Modeling the Main Physical Properties of Banana Fruit Based on Geometrical Attributes

Mahmoud Soltani[1,*], Reza Alimardani[2] and Mahmoud Omid[3]

1,2,3 Department of Agricultural Machinery Engineering
Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran
mahmoodsoltani39@yahoo.com

***Abstract* - To design and develop a machine for different tasks, the physical characteristics of fruit and their relationships must be known. The objective of this study was to develop models to predict the mass, surface and projected areas of banana fruit as functions of its physical properties. To measure the projected and surface areas, the image processing technique was used. Results showed that a multiple regression modeling based on the three dimensions had the highest R^2 with values of 0.972, 0.974 and 0.974 for mass, surface area and projected area, respectively. Modeling based on three independent variables is a time-consuming method; therefore, single regression models were also investigated. Among one-dimensional equations, models based on the length of the fruit were proper to predict the mass, surface and projected areas of fruit. It is ideal to predict the surface and projected areas as a function of fruit mass because of the easiness of mass measuring. A good model of surface area was found to be a function of the banana mass, but this result was not achieved for the projected area.**

Keywords– Banana Fruit, Modeling and Image Processing

Nomenclature

L_o	External length (mm)
L_i	Internal length (mm)
L	Length (mm)
W	Width (mm)
T	Thickness (mm)
M	Mass (g)
S	Surface area (cm^2)
P	Projected area (cm^2)
V_{ell}	Volume of ellipsoid (cm^3)
R^2	Coefficient of determination
RSE	Regression standard error
k_1, k_2, k_3	Regression coefficient

I. INTRODUCTION

Investigation of relations between some physical properties such as mass, among other properties such as dimensions and estimated volume is the subject of the researchers' studies. In this field, dimensions, projected area and volume of the fruit are employed to predict the mass, surface area and projected area of fruits and vegetables, the mass can also be predicted by the projected area. The present study has major advantages. There are some situations in which it is desirable to extract relationships between physical characteristics. To design and optimize a machine for handling, cleaning, conveying, sorting and peeling, the fruit physical characteristics and their relationships must be extracted. Therefore, studying the relationship between weight and geometric properties is essential (Khoshnam et al., 2007). A fruit's size and shape determine the number of fruits that can be placed in containers with a given size. Volume and surface area are beneficial in proper prediction of drying rates and hence the drying time in the dryer. Among these physical characteristics, mass, volume, surface and projected areas are the most important ones in determining sizing systems (Peleg and Ramraz, 1975; Khodabandehloo, 1999). For example, fruits are often graded by size, but it may be more economical to develop a machine which grades the fruit by weight. Grading fruits based on weight is important in packing and handling and provides suitable packing patterns (Keramat Jahromi et al., 2007). Since sizing agricultural products by electrical mechanism is a costly method and mechanical sizing mechanism reacts poorly, dimensional method (length, area, and volume) can be used. Determining a relationship between mass and projected areas and dimensions may be useful and applicable (Tabatabaeefar et al., 2000).

Also, surface and projected areas are important to indicate physical properties such as water loss, gas permeability and weight per unit surface area, heat transfer, quantity of pesticide applications, respiration rates, evaluation of fruit growth and quality, respiration rate and ripeness index to forecast optimum harvest time (Eifert et al., 2006; Hahn et al., 2000; Lee et al., 2006; Lorestani and Tabatabaeefar., 2006; Topuz et al., 2005; Wilhelm et al., 2005). The surface area and projected area information are also used in food technology to predict the amounts of applied chemical, estimate peeling times, and determine the microbial concentrations present in the produce (Sabilov et al., 2002). Different methods were devised to measure the surface area and projected area of fruits and vegetables. One of these techniques is tape method (TM). In this method, the tape is usually cut into small strips to fully cover the surface of the object, then these strips are peeled off and the total area is measured either by hand or by an area meter. The accuracy of this method is highly dependent on how precisely the object can be covered with tape strips, and also on how exactly the area for these tape pieces can be measured. The TM has been found time-consuming, labor intensive and prone to human error (Khojastehnazhand et al., 2009). Another method is based on the image processing (IP) technique. The IP method includes data acquisition task, determination of correlation formula, image processing task, and computation of estimated surface area or projected area (Omid et al., 2010). The major defect of this method is its expensive apparatus. The mathematical models and numerical methods are seemed to be useful for predicting the surface and projected areas by measuring the mass or dimensions of fruit or vegetable. This method only needs a digital balance with high accuracy and a digital caliper.

