INVESTIGATION ON THE USE OF ACOUSTIC TOMOGRAPHY FOR THE DETECTION OF *Ganoderma boninense* INFECTION IN OIL PALM

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ABSTRACT

Oil palm (*Elaeis guineensis*) is the leading vegetable oil crop particularly in South – East Asia countries especially in Indonesia and Malaysia since it brings great economic importance to the country. However, due to incurable disease known as Basal Stem Rot caused by *Ganoderma boninense* fungi, considerable yield losses has increased. Most of the management strategies for this disease failed due to inability to detect the disease at early stages. In this research, new model of stress wave based acoustic system is introduced to evaluate the internal condition of three different characteristics of oil palm standing trees namely; healthy, moderately infected and severely infected. Twelve samples were chosen for each characteristics with the average of 35 years and 45 cm for age and diameter size respectively. The acoustic system is consisted of a regular steel and rubber hammer, eight piezoelectric sensors, four amplifiers, cables, battery box and system software. Acoustic sensor probes were inserted perpendicularly around the oil palm trunk to obtain the readout data by tapping each sensor with a steel hammer. Data was collected by a computer and two dimensional (2D) tomography images were generated automatically by the system software. Results obtained were then compared with visual inspection of the real cross section after oil palm trees were cut down and the tress wave velocity distribution in each sample were analyzed. Tissue samples of each oil palm were collected and subjected to laboratory for ergosterol analysis. Findings of this study revealed that, there was a clear difference between tomography image of healthy, asymptomatic and severely infected sample. The 2D tomograms give a close correlation with the real cross section of oil palm that was cut down. Meanwhile, stress wave velocity distribution shows that, higher difference in velocity range leads to more color depth in tomography image compared to lower velocity range. Besides that, this system was proven to provide better information on stages of infection compared to the ergosterol analysis. Therefore, this study suggested that stress wave based acoustic tomography can be utilized as a new method of future detection *Ganoderma boninense* infection in oil palm. This method could give great benefits in oil palm industry especially in order to detect the infected area on an 'In-situ' basis so that the right remedial measure and treatment could be applied and most importantly reduce the economic losses in the industry.

ABSTRAK

KAJIAN PENGGUNAAN TOMOGRAFI AKUSTIK DALAM PENGESANAN JANGKITAN Ganoderma boninense PADA POKOK KELAPA SAWIT

Kelapa sawit (Elaeis guineensis) adalah tanaman minyak sayuran utama khususnya di negara-negara Asia Tenggara terutamanya Indonesia dan Malaysia kerana tanaman ini membawa kepentingan ekonomi yang besar kepada negara-negara tersebut. Walau bagaimanapun, ancaman penyakit Reput Pangkal Batang yang disebabkan oleh kulat Ganoderma boninense telah meningkatkan kerugian hasil tanaman yang agak mendadak. Kebanyakkan strategi pengendalian penyakit ini gagal kerana ketidakupayaan strategi-strategi tersebut untuk mengesan jangkitan pada peringkat awal. Dalam kajian ini, model sistem akustik baharu yang berasaskan gelombang tekanan telah diperkenalkan untuk mengkaji keadaan struktur dalaman bagi tiga ciri kelapa sawit iaitu; sihat, jangkitan sederhana dan jangkitan teruk. Dua belas sampel pokok kelapa sawit telah dipilih bagi setiap ciri yang berbeza dengan purata umur dan diameter pokok masing-masing adalah 35 tahun dan 45cm. Sistem akustik ini terdiri daripada tukul besi dan tukul getah, lapan sensor piezoelektrik, empat penguat, kabel-kabel penyambung, kotak bateri dan perisian sistem. Penderia akustik dimasukkan secara serenjang mengelilingi batang kelapa sawit untuk mendapatkan data bacaan data dengan menukul setiap penderia menggunakan tukul besi. Data direkodkan terus ke dalam komputer dan imej tomografi dua dimensi (2D) dihasilkan secara automatik oleh perisian sistem tersebut. Keputusan yang diperoleh telah dibandingkan dengan imej keratan rentas sebenar pokok kelapa sawit yang telah ditebang dan agihan halaju gelombang tekanan untuk setiap sampel juga dianalisis. Sampel tisu bagi setiap pokok kelapa sawit kemudian diambil dan dibawa ke makmal untuk tujuan analisis kolonisasi ergosterol. Dapatan dari kajian ini menunjukkan bahawa terdapat perbezaan yang jelas antara imej tomografi sihat, jangkitan sederhana dan jangkitan teruk. Terdapat kolerasi yang tinggi antara imej yang diperolehi melalui tomogram 2D dan keratan rentas sebenar kelapa sawit yang sudah ditebang. Sementara itu, hasil analisis daripada agihan halaju gelombang tekanan menunjukkan bahawa, julat halaju yang tinggi akan menghasilkan kedalaman warna yang lebih tinggi pada imej tomografi berbanding julat halaju yang rendah. Selain itu, sistem baru ini terbukti

dapat memberikan maklumat tahap jangkitan penyakit yang lebih baik berbanding dengan analisis berdasarkan kandungan ergosterol. Oleh itu, kajian ini mencadangkan bahawa kaedah tomografi akustik berasaskan gelombang tekanan berpotensi untuk digunakan dalam pengesanan jangkitan Ganoderma boninense pada pokok kelapa sawit di masa akan datang. Kaedah ini mampu memberikan faedah kepada industri kelapa sawit terutama sekali untuk mengesan kawasan jangkitan di dalam pokok secara 'In-situ' agar langkah pemulihan dan rawatan yang betul dapat diaplikasikan sekaligus mengurangkan kerugian ekonomi dalam industri ini.

