UNIVERSITI PUTRA MALAYSIA

NON-DESTRUCTIVE ASSESSMENT OF THE INTERNAL QUALITY OF WATERMELON USING ULTRAVIOLET NEAR-INFRARED SPECTROSCOPY

SITI SARIPA RABIAH BINTI MAT LAZIM

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By

SITI SARIPA RABIAH BINTI MAT LAZIM

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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Chairman : Nazmi Bin Mat Nawi, PhD
Faculty : Engineering

Watermelon is a popular tropical fruit in Malaysia especially during dry season because it considered as good thirst quenching fruit. Recently, the demand for high quality fresh watermelons has increased. In order to meet the customer's expectation, the watermelons need to be harvested at the right level of maturity level. Fruits harvested too early have a poor quality as they are not yet ripened properly. Therefore, optimal level of maturity level is important to preserve the quality of the fruit for a longer shelf life. Internal quality indices of watermelon such as soluble solids content (SSC), pH, firmness and moisture content (MC) are the main indicators to determine the maturity level of watermelons. However, the current practice to determine the maturity level of watermelon based on the sound produced by tapping the fruit is subject to errors. This method is not consistent even if it was performed by skillful and experienced farmers. Therefore, there is a need for an accurate and reliable in-situ measurement system to measure the quality of watermelons. Thus, the goal of this study was to investigate the possibility of using ultraviolet near infrared (UVNIR) spectroscopy to determine the internal quality parameters of watermelon for maturity level prediction.

A total of 63 watermelon samples at different level of maturities (unmatured, matured and over-matured) were used in this study. Each sample was vertically divided into three sections namely top, middle and bottom. Then, each portion was horizontally divided into two portions. Then, the spectral data of the skin surfaces was collected from each sub-portion. All the spectral measurements were carried out in the black box to minimize the influence of stray light on the

spectral data. Each portion underwent laboratory analysis to measure the SSC, pH and MC. In this study, the measurement of SSC was done using a reftractometer while the measurement for pH was undertaken using pH meter. The MC of the sample was measured using conventional oven dry method. The chemical properties obtained from the samples at different maturity levels were significantly difference at ($p<0.05$). The calibration and prediction models were developed to correlate the spectral data with internal quality properties of the samples using Partial Least Square (PLS) method. To improve the accuracy of the PLS models, the spectral data was first pre-processed using the baseline offset correction (BOC) method. The pre-processing methods and PLS exercises were run using Unscrambler V. 10.3 software.

SSC prediction of watermelon samples was the highest R^2 value of 0.57 for calibration model while R^2 value for prediction model was 0.50. While for pH prediction of watermelon samples, the calibration model gave R^2 value of 0.49 whereas the prediction model gave R^2 value of 0.43. For MC prediction of watermelon samples, the calibration model gave R^2 value of 0.43 whereas the prediction model gave R^2 value of 0.21. From the three chemical parameters, SSC was ` the best parameter to be predicted by UVNIR from all maturity levels since watermelon samples achieved higher correlation coefficient as compared to others parameters.

For the prediction of SSC for the samples at different maturity levels, it was found that the coefficient of determination (R^2) for calibration models of unmatured, matured and over-matured were 0.65, 0.81 and 0.78, respectively. While for the prediction models, it was found that the R^2 for unmatured, matured and over-matured were 0.60, 0.74 and 0.76, respectively. For the prediction of SSC of the samples at different portions, it was found that the R^2 for calibration models for top, middle and bottom were 0.72, 0.71 and 0.79, respectively. For the prediction models, it was found that the R^2 for top, middle and bottom portions were 0.63, 0 62 and 0.66, respectively.

The SVM model of maturity prediction for watermelon showed an excellent result with overall prediction of accuracy of 85%. Overall, it can be concluded that the application of spectroscopy is a promising technique for assessing the maturity level of watermelons. The proposed method has significant potential uses as a tool for prediction of watermelon quality parameters in the farm.

