UNIVERSITI PUTRA MALAYSIA

FREQUENCY VARIATION IN NON-DESTRUCTIVE MEASUREMENT OF IMPEDANCE OF OIL PALM FRUITS FOR MOISTURE AND OIL CONTENT DETERMINATION

NUR FIZURA BT CHIN @ HASHIM

FREQUENCY VARIATION IN NON-DESTRUCTIVE MEASUREMENT OF IMPEDANCE OF OIL PALM FRUITS FOR MOISTURE AND OIL CONTENT DETERMINATION

By

NUR FIZURA BT CHIN @ HASHIM

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

April 2016

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the Degree of Master of Science

FREQUENCY VARIATION IN NON-DESTRUCTIVE MEASUREMENT OF IMPEDANCE OF OIL PALM FRUITS FOR MOISTURE AND OIL CONTENT DETERMINATION

By

NUR FIZURA BT CHIN @ HASHIM

April 2016

Chairman: Samsuzana Abd Aziz, PhD
Faculty: Engineering

Moisture and oil content are important elements in oil palm fruits quality monitoring during ripening process. Conventionally, moisture and oil content were determined by oven dried and Soxhlet extraction methods, respectively. However, both of these methods are commonly time consuming, laborious and tedious. In this study, impedance spectroscopy technique was introduced to measure moisture and oil content of oil palm fruits. A total of 90 fruits sample from 12 weeks after anthesis (WAA), 16 WAA and 20 WAA at different maturity stages were tested. Fruits sample was divided into two sets which were 60 fruits for testing and another 30 fruits for validation. A pair of an electrocardiogram (ECG) electrodes were attached to the Kelvin clip leads (16089E, Agilent Technologies, Japan) which was connected to a LCR meter (4263B, Agilent Technologies, Japan) at four discrete frequencies of 1 kHz, 10 kHz, 20 kHz and 100 kHz to measure impedance value of each oil palm fruits. Statistical analysis showed that impedance value change with different maturity stages and it was observed that high maturity stage (20 WAA) showed the highest impedance value due to the less moisture and high oil content inside the fruits. A good correlation was found at frequency of 100 kHz which has the highest regression coefficient (R^2) and lowest root mean square error (RMSE) for moisture and oil content prediction. For moisture content prediction, a linear regression equation of $y_{100} = -17.85x + 79.08$ was develop with R^2 of 0.77 and RMSE of 5.85% while for oil content prediction, another linear regression equation of $y_{100} = 16.07x + 23.65$ was develop with R^2 of 0.72 and RMSE of 5.71%. These results indicated that non-destructive measurement of impedance has good potential to determine moisture and oil content of oil palm fruits.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

KEPELBAGAIAN FREKUENSI DALAM PENGUKURAN IMPEDANS TANPA MEROSAKKAN BUAH KELAPA SAWIT UNTUK PENENTUAN KELEMBAPAN DAN KANDUNGAN MINYAK

