PREDICTION OF FREE FATTY ACID IN CRUDE PALM OIL USING NEAR INFRARED SPECTROSCOPY

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Dedicated to all readers. Especially you.

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ABSTRACT

Free Fatty Acid (FFA) value is widely used as an indicator for crude palm oil (CPO) quality. However, current methods used to measure FFA value are quite time consuming and complex. The application of near infrared (NIR) spectroscopy has drawn the interest to replace the conventional methods to measure FFA value as NIR has been shown to be effective in other food and agriculture industries. At the same time, improved predictive models have facilitated FFA estimation process in recent years. In this research, 176 CPO samples acquired from Felda Johor Bulker Sdn Bhd were investigated. A FOSS NIRSystem was used to take absorbance measurements from these samples. The wavelength range for the spectral measurement is taken at 1600nm to 1900nm. FFA content of each sample was determined by chemical titration method and three prediction models were developed relating FFA value to spectral measurement. The first prediction model based on Partial Least Square Regression (PLSR) yielded a regression coefficient (R) of 0.9808 and 0.9684 for the calibration and validation set respectively. The second prediction model built from Principal Component Regression yielded an R of 0.8454 and 0.8039 for the calibration and validation set respectively. The third prediction model built from Artificial Neural Network (ANN) yielded R of 0.9999 and 0.9888 for the calibration and validation set respectively. Results show that the NIR spectroscopy in a spectral region of 1600nm to 1900nm is suitable and adequate for FFA measurement of CPO and that the accuracy of prediction is high. Results shows that the prediction model using ANN gives the best prediction model of all three models tested.

ABSTRAK

Nilai Asid Lemak Bebas (FFA) telah digunakan secara menyeluruh sebagai kayu ukur kualiti minyak sawit mentah (CPO). Walau bagaimanapun, kaedah-kaedah sedia ada untuk mengukur nilai FFA mengambil masa yang agak lama dan rumit. Penggunaan spektroskopi infra-merah (NIR) telah menarik minat kajian ini bagi menggantikan kaedah sedia ada untuk mengukur FFA kerana keberkesanan kaedah tersebut dalam bidang makanan dan agrikultur. Pada masa yang sama, perkembangan model ramalan telah banyak membantu dalam proses anggaran FFA pada tahun-tahun kebelakangan ini. Dalam kajian ini, sebanyak 176 sampel CPO diperoleh daripada Felda Johor Bulkers Sdn Bhd untuk tujuan penyelidikan. FOSS NIRSystem telah digunakan untuk mengambil bacaaan serapan gelombang daripada sampel. Julat panjang gelombang bagi bacaan tersebut diambil daripada 1600nm sehingga 1900nm. Kandungan FFA yang terdapat dalam setiap sampel ditentukan dengan menggunakan kaedah penitratan kimia dan tiga model ramalan dibentuk bagi meramal kandungan FFA daripada gelombang tersebut. Model ramalan pertama menggunakan Regresi Kuasa Dua Terkecil Separa (PLSR) menghasilkan ralat umum ramalan (R) sebanyak 0.9808 dan 0.9684 bagi kumpulan data untuk latihan dan percubaan masing-masing. Model ramalan kedua pula mengunakan Regresi Komponen Utama (PCR) menghasilkan R sebanyak 0.8454 dan 0.8039 bagi kumpulan data untuk latihan dan percubaan masing-masing. Model ramalan ketiga menggunakan Jaringan Saraf Buatan (ANN) menghasilkan R sebanyak 0.9999 dan 0.9888 bagi kumpulan data untuk latihan dan percubaan masing-masing. Dapatan ini menunjukkan bahawa julat gelombang 1600nm hingga 1900nm adalah sesuai dan memadai bagi mengukur nilai FFA yang terkandung dalam minyak sawit mentah dengan nilai ramalan yang tinggi. Keputusan menunjukkan bahawa model ramalan menggunakan ANN adalah model ramalan terbaik di antara ketiga-tiga model yang dikaji.

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LIST OF ABBREVIATION

ANN	-	Artificial Neural Network
CPO	-	Crude Palm Oil
FFA	-	Free Fatty Acid
PCR	-	Principal Component Regression
PLSR	-	Partial Least Square Regression
RMSE	-	Root Mean Square Error
SD	-	Standard Deviation
SG	-	Savitzky-Golay
SVD	-	Singular Value Decomposition

LIST OF SYMBOLS

N	-	Normality of NaOH
V	-	Volume of sample
W	-	Weight of sample
Y	-	Dependent variables (Responses)
X	-	Independent variables (Predictors)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Palm oil has been a major source of edible oil that is safe and nutritious for humans since thousands years ago. Palm oil yields per hectare the most compare to other oil crops like rapeseed oil, groundnut oil, sunflower oil and soya bean oil [1]. Palm oil is used around the world as cooking oil and as an ingredient in margarine and shortening. This oil is also included in the mixture of fats and used in the manufacturing of various products including cosmetics.

1.1.1 Palm Oil Industry in Malaysia

The palm oil industry is a very vital industry which contributes tremendously towards the Malaysian economy. In May 2014, Malaysia's Palm Oil Board (MPOB) reported that, Malaysia had produced more than 7 million tonnes of raw oil or most known as crude palm oil (CPO) [2]. This amount is about 1 million tonnes more than what was produced in 2013. In the near future, Malaysia aims to produced 26-35 tonnes per hectare from the current production of 20.2 tonnes per hectare [2].

