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A Short Report on Application of Acoustic Tomography for Basal Stem Rot Disease Severity Assessment in Oil Palm

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Basal stem rot (BSR) disease caused by Ganoderma boninense *remains as one of the most devastating diseases of the oil palm industry especially in South East Asia. Currently there is no remedy mainly due to inability to detect BSR disease at the early stage. Therefore, early diagnostic method is vital to detect the BSR disease effectively. This study examined the potential application of acoustic tomography method to observe the internal parts of the oil palm consisting of different levels of BSR disease severity: i) healthy, ii) moderate and iii) severe. Ten oil palm trees were selected for each level of BSR disease. The tomography data of the cross-section of the oil palm trunk was measured at one meter from the stem base for each palm using acoustic measurement system known as TomoSawit. The palm was then cut down at the tomography measurement height and compared with the acquired tomography image. The results showed that the method can provide tomography images of different BSR disease severity conditions. Detailed examination of the tomography results revealed the differences in acoustic wave speed while travelling across different densities of the cross-section of the palms that contribute to the differences in tomography image characteristics. The difference in the density could be associated with the severity of the BSR disease. All the generated tomography images have shown to be similar with the actual cross-section samples of the palm. In this study, the severely infected sample shows that an estimate of 33.3 per cent and 54.7 per cent of the cross-section was already degraded, respectively. The confirmation of BSR disease was conducted using ergosterol and* Ganoderma *Selective Medium (GSM) assessment. It can be concluded that the acoustic tomography could be a potential solution for early detection of BSR infection in oil palm especially for field application.*

Keywords: *Acoustic tomography, basal stem rot, early detection, oil palm,* Ganoderma boninense.

Malaysia is one of the countries that has successfully harnessed the benefits of the oil palm industry and is responsible for promoting this industry globally through significant contributions and continuous commitment (Awalludin *et al.*, 2015). For decades, Malaysia

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has been one of the most productive palm oil producers in the world. In 2020 for example, Malaysia accounted for 25.8 per cent and 34.3 per cent of the world's palm oil production and exports, respectively (MPOC, 2021). Unfortunately, it has been common knowledge that the oil palm industry in this country is being threatened by the disease, basal stem rot (BSR) caused by white rot fungi, *Ganoderma boninense* which is capable of degrading the lignin component of a wood (Chong *et al.,* 2017).

The disease spreads through contact of infected soils with the roots and then moves up to the base of the stem (Govender & Wong, 2017). In young palms, external symptoms of BSR usually comprise a one-sided yellowing or mottling of the lower frond, followed by necrosis (Singh, 1991). Young, unfolded leaves will become chlorotic and may be reduced in length, sometimes with necrotic on the tips. Similar symptoms were also observed in mature palms, with multiple unopened spears, flattening of the crown, generally pale leaf canopy and production of basidiocarps (Turner, 1981). Basidiomata may develop at the stem base, leaf base, or infected root; the location provides a guide to the diseased area inside the palms (Paterson, 2007). In severe cases, affected palms will die and fall. Severe infection by *G. boninense* may lead to fracture at the base of the oil palm and make it collapse, leaving diseased bole tissues on the ground. All these symptoms can occur as a combination and there is no fixed pattern or progression of symptoms. When the infection reaches later stage, basidiomata would grow at the base of the trunk. The growth of fruiting body outside the oil palm trunk indicates that almost half of the internal structure is already rotten (Mazliham *et al.,* 2008).

Numerous studies have been carried out to develop measurement and testing techniques for predicting the internal qualities of trees and wooden structures. Non-Destructive Testing (NDT) measurement using acoustic tomography has been considered as one of the adequate methods. NDT has been widely used to detect internal decay of urban trees and has shown great success especially in detecting moderate to severe decay of a standing tree (Li *et al.,* 2012). The success of previous studies on the application of NDT acoustic tomography for internal decay assessment had motivated us to conduct acoustic tomography for detection of decay due to BSR disease in oil palm.

