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Modeling of Apricot Mass Based on Geometrical Attributes Using Linear Regression Models

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Abstract: Eighteen linear regression models for modeling of apricot mass based on its geometrical attributes such as major diameter (a), intermediate diameter (b), minor diameter (c), geometrical mean diameter (GMD), first projected area (PA_1), second projected area (PA_2), third projected area (PA_3), criteria area (CAE), estimated volume based on an ellipsoid assumed shape (V_{Ell}) and measured volume (V_M) were suggested. Models were divided into three main classifications, i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes). The statistical results of the study indicated that in order to predict apricot mass based on outer dimensions, the mass model based on GMD as $M = -26.79 + 1.45\ GMD$ with $R^2 = 0.93$ can be recommended. Moreover, to predict apricot mass based on projected areas, the mass model based on CAE as $M = -5.08 + 3.05\ CAE$ with $R^2 = 0.93$ can be suggested. Besides, to predict apricot mass based on volumes, the mass model based on V_{Ell} as $M = 2.24 + 1.01\ V_{Ell}$ with $R^2 = 0.92$ can be utilized. These models can also be used to design and develop sizing machines equipped with an image processing system.

Key words: Apricot mass · Modeling · Geometrical attributes · Linear regression models

INTRODUCTION

Apricot (*Prunus armenia* L.) is classified under the *Prunus* genus, *Prunaidea* sub-family and the *Rosaceae* family of the Rosales group [1]. Average fruit mass ranges between 20 and 60 g, dried substance percentage in fruit is 18-28%, pH value is between 4.0 and 5.0 and fruit color is yellow. Apricot has an important place in human nutrition and apricot fruits can be used as fresh, dried or processed fruit [2]. Also, the fruit of apricot is not only consumed fresh but also used to produce dried apricot, frozen apricot, jam, jelly, marmalade, pulp, juice, nectar and extrusion products. Moreover, apricot kernels are used in the production of oils, cosmetics, active carbon and aroma perfume [3]. Apricot has an important place in terms of human health. Apricot is rich in minerals such as potassium and vitamins such as vitamin A. Vitamin A is necessary for epithelia tissues covering our bodies and organs, eye-health, bone and teeth development and working of endocrine glades. In addition, it plays important role in reproduction and growing functions of our bodies, in increasing body resistance against infections [4]. Iran is the second apricot producer in the world with 275, 580 tons production and 8.2% share. Turkey, Iran, Italy, Pakistan and France are the principal apricot producer countries. Apricot trees are also grown in Spain, Japan, Syria and Algeria. Iran has exported more than 680 tones to different countries in 2005 [5]. In Iran, the most widely produced types are Tabarzeh, Kardi, Damavandi, Nakhjavan and Sonnati [2, 4].

Similar to other fruits, apricot size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer fruits of equal size and shape. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [6-9]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [10-12]. Sorting manually is associated with high labor costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [13]. However, replacing human with a machine may still be questionable where the labor cost is comparable with the sorting equipment [14]. Studies on sorting in recent years

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have focused on automated sorting strategies and eliminating human efforts to provide more efficient and accurate sorting systems which improve the classification success or speed up the classification process [15, 16].

Physical and geometrical characteristics of products are the most important parameters in design of sorting systems. Among these characteristics, mass, outer dimensions, projected areas and volume are the most important ones in sizing systems [17-19]. The size of produce is frequently represented by its mass because it is relatively simple to measure. However, sorting based on some geometrical attributes may provide a more efficient method than mass sorting. Moreover, the mass of produce can be easily estimated from geometrical attributes if the mass model of the produce is known [20]. Thus, modeling of apricot mass based on some geometrical attributes may be useful and applicable. Therefore, the main objective of this research was to determine optimum mass model(s) based on some geometrical attributes of apricot.

MATERIALS AND METHODS

Experimental Procedure: One hundred randomly selected apricots (cv. Damavandi) of various sizes were purchased from a local market. Apricots were selected for freedom from defects by careful visual inspection, transferred to the laboratory and held at 5±1°C and 90±5% relative humidity until experimental procedure.

In order to obtain required parameters for determining mass models, the mass of each apricot was measured to 0.1 g accuracy on a digital balance. Moreover, the volume of each apricot was measured using the water displacement method. Each apricot was submerged into water and the volume of water displaced was measured. Water temperature during measurements was kept at 25°C.

By assuming the shape of apricots as an ellipsoid (Fig. 1), the outer dimensions of each apricot, i.e. major diameter (a), intermediate diameter (b) and minor diameter was measured to 0.1 mm accuracy by a digital caliper. The geometric mean diameter (GMD) of each apricot was then calculated by equation 1.

$$GMD = (abc)^{1/3} \quad (1)$$

Three projected areas of each apricot, i.e. first projected area (PA_1), second projected area (PA_2) and third projected area (PA3) was also calculated by using equation 2, 3 and 4, respectively. The average projected area known as criteria area (CAE) of each apricot was then determined from equation 5.

