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NON-DESTRUCTIVE ESTIMATION OF OIL PALM YIELD AND QUALITY WITH FLUORESCENCE SENSING

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By

NORUL HUSNA BINTI ABU KASSIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

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Thank you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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Chair : Assoc. Prof.Siva Kumar Balasundram, PhD
Faculty : Agriculture

Fluorescence sensing is one of the proximal sensor techniques which use instruments operating very close to or in contact with the object of inquiry. It is an emerging approach in assessing and monitoring crop yield and quality. At present, ineffective Fresh Fruit Bunch (FFB) maturity assessment and untimely harvesting are problematic to the Malaysian oil palm industry. The current method of FFB assessment is extremely tedious and a time-consuming process that is destructive, prone to errors and inconsistent. Thus, implementation of an oil palm harvesting protocol that deploys a non-destructive sensor-based approach to assess FFB ripening is highly desirable. The objectives of this study were: i) to quantify the relationship between palm oil quality (DOBI) and fluorescence-sensed anthocyanin and flavonol contents across different palm ages, ii) to quantify the relationship between palm oil yield (OER) and fluorescence-sensed anthocyanin and flavonol contents across different palm ages, and iii) to identify the best-fitted model and validate the spatial distribution of palm oil quality, yield and fluorescence-sensed anthocyanin and flavonol contents across different palm ages. In this study, three 2-ha plots were demarcated based on different year of planting; 2002 (12 year old palms), 2005 (9 year old palms) and 2008 (6 year old palms). Sixty FFBs and their corresponding loose fruits were scanned for each plots using fluorescence sensor (Multiplex®). Overall, secondary metabolites such as anthocyanin and flavonol are proven to be a reliable indicator of palm oil quality and yield (r=0.6 of anthocyanin and r=0.8 of flavonol). However, fluorescence indices (Anth_B, Flav_B and NBI) show mixed correlation strengths with DOBI and OER across different palm ages. For the first objective, the secondary metabolites; anthocyanin and flavonol, were analysed to determine the relationship between Deterioration of Bleacheability Index (DOBI) and secondary metabolites content. Results showed that the estimated strength of secondary metabolites was more pronounced toward oil quality in 6 and 9 year old palms (younger palms). For the second objective, the secondary were analyzed to determine the relationship between Oil Extraction Rate (OER) and secondary metabolites content. Results showed that the estimated strength of secondary metabolites was more pronounced toward oil yield in 9 and 12 year old palms (older palms). As a conclusion, both palm oil quality and oil yield

determinations using fluorescence indices are most applicable in matured 9 year palms (*r*=0.63 and 0.52 with DOBI; *r*=0.65 and 0.53 with OER, respectively). This indicates that palm oil quality and yield, particularly of 9 year old palms, are highly related to fluctuations in anthocyanin and flavonol contents in the fruit. According to Corley and Tinker 2003, oil palm has reached its maturity and their growth becomes more stable at 9-10 years after planting which is when their productivity is at its maximum. This could also infer that anthocyanin and flavonol contents in the 6 and 12 year old palms are more indicative of their metabolic process rather than their oil quality or oil yield. This observation is in agreement with Muller et al. (2013) who reported that during plant growth (particularly in 6 and 12 year palms), higher accumulation of anthocyanin and flavonol contents will act as a trade-off between the plant's primary and secondary metabolic system, which are not stable as compared in 9 year old palms. For the third objective, ten variables of spatial distribution of palm oil quality, palm oil yield and fluorescence-sensed secondary metabolites were modeled and validated for each age group. Majority of variables for all three age groups have a short effective range (<153 m) with a strong spatial dependence (>99.7%) except for OER of 2008. Most of the tested variables could be had 99% variability that is explainable. Across different age groups, TFC was recorded with lowest R^2 values ranging between 0.03-0.07 which due to secondary metabolism of flavonoid in palm oil meanwhile majority of the variables showing a moderate R^2 with value ranging between 0.5-0.7 (Anth_B, Flav_B, Anth_Lf, Flav_Lf and TAC). CV values of variables in all age groups can be divided into two groups; low and moderate variability (CV=7-49% in 2002; 13-41% in 2005; and 7.7-37.8% and 52.7-73.4% in 2008, respectively). This indicates that all variables are greatly being influenced and significantly associated with secondary metabolite concentrations in oil palm compared to spatial regularity. Fluorescence sensor has a promising potential in determining secondary metabolites in oil palm, however more research and future findings are needed to support and compliment this work.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN KUALITI DAN HASIL MINYAK SAWIT SECARA BUKAN MEMUSNAH DENGAN MENGGUNAKAN KAEDAH PENGESAN FLORESEN