The rapid growth in palm oil production is a valuable asset for our country. Malaysia's production of CPO and other palm oil based products is well known all over the world. In fact, Malaysia is the second world exporter after Indonesia [3-4].

1.1.2 Quality Assessment in Palm Oil Industry

High quality palm oil gives finer product. Therefore, it is important for the palm oil industry to produce high quality palm oil. However, producing a high quality palm oil requires it to be checked through several meticulous stages. With a lot of parameters to be checked and conventional method used, palm oil quality assessment can be a very time consuming procedure to be conducted.

How to assess the quality of palm oil for trading purpose? In daily life, as for most fruits, before buyers were about to buy them, they can simply tell the quality by looking at the skin, colour, or smell. However, it is quite troublesome to determine the oil palm condition only with physical observation alone. Despite the various stages of oil refining, good quality oil can only be processed from a good quality oil palm fruit. However, grading oil palm fruit is not an overnight and simple job. Traditionally, fruit pickers will depend on the fruit skin, colour or smell to determine the ripeness, even though it is not an accurate way to determine the quality of the fruit.

Therefore, another way of assessment is needed in order to tell the quality of palm oil. For crude palm oil, the quality can be assessed by two ways; physical properties and chemical characteristic. For physical properties, the parameters will be its smoking point, colour and viscosity. While for chemical characteristic, the parameters are iodine value, free fatty acid (FFA) value, peroxide value, dirt portion, moisture content and Deterioration of Bleaching Index (DOBI) (see Appendix A) [5].

For the purpose of this research, FFA value is used as the indicator for palm oil quality. In fact, the FFA value of palm oil is the most essential indicator of quality for selling palm oil especially in export and domestic industrial markets [6].

Besides, the fatty acid value plays a key role to the physiochemical properties therefore this is a useful information for future research [7].

As stated earlier, there are a few stages starting from the extraction process up to trading process that requires palm oil quality to be checked. The first stage is when oil is produce at the extraction mill before it being transported by the tankers. Second stage is when the tankers brought the oil to be stored at the bulkers while the third stage is before the oil being distributed for trading purpose. Figure 1.1 illustrates the stages of FFA value determination for the whole flow.

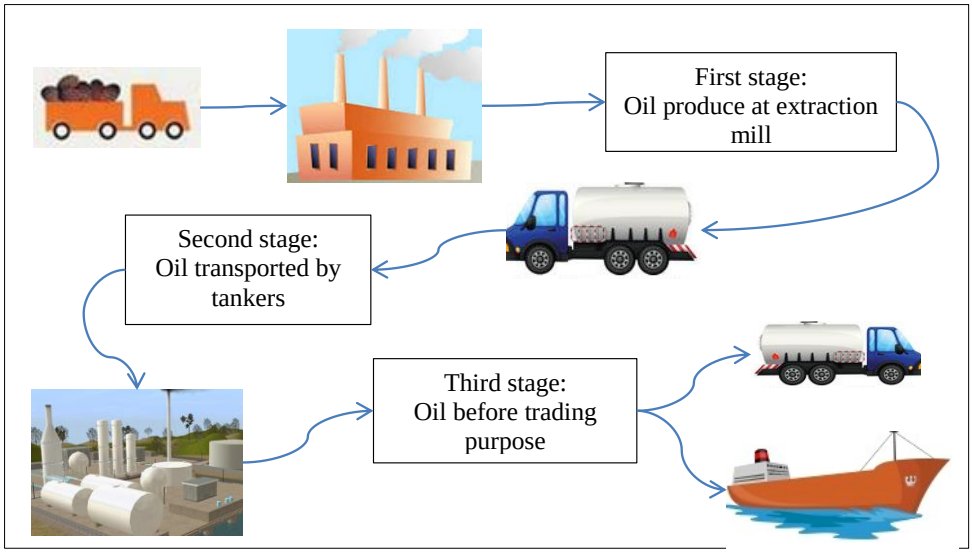

Figure 1.1 Stages for Quality Check Routine in Palm Oil Industry

1.2 Problem Statement

For the time being, most factories are using conventional wet chemical analysis for the FFA determination of palm oil. The method is time consuming [8] and less accurate due to limitations such as human error especially because the assessment is very complicated and only can be done by experts. S. Balasundram *et al.* [9] proposed the use of an automatic system to empower oil yield and/or oil quality mapping to expedite precision oil palm management. Therefore, an

automated-computerized system should be utilized to check for quality of CPO especially FFA.

1.3 Research Objectives

The objectives of this work are:

1. To determine the compatibility of using NIR for non-destructive measurement in predicting FFA value in CPO

2. To develop a prediction system to determine FFA value in CPO by using NIRs spectral data.

1.4 Scope of Study

The scope of this project comprises the following:

a) Using CPO samples throughout the project.

   i. 176 samples were used for this project.

   ii. CPO samples were taken from Felda Johor Bulkers Berhad, Pasir Gudang, Johor.

   iii. Samples were produced between 1st December 2012 and 7th December 2012.

b) Using NIRS absorbance mode to measure the spectrum of the samples.

   i. Wavelength used is from 1600nm to 1900nm only.

c) Consider only one quality parameter to assess which is FFA value.

For sample preparation, both conventional and proposed NIR method will be conducted. Analyses used for modelling prediction system are Partial Least Square (PLS) Regression, Principal Component Regression (PCR) and Artificial Neural Network (ANN) from MATLAB.

1.5 Significant of Study

The accomplishement of this project meet one of the Entry Point Project (EPP) for palm oil industry which is to improve worker's productivity [10]. This is because, by using computational techniques to determine FFA value in CPO, as proposed by this project, the procedure can be done rapidly. On the other hand, the companies can reduce their overdependence on manual labour. This can help them to work faster and increase efficiency in the lab during quality check routine.