Many researchers and workers investigated the relation between the mass and other properties of agricultural products. Tabatabaeefar and Rajabipour (2005) modeled the mass of apples by their geometrical properties. In their model, the mass and the smallest diameter of the apple had a strong relationship with a very high coefficient of determination. Khoshnam et al. (2007) modeled the mass of pomegranate fruit using some of its physical characteristics. They proposed that from economical and agronomical point of view, the suitable grading system of pomegranate mass was ascertained based on minor diameter as nonlinear relation. Naderi-Boldaji et al. (2008) predicted the mass of apricot fruit by its geometrical attributes. They reported that mass modeling of apricots based on their minor diameter and three projected areas is the most appropriate model which is a function of their dimensions, but the best model was obtained on the basis of the actual volume. Ebrahimi et al. (2009) studied some morphological and physical attributes of walnuts used in mass models. They found among the dimension-based grading system of walnuts a model in which the minor diameter of the walnut had a nonlinear relation with its mass, which was regarded the best model and could be considered as a good model for economical and horticultural designing systems. Hassan-Beygi et al. (2010) modeled the saffron crocus corm using its physical properties such as dimension, projected area and volume. Their concluded mass modeling showed that the prediction of saffron corm mass based on the major diameter and the first projected area was the most appropriate methods. These studies show the importance of mass modeling of fruits and vegetables in agricultural engineering and activities. One of fruits that needs mass, surface area and projected area modeling is banana fruit, because these properties are widely used in postharvest operations.

The objective of this study was to develop models to predict the mass, surface and projected areas of banana fruit based on geometrical attributes. This information is used to design and develop grading systems based on the quality (ripeness) of banana fruit.

II. MATERIALS AND METHODS

Banana fruits (*Cavendish variety*) shipped out from the Ecuador were used in this experiment. The banana fruits have been stored at 14 ºC temperature during transportation. The samples were randomly selected from banana boxes in Damirchilo warehouse located in Karaj city of Tehran province and transferred to the Physical Properties of Materials Laboratory, Department of Agricultural Machinery Engineering, Faculty of Engineering and Technology, University of Tehran, Karaj, Iran.

The external and internal lengths of the bananas (Lo, Li) were measured by a flexible ruler (Fig. 1). The perpendicular diameters (W, T) were measured to 0.01 mm accuracy by a digital caliper (Fig. 2). The mass of each sample was measured by a digital balance with an accuracy of 0.01 g.

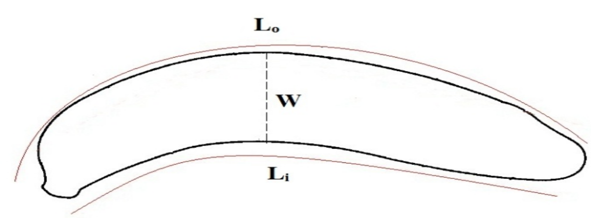

Fig. 1: Major Dimensions of Banana Fruit

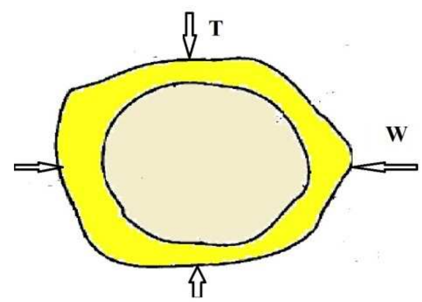

Fig. 2: The Perpendicular Diameters (W, T) of Banana Fruit

The value of mean length of fruit (L) is calculated from:

$$L = \frac{(L_O + L_i)}{2} \tag{1}$$

The actual projected area and surface area were measured by the image processing technique. This system consisted of a light emitting chamber utilized to emit light from behind the fruit. The equipment set as a whole is composed of three different basic sections of light source, diffuser, and camera holding stand. The function of the light source (4* 20W lamps) is to emit light to the bottom section of the diffuser. The diffuser task is to diffuse light at its level. The camera (Model Canon Power Shut A85, Japan) was mounted 40 cm above the diffuser. To measure the projected area, the banana fruit was laid on a flat surface and was allowed to reach its natural rest position, then the image was captured, after that the banana was peeled, the rind was set between the diffuser and a vitreous brede to tabulate it and the image was captured again. The captured images from digital camera were transmitted to the MATLAB 7 software and then the area was computed according to the following procedure:

