EPiC Series in Engineering
Volume 5, 2023, Pages 81–90
Proceedings of International Symposium on Applied Science 2022

Using VIS – NIR imaging for non-intrusive Musa Acuminata banana color changes assessment over a maturity period

Anh Xuan Nguyen[1,3*], Minh Chau Ta Ngoc[1,3*], Huu Tai Duong[1,3*], My Ngoc Nguyen Thi[1,3*], Quy Tan Ha[1,3*], Hong Duyen Trinh Tran[1,3*], Trung Nghia Tran[2,3*]

[1)] Faculty of Applied Science, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, Ward 14, District 10, Ho Chi Minh City, Vietnam

[2)] Laboratory of General Physics, Faculty of Applied Science, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, Ward 14, District 10, Ho Chi Minh City, Vietnam

[3)] Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc City, Ho Chi Minh City, Vietnam

xuan.nguyenjackie@hcmut.edu.vn; chau.tabkhcm@hcmut.edu.vn; tai.duong0602@hcmut.edu.vn; ngoc.nguyenbme@hcmut.edu.vn; tan.habk1612@hcmut.edu.vn; tt_hd2005@hcmut.edu.vn; ttnghia@hcmut.edu.vn

Abstract

Bananas are a source of nourishment that is essential for good health. During ripening, the pigment content, starch index and sugar content of banana fruit change, providing accurate indicators for maturity classification. However, at present, banana fruits are traded according to their color stage. The purpose of this study is to visualize analysis banana color changes using a nondestructive method based on multispectral image processing since fruit quality can be assessed quickly, while the fruit being tested is still whole and marketable. This experiment designed a monochromatic camera and a set of four different optical wavelengths in VIS-NIR bands of Blue (465-467nm), Green (522-525nm), Red (620-625nm) and Near-IR (peak at 940nm) to capture the multispectral images of Musa Acuminata banana. This advanced optical detection technique (multi-spectral imaging) can provide the spectral reflectance of any pixel, combined with the preprocessing of a binary mask to create image segmentation, the ROIs (Region of Interest segmentation) method is then used for extracting spectral intensity data on the banana surface of each single wavelength over the ripening process of banana. With an

[*] Created the first draft of this document

understanding of the optical characteristics of fruit tissues (both external and internal characteristics), this research focuses on external characteristics (color components) to properly assess banana quality. The outcomes demonstrate that the behavior of resulting graphs successfully determine spectral intensity profile changes to classify the color changes as well as four main stages of classification of raw, unripe, ripe and overripe banana.

1 Introduction

In Vietnam, the banana represents one of the most significant crops in agriculture, ranking first in terms of tropical fruit production. The short life of the banana due to its fast-ripening process which degrades the visual appearance starts with a greenish yellow peel and finishing with a brown yellow peel with black regions at the tip. The ripeness of a *Musa Acuminata* banana *(Chuoi Su)* is observed the color change of the peel and divided visually into 7 principal maturity levels (Table 1).

Day	Level	Picture of Banana	Peel color	Maturity Level
1	1		Green	Raw
	2		Green with a little yellow	Raw
2	3		Green more dominant than brown yellow	Unripe
	4		Brown yellow more dominant than green	Unripe
3	5		Flecked with brown spots and a little green in banana abdomen	Ripe
	6		Completely brown yellow with black at the tip	Ripe
4	7		Black region at the tip spread out	Overripe

Table 1. The seven phases of banana ripening

Techniques for evaluating the quality of fruits are crucial to both their production and consumption. Many research organizations worldwide have looked into the possibility of visible-near infrared (VIS-NIR) spectroscopic measurements for fruit grading since they may be performed in a non-destructive manner. While VIS-NIR absorption is connected to several significant chemical quality factors, such as total sugar concentration, scattering is related to the physical features of the fruit (e.g., density, particle size, and microstructure) [1].

With an understanding of the optical characteristics of fruit tissues, this research focuses on external characteristics (color components) to distinguish the banana quality at various maturity stages. Therefore, the purpose of this article is to analysis images based on multispectral imaging, useful for identifying the changes of color of a banana *(Musa Acuminata* banana*)* from the initial stage (completely green) of the growth phrase to the seventh stage (black region at the tip spread out).

