UNIVERSITI PUTRA MALAYSIA

APPLICATION OF LASER-INDUCED BACKSCATTERING IMAGING SYSTEM FOR CLASSIFYING DIFFERENT RIPENING STAGES OF Musa acuminata cv. Berangan BANANAS

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By

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

APPLICATION OF LASER-INDUCED BACKSCATTERING IMAGING SYSTEM FOR CLASSIFYING DIFFERENT RIPENING STAGES OF *Musa acuminata* cv. *Berangan* BANANAS

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Inadequacy and inefficiency of monitoring quality systems for fruits have made a great impact that leads to an increasing number of post-harvest losses as they could have been damage during storage. Fruits undergone complex changes in their biochemical and physicochemical during ripening process. This study evaluates the potential of the backscattering imaging system to evaluate the bananas at different ripening stages.

Backscattering image (BSI) of *Musa Acuminata* cv. Berangan was captured by a charge coupled device (CCD) camera and a laser diode emitting light at 658 nm. The system consisted of CCD camera with a zoom lens (focal length 18-108mm), a solid state laser diode of 658 nm at 1mm diameter as a light source and a computer equipped with an image processing software for automated image analysis. A total number of 360 samples of *Musa Acuminata* cv. Berangan from ripening stages 2 to 7 with 60 samples per stage group were used in this study. The gray level intensity and size of the backscattering area were used for estimating the quality properties of bananas. The results showed that the highest correlation was found between BSI parameters and total soluble solids content (TSS). Moreover, linear discriminant models were built for the two- class (unripe, ripe) and six-class (based on the commercial colour index) of ripening stages classifications. The overall accuracy for two-class and six-class classifications resulted in 94.2% and 59.2% classification accuracies, respectively. It can be concluded that the laser light-induced backscattering imaging could be potentially used for predicting the ripening stages of bananas and could be further developed for an automated quality control system.

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

PENGGUNAAN SISTEM PENGIMEJAN LASER SECARA SERAKAN BALIK CAHAYA DALAM PENGKLASIFIKASIAN TAHAP KEMATANGAN *Musa acuminata* cv. PISANG BERANGAN

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Ketidakcekapan dalam sistem kualiti pemantauan buah-buahan telah memberikan impak yang besar yang membawa kepada peningkatan jumlah kerugian lepas tuai. Perubahan kompleks dalam biokimia dan fizikokimia berkait rapat dengan proses kematangan buah selepas penuaian. Oleh kerana itu, kajian ini bertujuan untuk menilai potensi sistem pengimejan laser pembalikan untuk menilai tahap kematangan buah yang berbeza.

Imej pembalikan *Musa Acuminata* cv. Berangan dirakam oleh peranti camera (CCD) dan sinaran laser yang memancarkan cahaya pada 658 nm. Sistem ini terdiri daripada kamera CCD yang ditambah dengan lensa zoom (panjang fokus 18-108mm). Komputer yang dilengkapi dengan perisian pemprosesan imej digunakan untuk imej automatik analisis. Sebanyak 360 sampel pisang Berangan dari peringkat tahap kematangan yang berbeza (2-7) telah digunakan dalam kajian ini. Keamatan imej dan saiz yang menunjukkan penyerakan cahaya telah dipilih sebagai faktor bagi menentukan tahap kematangan buah. Keputusan menunjukkan korelasi yang paling tinggi didapati antara parameter imej dengan dan jumlah gula larut pepejal . Selain itu, model diskriminan linear telah dibina untuk dua kelas (muda, masak) dan enam kelas (berdasarkan indeks warna komersial).Klasifikasi ketepatan keseluruhan untuk pengelasan dua kelas dan enam kelas masing-masing adalah sebanyak 94.2% dan 59.2%. Sebagai kesimpulan, sistem pengimejan laser pembalikan boleh digunakan untuk meramal tahap kematangan lepas tuai pisang dan mempunyai potensi yang tinggi untuk digunakan bagi sistem kawalan kualiti automatik dalam industri pertanian.

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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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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.

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LIST OF ABBREVIATIONS

BSI	Backscattering image
HIS	Hyperspectral imaging system
LBI	Light backscattering imaging
LLBI	Laser light backscattering imaging
MHI	Multispectral imaging system
MLD	Modified Lorentzian distribution
Ph	Potential hydrogen
RGB	Red, green, blue
RH	Relative humidity
ROI	Region of interest
SSC	Soluble solid contents
TA	titratable acidity
TSS	Total soluble solids
ANOVA	Analysis of variance
CHLa	Chlorophyll a
CHLb	Chlorophyll b.
CIELAB	Commission Internationale de l'Eclairage's
HIS	Hue, saturation, intensity
HSV	Hue, saturation, value
HSL	Hue, saturation, lightness
HSB	Hue, saturation, brightness
MGF	modified Gompertz function
RMSE	Root mean square error
R^2	Coefficient of determination
MLR	Multilinear regression
SVM	Support vector machine
PCA	Principle component analysis
NN	Neural network
LDA	Linear discriminant analysis
PLS	Partial least squares
GL	Gaussian–Lorentzian cross product
FWHM	Full width at half maximum
NAI	Normalized anthocyanin index
IP	Inflection point

CHAPTER 1

INTRODUCTION

1.1 Background of study

Definition of fruit quality has been described by numerous perspectives which can be classified based on product and custom orientation (Shewfelt, 1999). However, the interpretation of quality varies from individuals as the definition is subjective, depending on the perception of the sensation of smell, touch, sight and taste before making a response to the values of the fruit (Abbott, 1999). Shewfelt (1999) defined the term quality based on product orientation, which can be viewed as the accessibility to distribute products through a marketing chain by preserving the specific quality parameters that relate to consumer satisfaction. Numerous studies have been performed to describe fruits acceptance and consumption by relating to how customers define the quality attributes for fruits (Harker et al., 2003; Péneau et al., 2006; López et al., 2007; Harker et al.,2008).

