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***Original Article***

# Estimation of Cardamom Capsule Size and Surface Area Using Digital Image Processing Technique

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## Abstract

Manual grading and sorting of cardamom spices require a long time and considerable resources. The introduction of machine vision technology can substantially increase the timeliness of grading operation and reduce the associated drudgery. This research was carried out to contribute towards the use of machine vision technology in the grading of cardamom spices. In this regard, the utility of images captured by mobile devices was assessed using digital image processing techniques. The color images of cardamom capsules were acquired using an Apple iPhone 7 in the first place. The geometric features (major diameter, minor diameter, surface area, and perimeter) of the samples were calculated using MATLAB algorithms. The pixelated units were converted into SI units (mm). The predicted values of the parameters were compared with the actual values. The goodness of fit was assessed using the coefficient of determination ($R^2$), which was found to be 0.92, 0.88, 0.95, and 0.97 for the major diameter, minor diameter, surface area, and perimeter of the samples, respectively. In terms of mean absolute percentage error (MAPE), the accuracy of the model was found to be 95.64%, 94.74%, 95.32%, and 97.81% for the predicting major diameter, minor diameter, surface area, and perimeters of cardamom capsules, respectively. These results indicate that mobile images could be successfully incorporated in machine vision technology for the effective grading of cardamom capsules.



## Introduction

Postharvest processing of cardamom spices consists of a series of unit operations, including cleaning, curing, bleaching, grading, packing, transport, and storage (Parthasarathy and Prasath, 2012). Among these works, grading requires the most amount of time and labor. In addition, immense care is needed to pick and separate a superior product from a less superior one as the entire work is dependent on manual labor (Jose and Krishnan, 2015). The grading of cardamom is based on the capsules' external color, size, and shape as specified by the Indian Standards Institution (ISI). For this, manual inspection is often followed by sieving of capsules leading to inconsistency in the final product. The introduction of automated grading and sorting systems could potentially overcome such hurdles in the postharvest processing of cardamom.

To develop an automated grading-sorting system, quantification of the size, shape and colorimetric values are important (Rahman and Oliver, 2019). In addition to these parameters, ripeness, mass, bruising, disease, and rot in the product has also been incorporated in image processing techniques by many researchers (Chen et al., 2002; Mahendran et al., 2012; Patel et al., 2012; Spreer et al., 2011). The advantage is that digital image analysis allows quick and accurate size measurements. In this way, computer vision enables the non-invasive evaluation of quality characteristics in food products (Brosnan and Sun, 2004). Similar approaches for image processing technology for fruits (Blasco et al., 2009; Feng and Qixin, 2004; Kondo, 2010; Mahendran et al., 2012; Nandi et al., 2016; Omid et al., 2010; Pandey et al., 2013; Sahu and Potdar, 2017; Yu et al., 2020),

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vegetables (Deng et al., 2017; Deulkar and Barve, 2018; Yongsheng et al., 2016) and legume seed (Fıratlıgil-Durmus et al., 2010) have also been reported in the literature.

In Bangladesh, Momin et al. (2017) successfully graded mangos into three mass grades based on the image processing techniques. Rahman and Oliver (2019) reported similar techniques regarding a popular Jujube variety (BAU-Kul) in Bangladesh. Nonetheless, very little information is available regarding how spices like cardamom could be graded using portable image processing techniques. According to Jose and Krishnan (2015), the machine learning approach could play a vital role in the cardamom grading industry. The scientific literature regarding machine vision has elaborated the engagement of different ways to improve precision outcomes. Most of the machine vision systems use a filtrated DSLR camera for image acquisition. On the other hand, there are but few studies that show how portable smartphone camera-based image acquisition can be incorporated into machine vision systems. In this study, we have attempted such an effort to investigate with cardamom samples. In this regard, mobile images of cardamom samples were taken and subjected to standard algorithms to estimate the dimensional parameters. This ultimate objective was, therefore, to check for the utility and accuracy of such an approach in machine vision technology for cardamom samples.