2 Materials and Methods

2.1 Sample Preparation

The *Musa Acuminata* banana sample set was purchased from a local market and was manually chosen to be as uniform as possible. The experiment employed 10 banana hands in total and all of the bananas were chosen at the beginning of the first stage, when the banana peel was totally green (see *Figure 1*). Experiments were performed after the bananas had been kept at room temperature (~29°C) for at least one day.

2.2 Model Setup and Methodology

The detection of the color changes during the banana ripening process was performed through the following methodology:

(a) *Figure 1* depicts the schematic of the multispectral imaging prototype. All the required elements are present in The Dark Room (light isolated box). There are two distinct chambers within The Dark Room. In order to reduce the quantity of reflected light surrounding the sample, the Chamber's walls are painted entirely black.

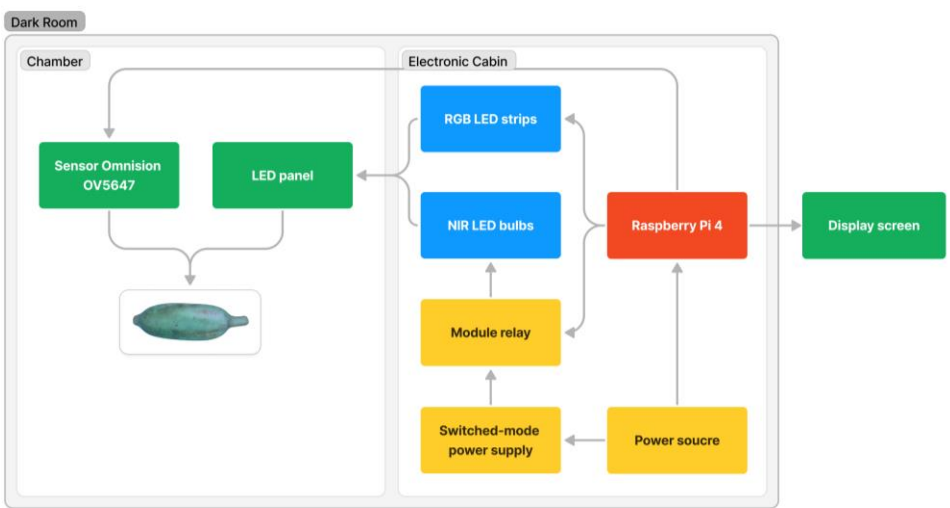


Figure 1. Diagram of Multispectral Imagery System

The selected bananas were placed in a multispectral imagery system for a period of 5.5 days. Each sample was moved to the front of the camera for 3-hourly (for R, G & B wavelengths) and 12-hourly (for NIR wavelength) capturing iterations of the multispectral imagery.

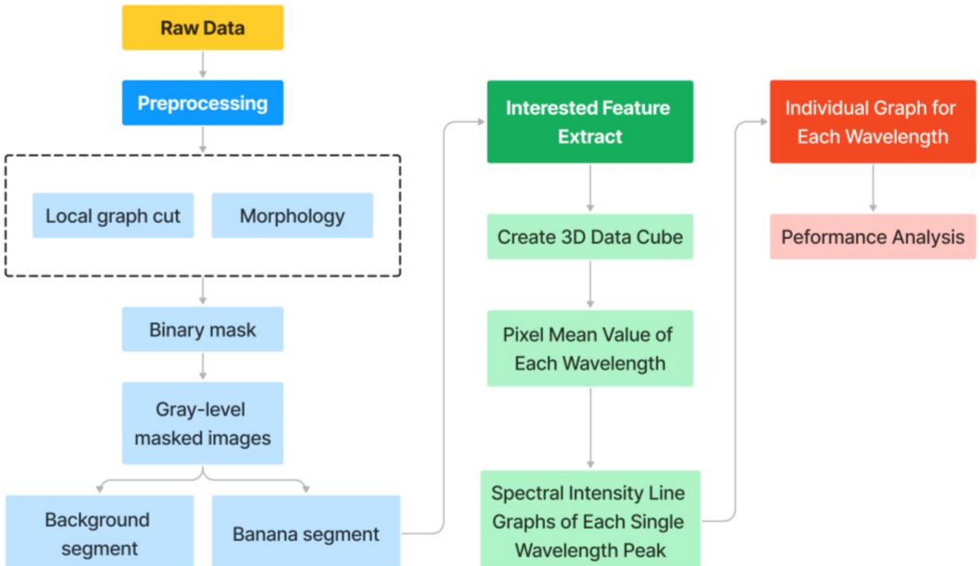


Figure 3. Banana Multispectral Imaging Analysis Process

(b) *Figure 2*. Input: Since the setup includes four different wavelength light source, the daily database consisted of four sets of four separated spectrum images. After 5.5 days, a total of 44 sets under each single R, G, and B illumination (132 images per each sample) and 12 sets of NIR illumination (12 images per each sample) were acquired.

