

VISIBLE SPECTRAL IMAGING TECHNOLOGY FOR EARLY DETECTION OF MECHANICAL DAMAGE IN MANGO (*MANGIFERA INDICA* L.)

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ABSTRACT

This study aimed to detect early mechanical damage on mango fruits based on optical reflectance using a proposed visible spectral imaging technique. An experimental visible spectral imaging device was developed to acquire images from the surface of mango fruit. Acquired mango images underwent image processing and analysis using the ImageJ software. The composite and the adjusted threshold images were used in the evaluation of bruise signatures. Bruise signatures were detected in the form of dark spots at minimum and maximum threshold values of 24.70 and 39.88, respectively. The first three days of mango fruits were categorized as early stage of detection. The highest device efficiency in detecting early mechanical bruises of mango fruit was established on the third day using the threshold RGB image with a mean bruise detection efficiency of 51.11%. The developed protocol was proved to be an effective technique in detecting early mechanical bruises in mango fruit.

Keywords: Red, Green, Blue (RGB); Bruise detection efficiency; Protocol

INTRODUCTION

Mango (*Mangifera indica* L.) is the national fruit of the Philippines and is the third most important fruit crop of the country. It ranked third both in terms of volume and value among the exported fruits of the country.

Current sorting techniques of marketable mango fruits are done manually. This method of manual sorting is tedious, laborious, time-consuming, inconsistent, less efficient, inaccurate process and costly [2]. Also, a manual sorting cannot detect mechanical bruises during the unripe or early yellow stage of mango.

The application of visible spectral imaging technology to the mango fruit quality inspection has the potential in estimating the internal properties or detecting invisible damage. If the quality evaluation is achieved automatically, mango fruits will be properly sorted and a high quality mango fruit product will be achieved.

Detecting early mechanical damages in mango is necessary to remove low quality

fruits. This saves time, money and energy in transporting the low market value fruits to the consumers because the damaged ones are earlier identified and separated from the good ones.

Specifically, the study aimed to: devise and implement a visible spectral imaging setup based on an open spectrum digital single lens reflex camera (digital SLR or DSLR) with a charge-coupled device (CCD) image sensor within the visible (VIS) region of the light spectrum; calibrate and evaluate the visible spectral imaging setup; acquire and extract reflectance spectral signatures of mango fruit in the red, blue and green color channels using the computer imaging software; and, develop a protocol for early detection of bruises in mango and evaluate its effectiveness.

REVIEW OF LITERATURE

The light consists of various wavelengths that reveal something about the composition of the object. This is because every chemical has

its own spectroscopic fingerprint. Applying the method to fruit or vegetables in essence allows their composition to be determined, not only at the surface but also deeper below the skin [3]. The information about interaction between light and biological tissue is essential in visual evaluation of fresh horticultural produces, raw materials and food, since optical signal is significantly affected by physical stage and valuable compounds of the tissue [1].

Optical properties as shown in Figure 1 are based on reflectance, transmittance, absorbance, or scatter of light by the product. When light beam hits the fruit, a small fraction is reflected at the surface (specular reflectance) and the rest will penetrate into fruit tissue. Upon entering the fruit tissue, photons scatter in different

directions for various times before being absorbed or exiting from the fruit at various distances from the incident point (this reflected light is called diffuse reflectance). Absorption and scattering are the two basic phenomena as light interacts with biological materials. Lights absorption is related to certain chemical constituents in the fruits, such as sugar, acid, water, etc. [6].

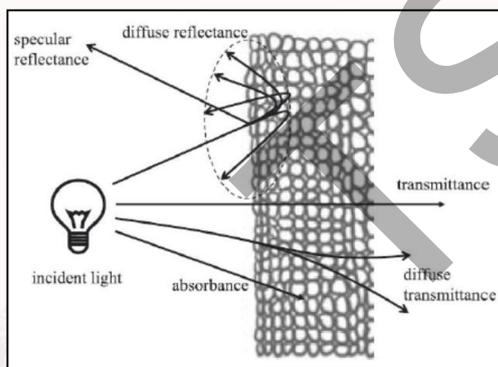


Fig.1. The incident light striking the tissue cells of food and undergoing reflection, absorption and transmission

A large volume of literature and authors relate relationship of bruised or damaged part of fruit and its reflectance characteristics. Bruising normally happens to the tissue beneath the fruit skin. After the fruit tissue is damaged, its cells are initially filled with water and turn brownish. As time elapses, the damaged cells start to lose moisture and eventually become desiccated.