A single grayscale threshold was used to determine if an image pixel belongs to the background or the object. Once the threshold was determined, the object boundary can be drawn and the number of pixels can be counted. System calibration was performed by attaching a quadrangular card (100 cm^2 area). The card was employed to provide pixel per cm^2 ratio.

Geometric mean diameter (D_g) and sphericity (ϕ) values were determined using the following equations (Mohsenin, 1986):

$$Dg = \sqrt[3]{LWT} \tag{2}$$

$$\phi = \frac{D_g}{L} \tag{3}$$

To estimate the mass, the projected area and the surface area models of banana fruit, the following models were considered:

1. Single or multiple variable regressions of banana fruit mass, based on dimensional characteristics: length (L), width (W), thickness (T) and geometric mean diameter (D_g).
2. Single regression of banana fruit mass, based on the surface area and projected area.
3. Single regression of banana fruit mass, projected area and surface area, based on the volumes of the assumed shape (ellipsoid).
4. Single regression of banana fruit projected area and surface area based on mass.

At the first classification, mass, projected area and surface area modeling were accomplished with length, width, thickness and geometric mean diameter as follows:

$$M = k_1 L + k_2 W + k_3 T + k_4 \tag{4}$$

$$S = k_1 L + k_2 W + k_3 T + k_4 \tag{5}$$

$$P = k_1 L + k_2 W + k_3 T + k_4 \tag{6}$$

$$M = k_1 D_g + k_2 \tag{7}$$

$$S = k_1 D_g + k_2 \tag{8}$$

$$P = k_1 D_g + k_2 \tag{9}$$

where k_1, k_2, k_3 and k_4 are constant values which are different in each equation.

In the second classification models, mass modeling of banana fruit was estimated based on the surface area and projected area as follows:

$$M = k_1 S + k_2 \tag{10}$$

$$M = k_1 P + k_2 \tag{11}$$

In the third classification, to achieve the models which can predict banana fruit mass, projected area and surface area on the basis of volume, ellipsoid volume values were calculated. The banana fruit shape was assumed as an ellipsoidal shape and thus its volume was calculated as:

$$V_{ell} = \frac{\pi}{6 \times 1000} LWT \tag{12}$$

So, the mass, projected area and surface area can be estimated by V_{ell} using single regression as:

$$M = k_1 V_{ell} + k_2 \tag{13}$$

$$S = k_1 V_{ell} + k_2 \tag{14}$$

$$P = k_1 V_{ell} + k_2 \tag{15}$$

where k_1 and k_2 are constants.

In the fourth classification, the projected and surface areas of banana fruit, were estimated based on mass as follows:

$$S = k_1 M + k_2 \tag{16}$$

$$P = k_1 M + k_2 \tag{17}$$

where k_1 and k_2 are constants.

Spreadsheet software, Microsoft Excel 2007, was used to analyze data and determine the regression models between the studied attributes. The best fitted models were selected based on a higher coefficient of determination (R^2, $p < 0.05$) and a lower regression standard error (RSE).

III. RESULTS AND DISCUSSION

A. Physical characteristics

Some physical properties of banana fruit such as mass, internal and external length, average length, intermediate and minor diameter, geometric mean diameter, sphericity, projected area and surface area and estimated ellipsoid volume are shown in Table 1. Variations in mass and length of banana were great, in intermediate and minor diameters were slight, the sphericity of banana was also low. Since banana is an elongated shape fruit, these results were predictable.

B. First classification models

Among the first classification models of mass (ie. nos. 1 to 8 that are shown in Table 2), model 7 was considered to have the highest value of R^2 and the lowest RSE. However, all three diameters must be measured for model 7, which make the sizing mechanism more expensive. Among the one-dimensional mass models, model 1 had the highest R^2 and the lowest RSE; therefore it is more conscionable to select this model for predicting banana mass as shown in Fig. 3.

