actual cut out of the tree at the measurement level where their images are shown in the second column of Table 1.

Table 1. Acoustic tomography image of healthy oil palm tree and the corresponding tree trunk cross section view.

	Sample A	**Sample B**	**Sample C**
Tomography image			
Corresponding tree trunk cross section image			

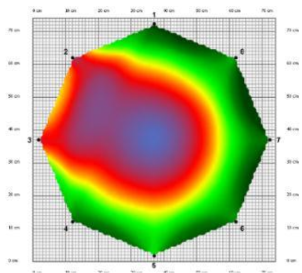
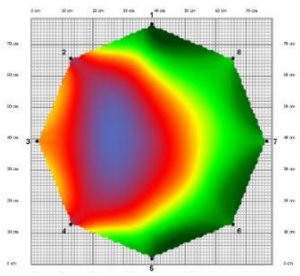
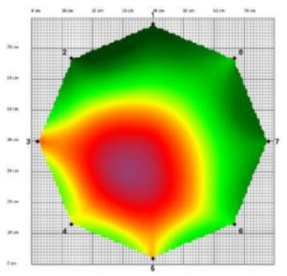
The tomography image for asymptomatic palm tree is less symmetric compared to the healty tree. In addition, the wave speed range also decreased to 410 - 1081 m/s from 465 - 1401 m/s for the healthy tree. Table 2 shows the tomography images for three asymptomatic oil palm trees and their corresponding cross sectional view of the cut out. It can be seen that the images are slightly skewed to a certain direction. This shows that the density does no longer homogeneously increasing in radial direction as in the healthy tree. For asymptomatic palm tree, at the same radial distance from center of the tree cross section, some directions has a higher density or harder compared to other directions, in contrast to healthy tree where generally the hardness is almost similar in all radial distance from the center. In Table 2, the tomogram with reddish-yellow color has speed range between 410 - 590 m/s whereas the green color is 591 - 1081 m/s. Again, brief examining of the corresponding actual cut out of the tree confirmed the tomogram profile.

Table 2. Acoustic tomography image of asymptomatic oil palm tree and the corresponding tree trunk cross section view.

	Sample A	**Sample B**	**Sample C**
Tomography image			
Corresponding tree trunk cross section image			

Tomography image for severely infacted oil palm is totally skewed and this can be clearly seen in Table 3. The tomography image for Sample A for example is no longer in circular form an in healthy and asymptomatic palm tree, but in a U shape to the north-west direction whereas the other parts remain the same as in healthy image. Sample B has similar condition but with wider U opening or a bowl shape in the west direction. Comparison of the tree trunk actual cross sectional image shows Sample B has lager degraded region compared to Sample A. For Sample C, the tomography image is also in a bowl shape to the south-west direction.

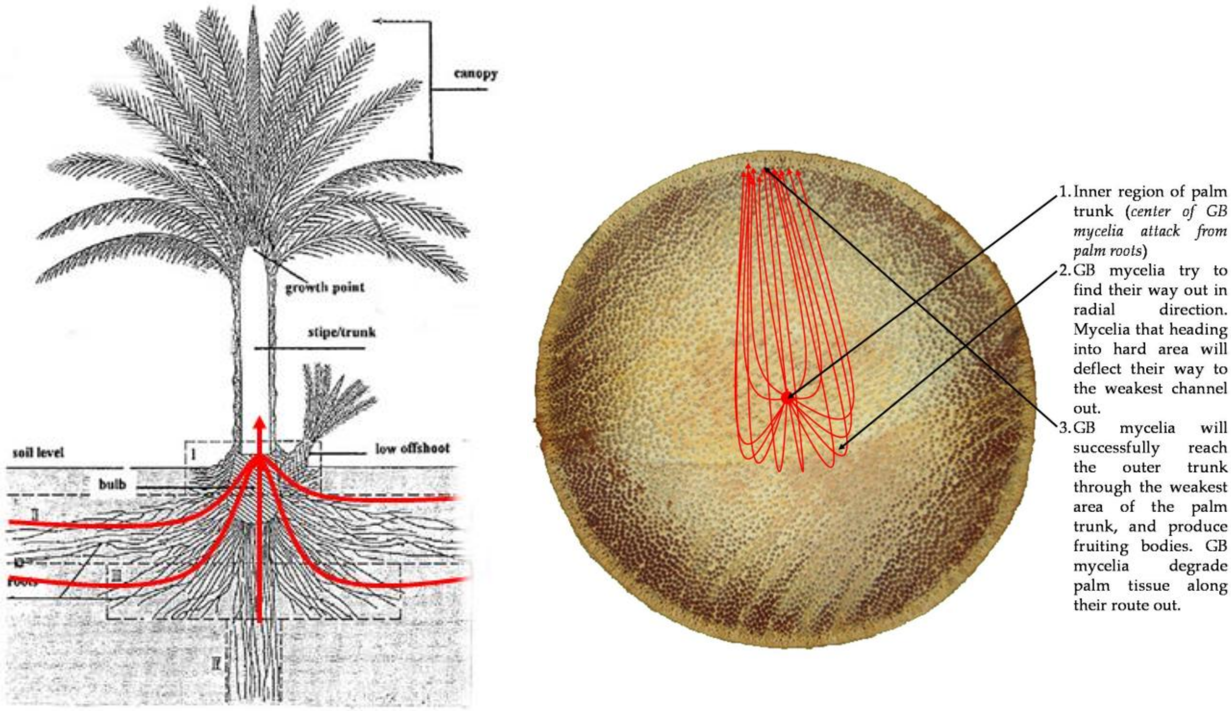
Table 3. Acoustic tomography image of severely infected oil palm tree and the corresponding tree trunk cross section view.