It was suggested that control of this disease would be more practical if is detected before any visual symptoms appeared (Najmie *et al.,* 2011). Researchers agreed that limitation of early detection of the infection is the reason why this disease remains devastating (Alexander *et al.,* 2014). In recent years, a non-destructive technique such as the use of acoustic wave has emerged in the practice of tree analysis (Ishaq *et al.,* 2014). This paper reports a preliminary result of the application of ultrasonic stress wave based acoustic tomography to inspect the internal structure of oil palm by reconstructing two-dimensional (2D) tomography image of the palm cross-sections which were then correlated with the severity of BSR disease in oil palm.

MATERIALS AND METHODS

Study area

The study was conducted at Kam Cheong Plantation Sdn Bhd in Sandakan, Sabah. The company has two estates, namely Mile 25 and LungManis in Sandakan, Sabah. Mile 25 Estate had just started its replanting programme, therefore, LungManis Estate was selected for this investigation. Palm trees in this area are around 21 years old and were planted as the first generation.

Ground-based sampling

Several standing palm trees were chosen based on three classes of BSR disease visual symptoms which are healthy - no yellowing and skirting fronds; moderately infected - oil palm with pale/skirting fronds; and severely infected - pale/skirting fronds with fruiting body. Oil palm samples' visual appearances observed are shown in *Figure 1*.

Acoustic data measurement

The selected standing oil palm based on BSR disease category was marked at a height of one meter above the ground for the acoustic data measurement and the left fronds were cleared by using a chainsaw before measurement was conducted for acoustic probe sensor insertion. This height was used for tomography measurement based on practical reasoning such as the height, which is much easier to perform clearing of the trunk, sensor insertion and cutting the tree for visual cross-section inspection. By assuming the trunk of the tree is round in shape, oil palm circumference was measured to determine points of equal distance for placement of the acoustic sensors. An acoustic system device known as TomoSawit, which consists of eight acoustic probe sensors was used to conduct the measurements. Sensors were inserted horizontally at equal distance around the palm tree using rubber hammer. The experimental TomoSawit set up is shown in *Figure 2*.

Data processing and analysis

The time of travel for ultrasonic waves between sensors that circumference the palm trunk was measured sequentially by tapping each sensor with a steel hammer. All data were collected automatically by connecting the device to a laptop. Two-dimensional tomography image was then constructed using the system's software. After the required images were

a) Healthy *b) Moderate* *c) Severe*

Figure 1 The visual symptoms of BSR disease in oil palm

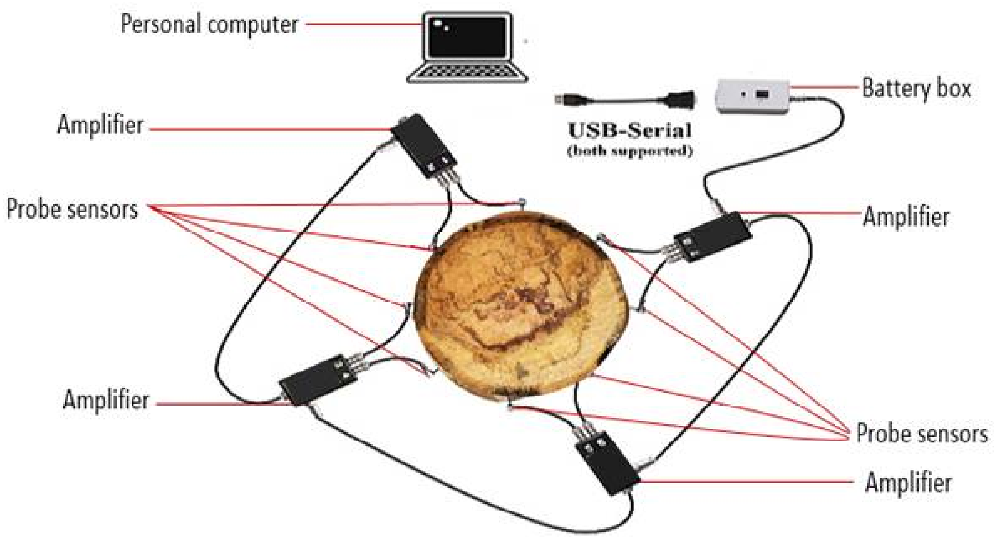


Figure 2 Experimental set-up of TomoSawit for acoustic tomography data acquisition

constructed, the palms were felled and cut down to the same height where the acoustic measurement was conducted for visual comparison between actual decay and the tomography image.