Model 3 had the lowest power of mass prediction, while Tabatabaeefar and Rajabipour (2005) recommended an equation calculating apple mass and Khoshnam *et al.* (2007) recommended an equation calculating pomegranate

Table **1**

Property	Mean	Min	Max	SD
M (g)	180.56	121.10	272.50	36.25
L_o (mm)	235.3	202	288.00	24.24
L_i (mm)	165.2	135	220.00	21.95
L (mm)	200.3	168.50	247.50	22.29
W (mm)	39.72	33.84	49.03	2.78
T (mm)	36.30	31.32	40.80	2.29
D_g (mm)	66.20	56.31	77.79	4.51
Φ	0.33	0.30	0.370	0.02
P (cm^2)	75.87	54.78	116.29	13.38
S (cm^2)	181.48	141.28	242.63	27.67
V_{ell} (cm^3)	152.68	93.45	246.37	32.33

Table 2

No.	Models	Relation	R^2	RSE
1	$M=k_1L+k_2$	M=1.55L-130.8	0.915	10.71
2	$M= k_1W+k_2$	M=10.50W-236.8	0.649	21.7
3	$M= k_1 T+k_2$	M=9.39T-160.4	0.353	29.5
4	$M=k_1L+k_2W+ k_3$	M=1.38L+1.72W-165.31	0.921	10.41
5	$M=k_1L+k_2T+ k_3$	M=1.39L+4.00T-242.8	0.968	6.62
6	$M=k_1 W+k_2 T+ k_3$	M=8.87W+5.55T-373.5	0.757	18.28
7	$M=k_1 L+k_2W+k_3 T+k_4$	M=1.26L+1.37W+3.91T-268	0.972	6.25
8	$M=k_1D_g+k_2$	$M=7.83D_g-336.6$	0.948	8.33
9	$M=k_1P+k_2$	M=2.55P-12.73	0.884	12.49
10	$M=k_1S+k_2$	M=1.28S-51.8	0.955	7.73
11	$M=k_1V_{ell}+k_2$	$M=1.1V_{ell}+13.36$	0.954	7.87

mass on the basis of minor diameter. This difference is probably the result of the dissimilarity between the shape of a banana and an apple or a pomegranate.

For surface area modeling based on dimension, model 7 had the highest R^2 and the lowest RSE, but measuring all dimensions is time-consuming. Among the one-dimensional surface area modeling, model one predicted the surface area of banana fruit as shown in Fig. 4, as well as model 7. The difference between R^2 of model 1 and that of model 7 was only 0.01 (Table 3), thus model 1 can predict the surface area of banana fruit without any extra dimensions measuring.

Among the projected area modeling, model 4 and model 7 had the highest power of prediction (Table 4), but modeling the projected area by one dimension is a more economical method, however a higher standard error must