## Materials and Methods

### *Samples*

Cardamom (*Elettaria cardamomum* (L.) Maton) samples popularly known as elachi were collected from the wholesale market of Gazipur, Bangladesh on 22$^{nd}$ January 2020. A total of 62 cardamom samples having different sizes were selected for this research as shown in table 1. According to the Indian Standard specification for cardamom (IS: 1907–66), samples (crooked green category) were graded based on their physical color and size factor.

**Table 1.** Categorization of crooked green types of cardamom samples

| Sample types | No of sample | Picture |
|---|---|---|
| CGEB Extra Bold | 9 |  |
| CGB Bold | 12 |  |
| CG-1 Superior | 21 |  |
| CG-2 Mota, Green | 5 |  |
| CG-3 Shipment | 11 |  |
| CG-4 Light | 4 |  |
| Total | 62 | |

*Size class of Coorg Green (CG) cardamom is defined as: CGEB Extra Bold (≥ 8 mm); (8 mm < CGB Bold ≥ 7.1mm); CG-1 Superior (6.5-7 mm); CG-2 Mota, Green (6mm); CG-3 Shipment (5-5.9 mm); CG-4 Light (3.5mm).

### *Measurement of Physical parameters*

Major and minor diameter: The major and minor diameter were calculated manually using a vernier caliper (Series 532 Mitutoyo, Japan), where the measurement range and accuracy of that vernier calipers were fixed around 0-130 mm and 0.03 mm, respectively. Generally, the major diameter of a cardamom capsule is defined as the distance between the apex and the basal ends, while the minor diameter is measured at the midpoint of the cardamom capsules. According to the grading requirement (Indian Standard specification for cardamom. IS: 1907–66. Indian Standards Institution, New Delhi-1) and maintain the consistency of measurement, we measured the minor diameter of cardamom samples along the midpoint.

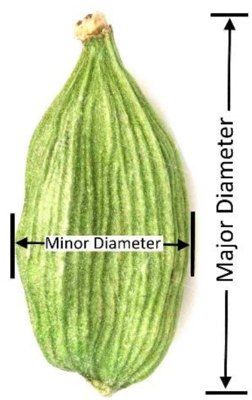


Figure 1. Physical dimensional parameters of a cardamom capsule

Surface area: The estimated capsule surface area was obtained by using graph papers graduated with one-millimeter square grid lines. The capsule was placed on the graph paper sheet and the perimeter of the capsule was sketched by a pencil on the paper. Finally, the full and half square blocks of encircling the outline of the capsule were considered for surface area calculation by using the following equation (Dey et al., 2019).

Surface Area = NOC × AGP ……………. (1)

NOC = number of full and half-square blocks of outlined capsule
AGP = area of each square block of graph paper

Perimeter: The perimeter of a cardamom capsule was measured using a thin ribbon placed around the circumference of the cardamom capsule. The ribbon was then straightened, and the perimeter was recorded by putting the ribbon along the ruler scale.

*Images acquisition system*

There are many types of cameras for imaging a particular product. Despite the uses of digital cameras, camcorders, and PC-cams, the portable cellphone camera has also emerged as a potential imaging device (Liang et al., 2005). There have been several efforts that employed images that were not captured under structured specific lighting for illumination. Instead, Yongsheng et al. (2016) reported promising results in the case of potato tuber grading when they used images captured under normal room lighting conditions. Rahman and Oliver (2019) also reported that images captured through mobile devices could be used for the detection and contouring of Jujube samples with fairly high accuracy (92.02%). Considering these recent endeavors, the images of cardamom in this research were acquired by using an iPhone 7 device without flash under stationary conditions.

Figure 2. Color (RGB) image acquisition of cardamom capsule by the machine vision system.

The phone was attached to a stick-shaped holder and the distance between the phone camera and object was 25 cm. Cardamom capsules were placed on a black cloth of laboratory bench. The camera lens was parallel to the bench surface ensured with a leveler. The parameter of the camera such as ISO, shutter speed, focal length, and aperture was kept 125, ¼ s, 4 mm 1.8 respectively for all images. A fluorescent tube lamp of laboratory lighting was used for the illumination. The image's resolutions were 768 × 1024 pixels each and were stored in a jpeg format. A circular blob of known dimensions was used as a reference for dimensional calibration in each image. Reference was also used to convert the pixel values of major diameter, minor diameter, surface area, and perimeter to SI units.