The non-destructive, laser light backscattering imaging (LLBI) is one of recent advanced computer vision techniques in the agriculture industry which is based on the investigation and measurement of signal produced in a specific spectral range of an electromagnetic spectrum upon an interaction with the materials (Mollazade et al., 2012). Physical, chemical and mechanical properties of a fruit are described based on the recorded BSIs as the scattered photons are influenced by the cell size and the connected tissue matrices (Lu, 2004).

There has been much progress on developing this non-invasive technique to assess the internal and external qualitative attributes for various fruits. The technique has been used to detect quality in oranges (Lorente et al., 2015), bell peppers (Romano et al., 2012), kiwis (Baranyai and Zude, 2009) and apples (Qing et al., 2008). However, most researches on the applicability of this technique are only limited in evaluating non-climacteric fruits. Only a few reference analyses regarding the physicochemical properties of bananas that cause changes in BSI properties have been studied. For example, previously, the research on the applicability of LLBI techniques to monitor chilling injury (Hashim et al., 2013) and evaluating the effects of the drying treatment (Romano et al., 2008) for bananas have been reported. At the present time, not much research has been done to discover the applicability of LLBI to evaluate the quality of bananas at different levels of maturity.

1.2 Problem statements

Banana (*Musa spp.*) is an industrial crop which covers 27,085 hectares of the planted area in Malaysia with an average yield of 12.7 tonnes per hectare (Ministry of Agriculture and Agro-Based Industry, Malaysia, 2014). It is important to apply the best production practice for a consistent supply of high-quality banana since the demand is high for export and local consumption. Therefore, the formation of bananas' commercial standards needs to be upgraded by identifying the quality attributes that relate with the new trend of market acceptance.

Standard reference methods in determining the fruit quality only represent the batch size of experiments; they are destructive, expensive, require considerable analytical skill and are not suited for automation. Therefore, the simplification for quality automatic detection technique such as the LLBI system is explored in order to achieve the expectation of quality in bananas, hence reducing the production and management costs. By using this imaging technique, the evaluation of light scattering image captured at a specific wavelength is performed to quantify the spatial variation for facilitating the assessment of visual quality characteristic for bananas.

1.3 Importance of the study

This study is concentrated on evaluating the potential of LLBI technique using a single laser diode as an illumination source to classify the fruit according to the respective ripening stages. The development of this imaging system is a better proportion among non-destructive techniques to determine the quality of banana to overcome the shortfalls in using the destructive methods. The evaluation on physicochemical properties of bananas at different ripening stages can facilitate the wholesalers or fruit distributers to improve post-harvest operations, including cleaning, sorting, packing etc.

The acquisition set up of LLBI system can be easily adjusted due to the coherent behavior of the laser beam. Most laser diodes can be operated using small battery-powered supplies and require low current to provide a highly proficient light delivery instrument penetrating through the fruit surface. Proper selection of image acquisition devices and their configuration set up are important to acquire good image data. A simple algorithm could also be developed for image processing as the setting up of the imaging environment is already improved during the acquisition of BSIs. Most importantly, this imaging technique requires minimal number of samples that can be non-destructively evaluated, thus replacing the available standard reference techniques.

1.4 Objectives of the study

The main objective is to study the potential of backscattering imaging in evaluating bananas at different ripening stages. Meanwhile, the specific objectives are:

i. To analyze the colour , firmness, total soluble solids (TSS) and pH of bananas at different ripening stages by means of LLBI technique and standard measurements
ii. To evaluate the relationship between fruit properties and BSIs
iii. To formulate quantitative prediction models relating the best combination of backscattering parameters to the selected standard values
iv. To develop and validate discriminant models for classification by means of assessing the ripening stages of bananas

1.5 Scope and limitation

The study is only focused on the Berangan bananas (*Musa Acuminata* cv.Berangan) for the range of maturity level between 2 to 7. Variation in colour, firmness, SSC and pH of bananas stored without any inducement to fasten the ripening process have been investigated by acquiring BSIs at 658 nm wavelength.

1.6 Thesis overview

This thesis comprises of five (5) chapters, where Chapter 1 explains the background, problem statements, importance of the study, research objectives, scope and limitation of the study. Chapter 2 provides the literature review on quality properties of bananas and the changes that occur during the ripening process, current post harvest practices, non-destructive techniques used to evaluate fruit quality, the development and the application of laser light backscattering imaging (LLBI) system. Chapter 3 will then describe the experimental set up of the acquisition of BSIs using the LLBI system, standard reference measurements and statistical analyses. The results and findings of the issues will be discussed in Chapter 4. Finally, the last chapter will provide the summary and conclusion of the study. Besides that, several recommendations are given based on the findings discussed in previous chapters.

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