MATERIALS AND METHODS

For the development of experimental visible spectral imaging device, the concept of machine vision in visible spectral imaging was considered. The device setup was composed of an imaging unit and a lighting unit for its hardware. For the imaging unit, a digital camera with CCD image sensor was used to capture the reflected visible lights in the electromagnetic spectrum. Also, LED (light-emitting diodes) technologies that are capable of emitting the visible light ranges, were the primary components of the lighting unit.

Preliminary testing and calibration were conducted to secure proper imaging performance of the device before the image acquisition process. The experiment was conducted in a dark setting. The camera and the imaging chamber dark references were validated by acquiring images at the closed lens setting of the camera and inside the totally closed chamber. Also, the pre-image acquisition procedure was conducted to establish a correct imaging setting of the device. Mango fruit images were acquired at 0, 10, 20, 30 and 40 cm vertical distance of the sample stage from the bottom of imaging frame and at 18, 35 and 55 mm focal length of camera.

Ninety defect-free samples were manually selected through visual and touch inspection. Collection of mangoes was performed in 3 batches within 3 consecutive days and in each batch 30 mangoes were collected. Mechanical damage induction to the samples was executed immediately in 24 hours after harvesting. This assured that latex no longer dripped from a mango fruit. Images of the samples were acquired before and after inducing mechanical damage.

Eighteen samples were dropped on one face of the fruit from each of the four different vertical heights (30, 54, 78 and 102 cm) to the impact platform. A mango sample was carefully positioned by hand using a meter stick placed and legibly calibrated on the wall. Newsprint spread over the concrete floor was used as the impact surface since newsprint is a common cushioning material used in handling mango fruits. Since it was difficult to control the impact position of the mango fruit, the fruit was allowed to free fall and the fruit surface in contact with the floor was marked as the point of impact.

Imaging of mango samples was done in two dimensions with one image in every shot. Also, a white background of the samples was used to facilitate segmentation. Images were acquired manually by placing the fruit inside the inspection chamber and preparing it for image acquisition. Imaging of samples was performed daily for six days, the period when fruits were expected to ripen. Samples were placed at room temperature during the course of imaging. Acquired mango images underwent image processing and analysis using the ImageJ software which included: image segmentation; extraction of region of interest (ROI) image; red blue, green (RGB) color channel and image pixel intensity extraction and image thresholding. The composite and the adjusted threshold images were used in the evaluation of bruise signatures.

Detection of mechanical bruises was done by daily evaluation of each of the acquired images. Bruises were expected to be detected in the RGB images, and they could appear as either dark, brown or bright spots, not necessarily following the same pattern in the original or untransformed images. In the case where bruises were not detected in any RGB images, another composite image was created by a combination process (addition, subtraction, multiplication or division of the RGB channel) using the corresponding pixel values of the three color channels. RGB image was adjusted into threshold type of image for easier interpretation.

The detected spots were confirmed, as true bruise or not, by peeling off the mango fruit or by waiting for it to ripen and have the bruise presented itself. This method validated if the location of damage inside the fruit was the same location of the detected spots. Also, the detected spots were checked by comparing the images taken before and after inducing impact force on the uncontrolled mango samples (samples under L1, L2, L3 and L4 treatments). All detected bruises were checked if some of the bruise features appeared on the undamaged fruits.

The analysis of bruises on the composite type of image was based on the range of subjective bruise scores to characterize visual bruising [5]. A binary response for bruise description was a score of 0 and 1 for the absence and presence of bruises, respectively.