1.6 Thesis Outline

The thesis consists of six chapters. Chapter 1 represent a general introduction about palm oil and FFA measurement procedure, the objectives and the scope of work of the research.

Chapter 2 presents the literature review that provides the background of the research reported in this thesis. The review focuses on the research activities in the NIR development in agriculture. This chapter also describes studies pertaining to the successful development and deployment of various applications using NIR spectral data and system regression model which include the linear (PLSR and PCR) and non-linear (ANN) modelling.

Chapter 3 describes the theoretical background on topics related to FFA, definition of chemical composition of FFA in relation to NIR capability,

understanding on linear and non-linear prediction theories, description of system modelling and finally recommended validation model to be used.

Chapter 4 discusses the data collection processes in this research. This is followed by the analysis of the obtained data. The design of the system identification models are described as well.

Chapter 5 describes the analysis of the result on models using linear and non-linear regression technique to determine the FFA value of CPO. These models is evaluated and validated through the analysis of the performance indicators applied in previous research.

Finally, Chapter 6 discusses the overall conclusion and includes some recommendations for future work.

REFERENCES

[1] S. Yusoff And S. B. Hansen, "Lca Case Studies Feasibility Study Of Performing An Life Cycle Assessment On Crude Palm Oil Production In Malaysia," *Int. J. Life Cycle Assess.*, Vol. 12, No. 1, Pp. 50–58, 2007.

[2] "Official Portal Of Malaysian Palm Oil Board," 2014. [Online]. Available: Http://Www.Mpob.Gov.My/.

[3] H. Stichnothe And F. Schuchardt, "Life Cycle Assessment Of Two Palm Oil Production Systems," *Biomass And Bioenergy*, Vol. 35, No. 9, Pp. 3976–3984, Oct. 2011.

[4] F. Sulaiman, N. Abdullah, H. Gerhauser, And A. Shariff, "An Outlook Of Malaysian Energy, Oil Palm Industry And Its Utilization Of Wastes As Useful Resources," *Biomass And Bioenergy*, Vol. 35. Pp. 3775–3786, 2011.

[5] "Poram – Palm Oil Refiners Association Of Malaysia," 2014. [Online]. Available: Http://Poram.Org.My/.

[6] E. Kardash And Y. I. Tur, "Acid Value Determination In Vegetable Oils By Indirect Titration In Aqueous-Alcohol Media," *Croat. Chem. Acta*, Vol. 78, No. 1, Pp. 99–103, 2005.

[7] E. Dauqan And H. Sani, "Fatty Acids Composition Of Four Different Vegetable Oils (Red Palm Olein, Palm Olein, Corn Oil And Coconut Oil) By Gas Chromatography," In *International Conference On Chemistry Engineering*, 2011, Vol. 14, Pp. 31–34.

[8] S. Abdullah And E. C. Tiong, "Prediction Of Palm Oil Properties Using Artificial Neural Network," *Int. J. Comput. Sci. Netw. Secur.*, Vol. 8, No. 8, Pp. 101–106, 2008.

[9] S. K. Balasundram, M. H. Ahmad Husni, And A. R. Anuar, "A Computerized Digital Imaging Technique To Estimate Palm Oil Content And Quality Based On Fruit Color," *J. Plant Sci.*, Vol. 1, No. 3, Pp. 217–227, 2006.

[10] "Economic Transformation Programme (Etp) - Palm Oil & Rubber." [Online]. Available: Http://Etp.Pemandu.Gov.My/Palm_Oil-@-Palm_Oil_-◘-_Rubber.Aspx.

[11] R. Sambanthamurthi, K. Sundram, And Y. Tan, *Chemistry And Biochemistry Of Palm Oil.*, Vol. 39, No. 6. 2000.

[12] R. Mohd Hudzari, A. S. M.A Halim, And S. Roslan, "A Review On Crop Plant Production And Ripeness Forecasting," *Int. J. Agric. Crop Sci.*, Vol. 4, No. 2, Pp. 54–63, 2012.

[13] A. Al-Alawi, F. R. Van De Voort, And J. Sedman, “A New Ftir Method For The Analysis Of Low Levels Of Ffa In Refined Edible Oils,” *Spectrosc. Lett. - An Int. J. Rapid Commun.*, Vol. 38, No. 4–5, Pp. 389–403, Jul. 2005.

[14] M. Z. Abdullah, L. C. Guan, A. M. Mohamed, And M. Am Noor, “Color Vision System For Ripeness Inspection Of Oil Palm Elaeis Guineensis,” *J. Food Process. Preserv.*, Vol. 26, No. 604, Pp. 213–235, 2002.

[15] P. Junkwon, T. Takigawa, H. Okamoto, H. Hasegawa, M. Koike, K. Sakai, J. Siruntawineti, And W. Chaeychomsri, “Potential Application Of Color And Hyperspectral Images For Estimation Of Weight And Ripeness Of Oil Palm (Elaeis Guineensis Jacq . Var . Tenera),” *Agric. Inf. Res.*, Vol. 18, No. 2, Pp. 72–81, 2009.

[16] M. Hudzari And H. Razali, “A Novel Technology Application In Agriculture Research,” *Int. Technol. Appl. Agriclture Res.*, Vol. 2, No. 11, Pp. 408–417, 2011.