Oleh

NUR FIZURA CHIN @ HASHIM

April 2016

Pengerusi: Samsuzana Abd Aziz, PhD
Fakulti: Kejuruteraan

Kelembapan dan kandungan minyak merupakan element yang penting dalam memantau kualiti buah kelapa sawit semasa proses buah masak. Kebiasaannya, kelembapan dan kandungan minyak ditentukan melalui kaedah pengeringan oven dan pengekstrakan Soxhlet, masing-masing. Walaubagaimanapun, kedua-dua kaedah ini kebiasaanya mengambil masa, susah dan membosankan. Dalam kajian ini , teknik spektroskopi impedans telah diperkenalkan untuk mengukur kelembapan dan kandungan minyak buah kelapa sawit. Sebanyak 90 sampel buah dari 12 minggu selepas berbunga (WAA), 16 WAA dan 20 WAA pada peringkat kematangan yang berbeza telah diuji. Sampel buah telah dibahagikan kepada dua set iaitu 60 buah untuk ujian dan 30 buah untuk pengesahan. Sepasang elektrokardiogram (ECG) elektrod yang diletakkan kepada klip Kelvin (16089E, Agilent Technologies, Jepun) yang telah disambungkan kepada meter LCR (4263B, Agilent Technologies, Jepun) di empat frekuensi diskret 1 kHz, 10 kHz, 20 kHz dan 100 kHz untuk mengukur nilai impedans setiap buah kelapa sawit. Analisis statistik menunjukkan bahawa perubahan nilai impedans dengan peringkat kematangan yang berbeza dan ia telah diperhatikan bahawa pada peringkat kematangan yang tinggi (20 WAA) menunjukkan nilai impedans tertinggi kerana kelembapan kurang dan kandungan minyak yang tinggi di dalam buah. Persamaan terbaik ditemui pada frekuensi 100 kHz yang mempunyai pekali regresi tertinggi (R^2) dan akar min ralat kuasa (RMSE) untuk pengukuran kelembapan dan kandungan minyak. Untuk mengukur kelembapan, persamaan regresi linear Y_{100} = -17.85x + 79.08 telah dibangunkan dengan R^2 sebanyak 0.77 dan RMSE sebanyak 5.85% manakala untuk mengukur kandungan kandungan minyak, satu lagi persamaan regresi linear Y_{100} = 16.07x + 23.65 telah dibangunkan dengan R^2 sebanyak 0.72 dan RMSE sebanyak 5.71%. Keputusan ini menunjukkan bahawa ukuran impedans tanpa merosakkan buah kelapa sawit mempunyai potensi yang baik untuk menentukan kelembapan dan kandungan minyak buah kelapa sawit.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. Praised and greet upon Prophet Muhammad s.a.w., his family and friends. Alhamdulillah, I am grateful to Almighty Allah S.W.T for giving me strength to complete this study and thesis.

Special appreciation goes to my supervisor, Dr. Samsuzana Abd Aziz, for her good advices, consistent guidance and full encouragement that I have received during the study that lead to the success of this research study. Not forgotten, to my co-supervisor, Associate Professor Dr. Abdul Rashid Mohamed Shariff for support and guidance regarding this topic.

I am thankful to all the staff and technicians of Department of Biological and Agriculture Engineering, Faculty of Engineering, Universiti Putra Malaysia for their help and technical assistant.

To my loving parents, Chin @ Hashim Ahmad and Hasnah Hussain who have always understand, motivate and encourage me to complete my study. I would like to express my fully appreciation from deep of my heart to them.

Last but not least, to research group members; Diyana Jamaludin, Alfadhl Yahya Khaled Al-khaled, Nur Ul Atikah Ibrahim, Munirah Hayati Hamidon and Ng Jing Lin for their kind supporting, cooperation and valuable advice. May Allah bless all of us. Amin.

I certify that a Thesis Examination Committee has met on 11 April 2016 to conduct the final examination of Nur Fizura binti Chin@Hashim on her thesis entitled "Frequency Variation in Non-Destructive Measurement of Impedance of Oil Palm Fruits for Moisture and Oil Content Determination." 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.

Members of the Thesis Examination Committee were as follows:

Rimfiel bin Janius, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Khairunniza binti Bejo, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ibni Hajar bin Haji Rukunidin, PhD
Professor Ir.
School of Bioprocess Engineering
Universiti Malaysia Perlis
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 July 2016

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

Samsuzana Abd Aziz, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdul Rashid Mohamed Shariff, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of the thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ____________________________ Date: ________________________

Name and Matric No.: Nur Fizura binti Chin@Hashim (GS30860)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee:
Samsuzana Abd Aziz, PhD

Signature: ______________________________
Name of Member of Supervisory Committee:
Abdul Rashid Mohamed Shariff, PhD

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MPOB	Malaysia Palm Oil Board
CPO	crude palm oil
PKO	palm kernel oil
FFB	fresh fruit bunch
OER	oil extraction rate
TRI	toxic release inventory
NIR	near infrared
FTIR	fourier transform infrared
NMR	nuclear magnetic resonance
VIR	visible near infrared
VNA	vector network analyzer
UPM	Universiti Putra Malaysia
PORIM	Palm Oil Research Institute of Malaysia
FRIM	Forest Research Institute Malaysia
WAA	weeks after anthesis
FFA	free fatty acid
PV	peroxide value
AC	alternating current
ECG	electrocardiogram
RGB	red, green and blue
O/M	oil/mesocarp
M/M	moisture/mesocarp
O/B	oil to bunch
O/WM	oil to wet mesocarp
O/DM	oil to dry mesocarp
TD-NMR	time domain nuclear magnetic resonance
DOBI	deterioration of bleacheability index DOBI