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

PENGUKURAN TANPA MUSNAH MENGENAI KUALITI DALAMAN BUAH TEMBIKAI MENGGUNAKAN SPEKTROSKOPI DEKAR-INFRAMERAH

Oleh

SITI SARIPA RABIAH BINTI MAT LAZIM

November 2018

Pengerusi : Nazmi Bin Mat Nawi, PhD
Fakulti : Kejuruteraan

Tembikai merupakan buah tropika yang terkenal di Malaysia terutamanya pada musim panas kerana ianya mempunyai kandungan air yang banyak. Kebelakangan ini, permintaan terhadap buah tembikai segar dan berkualiti tinggi telah meningkat. Bagi memenuhi kepuasan pelanggan, buah tembikai perlu dituai pada tahap kematangan yang sesuai. Buah tembikai yang dituai terlalu awal akan mempunyai kualiti yang rendah kerana ianya belum masak dengan sepenuhnya. Oleh demikian, penuaian buah tembikai pada tahap kematangan yang optimum adalah penting untuk mengekalkan kualiti buah. Kualiti dalaman buah tembikai seperti kandungan pepejal larut (SSC), pH, ketegasan dan kandungan kelembapan merupakan petunjuk utama untuk menentukan kematangan buah tembikai. Kebiasaannya, kematangan buah tembikai ditentukan berdasarkan bunyi yang dihasilkan apabila buah tersebut dijentik namun kaedah ini lebih cenderung kepada ralat. Kaedah ini juga tidak seragam walaupun diamalkan oleh petani yang mahir dan berpengalaman. Oleh yang demikian, keperluan terhadap sistem pengukuran di ladang yang tepat dan boleh untuk mengukur kualiti buah tembikai sangat diperlukan. Oleh itu, objektif kajian ini adalah untuk mengkaji kemungkinan penggunaan spektroskopi ultravoilet dekat-inframerah (UVNIR) dalam menentukan parameter kualiti dalaman buah tembikai dalam meramal kematangan buah.

Enam puluh tiga buah tembikai pada tahap kematangan yang berbeza (tidak matang, cukup matang dan terlebih matang) telah digunakan dalam kajian ini. Setiap sampel dibahagikan secara vertikal kepada tiga bahagian iaitu bahagian atas, tengah dan bawah. Kemudian, setiap bahagian dibahagikan secara mendatar kepada dua bahagian. Setelah itu, data spektrum dari setiap bahagian

pada permukaan kulit telah di kumpul. Semua pengukuran spektrum dilakukan di dalam kotak hitam untuk meminimumkan pengaruh cahaya terbias pada spektrum. Setiap sub-bahagian menjalani analisis makmal untuk mengukur SSC, pH dan MC. Dalam kajian ini, pengukuran SSC dijalankan dengan menggunakan reftractometer manakala pengukuran pH dilakukan dengan menggunakan meter pH. Sampel MC diukur dengan menggunakan kaedah oven kering secara konvensional. Sifat – sifat kimia yang diperoleh dari sampel adalah perbezaan ketara pada ($p< 0.05$) di tahap kematangan yang berbeza. Model penentukuran dan ramalan telah dirumuskan untuk menghubungkan data spektrum dengan sifat kualiti dalaman sampel menggunakan kaedah separa kuasa dua terkecil (PLS). Untuk meningkatkan ketepatan model PLS, data spektrum telah diproses terlebih dahulu dengan menggunakan kaedah pelarasan Savitzky-Golay dan pembetulan mengimbangi asas (BOC). Kaedah pra-pemprosesan dan latihan PLS dijalankan menggunakan perisian Unscrambler V. 10.3.

Ramalan SSC untuk sampel tembikai merupakan nilai R^2 yang tertinggi dengan model penentukuran adalah 0.67 manakala nilai R^2 bagi model ramalan adalah 0.50. Untuk ramalan pH di dapati dari sampel yang sama, nilai R^2 bagi model penentukuran adalah 0.49 manakala nilai R^2 bagi model ramalan adalah 0.43. Bagi ramalan MC pada sampel tembikai, nilai R^2 bagi model penentukuran adalah 0.43 manakala nilai R^2 bagi model ramalan adalah 0.21. Secara keseluruhannya, ia didapati bahawa SSC menunjukkan parameter terbaik yang akan diramalkan oleh UVNIR dari semua peringkat kematangan sampel tembikai memandangkan ianya mencapai pekali penentuan yang tertinggi berbanding parameter yang lain.

