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Prediction of Apricot Mass Based on Some Geometrical Attributes

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Abstract: Apricots are often graded on the basis of size, but it may be more suitable and economical to develop a system which grades by mass. Thus, a relationship between apricot mass and some geometrical attributes of apricot is needed. In this study, eighteen linear regression models for predicting apricot mass from some geometrical attributes of apricot 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 % Geometrical attributes % Modeling % Prediction % Iran

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 and agricultural products of equal size and shape [6]. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [7-10]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [11-13]. Sorting manually is associated with high labor costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [14]. However, replacing human with a machine may still be questionable where the labor cost is comparable with the sorting equipment [15]. Studies on

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sorting in recent years 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 [16, 17].

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 [18-21]. 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 in known [22]. Therefore, modeling of apricot mass based on some geometrical attributes may be useful and applicable.

In spite of second great apricot producer in the world is Iran, but exportation of this product and its process is so low. Therefore, the main objectives of this research were: (a) to determine optimum mass model(s) based on some geometrical attributes of apricot and (b) to verify determined mass model(s) by comparing their results with those of the measuring method.

MATERIALS AND METHODS

Experimental Procedure: Eighty five 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 (c) 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.

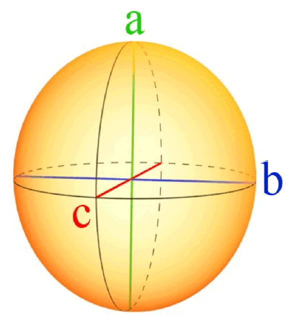

Fig. 1: The outer dimensions of an apricot, i.e. major diameter (a), intermediate diameter (b) and minor diameter (c) by assuming the shape of apricot as an ellipsoid

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

Three projected areas of each apricot, i.e. first projected area (PA_1), second projected area (PA_2) and third projected area (PA_3) 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.

$$PA_1 = B\ ab/4 \quad (2)$$

$$PA_2 = B\ ac/4 \quad (3)$$

$$PA_3 = B\ bc/4 \quad (4)$$

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

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

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

Table 1 shows some physical and geometrical properties of the apricots used to determine mass models. Also, in order to verify mass models, physical and geometrical properties of fifteen randomly selected apricots of various sizes were determined as described before. Table 2 shows some physical and geometrical properties of the apricots used to verify mass models.

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

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of some physical and geometrical properties of the 85 randomly selected apricots used to determine mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	11.7	23.9	17.0	2.36	13.9
Major diameter (a), mm	27.3	37.0	32.5	2.03	6.22
Intermediate diameter (b), mm	26.0	34.0	30.4	1.67	5.49
Minor diameter (c), mm	23.3	32.2	28.0	1.70	6.07
Geometrical mean diameter (GMD), mm	26.0	34.1	30.2	1.56	5.16
First projected area (PA_1), cm^2	5.91	9.72	7.77	0.82	10.5
Second projected area (PA_2), cm^2	5.16	9.29	7.18	0.78	10.8
Third projected area (PA_3), cm^2	4.88	8.59	6.70	0.72	10.7
Criteria area (CAE), cm^2	5.32	9.17	7.22	0.74	10.3
Estimated volume (V_{Ell}), cm^3	9.18	20.9	14.6	2.24	15.4
Measured volume (V_M), cm^3	10.5	23.1	16.0	2.39	14.9

Table 2: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of some physical and geometrical properties of the fifteen randomly selected apricots used to verify mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	12.2	22.6	16.8	2.66	15.8
Major diameter (a), mm	30.2	35.2	32.4	1.45	4.48
Intermediate diameter (b), mm	28.2	34.5	30.7	1.77	5.79
Minor diameter (c), mm	25.4	29.9	28.4	1.30	4.58
Geometrical mean diameter (GMD), mm	28.2	33.0	30.4	1.24	4.06
First projected area (PA_1), cm^2	6.89	9.53	7.81	0.76	9.75
Second projected area (PA_2), cm^2	6.10	8.21	7.21	0.50	6.94
Third projected area (PA_3), cm^2	5.72	8.04	6.83	0.62	9.07
Criteria area (CAE), cm^2	6.24	8.59	7.28	0.60	8.18
Estimated volume (V_{Ell}), cm^3	11.7	18.9	14.8	1.82	12.3
Measured volume (V_M), cm^3	10.5	23.0	16.1	2.96	18.4

Table 3: 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	$M = k_0 + k_1 V_M$	$M = 2.64 + 0.89 V_M$

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

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, …,

k_n = Regression coefficients.