(c) Preprocessing: draw local graph cut to create a binary mask. Then the mask was processed by morphology method to generate a new binary mask. Finally, these images were converted into gray-level masked images (banana segment and background segment).

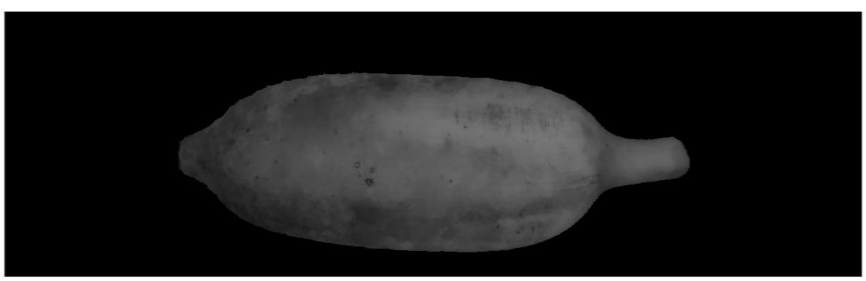


Figure 2. A gray-level masked image

(d) Interested Feature Extract: merge 3 R, G, and B channels data and a separated NIR channel data to create 3D data cube (providing image information in the spatial domain (x, y) as well as in the spectral domain (λ)). Then, the sum of each channel's pixels was divided by the channel's accessible pixels (banana pixels only; background pixels were not included). This gave the (object) **pixel mean intensity** for each channel.

(e) Output: Plotting the spectral intensity line graphs with 4 certain wavelength peaks of Blue (465 nm), Green (525 nm), Red (625 nm) and NIR (940 nm) and analysis banana color performance over the time.

2.3 Optical Reflectance Characteristics in Banana Tissues

In general, fruit quality is associated with the development of characteristic varietal flesh and skin color. Various fruits exhibit different physiological and chemical changes as they mature. Most common to all and perhaps the most obvious and significant is the loss of green color. Furthermore, reflectance is a representation of the chemical composition of a banana, some of which are more abundant while the banana is raw and others when it is ripe.

The luminance of the surface of an object being observed for each channel is the product of the corresponding illumination and the reflectance, The pixels intensity of the surface of an object being observed for each channel is proportionally to its reflectance [2]. In other words, the mean pixel intensity and the reflectance have the similar trend.

Pixel Mean Intensity (m) Formula:

$$m = \frac{\sum_{k=1}^{n} i_k}{n}$$

where k: pixel number (1, 2, 3, …, n)
n: total pixels of banana segment
i_k: pixel intensity at k

2.4 Region of Interest segmentation (ROIs)

Local graph cut is a simple and fast technique for characterizing image regions based on constant reflectivity or light absorption of their surfaces. Edge-based segmentation relies on edge detection by edge operators. Edge operators detect the sharp discontinuities in gray level, color, texture, etc., in the image. Region-based segmentation involves the grouping together of similar pixels to form regions representing single objects within the image (such as in the seeded region growing method). The segmented image may then be represented as a boundary or a region. Boundary representation is suitable for analysis of size and shape features, while region representation is used in the detection and evaluation of texture, defects or simply ROIs. A region of interest (ROI) is a portion of an image needed to filter or operate on in some way. ROI was presented as a binary mask image. In the mask image, pixels that belong to the ROI are set to 1 (white) and pixels outside the ROI are set to 0 (black) [3].

In general, successful results are found for the identification of the true area of a banana since the intensity distribution of the banana peel and background pixels are sufficient distinct. The sample of multispectral image segmentation used in this research is simple ROI to get the reflectance data on the banana surface. An ROI took manually around the banana by drawing a polygon with 2160 x 3840 pixels size covering the whole banana peel. This step will produce a set of cube image with dimension 2160 x 3840 x 4. The aim of using a ROI polygon is to optimize the separation of the object and the background segments since it reduces the noise of the background as well as the surrounding condition, compared to a ROI rectangular.