Accuracy assessment and validation

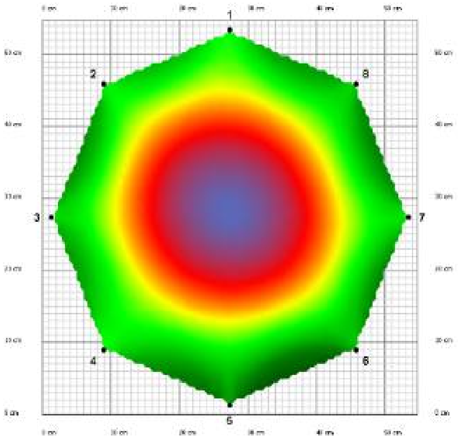
The tissue samples from the cross-section were collected for ergosterol *Ganoderma* Selective Medium (GSM) analysis to verify the presence of *Ganoderma* fungus in the samples.

RESULTS AND DISCUSSION

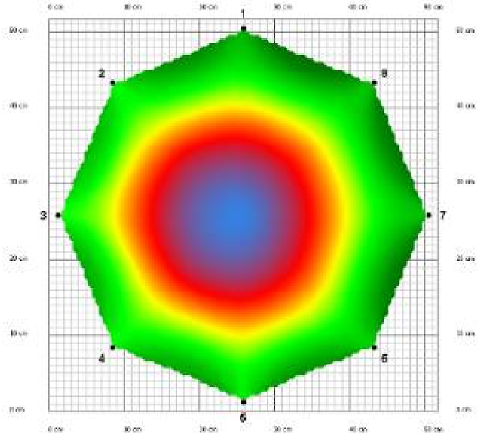
Acoustic tomography

The study was conducted on 30 standing oil palm consisting of 10 palms per BSR disease categories. Two palms per BSR disease categories were selected and analysed. Analysis was conducted by comparing the tomography image and the actual cross-section of each BSR disease categories collected in the field.

The tomography images of the healthy palms together with their corresponding actual cross-section of palm trunk collected in the field are as shown in *Figure 3 (a-c)*. Almost complete circular images that are homogeneous with high symmetricity colour of ocean blue at the centre, yellow-reddish ring in the middle and an outer green ring were seen as in *Figure 3 (a & c)*. Detailed examination of the acoustic wave speed data showed that the acoustic wave speed gradually increased from the inner region (ocean blue colour) with a minimum speed of 554 metres per second (m/s), to the outer tree trunk (green ring) with the maximum speed of 1 401 m/s. This implies that the cross sectional density of a healthy palm tree gradually increased from the inner to outer region where the outer region is the hardest. This agrees with the report by Killmann and Lim (1987) and also by Dangwilailux *et al.* (2019) where the cross-section of the tree was divided into three parts: cortex being the outer region, peripheral in between and central zone at the centre



a) Tomogram of healthy oil palm sample 1



c) Tomogram of healthy oil palm sample 2

b) Actual cross-section image of healthy oil palm

d) Actual cross-section image of healthy oil

Figure 3 Tomography images of healthy oil palm samples and their corresponding actual cross-section images

(*Figure 4*). This is in contrast with the tomography images reported elsewhere such as by Ishak *et al.* (2014) where their images could not be associated with the reported anatomy of palm tree described by Killmann and Lim (1987), Dangwilailux *et al.* (2019) or by Fathi (2014). Sectional oil palm trunk density is directly related to the number and thickening of the vascular bundles, and these increase radially from the core to the periphery of the trunk (Killmann & Lim, 1987) which is propotional to the density of the region (Fathi, 2014). The actual cross-section as indicated in *Figure 3(b&d)* are in good correlation with their corresponding tomography images where brief hardness test shows that the inner region is softer compared to the outer region.