Ramalan SSC untuk sampel pada tahap kematangan yang berbeza, didapati bahawa nilai pekali penentuan (R^2) bagi model penentukuran yang tidak matang, cukup matang dan terlebih matang adalah 0.66, 0.73, dan 0.74. Manakala untuk model ramalan, didapati bahawa nilai R^2 bagi sampel yang tidak matang, cukup matang dan terlebih matang adalah masing – masing, 0.60, 0.62 dan 0.76. Bagi ramalan SSC pada sampel bahagian yang berbeza, didapati nilai R^2 untuk model penentukuran pada bahagian atas, tengah dan bawah adalah masing – masing, 0.72, 0.67 dan 0.76. Bagi model ramalan, didapati bahawa R^2 untuk bahagian atas, tengah dan bawah adalah masing – masing,0.65, 0.65 dan 0.62.

Model ramalan SVM untuk meramal kematangan tembikai menunjukkan hasil yang memuaskan dengan ramalan ketepatan keseluruhan adalah 85%. Secara keseluruhannya, disimpulkan bahawa aplikasi spektroskopi merupakan teknik yang berpotensi untuk menilai kematangan tembikai. Kaedah ini mempunyai potensi penggunaan yang besar sebagai alat untuk meramal parameter kualiti buah tembikai di ladang.

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Nazmi Bin Mat Nawi, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Khairunniza Binti Bejo, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

____

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No.: Siti Saripa Rabiah Binti Mat Lazim (GS44240)

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature : ______________________________
Name of Chairman of
Supervisory Committee : Dr. Nazmi Bin Mat Nawi

Signature : ______________________________
Name of Member of
Supervisory Committee : Associate Professor Dr. Siti Khairunniza Bejo

Signature : ______________________________
Name of Member of
Supervisory Committee : Professor Dr. Abdul Rashid Bin Mohamed Shariff

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LIST OF ABBREVIATIONS

a*	Grenness
ANN	Artificial Neuron Network
ANOVA	Analysis of variance
b*	Yellowness
BOC	Baseline of correction
C	Chroma
CCD	Charge-coupled device
CMOS	Complementary metal-oxide-semiconductor
EPA	Elliptic Fourier analysis
FFT	Fast Fourier transform
HSI	Hue-saturation-intensity
kNN	k-nearest neighbours
L*	Lightness
LDV	Laser Doppler Vibrometry
LV	Latent variable
MC	Moisture content
MLR	Multi linear regression
MRI	Nuclear magnetic imaging
MSC	Multiple scatter correction
NIR	Near-Infrared
NIR	Near-infrared
PC	Principle Component
PCR	Principle component regression
PLS	Partial least square
R^2	Coefficient of determination
RBF	Radial basic function
RMSEC	Root mean square of calibration
RMSEP	Root mean square of prediction
SMLR	Step-wise multiple linear regression
SNV	Standard normal variate correction
SSC	Soluble content
SVM	Support vector machine
TSS	Total Soluble Solid

UVNIR	Ultra-violet near-infrared
Vis/NIR	Visible near-infrared
Vis/SWNIR	Visible and shortwave near-infrared

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Watermelon *(Citrullus lanatus)* is one of the popular fruits for fresh consumption in Malaysia. It is an annual plant of the cucurbitaceous family along other cucurbit such as pumpkin and cucumber. Watermelon is an edible fruit which can be eaten in a raw or consumed as fruit juice or salad especially during hot season (Gichimu et al., 2008). In the global production, watermelon is the largest produced fruit with approximately 117.02 million metric tonnes (FAO, 2016). The external features of this fruits are glossy, deep green to yellow and thick outer rind with light-green colored vertical lines adorning its outer surface.

Watermelon is a non-climacteric fruit which does not ripen after being harvested (Wecther et al., 2008). The fruit has higher source of vitamin C and A, sugar, minerals such as iron, potassium, calcium, magnesium, phosphorus, dietary fiber organic acids and zinc (Jie et al., 2013; Tlili et al., 2011). Watermelon contains high amount of lycopene and citrulline (Perkin-Veazine & Collins, 2004; Rimando & Perkin-Veazie, 2005). Lycopene is red carotenoid. Liu et al (2010) reported that caretenoid gives different red color of flesh watermelon whereas the citrulline is a non-essesntial amino acid.