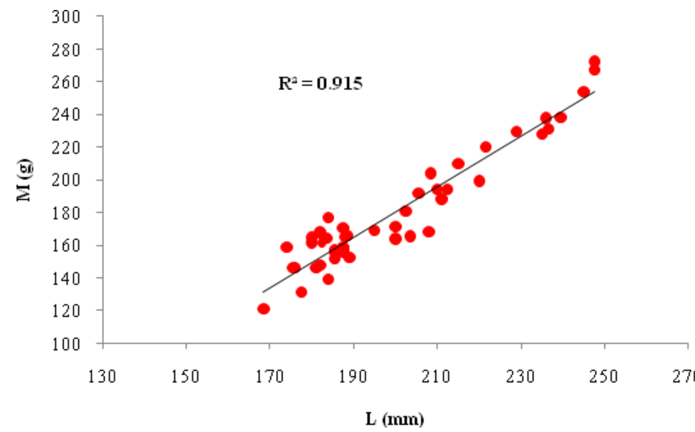

Fig. 3: Banana Fruit Mass Model Based on its Length

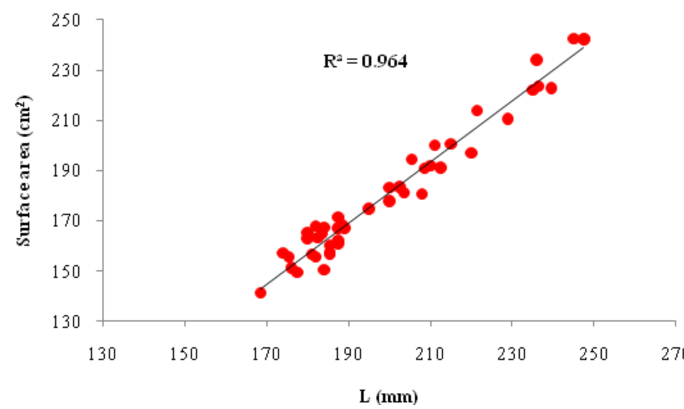

Fig. 4: Surface Area Modeling of Banana Fruit Based on its Length

be accepted. Therefore model 1 was selected among the first classification models of projected area, because the model 1 had the highest R^2 and the lowest RSE (Table 4). Fig. 5 shows the projected area values that were predicted by model 1 based on L values.

C. Second classification models

As shown in Table 2, the mass model of banana fruit based on projected area is approximately appropriate in the second classification, also the mass model of banana fruit based on the surface area had a higher R2 and a lower RSE than the model based on the projected area, but for measuring the surface area, the banana fruit must be peeled, which destructs the fruit, so this modeling is an impractical method. The best fitting line for mass model, based on the projected area had a linear trendline, while Khoshnam *et al.,* (2007) found a power function of mass modeling for pomegranate by its projected area. This method of modeling

Table 3

No.	Models	Relation	R^2	RSE
1	$S=k_1L+k_2$	$S=1.22L-62.52$	0.964	5.33
2	$S= k_1W+k_2$	$S=8.04W-138$	0.653	16.487
3	$S= k_1 T+k_2$	$S=5.75T-27.11$	0.227	24.61
4	$S=k_1L+k_2W+ k_3$	$S=1.13L+0.848W-79.5$	0.966	5.19
5	$S=k_1L+k_2T+ k_3$	$S=1.17L+1.2T-96.33$	0.972	4.73
6	$S=k_1 W+k_2 T+ k_3$	$S=7.28W+2.6T-201.94$	0.693	15.68
7	$S=k_1 L+k_2W+k_3 T+k_4$	$S=1.1L+0.74W+1.16T-110$	0.974	4.6
8	$S=k_1D_g+k_2$	$S=5.85D_g-204.7$	0.91	8.53
9	$S=k_1V_{ell}+k_2$	$S=0.82V_{ell}+56.4$	0.920	8.11
10	$S=k_1M+k_2$	$S=0.75M+46.74$	0.955	5.91

Table 4

Nos	Models	Relation	R^2	RSE
1	$P=k_1L+k_2$	$P=0.577L-39.67$	0.925	3.72
2	$P= k_1W+k_2$	$P=4.31W-95.39$	0.80	6.00
3	$P= k_1 T+k_2$	$P=2.24T-5.65$	0148	12.49
4	$P=k_1L+k_2W+ k_3$	$P=0.41L+1.74W-74.5$	0.974	2.21
5	$P=k_1L+k_2T+ k_3$	$P=0.577L+0.005T-39.81$	0.925	3.75
6	$P=k_1 W+k_2 T+ k_3$	$P=4.18W+0.44T-106.34$	0.81	6.00
7	$P=k_1 L+k_2W+k_3 T+k_4$	$P=0.41L+1.75W-0.1T-71.9$	0.974	2.22
8	$P=k_1D_g+k_2$	$P=2.8D_g-109.1$	0.89	4.48
9	$P=k_1V_{ell}+k_2$	$P=0.4V_{ell}+15.6$	0.911	4.04
10	$p=k_1M+k_2$	$P=0.347M+13.22$	0.884	4.61

needs expensive apparatus (camera, computer) and time-consuming data processing.