2.5 Morphology method

Morphology is a broad set of image processing operations that process images based on shapes. Morphological operations apply a structuring element to an input image, creating an output image of the same size. In a morphological operation, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbors.

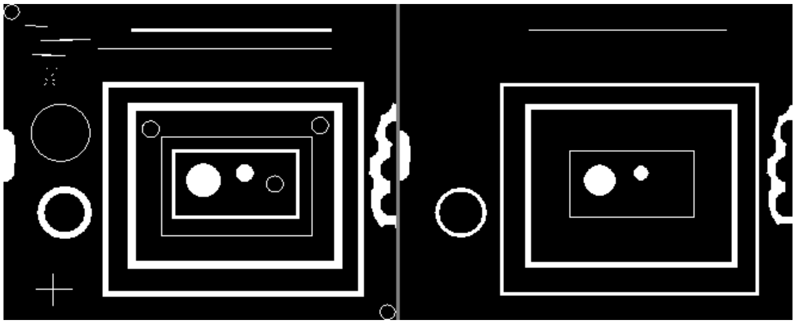


Figure 4. Morphological erosion illustration

Erosion is one of the most basic morphological operations that removes pixels to the boundaries of objects in an image. The value of the output pixel is the minimum value of all pixels in the neighborhood. In a binary image, a pixel is set to 0 if any of the neighboring pixels have the value 0. Morphological erosion removes floating pixels and thin lines so that only substantive objects remain. Remaining lines appear thinner and shapes appear smaller [3] .Thereby, the separation of the object and the background segments were optimized.

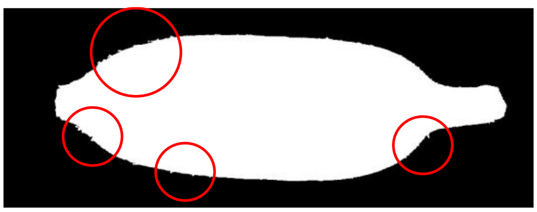


Figure 5. A binary mask before erosion

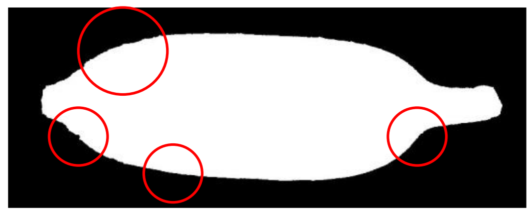


Figure 5. A binary mask after erosion

3 Results and Discussion

3.1 Spectral Analysis

a. Our experimental results:

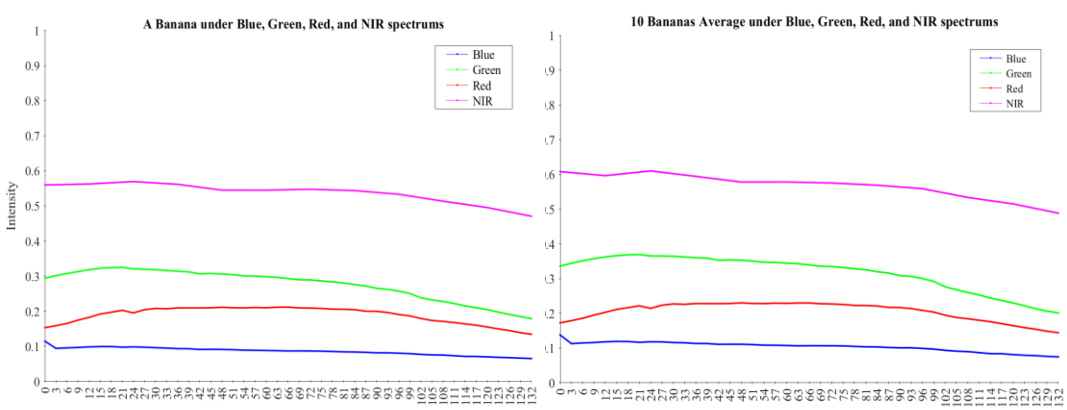


Figure 6. Intensity line graphs of four wavelength peaks over the maturity time of one banana and the ten-average banana