Recently, the demand for high quality watermelon is increasing among the customers. In order to provide fresh watermelon at high quality level, the fruit need to be harvested at the right stage of maturity. If the fruit harvested too early, it will have poor attribute as they are not ripened very well. In contrast, harvesting at an over-mature stage leads to a short shelf life and disease exposure (Wanitchang et al., 2011). A good quality fruit is obtained when harvesting is done at the appropriate level of maturity. It is the stage where any organs of the plant have attained full growth and development. Therefore, optimal stage of maturity during harvest is an important factor to be considered to preserve a good quality of the fruit and minimize postharvest losses.

The physical properties of fruits as such shape, size, and color are the common factors in determining the maturity level of the fruits. However, the physical properties or external appearances alone are not enough to define the quality of watermelons. In addition chemical properties such as SSC, pH and MC are also important internal parameters used to determine the quality of watermelons. In conventional method, both the internal and external properties of watermelon were mostly assessed by human experience (Stone et al., 1996). However, the properties which were determined based on the human evaluations subject to subjective experience, low supervision efficiency, and is weak to manage with the huge scale of production (Diezma-Iglesias et al., 2004 and Jie et al., 2013).

The advanced technology in non-destructive application has been developed rapidly in the agricultural sector to fill in the requirement for rapid quality inspection (Kamruzzaman & Oshita, 2015). In recent years, non-destructive techniques have been used for monitoring quality changes externally and internally of various crops and agricultural produce. The most recommended techniques are generally based on the food properties including optical, vibration, sound, and electrical properties. These assessments are very much related to the relationship of physicochemical properties and the features of the non-destructive method. For instance, non-destructive applications have been tested on watermelon using acoustic impulse response (Armstrong et al., 1997; Diezma-Iglesias et al., 2004; Mao et al., 2016), laser doppler vibrometry (Abbaszadeh et al., 2011; Abbaszadeh et al., 2014; Taniwaki et al., 2009), image-based methods (Abdul Rahman et al., 2009; Koc, 2007; Syazwan et al., 2012), infrared spectroscopy (Jie et al., 2014; Lohumi et al., 2013; Yao et al., 2013), and dielectric spectroscopy (Nelson et al., 2007a; 2007b). Nevertheless, the techniques involving vibration property are sensitive to the noise of surrounding and mechanical vibration (Tian et al., 2007). Saito et al. (1996) have studied the application of nuclear magnetic resonance imaging (MRI) in detecting soluble solids content of watermelon. However, the equipment used in MRI is quite expensive and more complex since this technique is not dependent on the difference between internal flesh and external surface of the fruit. Therefore, effective non-destructive techniques are needed to increase the commercial value of agricultural produce.

Currently, the selection of matured fruit with a great quality is manually performed by thumping the skin of the fruit and listening to the sound produced. Another technique is by seeking for yellow spots on the outer surface which is used to indicate the maturity level of watermelon. However, this method is not suitable when dealing with a large number of fruits, especially during harvesting seasons. Thus, since the demand for a good quality is increasing, an automated system using non-destructive technique is desirable.

1.2 Problem Statement

Recently, demand for a good quality and fresh fruits watermelon has increased especially during hot season. Watermelon becomes preferred fruit for fresh consumption because the fruit give a significant role in human diet, being excellent source of vitamin, fiber, various carbohydrates, organic salt, and microelements (Ali et al., 2017). Previous research showed that high consumption of different fruits contributes to the prevention of numerous chronic diseases (Anguilera et al., 2016; Wang et. al., 2014; Nile & Park, 2014) and the whole maintenance of a fit physical body. The advantageous health effects of fruit are due to the existence of antioxidants and phytochemicals.

However, consistently harvesting matured fruit at optimum quality level is challenging since the current assessment method in the field involves the manual procedures. The application of manual assessment in harvesting process may lead to non-uniform result as the size-based sorting system may vary in terms of fruit density (Omid et al., 2010). In addition, manual harvesting is quite laborious which depends very much on the competency of manpower and human skills. Therefore, there is a need for the application of fast, automatic and non-destructive technology to perform the quality assessment. The effective non-destructive approach is needed to replace the application of conventional methods which apparently are not so practical in modern days. Wu & Sun (2013) claimed that, the non-destructive methods are recommended due to its rapid process, objective measurement and reliable results. The ability of non-destructive techniques in term of fast data processing and handling contributes to the high anticipation of good products for the consumers.