The total number of randomly selected mango fruit samples that were subjected to impact and underwent bruise detection using the imaging device was recorded. The correctly identified number of samples with bruises was counted. The bruise detection efficiency of the device, in percent, was evaluated using the equation:

$$\% = \frac{\text{number of samples correctly identified as damaged}}{\text{total samples subjected to detection}} \times 100$$

A 6 x 5 x 2 factorial experiment in RCBD was conducted to analyze the effects of the different factors (A: Day of detection; B: Impact level; C: Type of image). Blocking of samples was applied considering the variation in mango's maturity during harvest. Comparison among means (CAM) was done using the Duncan's Multiple Range Test (DMRT) at 1% and 5% levels of significance.

The different levels for each factor included the following:

Factor A: Day of detection	Factor B: Impact level (height of drop)
A1 – Day 1	B1 – L1 (30 cm from the floor)
A2 – Day 2	B2 – L2 (54 cm from the floor)
A3 – Day 3	B3 – L3 (78 cm from the floor)
A4 – Day 4	B4 – L4 (102 cm from the floor)
A5 – Day 5	B5 – L5 controlled level (no impact)
A6 – Day 6	
Factor C: Type of image	
C1 – I1 composite image	
C2 – I2 threshold RGB image	

RESULTS AND DISCUSSION

The developed experimental visible spectral imaging device (Figure 2) has the following components: 1. rectangular imaging chamber/enclosure, 2. standard laptop personal computer, 3. frame, 4. firefly FEL 313 LED panel lamp, 5. Nikon D3000 DSLR camera, 6. yongnou Digital MR-58 LED macro ring lamp and 7. sample stage

The frame is made up of a 3.81 cm x 5.08 cm x 2.0 mm slotted angle bars with joints secured using bolts and nuts. The dimension of the frame is 46 cm x 46 cm x 100 cm. The chamber has an outside dimension of 61 cm x 62 cm x 122 cm that fits and encloses the frame and is made up of 0.635 cm ordinary plywood.



Fig.2. Setup of the developed visible spectral imaging device

Each component was properly mounted using the assembled slotted angle bar frame and enclosed by the imaging box. The DSLR camera, LED macro ring lamp and LED panel lamps were focused at the sample. The stage for the mango fruit sample was placed under the camera, panel lamp and ring lamp. The LED macro ring lamp was mounted at the end of the camera's lens.

The device underwent pre-testing and calibration procedure to establish proper imaging parameters and to ensure that the device is working well. The optimal camera settings were found at the settings: 55mm focal length, 3200 ISO, 1/125 shutter speed, f/5.6 aperture, and zero exposure compensation, with the camera placed at 46 cm, above the sample stage. The panel lamp and the ring lamp distances were 35 cm and 40 cm, respectively, above the sample stage.

Seventy two mango (carabao variety) fruits were acquired and prepared for a simulated mechanical induction of damage by dropping the individual fruit at vertical heights of 30, 54, 78 and 102 cm. Results showed that the resulting impact energy on mango fruit was consistently influenced by the drop of height.

Acquired images underwent image processing and analysis using the ImageJ software. Image processing included image segmentation, extraction of ROI image, RGB color channel and image pixel intensity extraction and image thresholding. The composite and the adjusted threshold images were used in the evaluation of bruise signatures. Bruise signatures were detected in the form of dark spots on the 24.70 minimum and 39.88 maximum threshold values.

Bruise Detection

Bruise signatures were slightly detected as dark spots during daily visual inspection on the composite image of damaged fruit. Results using the composite image represent the visual inspection done on manual sorting. At the first inspection, bruise signatures cannot be recognized as true bruises unless strict attention was made. Moreover, those signatures on the composite image cannot be identified properly because of their colour references. Bruises on mango fruit were detected on the day it reached its yellowing stage. This observation is in agreement with the statement of Van Linden et. al. in 2006 [5] that the efficiency of produce quality inspectors reduces rapidly which may lead to incorrect and inconsistent grading results.