*Image processing system*

Image processing and analysis were carried out by using MATLAB (R 2018b). The processing system consists of cropping, conversion of RGB image to a grayscale image, contrast enhancement of grayscale image, image segmentation by Otsu thresholding method, and morphological operation (eroding and dilating). First, we cropped only the cardamom capsule. Then the RBG image was converted into a grey image by the rgb2gray command in MATLAB. To enhance the contrast of the grayscale image, adjust command was applied on grayscale images. After that, the Global thresholding method was applied to partition the image into two classes as foreground or cardamom surface (white) and background (black).

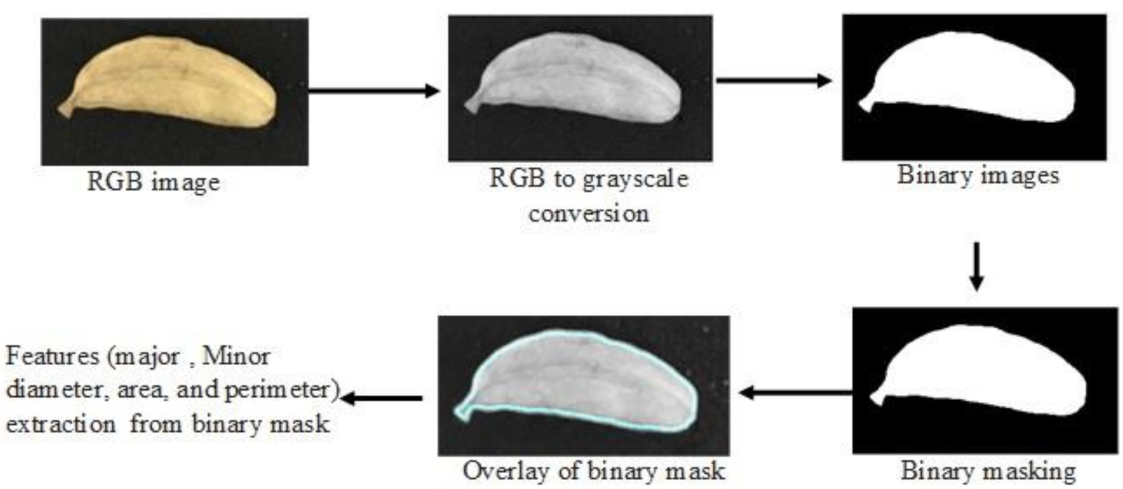


Figure 3. The overall flow diagram of image processing techniques

In Otsu thresholding methods, the threshold value is chosen automatically by the *gray thresh ()* function in MATLAB. Then image binarization (black and white image) was created from gray images by *binarize* algorithm using the selected thresholding level. All the pixels of gray images with equal or lower than the threshold value is turned to zero and considered as background and those pixels greater than the threshold value to one and considered as object pixels or foreground or white portion (Otsu, 1979). Smoothing of the binary image was performed by *imerode ()* function which uses (morphological structuring element) diamond-shaped structuring element, where the distance from the structuring element origin to the points of the diamond is 1. The smoothed binary image is called a binary mask image. Then overlay of the binary mask on the grayscale image was done using *imoverlay ()* function. Finally, the image features like major, minor diameter, surface area, and perimeter were estimated using *region props ()* function from the outlined binary mask image of cardamom capsules. The overall flow diagram of image processing steps is shown in figure 3. The measured features like major diameter, minor diameter, surface area, and perimeter were calculated in pixel units from the image processing technique. The major axis diameter of the circular blob (reference) was extracted in the same ways as cardamom capsules. Finally, the estimated parameters were converted to SI units by multiplying pixel units with the conversion factor in the following equations:

$$Conversion\ factor\left(\frac{mm}{pixel}\right) = \frac{D_r}{D_I} \quad \text{............ (2)}$$

$$E_r = conversion\ factor\left(\frac{mm}{pixel}\right) * E_I \quad \text{......... (3)}$$

Where,
$D_r$ = maximum diameter of the circular blob(mm) using slide calipers.
$D_I$ = maximum diameter of the circular blob (pixel) from the image processing technique.
$E_r$ = Estimated Parameters of cardamom capsules in mm.
$E_I$ = Estimated Parameters of cardamom capsules in pixel by image processing technique.