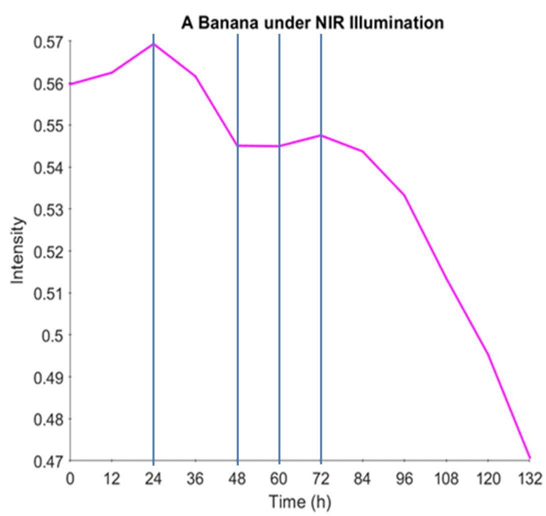
Figure 6 shows the mean intensity value of the spectral range of Blue (465 nm), Green (525 nm), Red (625 nm) and NIR (940 nm) at different maturity levels. The common trend of intensity as well as reflectance of the observed banana for Blue, Green and NIR spectrums is fluctuating, then eventually decreasing. Meanwhile, there is an escalation of mean intensity for Red channel before a descending over the maturity period.

In order to clear to compare the intensity trend of each channel, *Figure 7* and *Table 2* describe the approximate mean intensity value and four separated line graphs indicating the intensity change of a banana, respectively. Three main internal contents variations of banana are sugar content, chlorophyll, and moisture content significantly affect the mean intensity alteration of each spectral.

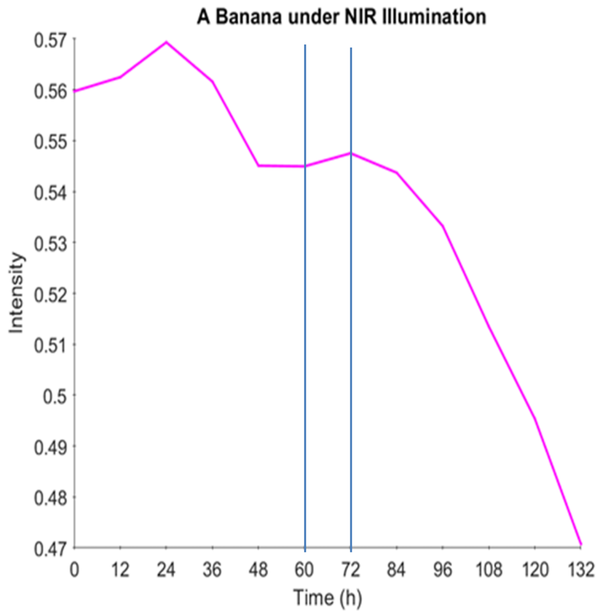
Maturity levels	**Stage**	**Intensity comparison of 4 channels (0 – 1 range)**
1 - 2	Raw	NIR (~ 0.6) > Green (> 0.3) > Red (> 0.15) > Blue (> 0.1)
3 - 4	Unripe	NIR (< 0.6) > Green (~ 0.3) > Red (> 0.2) > Blue (~ 0.1)
5 - 6	Ripe	NIR (~ 0.55) > Green (= 0.3) > Red (= 0.2) > Blue (~ 0.1)
7	Overripe	NIR (~ 0.5) > Green (~ 0.2) > Red (~ 0.15) > Blue (< 0.1)

Table 2. The mean intensity value of RGB & NIR components from banana maturity

Moisture content spectral bands last from 800 – 960 nm. The unripe banana has a little moisture compared with a ripe banana. The moisture content increases in fruit flesh at the onset of maturation because respiration breaks down starch and osmotic water movements from skin to flesh. Simultaneously, water is also lost from the skin externally due to transpiration until the maturity process ends [4].