In order to estimate apricot mass from geometrical attributes, eighteen linear regression mass 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 3), i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes).

Statistical Analysis: A paired samples t-test and the mean difference confidence interval approach were used to compare the apricot mass values predicted using models with the apricot mass values measured by digital balance. The Bland-Altman approach [23] was also used to plot the agreement between the apricot mass values measured by digital balance with the apricot mass values predicted using models. The statistical analyses were also performed using Microsoft Excel 2007.

RESULTS

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 4.

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 4, 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.

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

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 4, among the second classification models (models No. 9-16), model No. 12 had the highest R^2 value (0.93).

Table 4: 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

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.

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

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 4, between the third 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 chosen as the best model of third classification. Model No. 17 is given in equation 10.

$$M = 2.24 + 1.01\,V_{Ell} \qquad (10)$$

DISCUSSION

Among the linear regression models (models No. 1-18), models No. 4, 12 and 17 were chosen based on the statistical results. A paired samples t-test and the mean difference interval approach were used to compare the apricot mass values predicted using models No. 4, 12 and 17 with the apricot mass values measured by digital balance. The Bland-Altman approach [23] was also used to plot the agreement between the apricot mass values measured by digital balance with the apricot mass values predicted using the selected mass models.

Comparison of Model No. 4 with Measuring Method: The apricot mass values predicted by model No. 4 were compared with the apricot mass values measured by digital balance and are shown in Table 5. A plot of the apricot mass values determined by model No. 4 and digital balance with the line of equality (1.0: 1.0) is shown in Fig. 2. The mean apricot mass difference between two methods was 0.20 g (95% confidence interval: -0.26 and 0.66 g; P = 0.3645). The standard deviation of the apricot mass difference was 0.83 g (Table 6). The paired samples t-test results showed that the apricot mass values predicted by model No. 4 were not significantly different than that measured by digital balance. The apricot mass values difference between two methods were normally distributed and 95% of these differences were expected to lie between ì-1.96ó and ì+1.96ó, known as 95% limits of agreement. The 95% limits of agreement for comparison of the apricot mass values determined by digital balance and model No. 4 was calculated at -1.42 g and 1.82 g (Fig. 3).

Table 5: Geometrical attributes of the fifteen apricots used in evaluating selected mass models

	Geometrical attributes of apricot			Apricot mass (g)			
Sample No.	GMD (mm)	CAE (cm^2)	V_{Ell} (cm^3)	Measured by digital balance	Predicted by model No. 4	Predicted by model No. 12	Predicted by model No. 17
1	29.8	7.0	13.9	16.2	16.5	16.2	16.3
2	28.2	6.2	11.7	13.2	14.0	13.9	14.0
3	29.1	6.7	12.9	14.2	15.5	15.3	15.3
4	30.2	7.2	14.4	15.3	17.0	16.7	16.8
5	29.7	6.9	13.7	15.5	16.2	16.0	16.1
6	29.2	6.7	13.1	16.0	15.6	15.4	15.4
7	29.5	6.8	13.5	16.3	16.0	15.8	15.8
8	30.2	7.2	14.4	16.9	17.0	16.7	16.8
9	31.0	7.6	15.6	17.3	18.2	18.0	18.0
10	30.6	7.4	15.1	17.7	17.6	17.4	17.4
11	31.3	7.7	16.1	18.0	18.7	18.5	18.5
12	31.1	7.6	15.7	18.8	18.3	18.2	18.1
13	31.3	7.7	16.0	19.1	18.6	18.4	18.4
14	31.8	8.0	16.9	19.6	19.4	19.2	19.3
15	33.0	8.6	18.9	22.6	21.1	21.1	21.3