### *Performance analysis of prediction method*

We developed the prediction model by linear regression analysis which shows the relationship between actual and estimated parameters of cardamom capsules. This regression analysis was done in Microsoft excel 2016 by plotting of estimated and actual values of cardamom capsules in the X and Y axis, respectively. The geometric features estimated by image processing approaches were evaluated based on the actual estimations. For the evaluation of the prediction model, several metrics were used to illustrate the differences between the estimated and actual values. Two absolute error indices namely mean absolute error (MAE) and root mean squared error (RMSE), were used for the evaluation. Furthermore, the mean absolute percentage error (MAPE) is a relative error index that was also used (Utai et al., 2019). The performance indices were calculated as the following equations:

$$MAE = \frac{1}{n}\sum_{i=0}^{n}\left|Y_i^{act} - Y_i^{pre}\right| \quad \text{.................... (4)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=0}^{n}\left(Y_i^{act} - Y_i^{pre}\right)^2} \quad \text{................ (5)}$$

$$MAPE = \frac{1}{n}\sum_{i=0}^{n}\left(\frac{Y_i^{act} - Y_i^{pre}}{Y_i^{act}}\right).100 \quad \text{......... (6)}$$

where $Y_i^{act}$ is the i$^{th}$ measured value, $Y_i^{pre}$ is the i$^{th}$ estimated value, and n is the total number of measurements.

A two-sample t-test with a p-value of 0.05 was used to analyze the differences between the means of the actual and measured values of Major diameter, Minor diameter, Surface area, and Perimeter in Microsoft excel 2016.

## Results and Discussion

### *The major diameter*

The results of the comparison of the actual major diameter (measured by slide calipers) and estimated major diameter (measured by image processing) of sixty-two cardamom samples are shown in figure 4. The coefficient of determination ($R^2$) for the major diameter of the cardamom was 0.926. The higher $R^2$ values indicate a very close fit of the predicted model of the major diameter of cardamom samples with the actual measurement. The Pearson’s correlation coefficient in this case (0.9632) was also found to be strong enough to support the model. The proportion of the variance in the estimating features to the actual measurements can be interpreted as the RMSE and MAPE values. The lower the RMSE and MAPE values indicate the closer prediction of image processing result with the actual measurement of major diameter in cardamom samples.

**Table 2.** Overall performance of estimation model of cardamom samples

| Features | MAE (mm) | MPAE (%) | RMSE (mm or mm$^2$) | Accuracy (%) |
|---|---|---|---|---|
| Major diameter | 0.740 | 4.353 | 0.969 | 95.64 |
| Minor diameter | 0.330 | 5.259 | 0.456 | 94.74 |
| Surface area | 4.310 | 4.687 | 5.650 | 95.32 |
| Perimeter | 0.930 | 2.183 | 1.238 | 97.81 |

**Table 3.** A two-sample t-test with a p-value of 0.05 of actual and estimated values of cardamom capsules

| | Major diameter (mm) | | Minor diameter (mm) | | Surface Area (mm$^2$) | | Perimeter (mm) | |
|---|---|---|---|---|---|---|---|---|
| | Act | Est | Act | Est | Act | Est | Act | Est |
| Max$^m$ | 24 | 24.98 | 9 | 9.60 | 190 | 202.16 | 62 | 63.01 |
| Min$^m$ | 12 | 11.92 | 3.50 | 4.51 | 46.875 | 41.94 | 29 | 27.71 |
| Mean | 17.53 | 18.06 | 6.64 | 6.92 | 98.43 | 97.72 | 43.92 | 44.66 |
| P-value | 0.310 | | 0.186 | | 0.929 | | 0.669 | |