The RGB color images enhanced the bruise signatures using the gray scale reference. The darkness and the brightness of the spectral signatures in the gray scale color helped to identify the bruises. However, in RGB images, the suspected bruise region was not highlighted. The threshold combination results (Red image – Blue image) have the potential as the reference image for bruise detection. Also, threshold image used binary color (the black and white color) which made it easy to identify the bruised and non-bruised regions.

Normally, in damaged fruit surface, based on the threshold image, bruise signature formed as black spot and its shape and location were patterned parallel to the verified damage during the yellow stage of mango fruit (Figure 3).

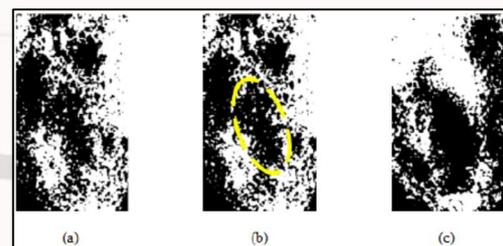


Fig.3. Emphasized bruise signatures: (a) Spectral reflectance of a 3-day old mango fruit; (b) Encircled suspected damaged area; (c) Verified shape and location of bruised area on a 6-day old mango fruit

Figure 4 shows a graphical relationship of the bruise detection efficiency against the days of detection at different impact levels (L1, L2, L3, and L4) using the threshold image.

On the first day of detection, the highest bruise detection efficiency of 22.22% was observed at impact level 4 (L4). On the succeeding days, the bruise detection efficiency of the device increased, from 44.44% on the second day to 84.89% on the sixth day. The lowest detection efficiency was at impact level 1 (L1), occurring on the first and last days of detection. The data showed that the device detected more number of damaged mangoes as the fruits turned into yellowing stage. The daily development of bruises in mango fruit from first day to sixth day affected the bruise detection performance of the device

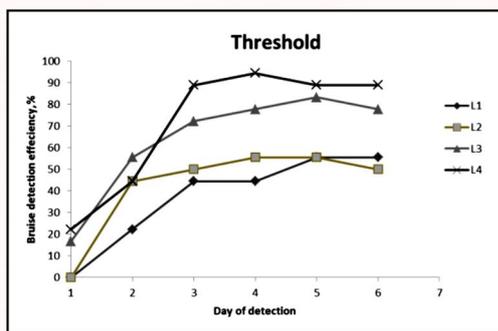


Fig.4. Characteristic lines describing the relationship between bruise detection efficiency and day of detection as influenced by the different impact levels based on threshold image

Figure 5 shows a graphical relationship of the bruise detection efficiency against the days of detection at different impact levels (L1, L2, L3, and L4) using the composite image.

The highest bruise detection efficiency was observed at impact level 4 (L4) during the first and last day of detection; impact level 1 (L1) had the lowest detection efficiency. Also, there was an increase in bruise detection efficiency at the first day of mango fruit until the sixth day or during the ripening period. This observation was also noted using the threshold image in detecting bruises in mango fruit.

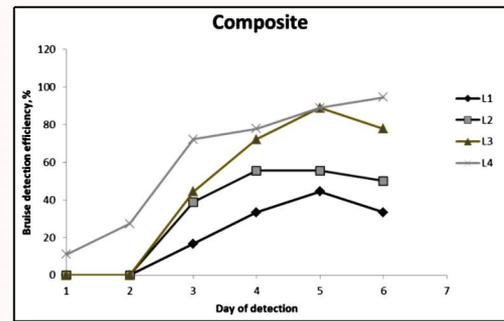


Fig.5. Characteristic lines describing the relationship between bruise detection efficiency and day of detection as influenced by the different impact levels based on composite image

Statistical Analysis

The results of this study showed that the day of detection (A), impact level (B) and type of image (C) had highly significant influenced on the bruise detection efficiency of the developed visible spectral imaging technology. The interaction A x B showed highly significant effect, while the interaction A x C only showed significant effect. The interaction A x C and A x B x C gave no significant effect.