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LIST OF SYMBOLS

C_D	dynamic stiffness
ρ	density
V_L	velocity of the longitudinal wave
V	stress wave velocity
E	modulus of elasticity
s	distance between transducers
t	time of flight
λ	wavelength
V	velocity
f	frequency
$s\ (x,y)$	slowness in wood at (x,y) point
C_a and C_b	positions of a^{th} and b^{th} sensors
t_i	time measured between i^{th} sensors
s_j	slowness of j^{th} cell
l_{ij}	length of i^{th} wave path through j^{th} cell
M	matrix
s	vector s
t	vector t
sgn	1 if x > 0
	0 if x = 0
s_i	i^{th} line slowness
p	line integral along line L whose distance from the origin
ϕ	angle between line and y axis
$\hat{f}(p, \emptyset)$	measured time in (p,ϕ)
$f\ (x,y)$	slowness function s (x,y)
Rf	Radon transform of the slowness function
I_2	two-dimensional Fourier transform
I_1^{-1}	one-dimensional Inverse Fourier transform

$\int$	Integral
π	pi
d()	differential of variable

LIST OF ABBREVIATIONS

BSR	Basal stem rot
GSM	*Ganoderma* Selective Media
ELISA	Enzyme-Linked Immunosorbet Assay
PCR	Polymerase Chain Reaction
NDT	Non Destructive Testing
NDE	Non Destructive Evaluation
MPOB	Malaysia Oil Palm Board
HPLC	High Performance Liquid Chromatography
TLC	Thin Layer Chromatography
UV	Ultraviolet
DNA	Deoxyribonucleic Acid
ITS	Internal Transcribes Spacer
RNA	Ribonucleic Acid
MPCR	Multiplex PCR
E-nose	Electric Nose
TOF	Time of Flight
OPT	Oil palm tree
2D	Two-dimensional

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CHAPTER 1

INTRODUCTION

1.1 Oil Palm Industry

Oil palm (*Elaesis Guineensis*) is a tropical tree crop which belongs to *Palmae* family. Oil palm was considered as a rich crop, contribute to higher yield production compared to soybean, sunflower and rapeseed (Murphy, 2007). It was reported that, in 2019 the global oil palm production has reached 73% all over the world where most of it are grown in South-East Asia with Indonesia as a leading country (USDA, 2019). Palm oil was reported as the highest consumed products among major oil and fats. China, India, Indonesia and European Union (EU) are the main consumers country of palm oil (Chong *et al.,* 2017).

The global trades of oil palm production also increase through the years, for example as in Malaysia, the palm oil exports has increased 12% in 2019 compared to 18.47 million tonnes in 2018 (MPOB, 2019). Due to this high demand, continuation of palm oil productions is needed in upcoming years to satisfy food and biofuels necessity. However, oil palm industry nowadays facing a major problem related to fungal diseases, known as Basal Stem Rot (BSR). Due to this disease, oil palm products is expected to decreases in the future. If there is no solution, this could lead to a significant economic losses to the industry (Kamu, 2016).

1.2 Detection of Basal Stem Rot Disease

Basal stem rot (BSR) is the main disease manifestation caused by *Ganoderma boninense.* This problem is definitely causing big concern as BSR infection was found more severe in Malaysia and Indonesia compare to other palm oil-producing countries such as Africa, Papua New Guinea and Thailand (Abu Seman *et al.,* 2004). Therefore, researchers had been looking for solutions for this matter but to date, the solution still not conclusive. The absence of physical symptoms at early stage of infection is the main reason why planter failed to notice the infection at the first stage. Symptoms only appeared at the later stage where any treatment may not possible to save the palm anymore.

Some established indicative tools such as semi selective media for infected oil palm cultures (Darus *et al.,* 1993) and *Ganoderma* Selective Media (GSM) (Darus & Abu Seman, 1992) is said to be effective in detecting the presence of *Ganoderma* in oil palm even though there are no external symptoms. However, it is not suggested for large application because of its inaccuracy since other basidiomycete can also grow on the media. More advance molecular technique that commonly used in *Ganoderma* detection has also been introduced which are enzyme-linked immunosorbet assay (ELISA) and polymerase chain reaction (PCR). Nevertheless, these methods are bonded by difficult protocol, high chemical cost and requirement of highly skilled person. Besides, these method are laboratory oriented lead to time consuming analysis.