[17] W. Ishak And W. Ismail, “Outdoor Colour Recognition System For Oil Palm Fresh Fruit Bunches (Ffb),” *Int. J. Mach. Intell.*, Vol. 2, No. 1, Pp. 1–10, 2010.

[18] T. An Y. Ai, A. Kuntom, M. Yusof, L. C. Khiam, And L. K. Sang, “Lovibond Scale For Colour Measurement Of Palm Oil And Palm Oil Products Viability Of Using A One-Dimensional Lovibond Scale For Colour Measurement Of Palm Oil And Palm Oil Products,” *J. Oil Palm Res.*, Vol. 18, No. June, Pp. 239–246, 2006.

[19] S. Egbuna, A. Ujam, And P. C. N. Ejikeme, “Determination Of The Factors That Affect The Quality And Stability Of Physically Refined Palm,” *Int. J. Eng. Appl. Sci.*, Vol. 4, No. 6, Pp. 28–35, 2013.

[20] P. T. Gee, “Analytical Characteristics Of Crude And Refined Palm Oil And Fractions,” *Eur. J. Lipid Sci. Technol.*, Vol. 109, No. 4, Pp. 373–379, Apr. 2007.

[21] A. A. El Rahman And H. A. A. Badawy, “Ultraviolet, Visible, And Infrared Wavelengths For Determination Of Palm Oil Quality,” *New Trends Agric. Eng.*, Pp. 777–793, 2006.

[22] C. Scrimgeour, “Chemistry Of Fatty Acids,” *Bailey’s Ind. Oil Fat Prod.*, Vol. 6, Pp. 1–44, 2005.

[23] N. Akhmazillah, M. Fauzi, M. R. Sarmidi, U. Tun, H. Onn, P. Raja, B. Pahat, C. Engineering, P. Plant, R. Engineering, And H. Treatment, “Extraction Of Heat Treated Palm Oil And Their Stability On B-Carotene During Storage,” *J. Sci. Technol.*, Pp. 45–54, 2010.

[24] B. Saad, C. W. Ling, M. S. Jab, B. P. Lim, A. S. Mohamad Ali, W. T. Wai, And M. I. Saleh, “Determination Of Free Fatty Acids In Palm Oil Samples

Using Non-Aqueous Flow Injection Titrimetric Method," *Food Chem.*, Vol. 102, No. 4, Pp. 1407–1414, Jan. 2007.

[25] E. A. Udensi And F. . Iroegbu, "Quality Assessment Of Palm Oil Sold In Major Markets In Abia State, Nigeria," *Agro Sci. J.*, Vol. 6, No. 2, 2003.

[26] O. Otu And B. Okoro, "Storage Stability And Sensory Attributes Of Crude Palm Oil," *Eur. J. Agric. For. Res.*, Vol. 2, No. 1, Pp. 10–17, 2014.

[27] Y. He, Y. Zhang, A. G. Pereira, A. H. Gómez, And J. Wang, "Nondestructive Determination Of Tomato Fruit Quality Characteristics Using Vis / Nir Spectroscopy Technique," *Int. J. Inf. Technol.*, Vol. 11, No. 11, Pp. 97–108, 2005.

[28] K. S. Chia, H. A. Rahim, And R. A. Rahimc, "A Comparison Of Principal Component Regression And Artificial Neural Network In Fruits Quality Prediction," In *International Colloquium On Signal Processing And Its Applications*, 2011, Pp. 261–265.

[29] K. S. Chia, H. A. Rahim, And R. A. Rahim, "Artificial Neural Network Coupled With Robust Principal Components In Near Infrared Spectroscopic Analysis," In *International Colloquiuim On Signal Processing And Its Applications*, 2012, No. 36, Pp. 15–18.

[30] K. Chia, H. Abdul Rahim, And R. Abdul Rahim, "Neural Network And Principal Component Regression In Non-Destructive Soluble Solids Content Assessment: A Comparison.," *J. Zhejiang Univ. Sci. B*, Vol. 13, No. 2, Pp. 145–51, Feb. 2012.

[31] K. Brodersen And H. A. Bremner, "Exploration Of The Use Of Nir Re # Ectance Spectroscopy To Distinguish And Measure Attributes Of Conditioned And Cooked Shrimp (Pandalus Borealis)," *Leb. U.-Technol*, Vol. 541, Pp. 533–541, 2001.

[32] A W. Canaza-Cayo, D. Alomar, And E. Quispe, "Prediction Of Alpaca Fibre Quality By Near-Infrared Reflectance Spectroscopy.," *Animal*, Vol. 7, No. 7, Pp. 1219–25, Jul. 2013.

[33] J. Stuth, A. Jama, And D. Tolleson, "Direct And Indirect Means Of Predicting Forage Quality Through Near Infrared Reflectance Spectroscopy," *F. Crop. Res.*, Vol. 84, No. 1–2, Pp. 45–56, Oct. 2003.

[34] B. Igne, J.-M. Roger, S. Roussel, V. Bellon-Maurel, And C. R. Hurburgh, "Improving The Transfer Of Near Infrared Prediction Models By Orthogonal Methods," *Chemom. Intell. Lab. Syst.*, Vol. 99, No. 1, Pp. 57–65, Nov. 2009.

[35] J. Lee, J. G. Shannon, And M. Choung, "Application Of Nondestructive Measurement To Improve Soybean Quality By Near Infrared Reflectance Spectroscopy," In *Soybean - Applications And Technology*, 2008, Pp. 287–304.

