Applying a Computer Vision System to Monitor External Quality Attributes of Damaged Banana Fruit During Storage

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Abstract. Consumer's interest in food safety and quality is increasing, mainly due to the international food trade, which needs rapid and non-destructive inspection techniques. The computer vision system is highly correlated with recent usage in the food and agriculture industry. Therefore, this study aimed to perform the computer vision system (CVS) to investigate the external quality of mechanically damaged bananas 'Somali' after 25 days of storage at three temperature conditions. Bananas were damaged by the drop impact test by dropping a stainless-steel ball of 110 g through a hollow pipe at 40 and 60 cm drop heights. Bananas with no damage were set as control. Bruised and non-bruised bananas were stored at 5, 13, and 22 °C. A computer vision system was used to measure the external properties of bananas like color, surface area, and browning spots. The captured Red, Green, and Blue (RGB) images were analyzed by ImageJ software. The principal component analysis (PCA) was used to study the correlation between the studied parameters. The results of the study showed a high reduction percentage in surface area in 60 cm bruised bananas stored at 22 °C. Storage at 13 °C showed the least changes in color and browning spots after 25 days of storage. The study can confirm the effectiveness and efficiency of using a computer vision system and image processing in determining the most common sensory attributes in perishable fruit like bananas.

Keywords: Banana · total color difference · storage · image processing · browning spots

1 Introduction

External quality characteristics in fruit are very essential and immediate sensory features of agricultural produce. The external quality of fresh produce can be assessed by its visual defects, size, color, shape, and texture [1]. The external appearance of fresh produce influences the buying behavior of consumers and point-of-sale value. In some cases, defective, contaminated, and infected individual fruit can affect the whole fresh produce

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batch, leading to market value reduction, economic losses, and safety issues. Thus, the usual grading and inspection of external features within the postharvest supply chain (pre-processing phase) become very significant. Applying image processing like a computer vision system has been widely utilized in the agriculture and food industries. It has been confirmed to be a powerful and scientific technique for the automatic quality inspection of horticultural products [2].

The Banana fruit (*Musa spp.*) is a widely produced tropical fruit [3]. Bananas are considered a climacteric delicate and perishable fruit, thus increasing their susceptibility to postharvest losses, particularly during storage, handling, and transportation [4]. Banana fruit's quality can be influenced by different external defects resulting from mechanical damages [5]. These visual defects in bananas can highly reduce the most common quality features of the fruit, thus decreasing the profits of both growers and retailers [6]. Therefore, this study is aiming to perform the computer vision system (CVS) to investigate the external quality of mechanically damaged bananas 'Somali' after 25 days of storage at three temperature conditions.

2 Materials and Methods

2.1 Fruit Acquisition, Bruise Damage, and Storage

Fresh banana fruit 'Somali' were obtained from a farm located in Suhar, Al-Batinah North Governorate, Oman. The fruit were transported directly to the Postharvest Technology Laboratory at Sultan Qaboos University. The selected banana fruit were similar in weight, color, and firmness status.

To simulate the effect of inappropriate handling practices, fruit were subjected to damage by the drop test method [7] by dropping a steel ball of 110 g once from heights of 40 and 60 cm through a hollow PVC pipe onto the bananas. Accordingly, bananas were divided into groups consisting of impact from heights of 40 cm (low), 60 cm (high), and control (no bruise). Each group was divided into three other groups for storage (5, 13, and 22 °C). The total number of treatments was 9. The bruised fruit were stored for 25 days. Three replicates were used for each treatment.

2.2 Image Processing

Image analysis was applied by using a computer vision system as shown in Fig. 1 [8]. This system is comprised of a cardboard box which was used to prevent the external backscattering effects and to cover the whole system. It also includes two 36 W long fluorescent lights (Model: Dulux L, OSRAM, Milano, Italy) to illuminate banana samples and to provide a source of light over the sample with the same intensity. To capture the banana samples, a digital camera (Model: EOS FF0D, Canon Inc., Tokyo, Japan) was vertically fixed (center of the cardboard box) at a 0.30 m above the sample. To provide a high-contrast image, the samples were placed on a white background (stage).

All images were transferred from the RGB digital camera to the personal computer using the USB port for subsequent processing. The acquired image was saved in JPG format.