Act=actual value measured by Vernier caliper, Est=estimated value from image processing technique

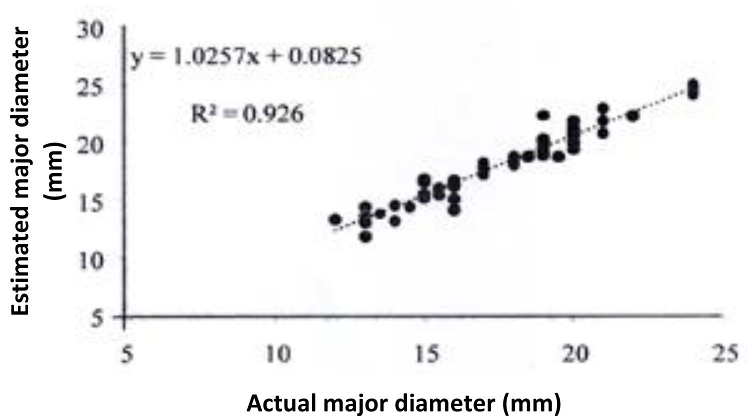


Figure 4. The estimated major diameter of cardamom capsules.

The root means squared error (RMSE) and means absolute percentage error (MAPE) were counted as 0.969 mm and 4.353% respectively (Table 2). These errors may have come from the erosion and dilation of morphological operation during image segmentation. This estimated major (4.353% error) diameter using the image processing technique can be considered as reliable based on the results found by Liming et al., (2010) who showed the results of the strawberry size detection error was not more than 5% between actual and measured values. The two-sample t-test (Table 3) revealed no significant differences ($p>0.05$) between the means of actual and measured major diameter values that also reveal the suggested automated image processing technique achieved high accuracy.

### *Minor diameter*

The measured minor diameter of the 62 samples was plotted against their actual measurements as shown in figure 5. The coefficient of determination ($R^2$) for cardamom in minor diameter was found to be 0.8838. However, Root means squared error (RMSE) and mean absolute percentage error (MAPE) was observed as 0.456 mm and 5.259% respectively (Table 2). Such higher error may be compensated by the fact that the Pearson's correlation coefficient was found to be 0.9153 which suggested a strong correlation and no significant (Table 3) differences ($p>0.05$) between the means of actual and measured values.

### *Surface Area*

The estimated surface area of the cardamom samples was plotted against the measured values as shown in figure 6. The coefficient of determination ($R^2$), root mean squared error (RMSE), and mean absolute percentage error (MAPE) were determined as 5.650 mm$^{2,}$ and 4.687 % respectively (Table 2).

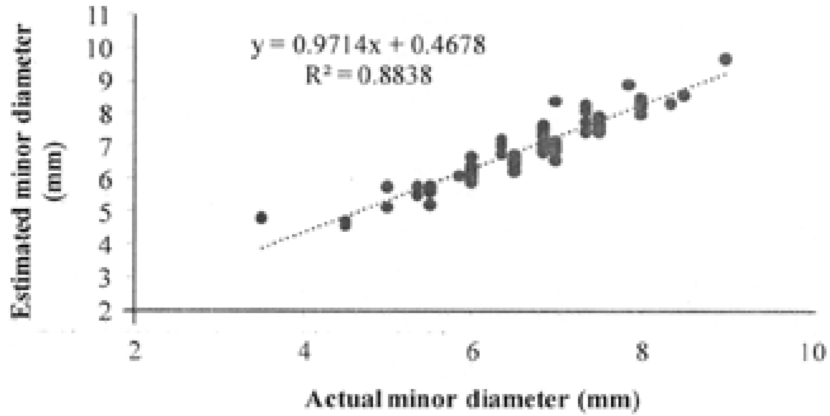


Figure 5. The estimated minor diameter of cardamom capsules.