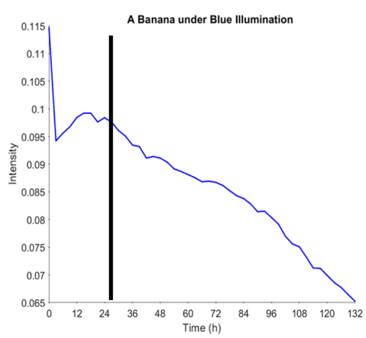


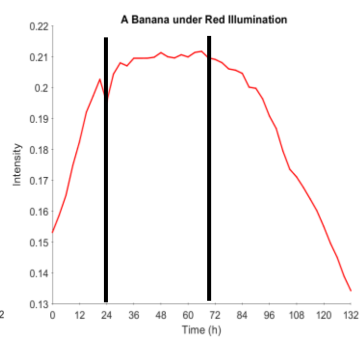
The unripe fruit peel had higher moisture and correspondingly the reflection was also higher for the unripe fruits representing stages 1-2 (raw). Since, water content is the most abundant constituent in the pulp and peel of banana. The water content increases in the pulp during the onset of ripening due to respiratory break down of starch and osmotic movement of water from peel to pulp. At level 3 and 4, the reflection was lower since the water is also lost from the peel externally due to transpiration until ripening process end. The peel tissue prevents further water losses from 4 to 5 stages. After that, the fruits had significantly higher amount of moisture in the pulp due to respiratory break down of starch and degradation of fruit. The fruits continuously lost moisture degradation of fruit throughout the next levels.

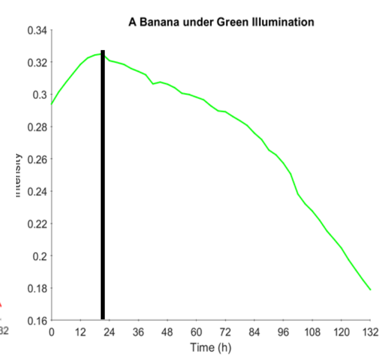


Raw fruit with little sugar content will have high reflectance, whereas mature or over-mature fruit with high sugar content would have low reflectance [5]. Sugar content spectral bands last from 734 – 946 nm. The starch content was found to be converted into sugars and soluble solids. Glucose, fructose, and sucrose contribute to the increase in sweetness with increasing ripening. However, sucrose was perceived in emphatic amount after 4th stage of ripening. At level 5 – 6, the sugar content was be associated with the increase in activity of enzymes which was accountable for starch hydrolysis and the decrease in the rate of sugar breakdown by respiration which increases sugar level. Due to decreased strength of starch hydrolysis, an increase of moisture and a decrease of soluble solids which decreases sugar content at the last level.

There are mainly two types of chlorophyll, named a and b, chlorophyll a (peaks at 430 nm & 662 nm) and chlorophyll b spectral bands (peaks at 453 nm and 642 nm. It involves the degradation of chlorophyll, resulting in the exposure of the carotenoids (yellow, orange, and red organic pigments) giving a characteristic maturity symptom of yellowing. Consequently, due to loss of chlorophyll as the banana maturity they exhibit reduced absorbance (increased reflectance) [6]. Three figures below show that Blue (465 nm) was strongly absorbed by chlorophyll b while Green (525 nm) was weakly absorbed by both chlorophyll a and b and Red (625 nm) was medium absorbed by both chlorophyll a and b. At level 1 – 3, total chlorophyll increases then decrease in the next levels.







b. Other Research Results Comparison:

Figure 8 shows the average reflectance value of the spectral range of 400 – 1000 nm at different maturity levels. Compared to this paper, in similarly, the trend of spectral reflectance of Blue channel (465 nm), Green channel (525 nm) and NIR channel (940 nm) is slightly decreasing, while the figure increased before reducing at Red channel (625 nm) over the *Musa Acuminata* banana maturity period. In the 680 – 700 nm spectral bands that identify chlorophyll levels can be seen when immature and very mature bananas have almost the same reflectance value, while ripe bananas have high reflectance values. There reflectance value at immature and very mature levels is not because it has the same chlorophyll content but at the very mature level the skin color [7]. In general, spectral bands of 800 - 960 nm indicates the moisture content of the fruit [8]. The reflectance curve that represents sugar content is about 734 – 946 nm [9].