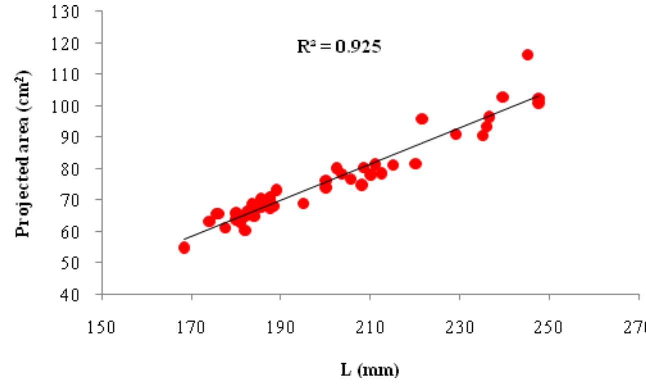

Fig. 5: Projected Area Modeling of Banana Fruit Based on its Length

D. Third classification models

A high correlation was perceived between mass and assumed ellipsoid volume of banana fruit (R^2 =0.954). For the surface area and the projected area, the R^2 was obtained as 0.92 and 0.911 respectively. It means that assumed ellipsoid volume can predict the surface area and the projected area well. Hassan-Beygi *et al.* (2010) also recommended a model of saffron crocus corm mass based on the estimated ellipsoid volume among actual and assumed sphere, oblate spheroid and ellipsoid shapes.

E. Fourth classification models

Measuring the surface area and the projected area of banana fruit is a troublesome process. But measuring the mass of banana is easy. By only a digital balance, one can measure the mass comfortably and precisely. Therefore by finding a relation between surface area or projected area and mass of fruit, these parameters can approximately be estimated. Results showed the surface area had a high correlation with the mass of banana fruit (Fig. 6). The R^2 was obtained as 0.955. The best fitted line for the data was a linear fitting. No difference was found between the R^2 of the linear trendline and the polynomial one. As shown in Fig. 7, the mass of fruit cannot predict the projected area ideally, but the result is satisfactory.

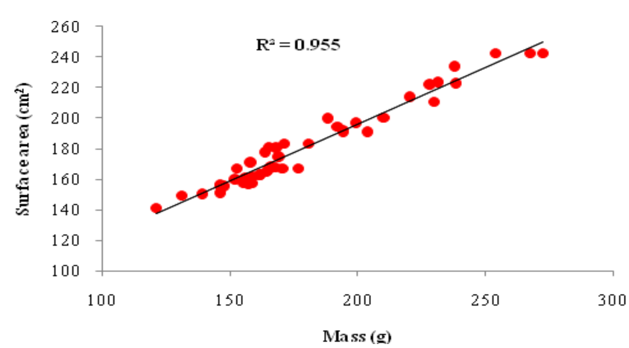

Fig. 6: Surface Area Model of Banana Fruit Based on Mass

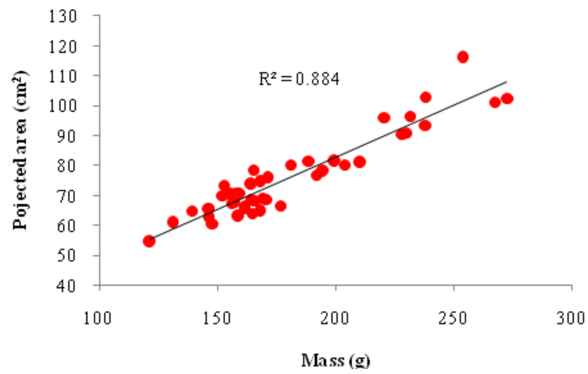

Fig. 7. Projected Area Model of Banana Fruit Based on Mass

IV. CONCLUSIONS

The equation modeling of banana mass, surface area and projected area as a function of physical properties was performed, the results of regression analysis, advantages and defects of each modeling were investigated, and then the most suitable modeling was selected. It was concluded:

i. For mass modeling, the appropriate modeling was based on one dimension (length) of the fruit. The assumed ellipsoid shape had also a good correlation with the mass of banana fruit.
ii. For surface area modeling, the appropriate modeling was based on one dimension (length) of the fruit, but the mass predicted the surface area better than the length of the fruit.
iii. For projected area modeling, the length of the fruit was appropriate to predict the projected area. Regression model based on the mass was able to predict the projected area but was not ideal; however, the easiest predicting method of projected area is weighing the banana fruit.
iv. The proposed models could be used for designing and developing the banana fruit electronically ripeness assessing equipments.

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