LIST OF NOMENCLATURES

ε	complex permittivity
ε’	dielectric constant
ε”	dielectric loss factor
m_1	weight of fresh mesocarp
m_2	weight of dry mesocarp
wb	wet basis
t/ha	tonne per hectare
r	correlation coefficient
R^2	regression coefficient

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The oil palm also known as *Elaeis guineensis* is a major plantation crop in Malaysia since 1960, with 54,000 hectares of planted on that year. Since then, the planted area has increased rapidly in every 5-year period beginning from 1965 until 1980 spurred by the government policy on crop diversification programme (MPOB, 2002). By 2014, the oil palm planted area has increased to 5.39 million hectares; more than two-third of Malaysia's agricultural land (MPOB, 2015). The increment is attributed to an increase in the demand of vegetable oil, both in the local and international markets.

Crude palm oil (CPO) and palm kernel oil (PKO) are produced from oil palm fresh fruit bunches (FFB) by extracting the oil from the mesocarp and kernel respectively. CPO is a primary product of oil palm FFB as it contains high nutritional value and being commercialized as edible vegetable oil for frying while PKO is a secondary product from palm oil kernel mainly used for soap manufacturing and other downstream products.

The optimum oil extraction rate (OER) and oil quality are of major concerns of the oil processing industry for a maximum profit. On the average, 3.51 tonnes of CPO is produced per hectare (t/ha) per year corresponding to an OER of 20.25 % as recorded by MPOB in 2013. In 2014, the oil yield of CPO has increased to 3.56 t/ha per year with an OER of 20.60 %; attributed to better technology used by the industry. As one of the main CPO exporters, Malaysian palm oil industry targets to increase the OER from the palm oil fruits to 23 % by 2020 to boost oil production. This is to be achieved through certification of mills and adherence to grading of fruits as part of ensuring only high quality and ripe FFB with optimum oil content are accepted and processed at all mills. Ripe FFB produces the highest oil content with high quality compared to under-ripe and over-ripe FFB grades. FFB grading and oil content prediction are usually closely related and therefore a very important protocol to be established during the palm oil processing.

The current grading of FFB practice by the local mills is through the use of human vision based on colour of oil palm fruits or by counting detached fruits from FFB (MPOB, 2003). The manual grading process is laborious and tedious or prone to error due to human subjectivity. The oil content measurement in FFB, on the other hand, is carried out by the mill through the conventional laboratory analysis using Soxhlet extraction technique. However, this procedure is laborious, time consuming and require skilled operators. The method is also not environmental friendly as it uses the highly volatile n-hexane as a solvent material. Furthermore, the n-hexane was listed as US toxic release inventory

(TRI) since 1994 under National Safety Council, USA, 2007 (Junaidah *et al*., 2011).

Recent advancement in technology leads to the wide use of sensing technique for FFB grading and oil measurement in oil palm mill. The more popular methods are image processing and various spectroscopy techniques such as Near-Infrared Spectroscopy (NIR), Fourier Transform Infrared Spectroscopy (FTIR) and Nuclear Magnetic Resonance Spectroscopy (NMR). Image processing, NIR and FTIR sensing systems have their own limitations as the performance is affected by the conditions of the surrounding environment such as inconsistent of light source, humidity, temperature and the conditions of oil palm FFB (Razali et al., 2008; Ishak and Razali, 2010). Junaidah *et al.* (2011) developed an alternative method to measure oil content using NMR technique instead of the laborious Soxhlet extraction method. This technique avoids the use of n-hexane which is harmful to the operator and the environment. In addition, 18 % of the work process was reduced under NMR technique and oil content measurement was found to be comparable with Soxhlet extraction method. Although NMR method had reduced the processing work, it is expensive and require skilled operator.