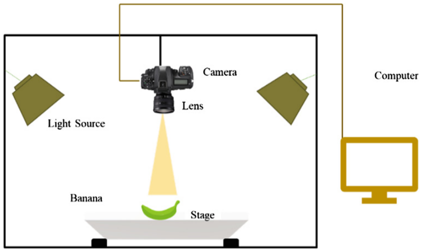

Fig. 1. Computer vision system component.

Fig. 2. Browning spots identification by image processing.

2.2.1 Browning Spot Increment %

To measure the % of browning spot increment, 3 replicates were used for each treatment after 25 days of storage. In this analysis, each RGB image of banana fruit was processed by converting the RGB image to an 8-bit image and then applying the appropriate method of threshold (Fig. 2) using ImageJ software (v. 1.53, National Institute of Health, MD). The whole banana was selected by using the polygon selection tool. The browning spots were determined from the whole fruit by analyzing particle tools.

2.2.2 Color Measurements

A total of fifteen external color readings were taken from 3 bananas per treatment before and after storage. Color evaluation of bananas was conducted by using the method of computer vision system as discussed earlier. The ImageJ software was performed to analyze all RGB values acquired from the system. Each sample was placed and oriented manually. A histogram tool was applied to obtain the RGB mean values which were converted to CIEL*a*b* color coordinates that are mostly used to describe food color quality in different studies [9]. L* value donates for lightness or darkness (0–100), a* expresses reddish or greenish (+ and -), and b* donates for yellowish or blueness (+ and -). The total color difference was also calculated as follows in Eq. (1):

$$TCD = \sqrt{\Delta a^{*2} + \Delta b^{2} + \Delta L^{*2}} \quad (1)$$

2.2.3 Surface Area Reduction %

To determine the % of reduction in surface area, 3 readings were used for each treatment after 25 days of storage. ImageJ was used to process the captured images. The scale

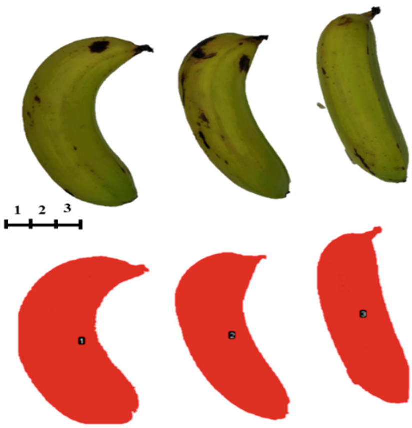

Fig. 3. Color threshold for surface area measurements

was calibrated to 3 cm. The brightness of the image was modified and then subjected to color thresholding (Fig. 3). Each banana was selected using a tracing tool. Later, the surface area was measured by identifying the region of interest. The browning spot (%) was determined by subtracting the browning spot of banana samples from their initial browning spots.

2.3 Statistical Analysis

Data were statistically analyzed using SPSS 20.0 (International Business Machine Crop., USA) software. Analysis of variance (ANOVA) was conducted to assess the effect of two investigated factors (A: impact level and B: storage temperature) and their interaction on color, surface area reduction %, and browning spot increment % of banana fruit at a 5% level of significance. Minitab statistical software 21.2 (State College, Pennsylvania, USA) was conducted to perform principal component analysis.

3 Results and Discussions

3.1 Browning Spot Increment % Analysis

Figure 4 shows the browning spot (%) of control and bruised banana fruit damaged from different impact levels (impact 1 = 40 cm; impact 2 = 60 cm) after 25 days of storage at 13 °C and 22 °C. The browning spot % recorded a significant effect with storage temperature ($P = 0.000614$) and drop height ($P = 0.00018$) after 25 days of storage. Banana fruit bruised from the 60 cm drop height showed a 32.02% increment in browning spots after 25 days of storage at ambient temperature (22 °C) compared to those damaged from 40 cm which showed a 22.78% browning spot increment under the same storage condition. Overall storage at 13 °C showed less increment in browning spots after 25 days of storage. Besides, the non-bruised fruit showed the least browning spot % at the end of the experiment with 6.28 and 9.64% at 13 and 22 °C, respectively.