[36] C. R. Moschner And B. Biskupek-Korell, “Estimating The Content Of Free Fatty Acids In High-Oleic Sunflower Seeds By Near-Infrared Spectroscopy,” *Eur. J. Lipid Sci. Technol.*, Vol. 108, No. 7, Pp. 606–613, Jul. 2006.

[37] H. A. Rahim And S. Ibrahim, “S E N S O R S & T R A N S D U C E R S Near Infrared Spectroscopy Measurement : The Assessment Of Amylose Content In Rice Grain,” *Sensors & Transducers*, Vol. 156, No. 9, Pp. 251–258, 2013.

[38] F. Westad, A. Schmidt, And M. Kermit, “Incorporating Chemical Band-Assignment In Near Infrared Spectroscopy Regression Models,” *J. Near Infrared Spectrosc.*, Vol. 16, No. 1, P. 265, 2008.

[39] H. Yang And J. Irudayaraj, “Comparison Of Near-Infrared, And Fourier Transform-Raman Methods For Determining Olive Pomace Oil Adulteration In Extra Virgin Olive Oil,” *J. Am. Oil Chem. Soc.*, Vol. 78, No. 9, Pp. 889–895, 2001.

[40] A. Yap, K. Chung, F. Yah, And A. B. D. Manaf, “Application Of Nir Spectrometer For Oil Loss Monitoring In Palm Oil Mill,” *J. Oil Palm Res.*, Vol. 26, No. 1, Pp. 84–95, 2014.

[41] M. Makky And S. Peeyush, “In Situ Quality Assessment Of Intact Oil Ffb Using Rapid Portable Non-Contact And Non-Destructive Approach,” *J. Food Eng.*, Vol. 120, Pp. 248–259, 2014.

[42] T. Sato, S. Kawano, And M. Iwamoto, “Near Infrared Spectral Patterns Of Fatty Acid Analysis From Fats And Oils1,” *J. Am. Oil Chem. Soc.*, Vol. 68, No. 11, Pp. 827–833, 1991.

[43] Y. B. Che Man And M. H. Moh, “Determination Of Free Fatty Acids In Palm Oil By Near-Infrared Reflectance Spectroscopy,” *J. Am. Oil Chem. Soc.*, No. 16, Pp. 557–562, 1998.

[44] R. Osibanjo, R. Curtis, And Z. Lai, “Infrared : Theory,” In *The Dynamic Chemistry E-Textbook*, 2008.

[45] Y. Kim And S. E. Kays, “Near-Infrared (Nir) Prediction Of Trans -Fatty Acids In Ground Cereal Foods,” *J. Agric. Food Chem.*, Vol. 57, Pp. 8187–8193, 2009.

[46] A. Garrido-Varo, M. D. Pérez-Marín, J. E. Guerrero, M. José, D. Haba, J. Bautista, A. Soldado, A. Martínez, B. De Roza-Delgado, And S. Termes, “Near Infrared Spectroscopy For Enforcement Of European Legislation Concerning The Use Of Animal By-Products In Animal Feeds,” *Biotechnololy Agron. Soc. Environ.*, Vol. 9, No. 1, Pp. 3–9, 2005.

[47] V. M. Fernández-Cabanás, O. Polvillo, R. Rodríguez-Acuña, B. Botella, And A. Horcada, “Rapid Determination Of The Fatty Acid Profile In Pork Dry-

Cured Sausages By Nir Spectroscopy," *Food Chem.*, Vol. 124, Pp. 373–378, 2011.

[48] "Partial Least Squares Regression And Principal Components Regression," *Matlab*, 2014. [Online]. Available: Http://Www.Mathworks.Com/Help/Stats/Examples/Partial-Least-Squares-Regression-And-Principal-Components-Regression.Html.

[49] R. D. Tobias, "An Introduction To Partial Least Squares Regression," *Sas Institue Inc*, 1997.

[50] P. T. Reiss And R. T. Ogden, "Functional Principal Component Regression And Functional Partial Least Squares," *J. Am. Stat. Assoc.*, Vol. 102, No. 479, Pp. 984–996, Sep. 2007.

[51] H. Abdi, "Partial Least Square Regression," 2001.

[52] H. J. He, D. Wu, And D. W. Sun, "Non-Destructive And Rapid Analysis Of Moisture Distribution In Farmed Atlantic Salmon (Salmo Salar) Fillets Using Visible And Near-Infrared Hyperspectral Imaging," *Innov. Food Sci. Emerg. Technol.*, Vol. 18, Pp. 237–245, 2013.

[53] H. He, D. Wu, And D. Sun, "Non-Destructive And Rapid Analysis Of Moisture Distribution In Farmed Atlantic Salmon (Salmo Salar) Fi Llets Using Visible And Near-Infrared Hyperspectral Imaging," *Innov. Food Sci. Emerg. Technol.*, Vol. 18, Pp. 237–245, 2013.

[54] B. M. Nicolaï, K. Beullens, E. Bobelyn, A. Peirs, W. Saeys, K. I. Theron, And J. Lammertyn, "Nondestructive Measurement Of Fruit And Vegetable Quality By Means Of Nir Spectroscopy: A Review," *Postharvest Biology And Technology*, Vol. 46. Pp. 99–118, 2007.

[55] K. A Dooley, S. Lomax, J. G. Zeibel, C. Miliani, P. Ricciardi, A. Hoenigswald, M. Loew, And J. K. Delaney, "Mapping Of Egg Yolk And Animal Skin Glue Paint Binders In Early Renaissance Paintings Using Near Infrared Reflectance Imaging Spectroscopy.," *Analyst*, Vol. 138, No. 17, Pp. 4838–48, Sep. 2013.