Comparison among means (Table 1) revealed that day 5 (A5) has highest bruise detection efficiency with a mean of 56.11% but it was comparable with day 6 (A6) and day 4 (A4) with values of 52.78% and 51.11%, respectively. There was an increase in the bruise detection efficiency from the day after the impact energy was induced (Day 1) until the yellowing stage of mango fruit (Day 6). This result is in agreement with the statement of Van Linden, et. al. in 2006 [5] that is, as the discoloration or softening of damaged tissue is related to the time elapsed after bruising; the efficiency and effectiveness of bruise detection during sorting and grading may be affected during sorting and quality control.

Table 1. Summary of data on the bruise detection efficiency of the visible spectral imaging device as influenced by day of detection and level of impact

DAY OF DETECTION	IMPACT LEVEL					MEAN
	B1	B2	B3	B4	B0	
A1	0.00 ^s	0.00 ^s	08.30 ^{sr}	16.70 ^{pqrs}	0.00 ^s	5.00 ^a
A2	11.10 ^{qrs}	22.20 ^{opqrs}	27.80 ^{nopqr}	36.10 ^{lmnopq}	0.00 ^s	19.44 ^b
A3	30.60 ^{mnopqr}	44.40 ^{lmno}	58.30 ^{ijkl}	80.60 ^{ij}	0.00 ^s	42.78 ^c
A4	38.90 ^{lmnop}	55.60 ^{ijklm}	75.00 ^{ijk}	86.10 ⁱ	0.00 ^s	51.11 ^{cd}
A5	50.00 ^{klmn}	55.60 ^{ijklm}	86.10 ⁱ	88.90 ⁱ	0.00 ^s	56.11 ^d
A6	44.40 ^{lmno}	50.00 ^{klmn}	77.80 ^{ij}	91.70 ⁱ	0.00 ^s	52.78 ^{cd}
MEAN	29.17 ^e	37.96 ^e	55.56 ^f	66.67 ^g	0.00 ^h	

Means with the same letters within rows, columns and interactions are not significantly different at 1% level using DMRT

The impact level L4 (B4) had the highest mean value of 66.67% which revealed that the highest level of impact gave the highest number of mango fruit samples detected with bruises. At high impact level, the possibility of bruise to develop was greatly increased. Severity of damage depends on fruit physiological and biochemical properties, such as plant cell chemical oxidation reaction [4].

Interaction between factors A and B showed that the highest bruise detection efficiency was found at the impact

level 4 (highest level of impact), having a mean value of 91.70% on the sixth day of detection.

Table 2. Summary of data on the bruise detection efficiency of the visible spectral imaging device as influenced by day of detection and type of image

DAY OF DETECTION	TYPE OF IMAGE		
	C ¹	C ²	MEAN
A1	02.22 ⁱ	07.78 ^j	5.00
A2	05.56 ^{kl}	33.33 ⁱ	19.44
A3	34.44 ^{hi}	51.11 ^{cdefg}	42.78
A4	47.78 ^{cdefg}	54.44 ^{cde}	51.11
A5	55.56 ^{cd}	56.67 ^c	56.11
A6	51.11 ^{cde}	54.44 ^{abc}	52.78
MEAN	32.8 ^a	43.0 ^b	

Means with the same letters within columns and intersections are not significantly different at 1% and 5% levels using DMRT

Comparison among means (Table 2) revealed that the threshold RGB image had significantly higher mean compared with the composite image in detecting mechanical damage in mango fruit, with values of 42.96% and 32.78%, respectively. Results of the study suggest that the threshold type of image is more effective for detecting mechanical damage.

The Protocol

The protocol for early detection of mechanical bruises in mangoes using a visible spectral imaging technology was developed following the flowchart shown in Figure 6.

Interaction results between the day of detection and the type of image showed that the minimum bruise detection efficiency was on day 4, based on the composite image.

Early Detection of Mechanical Bruises on

Mango Fruit

The detection of mechanical bruises was categorized into two phases, the early detection phase and the late detection phase. All detected bruises within the first three days were considered in the early bruise detection phase. Based on the observation, under standard room condition, most of the mango fruit samples started turning yellow, or at ripening stage, after three days.