Oleh

NORUL HUSNA BINTI ABU KASSIM

Januari 2016

Pengerusi : Prof. Madya Siva Kumar Balasundram, PhD
Fakulti : Pertanian

Pengesan floresen merupakan salah satu teknik pengesan jarak dekat yang menggunakan instrumen fungsi jarak dekat atau bersentuhan dengan objek yang dikesan. Pengesan floresen merupakan pendekatan yang kian mendapat perhatian dalam menganalisis dan mengawal hasil dan kualiti tanaman. Dewasa kini, ketidakcekapan dalam menganalisis tandan buah sawit dan penuaian pramatang merupakan masalah yang semakin menular terutamanya dalam industri kelapa sawit di Malaysia. Kaedah menganalisis tandan buah sawit sedia ada adalah sangat sukar dan merupakan proses yang mengambil masa yang lama sehinggakan ia akan merosakkan fizikal buah, terdedah kepada kesilapan dan tidak konsisten. Justeru, pelaksaanaan terhadap protokol penuaian kelapa sawit yang menggunakan kaedah pengesan secara tidak-memusnahkan-fizikal buah dalam menganalisis kemasakan tandan buah sawit ini adalah sangat diperlukan. Objektif kajian ini ialah: i) untuk mengkaji hubungan antara kualiti minyak sawit (DOBI) dan kandungan antosianin dan flavonol yang dikesan floresen berdasarkan usia pokok yang berbeza, ii) untuk mengkaji hubungan antara hasil minyak sawit (OER) dan kandungan antosianin dan flavonol yang dikesan floresen berdasarkan usia pokok yang berbeza, dan iii) untuk mengenal pasti model yang paling bersesuaian dan mengesahkan ruang agihan daripada kualiti minyak sawit, hasil minyak sawit dan kandungan antosianin dan flavonol yang dikesan floresen berdasarkan usia pokok yang berbeza. Dalam kajian ini, tiga 2-ha plot telah ditanda dalam usia pokok yang berbeza berdasarkan tahun penanaman: 2002 (12 tahun), 2005 (9 tahun) dan 2008 (6 tahun). Enam puluh tandan buah sawit dan buah terlerainya telah diimbas bagi setiap plot dengan menggunakan pengesan floresen (Multiplex®). Secara keseluruhan, metabolit sekunder seperti antosianin dan flavonol telah terbukti sebagai petunjuk yang dipercayai bagi kualiti dan hasil minyak sawit (r=0.6 of antosianin and r=0.8 of flavonol). Namun, index floresen (Anth_B, Flav_B and NBI) menunjukkan kekuatan kolerasi yang berbeza-beza terhadap DOBI dan OER dalam usia pokok yang berbeza. Bagi objektif pertama, metabolit sekunder, antosianin dan flavonol, dianalisis untuk mengetahui hubungan antara index kemerosotan meluntur (DOBI) dan kandungan metabolit sekunder. Hasil kajian mendapati anggaran kekuatan metabolit sekunder adalah lebih menonjol terhadap kualiti minyak