[56] J. G. Tallada, N. Palacios-Rojas, And P. R. Armstrong, "Prediction Of Maize Seed Attributes Using A Rapid Single Kernel Near Infrared Instrument," *J. Cereal Sci.*, Vol. 50, Pp. 381–387, 2009.

[57] M. Hafiz, M. Hazir, A. Rashid, And M. Shariff, "Oil Palm Optical Characteristics From Two Different Planting Materials," In *International Conference On Future Tehnology*, 2011, Vol. 13, Pp. 196–200.

[58] S. Tsuchikawa, "A Review Of Recent Near Infrared Research For Wood And Paper," *Appl. Spectrosc. Rev.*, Vol. 42, No. 1, Pp. 43–71, Feb. 2007.

[59] J. Wang, L. Cui, W. Gao, T. Shi, Y. Chen, And Y. Gao, "Prediction Of Low Heavy Metal Concentrations In Agricultural Soils Using Visible And Near-Infrared Refl Ectance Spectroscopy," *Geoderma*, Vol. 216, Pp. 1–9, 2014.

[60] B. M. Nicolaï, K. Beullens, E. Bobelyn, A. Peirs, W. Saeys, K. I. Theron, And J. Lammertyn, "Nondestructive Measurement Of Fruit And Vegetable Quality By Means Of Nir Spectroscopy: A Review," *Postharvest Biol. Technol.*, Vol. 46, No. 2, Pp. 99–118, Nov. 2007.

[61] O. Mohammed, B. Saeed, S. Sankaran, A. Rashid, M. Shariff, H. Zulhaidi, M. Shafri, R. Ehsani, M. Salem, M. Hafiz, And M. Hazir, "Classification Of Oil Palm Fresh Fruit Bunches Based On Their Maturity Using Portable Four-Band Sensor System," *Comput. Electron. Agric.*, Vol. 82, Pp. 55–60, 2012.

[62] E. Luedeling And A. Gassner, "Partial Least Squares Regression For Analyzing Walnut Phenology In California," *Agric. For. Meteorol.*, Vol. 158–159, Pp. 43–52, Jun. 2012.

[63] C. Petisco, B. García-Criado, B. R. V. De Aldana, I. Zabalgogeazcoa, S. Mediavilla, And A. García-Ciudad, "Use Of Near-Infrared Reflectance Spectroscopy In Predicting Nitrogen, Phosphorus And Calcium Contents In Heterogeneous Woody Plant Species," In *Analytical And Bioanalytical Chemistry*, 2005, Vol. 382, Pp. 458–465.

[64] Y. Liu, X. Sun, And A. Ouyang, "Nondestructive Measurement Of Soluble Solid Content Of Navel Orange Fruit By Visible-Nir Spectrometric Technique With Plsr And Pca-Bpnn," *Lwt - Food Sci. Technol.*, Vol. 43, Pp. 602–607, 2010.

[65] T. Bonnie Yen Ping, H. Nurul Ain, And S. Hoong Seng, "Determination Of Hydroxyl Value Of Palm-Based Polyols By Partial Least Squares Algorithm Using Nir Spectroscopy," *J. Oil Palm Res.*, Vol. 23, Pp. 1172–1177, 2011.

[66] C. Chang, D. A. Laird, M. J. Mausbach, And C. R. Hurburgh, "Analyses Of Soil Properties," *Soil Sci. Soc. Am. J.*, Vol. 65, Pp. 480–490, 2001.

[67] R. M. Balabin, R. Z. Safieva, And E. I. Lomakina, "Comparison Of Linear And Nonlinear Calibration Models Based On Near Infrared (Nir) Spectroscopy Data For Gasoline Properties Prediction," *Chemom. Intell. Lab. Syst.*, Vol. 88, Pp. 183–188, 2007.

[68] E. Marengo, M. Bobba, E. Robotti, And M. Lenti, "Hydroxyl And Acid Number Prediction In Polyester Resins By Near Infrared Spectroscopy And Artificial Neural Networks," *Anal. Chim. Acta*, Vol. 511, Pp. 313–322, 2004.

[69] C.-W. Chang, D. A. Laird, M. J. Mausbach, And C. R. Hurburgh, "Near-Infrared Reflectance Spectroscopy–Principal Components Regression Analyses Of Soil Properties," *Soil Science Society Of America Journal*, Vol. 65. P. 480, 2001.

[70] R. Wehrens, “The Pls Package: Principle Component And Partial Least Square Regression In R,” *J. Stat. Softw.*, Vol. 18, No. 2, 2007.

[71] S. Schumann, L.-P. Nolte, And G. Zheng, “Comparison Of Partial Least Squares Regression And Principal Component Regression For Pelvic Shape Prediction.,” *J. Biomech.*, Vol. 46, No. 1, Pp. 197–9, Jan. 2013.

[72] J. C. M. Pires, F. G. Martins, S. I. V. Sousa, M. C. M. Alvim-Ferraz, And M. C. Pereira, “Selection And Validation Of Parameters In Multiple Linear And Principal Component Regressions,” *Environ. Model. Softw.*, Vol. 23, No. 1, Pp. 50–55, Jan. 2008.

[73] T. Basics, P. C. Analysis, V. R. Procedure, A. Illustration, V. Redundancy, P. Component, O. Solutions, N. F. Analysis, P. O. Inventory, M. Instrument, M. Adequate, S. Size, S. A. S. Program, T. Data, T. P. Factor, P. Factor, T. Var, C. Principal, C. Analysis, I. Extraction, F. Solution, R. Solution, C. F. Scores, F. Scores, And F. Description, “Introduction : The Basics Of Principal Component Analysis,” Pp. 1–56.