The moderately infected samples have symptoms of yellowing and skirting fronds but without *Ganoderma* fruiting bodies. For this type of palm, the acoustic tomography images have lower depth of colour compared to a

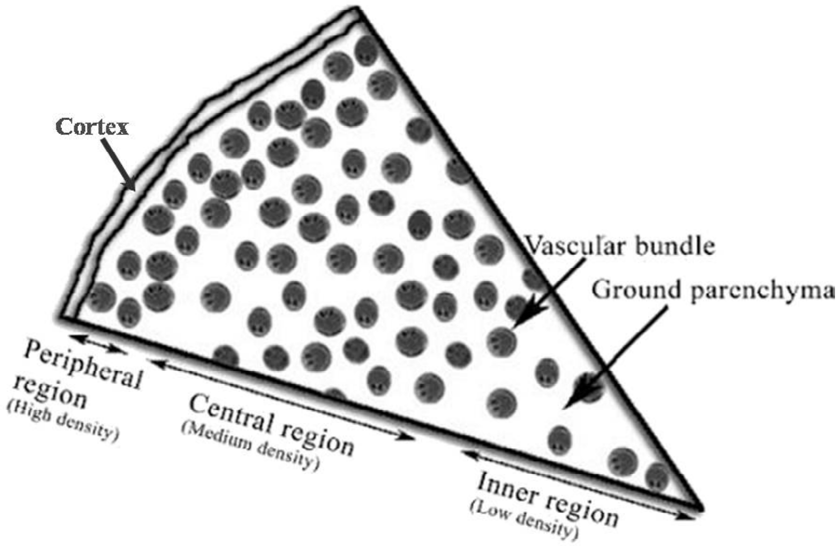
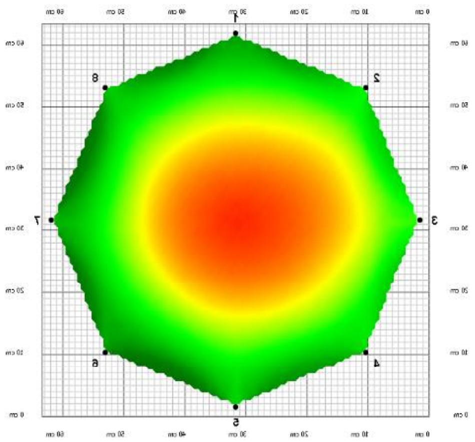


Figure 4 Cross-section of the oil palm stem (Dangwilailux et al.*, 2019)*

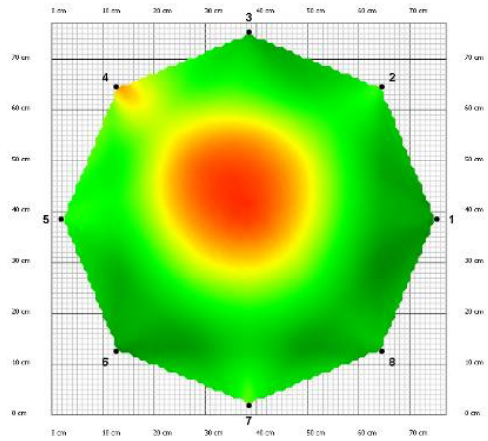
healthy palm. It consists of dark green, yellow and red colours as shown in *Figure 5 (a* & *c)*. The tomography images also showed less symmetric colour distribution compared to healthy oil palm images as in *Figure 3*. However, observation of the actual cross-section was still intact even though there was a high possibility of infection of the samples by *Ganoderma*, as shown in *Figure 5(b* & *d)*. There was no obvious visual symptom of decayed tissue in the cross-section. Again, detailed examination of the raw wave speed data showed that the acoustic wave speed also gradually increased from the inner region to the outer palm trunk. However, the speed range is smaller in comparison with the healthy palm which is from minimum 410 m/s at the centre to maximum of 1 081 m/s at the outer trunk. In terms of wave speed difference, acoustic wave travels over 100 m/s slower in the middle of the moderately infected palm and over 300 m/s slower at the outer trunk compared to healthy palm, respectively. This means that for moderately infected oil palm, the overall density has been reduced which could be associated with the presence of BSR disease at an early stage of infection.