In this study, dielectric spectroscopy technique also known as impedance spectroscopy was introduced to measure oil content in oil palm fruits. Many researchers used this technique to monitor various agricultural product and food materials such as fruits, vegetables, edible oils and others (Nelson, 2004; Nelson and Trabelsi, 2008; Lizhi, *et al*., 2008). In oil palm fruits, Abbas *et al.* (2005) indirectly determine the moisture content of the fruits by using micro-strip probe while You *et al.* (2010) used a fabricated open-ended coaxial probe to measure dielectric properties of oil palm fruits. However both procedures were destructive where fruits sample were needed to be sliced during the measurements. With the lack of non-destructive method for moisture and oil content measurement in oil palm fruits, further study is therefore needed on a non-destructive method to improve the measurement.

1.2 Research Objectives

The general objective of this study was to investigate the potential of using impedance spectroscopy technique for moisture and oil content measurement in oil palm fruits. In order to accomplish this goal, the following objectives were set:

i. to investigate the variation of impedance measurements at four discrete frequency levels (1 kHz, 10 kHz, 20 kHz and 100 kHz) at different WAA, moisture and oil content of oil palm fruits,
ii. to study the correlation between impedance measurements with moisture and oil content in oil palm fruits, and
iii. to develop a prediction equation of moisture and oil content in oil palm fruits using impedance measurements.

1.3 Scope and Limitations

This research was carried out at a specific conditions and criteria. The following are the research scope:

i. One type of oil palm variety, namely the *tenera* variety was tested in this research.
ii. All the fruits sample used in this study were randomly selected from oil palm bunches from oil palm plantation in Universiti Putra Malaysia (UPM) at different maturity stages.
iii. Only unbruised fruits with a diameter size in range between 20.5 mm to 21.5 mm were chosen during the experiment to reduce error during measurement.
iv. Data collection was carried out using a LCR meter (Inductance, L; Capacitance, C; and Resistance, R) at four discrete frequency levels (1 kHz, 10 kHz, 20 kHz and 100 kHz) in a room temperature. The highest frequency available for this LCR meter is at 100 kHz.

REFERENCES

Ariffin, A., Mat, S. R., Banjari, M., & Wan, O. W. E. (1990). Morphological Changes of The Cellular Component of The Developing Palm Fruit (*Tenera: Elaeis guineensis*), in PORIM, (21) (pp. 30–34).

Aziz, A. A. (1984). The Biochemical Aspects of Ripeness Standards. *Proceedings of the Symposium on Impact of the Pollinating Weevil on the Malaysian Oil Palm Industry, Kuala Lumpur, Malaysia*, (pp. 165-176).

Balasundram, S. K., Robert, P. C. & Mulla, D. J. (2006). Relationship between oil content and fruit surface color in oil palm Elaeis guineensis. Jacq. *Journal of Plant Sciences,* 1(3): 217-227.

Basri, M.W., Akmar, S.N.A. and Henson, I.E. (2004). Oil palm- Achievements and potential. Paper presented at *The Proceeding of the 4th International Crop Science Congress, Brisbane, Australia*. 26 Sept. – 1 Oct.

Bean, R. C., Rasor, J. P. & Porter G. G. (1960). Changes in electrical characteristics of avocados during ripening. *California Avocardo Society*, 44: 75-78.

Benavente, J., Ramos-Barrado, J. R. & Heredia, A. (1998). A study of the electrical behaviour of isolated tomato cuticular membranes and cutin by impedance spectroscopy measurements. *Colloids Surfaces A: Physicochem. Eng. Aspects,* 140: 333-338.

Blaak, G., L. D. Sparnaaij and T. Menendez. (1963). Breeding and inheritance in oil palm, Part 11. Methods of Bunch Analysis. *J. W. Afr. Inst. Oil Pal*, 4: 146-156.

Breure, C.J. (2006). Performance of ASD's oil palm parent material in South Sumatra Periodical. *Performance of ASD's oil palm parent material in South Sumatra.*

Cole, K.S. (1972). Membranes, Ions and Impulses*. A Chapter of Classical Biophysics. University of California Press, Berkeley, CA.*

Cozzolino, D. (2011). Infrared method for high throughput screening of metabolites: Food and medical applications*. Comb. Camp. High Throughput Screening,* 14: 125-131.