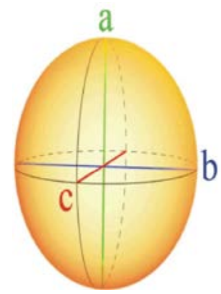

Fig. 1: The outer dimensions of an apricot, i.e. major diameter (a), intermediate diameter (b) and minor diameter (c) by assuming the shape of apricot as an ellipsoid

$$PA_1 = \pi\, ab/4 \quad (2)$$

$$PA_2 = \pi\, ac/4 \quad (3)$$

$$PA_3 = \pi\, bc/4 \quad (4)$$

$$CAE = (PA_1+PA_2+PA_3)/3 \quad (5)$$

In addition, the volume of ellipsoid assumed shape or estimated volume of each apricot (V_{Ell}) was calculated by using equation 6.

$$V_{Ell} = \pi\, abc/6 \quad (6)$$

Table 1 shows some physical and geometrical properties of the apricots used to determine mass models.

Regression Models: A typical linear multiple regression model is shown in equation 7:

$$Y = k_0 + k_1X_1 + k_2X_2 + \ldots + k_nX_n \quad (7)$$

where:

Y = Dependent variable, for example mass of apricot.

$X_1, X_2, \ldots, X_n$ = Independent variables, for example geometrical attributes of apricot.

$k_0, k_1, k_2, \ldots, k_n$ = Regression coefficients.

In order to model apricot mass based on geometrical attributes, eighteen linear regression models were suggested and all the data were subjected to linear regression analysis using the Microsoft Excel 2007. Models were divided into three main classifications (Table 2), i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes).

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of some physical and geometrical properties of the 100 randomly selected apricots used to determine mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	11.7	23.9	16.9	2.39	14.1
Major diameter (a), mm	27.3	37.0	32.5	1.94	5.98
Intermediate diameter (b), mm	26.0	34.5	30.4	1.68	5.52
Minor diameter (c), mm	23.3	32.2	28.1	1.65	5.86
Geometrical mean diameter (GMD), mm	26.0	34.2	30.3	1.51	5.00
First projected area (PA_1), cm^2	5.91	9.72	7.78	0.81	10.4
Second projected area (PA_2), cm^2	5.16	9.29	7.18	0.74	10.3
Third projected area (PA_3), cm^2	4.88	8.59	6.72	0.70	10.4
Criteria area (CAE), cm^2	5.32	9.17	7.23	0.72	9.95
Estimated volume (V_{Ell}), cm^3	9.18	20.9	14.6	2.18	14.9
Measured volume (V_M), cm^3	10.5	23.1	16.0	2.47	15.4

Table 2: Eighteen linear regression mass models and their relations in three classifications

Classification	Model No.	Model	Relation
Outer dimensions	1	$M = k_0 + k_1\ a$	$M = -12.61 + 0.91\ a$
	2	$M = k_0 + k_1\ b$	$M = -21.30 + 1.26\ b$
	3	$M = k_0 + k_1\ c$	$M = -15.44 + 1.16\ c$
	4	$M = k_0 + k_1\ GMD$	$M = -26.79 + 1.45\ GMD$
	5	$M = k_0 + k_1\ a + k_2\ b$	$M = -25.56 + 0.43\ a + 0.94\ b$
	6	$M = k_0 + k_1\ a + k_2\ c$	$M = -23.27 + 0.54\ a + 0.81\ c$
	7	$M = k_0 + k_1\ b + k_2\ c$	$M = -23.80 + 0.86\ b + 0.52\ c$
	8	$M = k_0 + k_1\ a + k_2\ b + k_3\ c$	$M = -27.20 + 0.39\ a + 0.63\ b + 0.44\ c$
Projected areas	9	$M = k_0 + k_1\ PA_1$	$M = -3.75 + 2.66\ PA_1$
	10	$M = k_0 + k_1\ PA_2$	$M = -3.10 + 2.79\ PA_2$
	11	$M = k_0 + k_1\ PA_3$	$M = -3.39 + 3.04\ PA_3$
	12	$M = k_0 + k_1\ CAE$	$M = -5.08 + 3.05\ CAE$
	13	$M = k_0 + k_1\ PA_1 + k_2\ PA_2$	$M = -4.20 + 1.49\ PA_1 + 1.33\ PA_2$
	14	$M = k_0 + k_1\ PA_1 + k_2\ PA_3$	$M = -5.30 + 1.46\ PA_1 + 1.63\ PA_3$
	15	$M = k_0 + k_1\ PA_2 + k_2\ PA_3$	$M = -4.50 + 1.43\ PA_2 + 1.67\ PA_3$
	16	$M = k_0 + k_1\ PA_1 + k_2\ PA_3 + k_3\ PA_3$	$M = -5.29 + 1.26\ PA_1 + 0.33\ PA_2 + 1.51\ PA_3$
Volumes	17	$M = k_0 + k_1\ V_{Ell}$	$M = 2.24 + 1.01\ V_{Ell}$
	18	$M = k_0 + k_1\ V_M$	$M = 2.64 + 0.89\ V_M$

RESULTS AND DISCUSSION

The p-value of the independent variable(s) and coefficient of determination (R^2) of all the linear regression mass models are shown in Table 3.