Table 6: Paired samples t-test analyses on comparing apricot mass determination methods

Determination methods	Average difference (g)	Standard deviation of difference (g)	p-value	95% confidence intervals for the difference in means (g)
Model No. 4 vs. measuring	0.20	0.83	0.3645	-0.26, 0.66
Model No. 12 vs. measuring	0.01	0.79	0.9743	-0.43, 0.44
Model No. 17 vs. measuring	0.05	0.79	0.7964	-0.38, 0.49

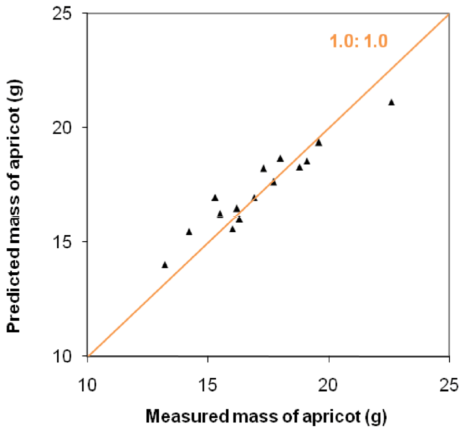

Fig. 2: Measured mass of apricot and predicted mass of apricot using model No. 4 with the line of equality (1.0: 1.0)

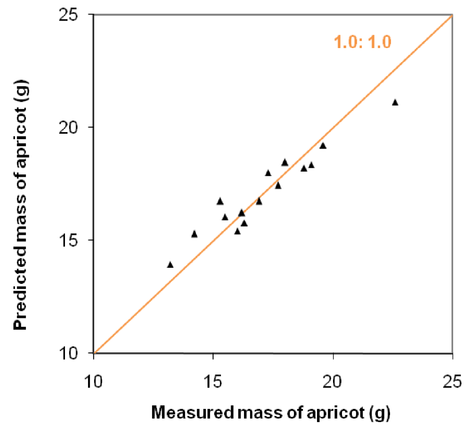

Fig. 4: Measured mass of apricot and predicted mass of apricot using model No. 12 with the line of equality (1.0: 1.0)

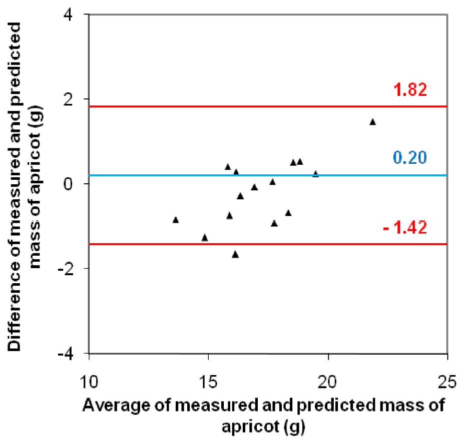

Fig. 3: Bland-Altman plot for the comparison of measured mass of apricot and predicted apricot mass of apricot using model No. 4; the outer lines indicate the 95% limits of agreement (-1.42, 1.82) and the center line shows the average difference (0.20)

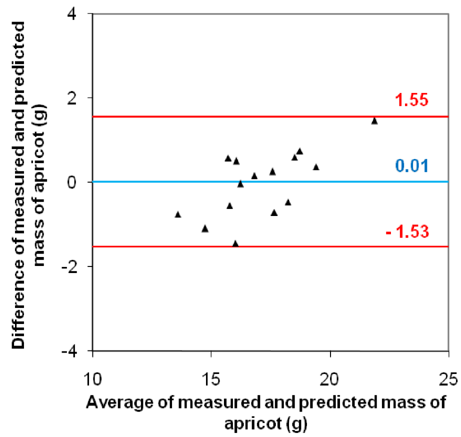

Fig. 5: Bland-Altman plot for the comparison of measured mass of apricot and predicted apricot mass of apricot using model No. 12; the outer lines indicate the 95% limits of agreement (-1.53, 1.55) and the center line shows the average difference (0.01)

Thus, the apricot mass values predicted by model No. 4 may be 1.62 g lower or higher than the apricot mass values measured by digital balance. The average percentage difference for the apricot mass values predicted by model No. 4 and measured by digital balance was 4.0%.