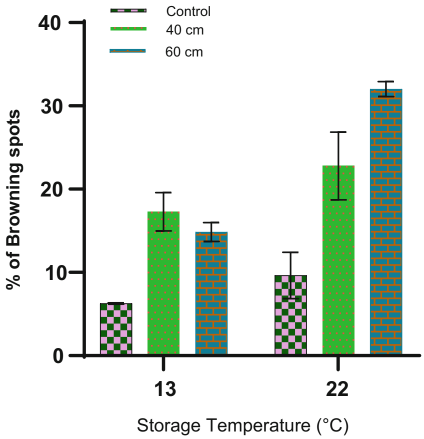

Fig. 4. Browning spot (%) of control and bruised banana fruit damaged from different impact levels (impact 1 = 40 cm; impact 2 = 60 cm) after 25 days of storage at 13 °C and 22 °C storage conditions. Error bars represent the standard deviation (SD) of the mean values ± S.D. of three replicates.

Table 1. The values of L*(lightness), a* (redness), and b* (yellowness) of control and bruised banana fruit damaged from different impact levels (impact 1 = 40 cm; impact 2 = 60 cm) after 25 days of storage at 5 °C, 13 °C, and 22 °C storage conditions. The values are presented as the standard deviation (SD) of the mean values ± S.D. of 15 readings of 3 replicates. ST; Storage temperature, DH; drop height, C; non-bruised samples (Control).

ST (C)	DH (cm)	Color parameters		
		L*	a*	b*
5	C	21.00 ± 2.75	0.034 ± 0.01	13.22 ± 0.79
	40	28.58 ± 0.55	0.20 ± 0.19	12.35 ± 1.90
	60	29.46 ± 0.65	-0.57 ± 1.64	16.52 ± 1.92
13	C	45.12 ± 11.17	-9.48 ± 3.44	39.29 ± 0.99
	40	44.5 ± 0.89	-8.64 ± 3.33	37.04 ± 0.57
	60	49.78 ± 1.77	0.86 ± 1.05	37.35 ± 2.14
22	C	45.00 ± 0.99	-3.56 ± 0.99	45.38 ± 0.83
	40	47.63 ± 1.83	1.11 ± 3.40	42.65 ± 1.97
	60	51.91 ± 0.35	4.44 ± 0.62	44.02 ± 0.26

3.2 Color

Table 1 presents the main color parameter values (L*, a*, and b*) after 25 days of storage. These color attributes were influenced by the storage temperature ($P < 0.05$), but there was no pronounced effect with drop impact height ($P > 0.05$).

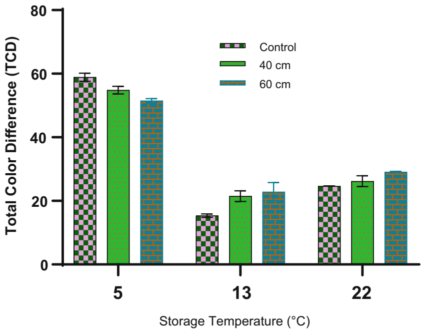

Fig. 5. Total color difference (TCD) of control and bruised banana fruit damaged from different impact levels (impact 1 = 40 cm; impact 2 = 60 cm) after 25 days of storage at 5 °C 13 °C and 22 °C conditions. Error bars represent the standard deviation (SD) of the mean values ± S.D. of 15 replicates per 3 fruit.

Storage at 22 °C showed the highest L* (51.91) and a* (4.44) values in 60 cm bruised banana fruit. However, the non-bruised (control) bananas stored at 22 °C showed the highest b* value (45.38). The lowest b* value was recorded in all banana fruit stored at 5 °C in the range of 13.22–16.52. The total color differences of the studied banana fruit (Fig. 5) were statistically affected by the storage temperature ($P < 0.00001$) and drop height impact ($P = 0.000460$). Changes in color attributes were highly observed on bruised bananas stored at higher temperature condition. This could probably be attributed to the chlorophyll degradation that existed in banana fruit peel after the storage period which resulted in the transformation of banana green color to yellow, particularly in those impacted from the highest drop height and stored at ambient temperature [7]. During ripening, banana fruit are classified with yellow peel and this is because of the carotenoid accumulation (synthesis) and chlorophylls reduction (green pigments degradation) [10].