	Sample A	**Sample B**	**Sample C**
Tomography image			
Corresponding tree trunk cross section image			

A Hypothesis on the propagation of Ganoderma boninense *in Palm Tree*

As previously mentioned, the purpose of this paper is to propose a hypothesis on how *Ganoderma boninense* (GB) infectections propagate in the palm tree in basal stem rot (BSR) disease, with the aid of acoustics computed assisted tomography (ACAT). It is a common knowledge that the BSR disease is the result of the infection from GB mycelia that originated from the palm root (Rees *et al.*, 2009). Once the GB mycelia has entered into palm roots system, it will move up into the trunk right at the center as it is the softest part of the tree as shown in Figure 1(a). It can be seen in the tomography image of a heatly tree in Table 1 that the centeral image is represented with ocean blue color corresponds to the lowest acoustics wave speed compared to other regions. This low acoustics wave speed implies that the density of this inner region is the lowest an therefore the hardness as discussed by Killmann & Lim (1987), Killmann & Wong (1988) and (Fathi, 2014).

The propagation of the GB mycelia infection from the root would next continue to find the way out in all radial directions after reaching certain height from the ground. Depending on the internal trunk condition, tissue in certain direction from the center is weaker in terms of structural integrity and therefore become the channel for GB mycelia to move further until its reach the outer trank. GB mycelia heading into a relatively hard section will deflect their direction to the weaker channel as shown in Figure 1(b). This is shown in the tomography image of asymptomatic palm samples in Table 2 where the color pattern or shape is shifted to a particular direction and no longer in a symmetric form. That direction is supposed to have a weaker structure compared other directions. As time progress, mycelia would evantually find its way out to produce fruiting body of GB. Along the way out, GB mycelia degrades palm tissue (Maluin, 2020) that makes the tree evantually fell down and dies.



(a). Incoming GB mycelia from palm roots (b). Mycelia route out from central zone

Figure 1. Proposed propagation of GB mycelia infection in oil palm tree.

CONCLUSION

In this paper, it is suggested that, the *Ganoderma boninense* mycelia that infects oil palm from the root will eventually propagate outside of the trunk to produce fruiting body. The invasion begins from the core of the oil palm trunk as a center of the initial attact as it is the softest structure. The invasions continue to progress where these mycelia will find the weakest tissue integrity throughout the palm trunk in radial direction before it spreads and ready to grow as *Ganoderma* fruiting body outside the trunk. The acoustics computed assisted tomography (ACAT) results of healthy, asymptomatic and severely infected oil palm trunk samples obtained from this study has reveal this infefction propagation whereby the color pattern of tomography images in asymptomatic and severely infected oil palm were all shifted in one direction only.

This finding in general could help planters especially in remedial measures for BSR treatment, where, by using this method, one would know which part of the palm trunk that contain GB the most which is the weakest structure by observing the tomography image so that treatment can be focused on that particular area. The acqusition of the tomography image is quite fast between 10 - 15 minutes and is considered very practical for site inspection.

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