1.3 Problem Statement

BSR is the main disease which attacked oil palm trees in South-East Asia especially in Indonesia and Malaysia, causing significant concern to the industry. Generally, BSR could damage the stem or root of the trees. Infected trees will cause several visible symptoms for examples; wilting of fronds, unopened spear leaves, pale leaf canopy, rot stem and presence of fruiting body on stem base (usually for severely infected trees) (Chong *et al.,* 2017). Therefore, early detection or inspection of trees is important in order to predict the stages of infection in each trees either with or without visible symptoms. The current situation is alarming due to increasing losses in the industry since the infection has now reached distressing level as more oil palm trees infected. It is reported that, BSR incidence causes USD 500 million loss per year worldwide (Rebitanim *et al.,* 2020). When the infection is detected at early stage, then it is easier to apply treatment and preventing disease to spread more.

Previously mentioned, numerous studies was conducted to make it possible to detect the BSR infection at early stage, however these detection methods are costly, time consuming and lab oriented. This study suggests a new approach of early detection which is by using Non Destructive Testing (NDT) tomography technology. NDT's technique provides a relatively cost-effective investigation and more reliable findings (Oliviera & Sales, 2006). Besides, it also has the ability of estimating discontinuities of a material in a short amount of time compared to destructive technique.

Few emerging tomography methods for evaluation of oil palm have been reported such as ultrasonic tomography, X-ray tomography, Gamma rays tomography and electrical resistance tomography. However, the application of these methods in field are still limited. Therefore, this study suggests a stress wave based acoustic tomography technique as a reliable early detection method.

1.4 Research Objectives

The main purpose of this present work is to establish NDT method applying acoustic tomography as one of the reliable technique to detect Basal Stem Rot disease infection in oil palm trees. Thus, investigations are conducted to fulfil the four acoustic studies as follows:

I. To establish a baseline acoustic tomography image profile for healthy oil palm.
II. To examine asymptomatic oil palm using acoustic tomography for potential application of early detection of *Ganoderma boninense* infection.
III. To develop acoustic tomography image profile for severely infected oil palm tree.

To achieve these objectives, acoustic tomography of healthy, asymptomatic and severely infected are compared with the visual inspection and ergosterol analysis.

1.5 Thesis Contribution

The findings of this research suggest the uses of acoustic tomography method to detect *Ganoderma boninense* infection in oil palm. This method could provide correct information of the health condition of palm trunk without damaging its' end-used capabilities. Right analysis would help plantation to manage the problem by making appropriate treatment process for the infected oil palm. Life span of treated oil palm could be prolonged and the yield production can be maintained for years. Therefore, this study would help planters in order to detect and treat the trees at early stage of infection to avoid more economic losses due to Basal Stem Rot disease.

1.6 Thesis Arrangement

This thesis is organized in five chapters. First chapter comprises the introductory section that develops the direction of this investigation. It also states the research background, problem statement and objectives; and provides contribution of the study and the thesis organization. Second chapter summarises the current states of knowledge by addressing the relevant literature. Topics covered in this chapter include the information on Basal Stem Rot disease and the current detection methods. It also covers the review on the knowledge of Non-destructive techniques which includes the conventional method and developed method which is the acoustic tomography. Overall, this chapter identifies the research gap, which justifies the need for this study. Meanwhile, third chapter describes the research methodology in details including; method flowchart; sample and data collection; research instrumentation; data analysis and validation of the results. Fourth chapter presents the discussion of experimental findings of the study which is; healthy oil palm, asymptomatic oil palm and severely infected oil palm; where all parameters in each samples are explained in details. The last chapter summarizes the research outcomes based on the research objectives. Finally, recommendations for future research are proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews research and study related on oil palm which focusing on Basal Stem Rot disease caused by *Ganoderma boninense* and the current detection method. The purpose of this review is to provide better understanding on the present work which includes the background of oil palm industry, the problem encountered and the theory of non-destructive acoustic tomography method as new approach of detecting *Ganoderma boninense* infection.

2.2 Palm Oil Industry

Oil palm or its scientific name *Elaeis guineensis Jacq* which came from family *'Palmae'* was a first crop cultivated in West Africa. Oil palm industry began on a small scale with only four pure oil palm trees introduced from West Africa to Botanical Garden Bogor, Indonesia. The development of oil palm trees cultivation showed significant increases during 1930's to 2000's. At some point in 1960's the income was very positive whereas, it has surpassed the income from rubber's products. Because of this, most of the cultivation companies focusing on both of these plants as their main cultivation (Basiron & Chan, 2004).

In 2019, the global production of oil palm has reached 73.9 million tonne where the highest recorded in Indonesia with 57% of the production (see Table 2.1). It was reported that, other than Malaysia and Indonesia, the expansion of oil palm producers also progressing in other countries such as Thailand, Colombia, Nigeria, Ecuador, Honduras, Papua New Guinea, Ghana, Guatemala, Costa Rica, Cameron and the Democratic Rebuplic of Congo (Palm Oil Analytics, 2017). This