Crombie, W. M. (1956). Changes in fatty acid composition of flax and safflower seed oils. *Journal of Botany,* 7: 181-193.

Dunlap, F. G., White, P. J., Pollak, L. M., & Brumm, T. J., (1995). Fatty acid composition of oil from adapted, elite corn breeding materials. *J. Am. Oil Chem. Soc*. 72: 981–987.

Eads, T. M., & Croasmun, W. R. (1988). *J. Am. Oil Chem. Soc*. 65: 78-83.

Engel, R., Long, D., & Carlson, G., (1997). On-the-go grain protein sensing. Better Crops with Plant Food , 81: 20–23.

Esnan, A. G., Zakaria, Z. Z. & Wahid, M. B. (2004). Perusahaan sawit di Malaysia- Satu panduan (A guide- oil palm industry). Millenium (Ed.) Selangor: Malaysia Palm Oil Board (MPOB).

Fassio, A. S., Restaino, E. A. & Cozzolino, D. (2014). Determination of oil content in whole corn (*Zea mays* L.) seeds by means of near infrared reflectance spectroscopy. *Journal of Computer and Electronics in Agriculture*, 110: 171-175.

Fatin, S. A., Rosnah, S. & Robiah, Y. (2014). The effect of storage time of chopped oil palm fruit bunches on palm oil quality. *Procedia Agriculture and Agricultural Science,* 165-172.

Gambhir, P. N., (1992). Application of low-resolution pulsed NMR to the determination of oil and moisture in oilseeds. *Trends Food Sci. Technol*. 3: 191–196.

Harker, F. R. & Maindonald, J. H., (1994). Ripening of nectarine fruit: changes in the cell wall, vacuole, and membranes detected using electrical impedance measurements. *Journal of Plant Physiology*, 106: 165-171.

Harker, F. R., Dunlop, J. (1994). Electrical impedance studies of nectarines during cool storage and fruit ripening. *Journal of Postharvest Biology Technology,* 4: 125–134.

Hartley, C. W. S. (1977). *The Oil Palm*. 2nd edn. Longman, New York, pp.67-69, 696-703.

Hartley, C.W.S (1967). *The Oil Palm*. 2nd Edition, Longman Group Limited, New York, pp. 67-69, 696-703.

Hippel, A. V. (1954). Dielectrics materials and applications. *Technology Press, USA*.

Huang, H., Yu, H., Xu, H. & Ying, Y. (2008). Near infrared spectroscopy for on/in-line monitoring of quality in foods and beverages: A review. *Journal of Food Engineering*, 87: 303-313.

Hudzari, M. R, Ishak, W. W. I., Ramli, A. R., Sulaiman, N. & Harun, H. (2011). Prediction model for estimating optimum harvesting time of oil palm fresh fruit bunches, 9 October, 0-5.

Inaba, A., Manabe, T., Tsuji, H., & Iwamoto, T., (1995). Electrical impedance analysis of tissue properties associated with ethylene induction by electric currents in cucumber (*Cucumissatius* L.) fruit. *Journal of Plant Physiology,* 107: 199–205.

Ishak, W. W. I., & Hudzari, R. M. (2010). Image based modelling for oil palm fruit maturity prediction. *Journal of Food, Agriculture and Environment* 8(2): 469-476.

Jamaludin, D., Aziz, S. A., & Ibrahim, N. U. A. (2014). Dielectric based sensing system for banana ripeness assessment. *International Journal of Environmental Science and Development,* 5 (3): 286-289.

Juansah, J., Budiastra, I. W. & Dahlan, K. (2002). The prospect of electrical impedance spectroscopy as non-desructive evaluation of citrus fruit acidity. *International Journal of Emerging Technology and Advanced Engineering,* 2 (11): 58-64.