[74] H. Cen And Y. He, “Theory And Application Of Near Infrared Reflectance Spectroscopy In Determination Of Food Quality,” *Trends Food Sci. Technol.*, Vol. 18, No. 2, Pp. 72–83, Feb. 2007.

[75] John, “Introduction : The Basics Of Principal Component Analysis,” Pp. 1–56.

[76] H. Abdi And L. J. Williams, “Principal Component Analysis,” *Wiley Interdiscip. Rev. Comput. Stat.*, Vol. 2, No. 4, Pp. 433–459, Jul. 2010.

[77] Å. Rinnan, F. Van Den Berg, And S. B. Engelsen, “Review Of The Most Common Pre-Processing Techniques For Near-Infrared Spectra,” *Trac Trends Anal. Chem.*, Vol. 28, No. 10, Pp. 1201–1222, Nov. 2009.

[78] M. Blanco And A. Peguero, “An Expeditious Method For Determining Particle Size Distribution By Near Infrared Spectroscopy: Comparison Of Pls2 And Ann Models,” *Talanta*, Vol. 77, Pp. 647–651, 2008.

[79] P. Z. P. Zuo, Y. L. Y. Li, J. M. J. Ma, And S. M. S. Ma, “Analysis Of Noninvasive Measurement Of Human Blood Glucose With Ann-Nir Spectroscopy,” *2005 Int. Conf. Neural Networks Brain*, Vol. 3, 2005.

[80] M. Blanco, J. Coello, H. Iturriaga, S. Maspoch, And J. Pagès, “Nir Calibration In Non-Linear Systems: Different Pls Approaches And Artificial Neural Networks,” *Chemom. Intell. Lab. Syst.*, Vol. 50, Pp. 75–82, 2000.

[81] R. M. Balabin And E. I. Lomakina, “Support Vector Machine Regression (Svr/Ls-Svm)--An Alternative To Neural Networks (Ann) For Analytical Chemistry? Comparison Of Nonlinear Methods On Near Infrared (Nir) Spectroscopy Data.,” *Analyst*, Vol. 136, Pp. 1703–1712, 2011.

[82] R. M. Balabin, R. Z. Safieva, And E. I. Lomakina, “Wavelet Neural Network (Wnn) Approach For Calibration Model Building Based On Gasoline Near Infrared (Nir) Spectra,” *Chemom. Intell. Lab. Syst.*, Vol. 93, Pp. 58–62, 2008.

[83] R. M. Balabin, R. Z. Safieva, And E. I. Lomakina, “Gasoline Classification Using Near Infrared (Nir) Spectroscopy Data: Comparison Of Multivariate Techniques,” *Anal. Chim. Acta*, Vol. 671, Pp. 27–35, 2010.

[84] M. Bampi, A. D. P. Scheer, And F. De Castilhos, “Application Of Near Infrared Spectroscopy To Predict The Average Droplet Size And Water Content In Biodiesel Emulsions,” *Fuel*, Vol. 113, Pp. 546–552, 2013.

[85] X. Li, Y. He, And H. Fang, “Non-Destructive Discrimination Of Chinese Bayberry Varieties Using Vis/Nir Spectroscopy,” *J. Food Eng.*, Vol. 81, Pp. 357–363, 2007.

[86] L. Wang, Y. He, And F. Liu, “Pattern Recognition Of Vis/Nir Spectroscopy From White Vinegar Based On Pls And Bp-Ann Model,” *2007 Ieee Instrum. Meas. Technol. Conf. Imtc 2007*, Pp. 1–4, 2007.

[87] H. Yang And Y. He, “Design And Implement Of Variety Discriminator Of Fragrant Mushrooms Based On Vis/Nir Spectroscopy And Bp-Ann,” In *Proceedings Of The Ieee International Conference On Automation And Logistics, Ical 2008*, 2008, Pp. 2727–2730.

[88] X. Li, Y. He, And C. Wu, “Non-Destructive Discrimination Of Paddy Seeds Of Different Storage Age Based On Vis/Nir Spectroscopy,” *J. Stored Prod. Res.*, Vol. 44, Pp. 264–268, 2008.

[89] Y. H. Uang, A. G. C. Avinato, D. M. M. Ayes, L. J. K. Angas, G. E. B. Ledsoe, And B. A. R. Asco, “Nondestructive Determination Of Moisture And Sodium Chloride In Cured Atlantic Salmon (Salmo Salar) (Teijin) Using Short-Wavelength,” Vol. 68, No. 2, 2003.

[90] M. Casale, P. Oliveri, C. Casolino, N. Sinelli, P. Zunin, C. Armanino, M. Forina, And S. Lanteri, “Characterisation Of Pdo Olive Oil Chianti Classico By Non-Selective (Uv-Visible, Nir And Mir Spectroscopy) And Selective (Fatty Acid Composition) Analytical Techniques,” *Anal. Chim. Acta*, Vol. 712, Pp. 56–63, 2012.

[91] M. Coppa, A. Revello-Chion, D. Giaccone, A. Ferlay, E. Tabacco, And G. Borreani, “Comparison Of Near And Medium Infrared Spectroscopy To Predict Fatty Acid Composition On Fresh And Thawed Milk,” *Food Chem.*, Vol. 150, Pp. 49–57, 2014.