On the other hand, the tomography image for severely infected palm is totally skewed in the decay area as seen in *Figure 6 (a* & *c)*. The tomography image in *Figure 6 (a)* for the first sample is no longer in circular form as in the healthy and moderately infected palm. Similar observations can be seen in the second sample [*Figure 6 (c)*]. Comparison with the actual cross-section of the palm trunk [*Figure 6 (b* & *d)*] shows both palm samples have a large decay area where most of the tissues in the area shown in red colour of the tomography image have turned rotten. As the infection of BSR progress, it consumes the lignin component of a palm tree in the infected area and cause it to decay (Chong *et al.*, 2017).

Additionally, as indicated in *Figure 6 (a* & *c)* the red area in the tomography image has reached the outer region of the palm trunk.



a) Tomogram of moderately infected oil palm sample 1



c) Tomogram of moderately infected oil palm sample 2

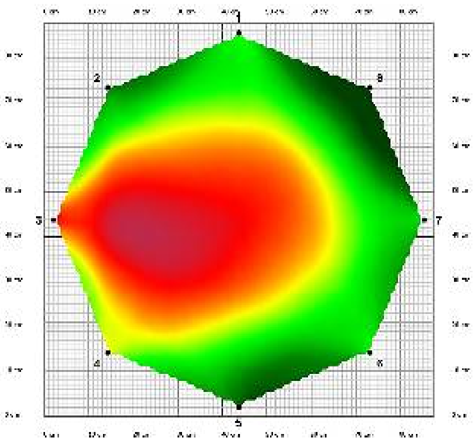
b) Actual cross-section image of moderately infected oil palm sample 1

d) Actual cross-section image of moderately infected oil palm sample 2

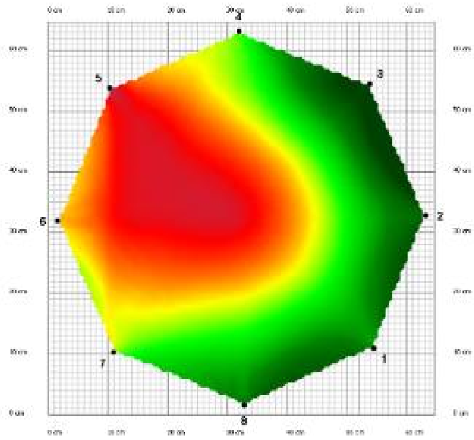
Figure 5 Pairing of tomography image and actual cross-section of moderately infected palm

This is a clear indication that the infection of the BSR disease has penetrated the palm trunk and therefore fruiting body of BSR disease could be visualised. This is completely different for healthy [*Figure 3(a* & *c)*] and moderately infected oil palm [*Figure 5(a* & *c)*] where the outer region of the palm are still intact with full circular form of green ring region. Especially for moderately infected sample, although there is an indication of BSR infections (low colour depth and less symmetric colour distribution), the BSR is still inside the palm trunk indicating that it is still at the moderate level of infection. The infection level for samples in *Figure 5* is classified as severe BSR and has penetrated outside the palm trunk and developed fruiting body.

Additional assessment on the proportionality of decay area of the cross-section of severely infected palm cut out was carried out using



a) Tomogram of severely infected palm sample 1



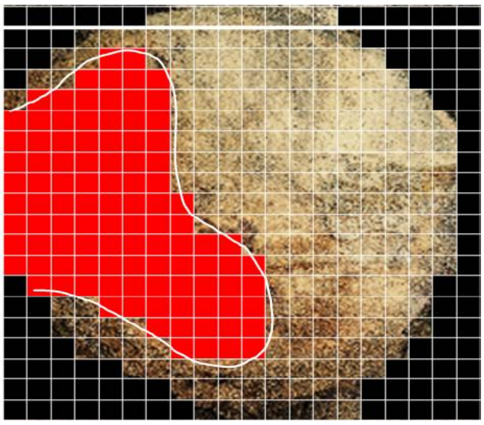
c) Tomogram of severely infected palm sample 2

b) Actual cross-section image of severely infected palm sample 1

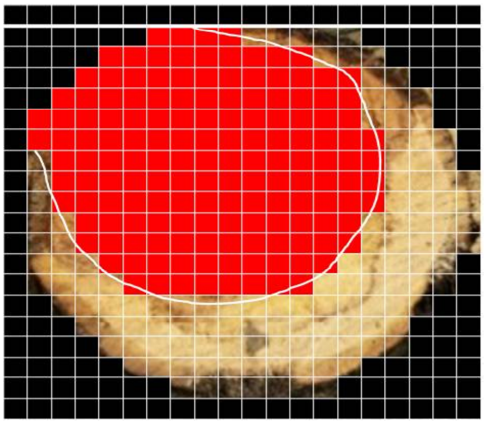
d) Actual cross-section image of severely infected palm sample 2