sawit pada usia 6 dan 9 tahun (buah sawit yang lebih muda). Bagi objektif kedua, metabolit sekunder tersebut dianalisis untuk mengetahui hubungan antara kadar perahan minyak (OER) dan kandungan metabolit sekunder. Hasil kajian mendapati anggaran kekuatan metabolit sekunder adalah lebih menonjol terhadap hasil minyak sawit pada usia 9 dan 12 tahun (buah sawit yang lebih tua). Secara keseluruhannya, penentuan kedua-dua kualiti dan hasil minyak sawit menggunakan pengesan floresen adalah paling sesuai diaplikasi pada pokok sawit matang yang berusia 9 tahun (*r*=0.63 dan 0.52 untuk DOBI; *r*=0.65 and 0.53 untuk OER, masing-masing). Ini menunjukkan bahawa kualiti dan hasil minyak sawit, terutamanya pokok berusia 9 tahun adalah sangat berkait rapat dengan penurunan atau kenaikan kandungan antosianin dan flavonol di dalam buah. Menurut Corley dan Tinker (2003), kelapa sawit telah mencapai tempoh matang dan proses pertumbuhan mereka telah menjadi lebih stabil pada usia 9-10 tahun selepas ditanam dan dimana produktiviti mereka adalah pada tahap maksimum . Ini membuktikan bahawa kandungan antosianin dan flavonol pada usia 6 dan 12 tahun adalah lebih menunjukkan proses metabolik mereka berbanding kualiti atau hasil minyak sawit. Pemerhatian ini bertepatan dengan penemuan daripada Muller et al. (2013) yang melaporkan bahawa pengumpulan kandungan antosianin dan flavonol yang lebih tinggi ketika pertumbuhan pokok (terutamanya di usia 6 dan 12 tahun), akan bertindak sebagai proses penyeimbangan “trade-off” antara sistem metabolisma pertama dan sekunder pokok, yang mana tidak stabil berbanding pokok berusia 9 tahun. Bagi objektif ketiga, sepuluh pemboleh-ubah ruang agihan daripada kualiti minyak sawit, hasil minyak sawit dan kandungan antosianin dan flavonol yang dikesan floresen telah dimodelkan dan disahkan untuk setiap kumpulan usia pokok. Kebanyakkan daripada ruang agihan kualiti minyak, hasil minyak dan metabolit sekunder yang telah dikesan mempunyai julat efektif (ER) yang pendek (<153 m) dan ruang pergantungan “spatial dependence” yang kuat (>99.7%) kecuali dalam OER bertahun 2008. Hampir keseluruhan parameter yang dikaji mungkin mempunyai 99% pembolehubah yang boleh diterangkan. Dalam usia pokok yang berbeza-beza ini, TFC telah merekodkan nilai R^2 terendah bernilai 0.03 hingga 0.07 yang berkemungkinan berlaku disebabkan oleh metabolisma sekunder (flavonoid) di dalam minyak sawit, manakala kebanyakan parameter yang lain mempunyai nilai R^2 sederhana bernilai 0.5 hingga 0.7 (Anth_B, Flav_B, Anth_Lf, Flav_Lf dan TAC). Nilai CV setiap parameter boleh dibahagikan kepada dua kumpulan; variabiliti rendah dan sederhana (CV=7-49% untuk 2002; 13-41% untuk 2005; dan 7.7-37.8% dan 52.7-73.4% untuk 2008, masing-masing). Ini menunjukkan bahawa kesemua parameter sangat dipengaruhi dan berkait rapat dengan kekerapan ruang. Maka, pengesan floresen berpotensi dalam menentukan metabolit sekunder dalam buah kelapa sawit, namun lebih banyak penyelidikan dan penemuan pada masa hadapan yang diperlukan untuk menyokong kerja penyelidikan ini.

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I certify that a Thesis Examination Committee has met on 12 January 2016 to conduct the final examination of Norul Husna binti Abu Kassim on her thesis entitled "Non-Destructive Estimation of Oil Palm Yield and Quality with Fluorescence Sensing" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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Signature: ______________________________
Name of Member of Supervisory Committee: Tan Chin Ping, PhD

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LIST OF ABBREVIATIONS

FFB	Fresh Fruit Bunch
DOBI	Deterioration of Bleachability Index
OER	Oil Extraction Rate
Anth_B	Anthocyanin Index of Bunch
Flav_B	Flavonol Index of Bunch
Anth_LF	Anthocyanin Index of Loose Fruit
Flav_B	Flavonol Index of Loose Fruit
TAC	Total Anthocyanin Content of Loose Fruit
TFC	Total Flavonoid Content of Loose Fruit
SFR	Simple Fluorescence Ratio (Chlorophyll content)
NBI	Nitrogen Balance Index
CPO	Crude Palm Oil
RPO	Refined Palm Oil
PKO	Palm Kernel Oil
FFA	Free Fatty Acid
GMQ	Good Merchantable Quality
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
%F/B	Percentage of Fruit Per Bunch
M/F	Mesocarp to Fruit Ratio
S/F	Shell to Fruit Ratio
K/F	Kernel to Fruit Ratio
%O/M	Percentage of Oil to Mesocarp
%O/K	Percentage of Oil to Kernel
%O/B	Percentage of Oil to Bunch
O/DM	Oil to Dry Mesocarp
LED	Light Emitting Diode
IR	Infra-Red
UV	Ultra-Violet
GPS	Global Positioning System
N	Nitrogen