Junaidah J., Kushairi, A., Jones, B., Kho, L. E., Isa, Z. A. & Rusmin, J. (2011). Innovation for oil extraction method using NMR in bunch analysis. *Proceeding of International Seminar on Breeding for Sustainability in Oil Palm 2011, Kuala Lumpur, Malaysia*.

Kawano, S., Fujiwara, T., & Iwamoto, M. (1993). Nondestructive determination of sugar content in satsuma mandarin using near infrared (NIR) transmittance. *Journal of the Japanese Society for Horticultural Science,* 62: 465–470.

Kawano, S., Watanabe, H., & Iwamoto, M. (1992). Determination of sugar content in intact peaches by near infrared spectroscopy with fiber optics in interactance mode. *Journal of the Japanese Society for Horticultural Science* 61: 445–451.

Khalid, K. & Abbas, Z. (1992). A microstrip sensor for determination of harvesting time for oil palm fruits *(Tenera: Elaise Guineesis), Journal of Microwave Power Electromagnetic Energy*, 27 (1): 3-10.

Kotyka, John J., Pagela, Marty D., Deppermannb, Kevin L., Collettib, Ronald F., Hoffmanc, Norman G., Yannakakisb, Elias J., Dasb, Pradip K., Ackermand, Joseph, J.H., (2005). High-throughput determination of oil content in corn kernels using nuclear magnetic resonance imaging. *Journal of American Oil Chemist Society*, 82.

Lewis, G. S., Aizinbud, E., & Lehrer, A. R. (1989). Changes in electrical resistance of vulvar tissue in Holstein cows during ovarian cycles and after treatment with prostaglandin $F_{2\alpha}$. *Journal of Animal Reproduction Science,* 18(1): 183-197.

Lim, C. C, Teow, K. W., Rao, V. & Chia, C. C. (2003). Performances of some pisifera of Binga, Ekona, Urt and Angolan origins: Breeding background and fruit bunch traits. *Journal of Oil Palm Res.* 15(1): 21-31.

Lizhi, H., Toyoda, K., & Ihara, I. (2008). Dielectric properties of edible oils and fatty acids as a function of frequency, temperature, moisture and composition. *Journal of Food Engineering*, *88*(2): 151–158.

Mahfoozur, R., Basem, A. J. A., Abu, I., Abdullah, M. Z. & Rizal, M. A. (2011). Assessment of quality of fruits using impedance spectroscopy. *International Journal of Food Science and Technology*, 46: 1303-1309.

Makkay, M. & Soni, P. (2013). In situ quality assessment of intact oil palm fresh fruit bunches using rapid portable non-contact and non-destructive approach. *Journal of Food Engineering,* 120: 248-259.

Montes, J. M., Melchinger, A. E., Reif, J. C. (2007). Novel throughput pheno typing platforms in plant genetic studies. *Journal of Trends Plant Science*, 12: 433–436.

Montes, J. M., Technow, F., Dhillon, B. S., Mauch, F., & Melchinger, A. E. (2011). High throughput non-destructive biomass determination during early plant development in maize under field conditions. *Field Crops Res.* 121: 268–273.

MPOB, *A Malaysian Weekly Report of Palm Oil Production* (2002). Malaysian Palm Oil Board: Kuala Lumpur, Malaysia.

Nelson, S. O. (2004). *Dielectric spectroscopy of fresh fruit and vegetable tissues*. Paper presented at ASABE Annual International Meeting. Ontario, Canada. 4 August 2004.

Nelson, S. O. & Trabelsi, S. (2008). *Dielectric spectroscopy measurements on fruit, meat, and cereal product.* Paper presented at ASABE Annual International Meeting. Rhode Island Convention Centre Providence. 29 June-2 July 2008.

Oo, K. C., Teh, S. K., Khor, H. T. & Ong, A. S. H. (1985). Fatty acid synthesis in the oil palm (Elaeis guineensis): *Incorporation of Acetate by Tissue Slices of The Developing Fruit. Lipids* 20:205-210

PORIM (1995). *PORIM Test Method: Methods of Test for Palm Oil and Palm Oil Production*. Kuala Lumpur: Palm Oil Research Institute of Malaysia Publisher.