Figure 6 Tomography and actual cross-section cut out images of severely infected palm

square area method. The area of the decayed cross-section was determined and compared with the total cross-section area. The red square shown in *Figure 7* indicates the area of the decayed tissue whereas the area covered by black coloured square is the boundary of the palm cross-sections. The analysis showed that for severely infected palm sample 1, 33.3 per cent of the cross-section was already degraded [*Figure 7(a)*] whereas for palm sample 2, the degraded tissue area was around 54.7 per cent [*Figure 7(b)*]. Comparison with the respective tomography images in *Figure 6* shows the proportionality of the first palm sample as in *Figure 6(a)*, only one sensor point was in the decayed area whereas for the sample as in *Figure 6(b)*, two sensor points were inside the decayed region. Therefore, the total decayed tissue for the second palm sample was larger compared to the first palm sample.



a) Decayed area in the cross-section of severely infected palm sample 1

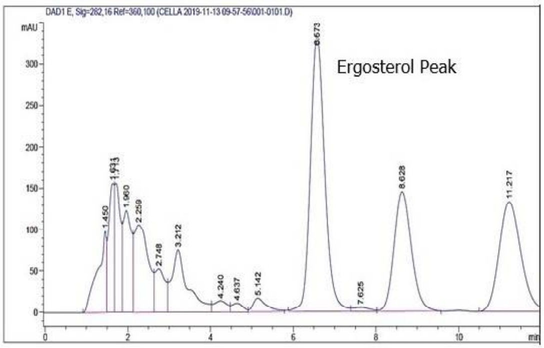


b) Decayed area in the cross-section of severely infected palm sample 2

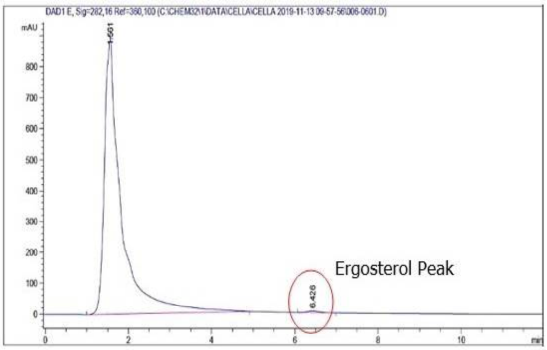
Figure 7 Determination of the decayed area in the cross-section of the severely infected palm sample using unit square method. Cross-section covered by red square indicates the area with decayed tissue whereas the area covered by the black square is the boundary of the cross-section

Ergosterol and *Ganoderma* Selective Medium (GSM) analysis

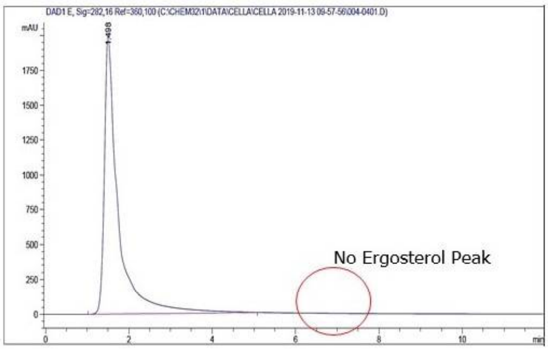
Analysis on the acoustic tomography image could provide information on the health condition of the palm as well as the infection level of BSR. In addition, the tomography image could also provide some estimates of the severity of the BSR infection in terms of percentage of decayed tissue in the cross-section of the palm. This finding is cross examined using ergosterol analysis and using *Ganoderma* Selective Medium (GSM) method. Ergosterol analysis of the tissue samples for healthy, moderately infected and severely infected palm was conducted using High Performance Liquid Tomography (HPLC) instrument, Agilent Series 1200 Chromatography System at the Natural Resource Laboratory, Faculty of Science and Natural Resources, Universiti Malaysia Sabah. The chromatogram of standard ergosterol (Sigma®) that was eluted between six to seven minutes and used as a reference in this investigation is shown in *Figure 8 (a)*. For the healthy palm tissue, no peak was seen at that retention time as shown in *Figure 8(b)* which confirms of no presence of BSR in the sample. On the other hand, a relatively low peak could be seen on the chromatogram of infected palm tissue as seen in *Figure 8 (c)* which indicates that low amount of ergosterol was detected. This indicates moderate level of BSR infection in the tree and is in agreement with the finding from the acoustic tomography image analysis. The chromatogram for severely infected palm tissue where higher peak is observed compared to the moderately infected palm tissue is as seen in *Figure 8 (d)*. This is indication of a higher amount of ergosterol compound compared to the moderately infected tissue shown in *Figure 8(c)* and therefore the infection level. Again, the result of this analysis is similar to the finding from the acoustic tomography analysis.