First Classification Models (Outer Dimensions): In this classification apricot mass can be predicted using single variable linear regressions of major diameter (a), intermediate diameter (b), minor diameter (c) and geometrical mean diameter (GMD) of apricot or multiple variable linear regressions of apricot diameters. As indicated in Table 3, among the first classification models (models No. 1-8), model No. 4 had the highest R^2 value (0.93). Also, the p-value of independent variable (GMD) was 3.23E-47. Based on the statistical results model No. 4 was selected as the best model of first classification. Model No. 4 is given in equation 8.

$$M = -26.79 + 1.45\ GMD \quad (8)$$

Second Classification Models (Projected Areas): In this classification apricot mass can be predicted using single variable linear regressions of first projected area (PA_1), second projected area (PA_2), third projected area (PA_3) and criteria area (CAE) of apricot or multiple variable linear regressions of apricot projected areas. As showed in Table 3, among the second classification models (models No. 9-16), model No. 12 had the highest R^2 value (0.93). Moreover, the p-value of independent variable (CAE) was 5.05E-48. Again, based on the statistical results model No. 12 was chosen as the best model of second classification. Model No. 12 is given in equation 9.

$$M = -5.08 + 3.05\ CAE \quad (9)$$

Third Classification Models (Volumes): In this classification apricot mass can be predicted using single variable linear regressions of estimated volume calculated from an ellipsoid assumed shape (V_{Ell}) or measured volume (V_M) of apricot. As indicated in Table 3, between the third

Table 3: Mass models, p-value of model variable(s) and coefficient of determination (R^2)

	p-value										
Model No.	a	b	c	GMD	PA_1	PA_2	PA_3	CAE	V_{Ell}	V_M	R^2
1	1.14E-18	---	---	---	---	---	---	---	---	---	0.61
2	---	2.06E-30	---	---	---	---	---	---	---	---	0.80
3	---	---	2.65E-23	---	---	---	---	---	---	---	0.70
4	---	---	---	3.23E-47	---	---	---	---	---	---	0.93
5	2.05E-11	4.59E-23	---	---	---	---	---	---	---	---	0.88
6	3.29E-14	---	8.41E-19	---	---	---	---	---	---	---	0.85
7	---	3.26E-15	4.18E-08	---	---	---	---	---	---	---	0.86
8	5.90E-13	5.99E-14	1.06E-09	---	---	---	---	---	---	---	0.92
9	---	---	---	---	5.87E-37	---	---	---	---	---	0.86
10	---	---	---	---	---	1.17E-35	---	---	---	---	0.85
11	---	---	---	---	---	---	1.40E-36	---	---	---	0.86
12	---	---	---	---	---	---	---	5.05E-48	---	---	0.93
13	---	---	---	---	1.91E-06	4.12E-05	---	---	---	---	0.89
14	---	---	---	---	3.06E-14	---	7.27E-14	---	---	---	0.92
15	---	---	---	---	---	6.53E-09	7.67E-10	---	---	---	0.90
16	---	---	---	---	5.33E-07	0.233342	2.40E-10	---	---	---	0.92
17	---	---	---	---	---	---	---	---	4.05E-48	---	0.92
18	---	---	---	---	---	---	---	---	---	4.99E-33	0.82

classification models (models No. 17 and 18), model No. 17 had the highest R^2 value (0.92). In addition, the p-value of independent variable (V_{Ell}) was 4.05E-48. Once more, based on the statistical results model No. 17 was preferred as the best model of third classification. Model No. 17 is given in equation 10.

$$M = 2.24 + 1.01\ V_{Ell} \tag{10}$$

CONCLUSION

To predict apricot mass (M) based on outer dimensions, the mass model based on geometrical mean diameter (GMD) as $M = -26.79 + 1.45\ GMD$ with $R^2 = 0.93$ can be recommended. Moreover, to predict apricot mass based on projected areas, the mass model based on criteria area (CAE) as $M = -5.08 + 3.05\ CAE$ with $R^2 = 0.93$ can be suggested. Besides, to predict apricot mass based on volumes, the mass model based on estimated volume calculated from an ellipsoid assumed shape (V_{Ell}) as $M = 2.24 + 1.01\ V_{Ell}$ with $R^2 = 0.92$ can be utilized. These models can also be used to design and develop sizing machines equipped with an image processing system.

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