NNI	Nitrogen Nutrition Index
BRR	Blue-to-Red fluorescence Ratio
NDVI	Normalized Difference Vegetation Index
CV	Coefficient of Variation
ME	Mean Error
MSE	Mean Squared Error
SMSE	Standardized Mean Squared Error
SD	Standard Deviation
SEM	Standard Error of Mean
SES	Standard Error of Skewness
SEK	Standard Error of Kurtosis
C_0	Nugget
$C_0 + C$	Sill
A_0	Range
ER	Effective Range
DEM	Digital Elevation Model

CHAPTER 1

INTRODUCTION

1.1 Background of oil palm

Oil palm (*Elaeis guineensis* Jacq.) is a multipurpose tree crop of high productivity, yielding a total of 19.22 million tons of crude palm oil in 2013. At present, oil palm produces the highest yields per hectare among commercial oil crops. The oil palm industry has become a major source of oils and fats production worldwide and has led to a rapidly expanding world oils and fats industry, which now is based in the tropical areas of Asian regions, Africa and America. The origin of oil palm is believed to be in Africa. However, today the most productive regions of the oil palm industry are located in Malaysia and Indonesia, which produce most of the oil entering international trade.

1.2 Problem statement

The oil palm industry has continually faced the problem of a significant gap between actual yields and potential yields. Ineffective harvesting and poor maturity/grading assessment had been identified as one of determinants of these problems. The common traditional methods of oil palm maturity assessment followed by quality and yield assessments are destructive, costly, laborious, inconsistent and time-consuming. At present, Fresh Fruit Bunch (FFB) ripeness is determined based on the number or percentage of fruits detached from the bunch. Collection of detached fruits is costly when manually carried out, but it is highly necessary because they influence the oil yield.

Commercial plantations commonly carry out FFB harvesting based on the minimum ripeness criterion, which usually comprising 1-5 detached fruit per FFB. The current method of FFB human grading which is based on the following parameters: 1) bunch ripeness, 2) bunch abnormality, 3) bunch weight, 4) bunch contamination and 5) number of detached fruit, is prone to errors and inconsistencies. It is therefore desirable to implement a better harvesting and grading assessment practices while reducing the number of labor needed by introducing a sensory system that will quantify the FFB ripening stages, oil content and quality in a more effective way.

1.3 Research objectives

1. To quantify the relationship between palm oil quality and fluorescence-sensed anthocyanin and flavonol contents across different palm age groups.
2. To quantify the relationship between palm oil yield and fluorescence-sensed anthocyanin and flavonol contents across different palm age groups.
3. To identify the best-fitted model and validate the spatial distribution of palm oil quality, yield and fluorescence-sensed anthocyanin and flavonol contents across different palm age groups.

1.4 Significance of study

Fluorescence sensing can provide an alternative to the current practice of FFB assessment and grading, which is tedious, costly and based on destructive methods. Assessment and grading of FFB in real-time will reduce the time load for field operation and can potentially increase the efficiency of assessment, which can affect the quality of oil content in FFB. The quality of oil in FFBs that are delayed in processing after harvest usually decrease due to build-up of free fatty acids. FFB assessment and grading via fluorescence sensing can produce consistency, as compared to the standard manual approach of using human eyes. Importantly, fluorescence sensing provides a non-destructive means to measure oil yield and quality, which is more practical than the current destructive method of palm oil quality determination via Deterioration of Bleachability Index (DOBI) and palm oil yield via Oil Extraction Rate (OER). DOBI and OER assessments are commonly conducted using standard laboratory procedures which are costly and time-consuming.

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