Prieto, N., Andre´s, S., Gira´ldez, F.J., Manteco´n, A.R., & Lavı´n, P. (2006). Potential use of near infrared reflectance spectroscopy (NIRS) for the estimation of chemical composition of oxen meat samples. *Meat Science,* 74: 487–496.

Rao, M. A., S.S.S, R., & A.K., D. (2005). Engineering properties of food (3rd edition). Taylor and Francis Group.

Razali, M. H., Ismail, W. I. W., Ramli, A. R., & Sulaiman, M. N. (2008). Modelling of oil palm fruits maturity for development of outdoor vision system. *International Journal of Food Engineering*, 4(3):

Sambanthamurthi, R., Tan, Y. A. & Chang, K. C. (1998). Proceedings of the National Seminar on Opportunities for Maximizing Production through Better OER and Offshore Investment in Palm Oil, 14-15 December 1998, Bangi, Selangor, Malaysia, (pp. 199-207).

Scotter, C. N. G. (1997). Non-destructive spectroscopic techniques for the measurement of food quality. *Trends in Food Science & Technology*, *8*(9): 285–292.

Settle, R. G., Foster, K. R., Epstein, B. R., & Mullen, J. L. (1980). Nutritional assessment: whole body impedance and body fluid compartments. *Nutr. Cancer,* 2: 72–80.

Smyth, H., & Cozzolino, D. (2013). Instrumental methods (spectroscopy, electronic nose and tongue) as tools to predict taste and aroma in beverages: advantages and limitations. *Chem. Rev*. 113: 1429–1440.

Tan, C. H., Hasanah, M. G., Ainie, K., Chin-Ping, T., & Abdul, A. A. (2009). Extraction and physicochemical properties of low free fatty acid crude palm oil. *Journal of Food Chemistry*, 113: 645–650.

Teo, K. W., Rao, V., Chia, C. C & Lim, C. C (2004). Performances of some pisiferas of Binga, Ekona, Urt and Angolan origins: Part2 –Fruit bunch yields, vegetative growth and physiological traits. *Journal of Oil Palm Res.* 16(1): 22-38.

Thomas, R. L., Sew, P., Mok, C. K., Chan, K. W., Easau, P. T. & Ng, S. C. (1971). Fruit ripening in the oil palm *Elaeis guineensis. Ann. Bot.,* 35: 1219-1225.

Uddin, M., Ishizaki, S., Okazaki, E., & Tanaka, M. (2002). Near-infrared reflectance spectroscopy for determining end-point temperature of heated fish and shellfish meats. *Journal of the Science of Food and Agriculture,* 82(3): 286–292.

Valous, N. A., Mendoza, F., & Sun, D. W. (2010). Emerging noncontact imaging, spectroscopic and colorimetric technologies for quality evaluation and control of hams: a review. *Trends in Food Science & Technology*, 21: 26-43.

Vozary, E. & Benko, P., (2010). Non-destructive determination of impedance spectrum of fruit flesh under the skin. *Journal of Physics: Conference Series 224.*

Wu, L., Ogawa, Y., & Tagawa, A. (2008). Electrical impedance spectroscopy analysis of eggplant pulp and effects of drying and freezing–thawing treatments on its impedance characteristics. *Journal of Food Engineering*, 87(2): 274-280.

Wun, S. J., Hunisom, A., & Abbas, Z. (2015). Dielectric properties of oil palm trunk core. *Journal of Clean Energy Technologies*, 3(6): 422-427.

Yildiz, G., Wehling, R. L., & Cuppett, S. L. (2001). Method for determining oxidation of vegetable oils by near-infrared spectroscopy. *Journal of the American Oil Chemists Society,* 78(5): 495–502.

You, K. Y., Abbas, Z., & Khalid, K. (2010). Application of microwave moisture sensor for determination of oil palm fruit ripeness. *Measurement Science Review*, 10(1): 7-14.

Zeaiter, M., Roger, J. M., & Bellon-Maurel, V. (2006). Dynamic orthogonal projection. A new method to maintain the on-line robustness of multivariate calibrations. Application to NIR-based monitoring of wine fermentations. *Chemometrics and Intelligent Laboratory Systems,* 80: 227–235.