Various applications have been reported to predict the internal quality of fruits using ultraviolet near-infrared (UVNIR) spectroscopy for fast measurement of mandarin (Kawano et al., 1993; McGlone et al., 2003); mango (Saranwong et al., 2004; Schmilovitch et al., 2000); kiwifruit (Clark et al., 2004; McGlone et al., 2002) apple (Moons et al., 1997; Lammertyn et al., 2000; Liu & Ying 2005; Fan et al., 2009; Mendoza et al., 2015) and pineapple (Chia et al., 2012). Nawi et al. (2013) used visible and shortwave near-infrared (Vis/SWNIR) spectroscopy to estimate the sugar content of sugarcane based on skin scanning. These researchers have been used the spectroscopic technology due to the robustness of the device, the lack of need for sample preparation and the ability to performed fast measurements, low cost, accurate and reliable method and can be used to analyze multiple attribute simultaneously (Alfatni et al., 2013).

1.3 Objectives

The goal of this research is to evaluate the potential application of a low-cost and portable software near-infrared spectroscopy in determining the maturity level of watermelon samples based on their chemical properties such as soluble solid content (SSC), moisture content and pH. Specific objectives are:

i. To investigate the potential use of reflectance spectrometer to determine chemical properties of watermelon
ii. To develop a prediction model of a SSC-based prediction model using UVNIR spectroscopy.
iii. To determine the best scanning position of watermelon fruit for classification of maturity level.
iv. To classify the watermelon based on their maturity level using SVM classifier.

1.4 The Scope and Limitation

The present study aimed at exploring the potential use of UVNIR spectroscopy for monitoring quality parameters of watermelons. This study was conducted to determine the quality of watermelon non-destructively by UVNIR spectroscopy. The study focused only on one variety cultivars of watermelon from each different maturity level. Besides, this investigation only focuses on reflectance mode spectroscopy.

1.5 Thesis Overview

This thesis is organized as follows. Chapter 1 describes the background study driving to this work. This chapter also outlines the research objectives, scope and limitation as well as the importance of the study. Chapter 2 provides a literature review of cultivation and quality evaluation of watermelons. This chapter also describes the postharvest handling of the fruit, application and future prospect of the UVNIR spectroscopy application. Chapter 3 explains the experimental for using UVNIR spectroscopy as well as the procedure of chemical and physical properties measurements. Spectral data analyses are also discussed in this chapter. Chapter 4 discusses the result and findings obtained for each research objective. Chapter 5 summarizes the conclusion and achievement of this research, alongside recommendation for future studies.

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BIODATA OF STUDENT

The student, Siti Saripa Rabiah Binti Mat Lazim was born on September 6, 1992 in Kota Bharu, Kelantan. She received her primary education at Sekolah Kebangsaan Raja Abdullah and her secondary education at Sekolah Menengah Kebangsaan Melor, both in Kota Bharu, Kelantan. She did her foundation at Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia (UPM). She then furthered her tertiary education at Univer) in siti Putra Malaysia and graduated with a Bachelor of Engineering (Agricultural and Biosystem in 2015. She currently a postgraduate student for Master of Science degree in Mechanization and Automation in Agricultural Engineering from Universiti Putra Malaysia.

LIST OF PUBLICATIONS

S. S. R. M. Lazim and N. M. Nawi (2016). ‘Potential application of spectroscopic method for size and shape detection fruirs; A review’. Proceedings of the “International Conference on Agricultural and Food Engineering (Cafei2016), 23-25 August 2016, Kuala Lumpur. Pp: 318-322.

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UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _______________

TITLE OF THESIS / PROJECT REPORT :

NON-DESTRUCTIVE ASSESSMENT OF THE INTERNAL QUALITY OF WATERMELON USING ULTRAVIOLET NEAR-INFRARED SPECTROSCOPY

NAME OF STUDENT : SITI SARIPA RABIAH BINTI MAT LAZIM

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