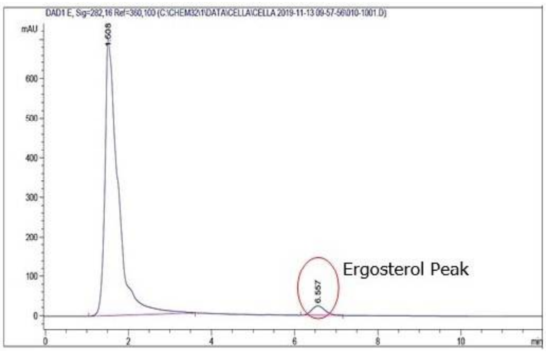
a) Chromatogram of ergosterol standard



c) Chromatogram of moderately infected oil palm tissue samples



b) Chromatogram of healthy tissue sample



d) Chromatogram of severely infected tissue samples

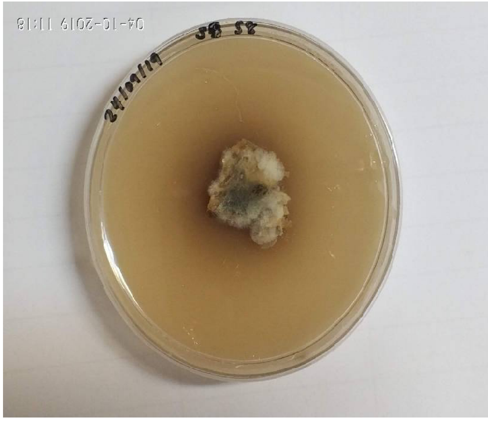
Figure 8 Chromatograms of ergosterol standard and palm tissue samples obtained from HPLC analysis

Isolates of the tissue from the oil palm on GSM are shown in *Figure 9*. The results showed no *Ganoderma* fungus growth were found in the healthy oil palm tissues [*Figure 9(a)*]. Meanwhile, growth of *Ganoderma* fungus was observed in the isolates of moderately infected and severely infected tissue samples as shown in *Figure 9 (b)*. Thus, the GSM assessment results are in good agreement with the previous acoustic tomography method and the ergosterol analysis results.

CONCLUSION

This study examined the possibility of using acoustic tomography to assess the BSR disease. Three categories were examined namely: healthy, moderately infected and severely infected. It was found that healthy oil palm produced almost perfect circular rings tomography image with a high colour depth and high symmetricity. On the other hand, the moderately infected palm tree produced less symmetric circular image with a lower colour depth which can be associated with early infection of BSR disease. For severely infected tree samples, the tomography image was totally skewed and no longer in circular form. Ergosterol and GSM assessment confirmed the presence of *Ganoderma boninense* in moderately infected and severely infected tree samples. One of the severely infected palms showed that 33.3 per cent of its cross-section

a) *No growth of* Ganoderma *from healthy palm tissue*



b) Ganoderma *growth from moderately and severely infected palm tissues*

Figure 9 Isolation of Ganoderma *on GSM*

was already degraded whereas the other sample had degraded tissue of around 54.7 per cent which is reflected by their corresponding tomography image. Thus, acoustic tomography could be a promising method for early detection of BSR disease infection in oil palm.

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