[92] K. A. Yookyung And S. E. Kays, “Near-Infrared (Nir) Prediction Of Frans-Fatty Acids In Ground Cereal Foods,” *J. Agric. Food Chem.*, Vol. 57, Pp. 8187–8193, 2009.

[93] N. Ebongue, G. Frank, M. Mpondo, E. Albert, D. Ekwe, E. Laverdure, And K. Paul, "Assessment Of The Quality Of Crude Palm Oil From Smallholders In Cameroon," *J. Stored Prod. Postharvest Res.*, Vol. 2, No. March, Pp. 52–58, 2011.

[94] D. T. De Almeida, I. L. Nunes, P. L. Conde, R. P. S. Rosa, W. F. Rogério, And E. R. Machado, "A Quality Assessment Of Crude Palm Oil Marketed In Bahia, Brazil," *Grasas Y Aceites*, Vol. 64, No. 4, Pp. 387–394, Jul. 2013.

[95] P. M. K. Kopas And G. Kopas, "Cosmeceutical Formulation Containing Palm Oils." Google Patents, 03-Sep-2013.

[96] B. Campus, "Factors Influencing Quality Of Palm Oil Produced At The Cottage Industry Level In Ghana," *Int. Food Res. J.*, Vol. 19, No. 1, Pp. 271–278, 2012.

[97] E. I. Ohimain, S. C. Izah, And A. D. Fawari, "Quality Assessment Of Crude Palm Oil Produced By Semi-Mechanized Processor In Bayelsa State , Nigeria," *J. Agric. Food Sci.*, Vol. 1, No. 11, Pp. 171–181, 2013.

[98] M. P. O. Board, "Analytical Methods." Pp. 3–5, 2014.

[99] Z. Xiaobo, Z. Jiewen, M. J. W. Povey, M. Holmes, And M. Hanpin, "Variables Selection Methods In Near-Infrared Spectroscopy.," *Anal. Chim. Acta*, Vol. 667, No. 1–2, Pp. 14–32, May 2010.

[100] M. Ruiz, L. E. Mujica, X. Berjaga, And J. Rodellar, "Partial Least Square/Projection To Latent Structures (Pls) Regression To Estimate Impact Localization In Structures," *Smart Mater. Struct.*, Vol. 22, No. 2, P. 025028, Feb. 2013.

[101] M. Richardson, "Principal Component Analysis," 2009.

[102] J. Shlens And B. Sciences, "Matlab Code For Pca," Vol. 5, No. V, Pp. 5–6.

[103] S. V. Decomposition, "Derivation , Discussion And Singular Value Decomposition," 2003.

[104] R. E. Madsen, L. K. Hansen, And O. Winther, "Singular Value Decomposition And Principal Component Analysis," In *Neural Networks For Pattern Recognition*, No. February, 2004, Pp. 1–5.

[105] P. Felizardo, P. Baptista, J. C. Menezes, And M. J. N. Correia, "Multivariate Near Infrared Spectroscopy Models For Predicting Methanol And Water Content In Biodiesel.," *Anal. Chim. Acta*, Vol. 595, No. 1–2, Pp. 107–13, Jul. 2007.

[106] S.A Ekop, B. . Etuk, And N. . Eddy, "Effect Of Some Local Additives On The Chemical Constituent Of Palm Oil Abstract :," *J. Appl. Sci. Environ. Manag.*, Vol. 11, No. 1, Pp. 85–89, 2007.

[107] P. Felizardo, P. Baptista, M. Sousa Uva, J. Menezes, And M. Neiva Correia, "Monitoring Biodiesel Fuel Quality By Near Infrared Spectroscopy," *J. Near Infrared Spectrosc.*, Vol. 15, No. 2, P. 97, 2007.

[108] P. Baptista, P. Felizardo, J. C. Menezes, And M. J. N. Correia, "Multivariate Near Infrared Spectroscopy Models For Predicting The Methyl Esters Content In Biodiesel.," *Anal. Chim. Acta*, Vol. 607, No. 2, Pp. 153–9, Jan. 2008.

[109] T. Field And P. Accreditation, "Agricultural Engineering Overview."

[110] M. Blanco, J. Coello, H. Iturriaga, S. Maspoch, And C. De Pezuela, "Critical Review Near-Infrared Spectroscopy In The Pharmaceutical Industry," *Analyst*, Vol. 123, No. August, Pp. 135–150, 1998.

[111] C. A. Roberts, J. Workman, J. B. R. Iii, E. A. S. A. Publications, K. A. Barbarick, E. C. Publications, E. S. Publications, And W. A. Dick, *Near-Infrared Spectroscopy In Agriculture*. 2004.

[112] T. Groenewald, "Near Infrared (Nir) Spectroscopy - The Rapid Analyses Technique Of The Future," *Near Infrared (Nir) Spectroscopy - Engormix*, 2006. .

[113] F. Estienne, F. Despagne, B. Walczak, O. E. De Noord, And D. L. Massart, "A Comparison Of Multivariate Calibration Techniques Applied To Experimental Nir Data Sets," *Chemom. Intell. Lab. Syst.*, Vol. 73, No. 2, Pp. 207–218, Oct. 2004.

[114] M. H. Beale, M. T. Hagan, And H. B. Demuth, "Neural Network Toolbox [Tm] User ' S Guide R 2014 A." Pp. 1–99, 2014.

[115] M. Saedi, "The Potential Of Artificial Neural Network (Ann) In Optimizing Media Constituents Of Citric Acid Production By Solid State Bioconversion," *Int. Food Res. J.*, Vol. 19, No. 2, Pp. 491–497, 2012.