3.3 Surface Area Reduction %

The surface area reduction % is presented in Fig. 6. The results of this study showed the high influence of both drop height (impact damage) and storage temperature ($P > 0.00001$) on the surface area reduction % of the banana fruit after 25 days of storage. The study confirmed the extreme effect of storage at 5 and 22 °C in increasing the reduction in the surface area of fruit compared to storage at 13 °C. Besides, the mechanical damages resulting from bruising of high and low impact damage accelerated the increment of surface area reduction %.

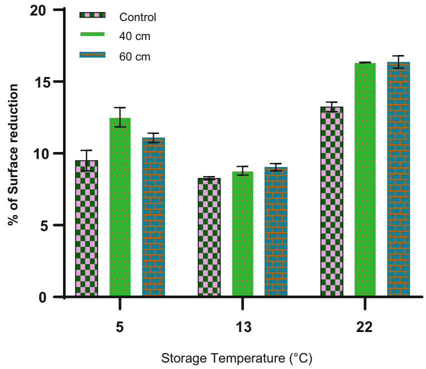

Fig. 6. Surface area reduction (%) of control and bruised banana fruit damaged from different impact levels (impact 1 = 40 cm; impact 2 = 60 cm) after 25 days of storage at 5 °C, 13 °C, and 22 °C conditions. Error bars represent the standard deviation (SD) of the mean values ± S.D. of 3 replicates.

For instance, 60 cm bruised banana fruit stored at ambient temperature (22 °C) recorded the highest % (16.36%) surface area reduction after storage days. The lowest recorded % of surface area (8.27%) reduction was observed in non-bruised bananas stored at 13 °C. Chilling injuries observed in damaged and non-bruised banana fruit are the main reason for the subsequent damages in external quality loss in fruit [7]. Also, the reduction observed in surface area during storage for all samples might occur due to water loss [11].

3.4 Principal Component Analysis (PCA)

Principal component analysis (PCA) was implemented to reveal the correlation between the studied quality attributes with the main factors of the study (impact height and storage temperature) of banana fruit during storage. Therefore, the variability of external attributes of bruised and non-bruised banana fruit are summarized in principal component analysis (PCA). The location of the impact height and storage temperature after 25 days of storage is demonstrated in Fig. 7A. While Fig. 7B defines the distribution of quality attributes by first and second principal component analysis (PCA1 and 2) dimensions. Figure 7B reveals that non-bruised (control) and bruised (by high and low impact) banana fruit stored at ambient temperature (22 °C) were more characterized by yellowness, surface area reduction %, higher browning spots, and total color difference.

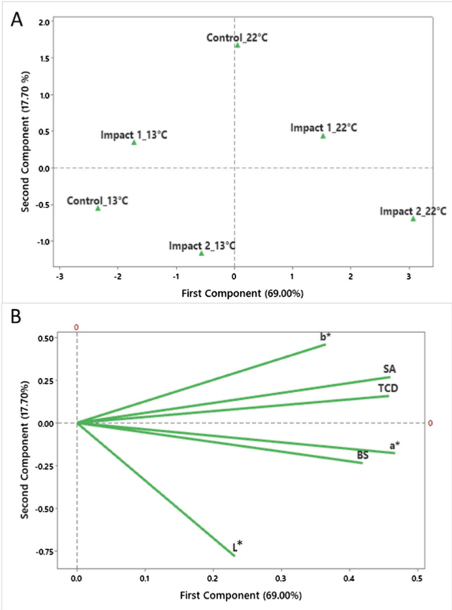

Fig. 7. Principal component analysis of the first two components (PC1 and PC2) showing observations (A) and variables **(B)** based on surface area reduction % (SA), browning spot increment % (BS), lightness (L*), redness (a*), yellowness (b*), and total color difference (TCD) of non-bruised, low (40 cm; impact 1), and high (60 cm; impact 2) impact bruised fruit after 25 days at 13 °C and 22 °C conditions.

4 Conclusions

External quality attributes are an essential and direct sensory attribute of agricultural products. A usual grading and inspection of external features within the postharvest supply chain (pre-processing phase) become very significant. Computer vision is an alternative non-destructive and cost-effective technique to accomplish these requirements. Besides, the results of this study emphasized the efficiency of storage at 13 °C in maintaining the quality of the fruit.

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