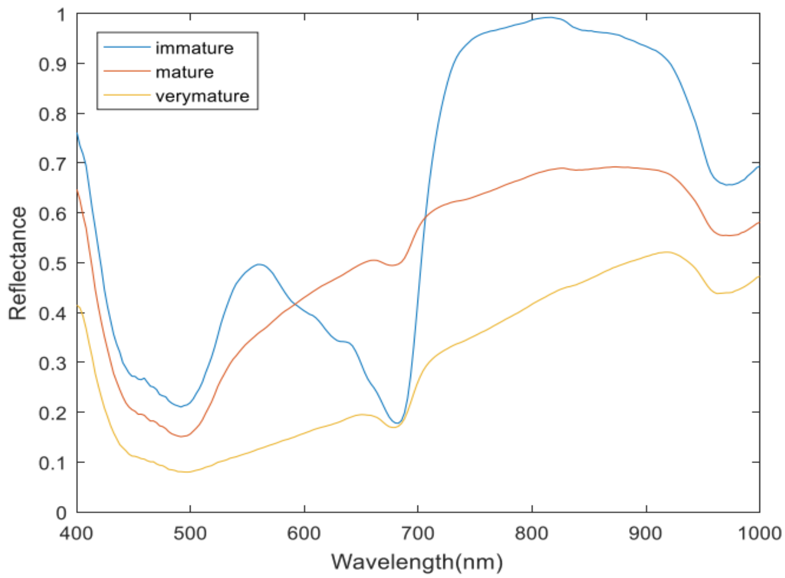


Figure 8. The average reflectance value of the spectral range of 400 – 1000 nm at different levels **[7]**

c. Limitation:

More wavelengths should be experimented to more data to analyze and more calculations to determine a general formula of the relationship between the pixel mean intensity of four R, G, B, and NIR spectrums in banana maturity level classifications.

4 Conclusion

This research has correctly identified spectral banana intensity variations to categorize color changes as well as the four primary phases of categorization of raw, unripe, ripe, and overripe bananas by using four-spectral imaging analysis. Mean intensity value for Blue (465-467nm) spectrum has a minimal difference over the banana maturity period compared to three other observed spectrums of Green (522-525nm), Red (620-625nm) and Near-IR (peak at 940nm), which mean it is less contributing in observation and classification of banana color than the others.

5 Acknowledgement

This research is funded by Ho Chi Minh City University of Technology (HCMUT) – VNU-HCM under grant number SVOISP– 2022–KHUD–xxxxx. We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

References

[1] Mauro Santoyo-Mora, Agustin Sancen-Plaza, Alejandro Espinosa-Calderon, et al, "Nondestructive Quantification of the Ripening Process in Banana (Musa AAB Simmonds) Using Multispectral Imaging," *Journal of Sensors,* vol. 2019, no. Article ID 6742896, p. 12 pages, 2019.

[2] A. Bovik, "Chapter 21 - Image Quality Assessment," in *The Essential Guide to Image Processing,* Academic Press, 2009, pp. 553-595.

[3] "Mathworks," [Online]. Available: https://www.mathworks.com/.

[4] S. T. Wahyuni Siregar, W. Handayani and A. H. Saputro, "Bananas moisture content prediction system using Visual-NIR imaging," *2017 5th International Conference on Instrumentation, Control, and Automation (ICA),* pp. 89-92, 2017.

[5] Omar AF, MatJafri MZ, "Near-Infrared Spectral Linearization in Quantifying Soluble Solids Content of Intact Carambola," *Sensors (Basel),* p. 4876–4883, 2013.

[6] S. Gunasekaran, M.R. Paulsen, G.C. Shove, "Optical methods for nondestructive quality evaluation of agricultural and biological materials," *Journal of Agricultural Engineering Research,* vol. 32, no. 3, pp. 209-241, 1985.

[7] Saputro, A. H., Juansyah, S. D., & Handayani, W., "Banana (Musa sp.) maturity prediction system based on chlorophyll content using visible-NIR imaging," in *2nd International Conference on Signals and Systems, ICSigSys 2018,* Bali, 2018.

[8] P. Rajkumar, N. Wang, G. EImasry, G. S. V Raghavan, and Y. Gariepy, "Studies on banana fruit quality and maturity stages using hyperspectral imaging," *Journal of Food Engineering,* vol. 108, no. 1, p. 194–200, 2012.

[9] D. Akmalia, A. H. Saputro and W. Handayani, "A non-destruction measurement system based on hyperspectral imaging for sugar content in banana (Musa sp.)," *2017 International Seminar on Sensors, Instrumentation, Measurement and Metrology (ISSIMM),* pp. 91-94, 2017.