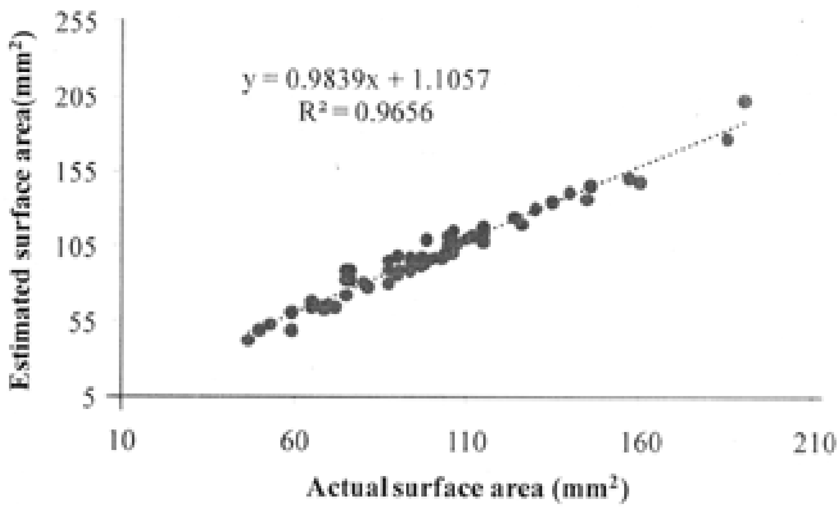


Figure 6. The estimated surface area of cardamom capsules

Sabliov et al. (2002) examined the surface area and volume of some agricultural products, and in all cases, the error was lower than 6% which was deemed acceptable. In our research, the surface area determination was carried out with considerable accuracy (95.32%) and no significant (Table 3) differences (p>0.05) between the means of the actual and measured surface area of cardamom capsules which suggesting the fact that the images captured by mobile devices can be used in machine vision technology.

### *Perimeter*

The measured perimeters of cardamom samples were highly correlated with the actual measurement since the coefficient of determination ($R^2$) was found at 0 .9762 (Figure 7). The root mean squared error (RMSE) and mean absolute percentage error (MAPE) was found to be 1.238 mm and 2.183 %, respectively (Table 2). The overall accuracy for determining the perimeter by using mobile images was therefore calculated to be 97.81% which is very satisfactory. The two-sample t-test (Table 3) revealed no significant differences (p>0.05) between the means of actual and measured perimeter values that verified the proposed technique of measuring the perimeter of cardamom using automated image processing achieved high precision.

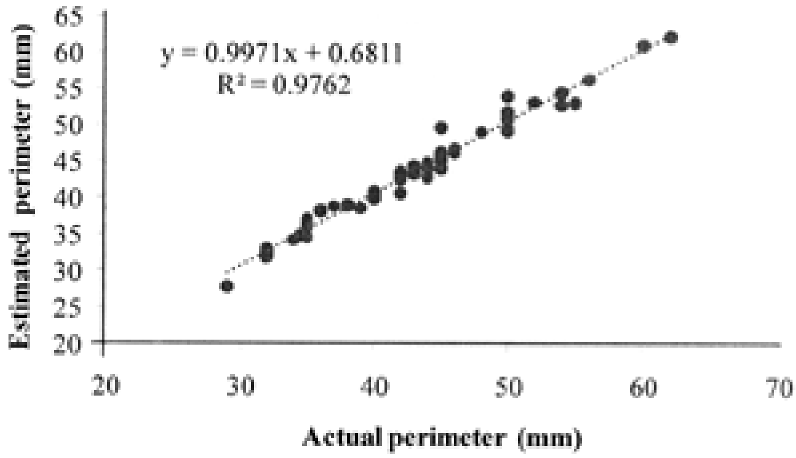


Figure 7. Perimeter estimation of cardamom capsule

## Conclusion

To contribute to the automated grading and sorting of cardamom spices, this research was carried out to quantify how images captured by mobile devices could be used for machine vision technology. For this, four features of cardamom samples, namely major diameter, minor diameter, surface area, and perimeter were estimated by image processing techniques using MATLAB. An algorithm was developed and employed on the images captured by an iPhone 7. This method was able to predict all the four geometric parameters of the samples. The results indicate that grading of cardamom samples based on their geometric features could be carried out by incorporating mobile images in machine vision technology in the future.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding this research and publication of this manuscript.

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