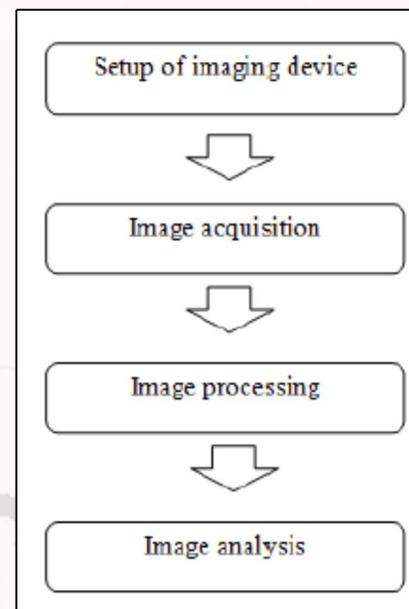


Fig.6. Flowchart of the developed protocol

Since this study aimed to detect mechanical bruises at the earliest day, results suggest that the threshold RGB image is an effective method to use to detect mechanical bruises of mango fruit. Furthermore, threshold RGB image had the highest detection efficiency within the third day of detection.

The imaging unit, lighting unit, imaging frame, fruit stage, imaging chamber and the personal computer are required to devise and implement the visible spectral imaging setup. Each of the components is mounted based on the machine vision concept, using the imaging frame, and enclosed by the imaging chamber.

The DSLR camera macro ring lamp and panel lamp are focused on the location of mango fruit at the fruit stage. The fruit stage is placed under the camera, panel lamp and the ring lamp. The macro ring lamp is mounted at the end of the camera lens. The device needs to be calibrated and evaluated to ensure that it functions well. The capturing settings of the camera and the distances of each component have to be evaluated.

The DSLR Camera Remote Pro Software is used as image capturing software to download and label the acquired images automatically. Fruit mango is to be placed manually inside the imaging chamber. Imaging of the mango fruit is done in two dimensions, with one image in every shot.

Any computer imaging software can be used to process images. The ImageJ software can be used for image processing as it is a freeware imaging software. Image processing includes image segmentation, ROI image extraction, RGB color channel and image pixel intensity extraction and image thresholding.

The analysis on the bruise signature is done on the threshold image of the mango fruit. With the average pixel range of 24.70 and 39.88 for the minimum the maximum threshold values, respectively, the bruise signatures are normally in the form of black spots on the threshold images.

CONCLUSIONS

1. The devised and implemented visible spectral imaging setup can be used to capture visible spectral reflectance of mango fruit for early detection of mechanical damage in mango fruit.

2. Bruise reflectance signatures can be detected in the form of black spots at average minimum and maximum threshold values of 24.70 and 39.88, respectively.

3. A protocol was developed to implement an effective technique in detecting mechanical bruises in mango fruit at early stage. The developed protocol was found effective in detecting mechanical bruises three days after impact energy was induced to the mango fruit.

RECOMMENDATIONS

Based on the results of the study, the following recommendations were drawn:

1. The visible spectral imaging device for early detection of mechanical bruises in mango fruit can find application in:

a. academic institutions, research groups and individuals in studying mango postharvest operation and optimization procedures;

b. automatic sorting line of mango fruits for export;

c. packing houses to address the need for an efficient and accurate sorting system in mango fruits. This will allow proper sorting and attainment of high quality mango fruits for higher marketable value.

2. The visible imaging technology has a potential to replace manual-based technique for sorting and grading of mango fruit, as the manual inspection poses problems in maintaining consistency in grading and uniformity in sorting.

3. The results of this study can be incorporated in the development of a robust classification system for quality evaluation and establishment of a machine vision system for automatic grading and sorting of mango based on the visible spectral imaging system.

4. For future works, a further study is needed to evaluate mechanical bruises on the first and second day. This will increase the efficiency and accuracy of the visible spectral imaging device in detecting early mechanical bruises in mango.

5. Visible spectral imaging technology can be used for other commercial fruits for defect detection at early stages even before the damage is manifest.

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