Comparison of Model No. 12 with Measuring Method: The apricot mass values predicted by model No. 12 were compared with the apricot mass values measured by digital balance and are shown in Table 5. A plot of the apricot mass values determined by model No. 12 and digital balance with the line of equality (1.0: 1.0) is shown in Fig. 4. The mean apricot mass difference between two methods was 0.01 g (95% confidence interval: -0.43 and 0.44 g; P = 0.9743). The standard deviation of the apricot mass difference was 0.79 g (Table 6). Again, the paired samples t-test results showed that the apricot mass values predicted by model No. 12 were not significantly different than that measured by digital balance. The 95% limits of agreement for comparison of the apricot mass values determined by digital balance and model No. 12 was calculated at -1.53 g and 1.55 g (Fig. 5). Therefore, the apricot mass values predicted by model No. 12 may be 1.54 g lower or higher than the apricot mass values measured by digital balance. The average percentage difference for the apricot mass values predicted by model No. 12 and measured by digital balance was 3.9%.

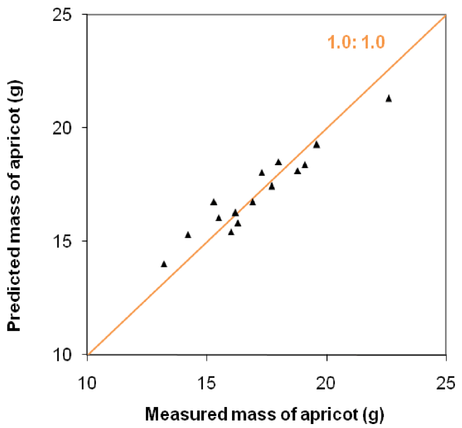

Fig. 6: Measured mass of apricot and predicted mass of apricot using model No. 17 with the line of equality (1.0: 1.0)

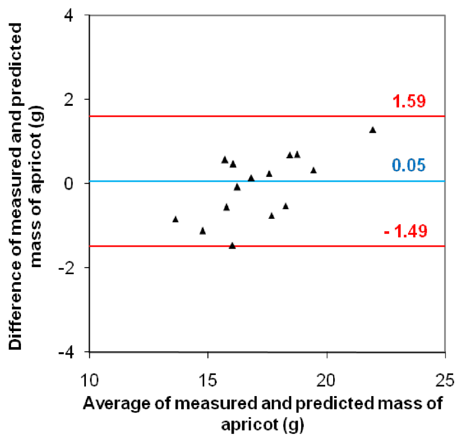

Fig. 7: Bland-Altman plot for the comparison of measured mass of apricot and predicted apricot mass of apricot using model No. 17; the outer lines indicate the 95% limits of agreement (-1.49, 1.59) and the center line shows the average difference (0.05)

Comparison of Model No. 17 with Measuring Method: The apricot mass values predicted by model No. 17 were compared with the apricot mass values measured by digital balance and are shown in Table 5. A plot of the apricot mass values determined by model No. 17 and digital balance with the line of equality (1.0: 1.0) is shown in Fig. 6. The mean apricot mass difference between two methods was 0.05 g (95% confidence interval: -0.38 and 0.49 g; P = 0.7964). The standard deviation of the apricot mass difference was 0.79 g (Table 6). Once more, the paired samples t-test results showed that the apricot mass values predicted by model No. 17 were not significantly different than that measured by digital balance. The 95% limits of agreement for comparison of the apricot mass values determined by digital balance and model No. 17 was calculated at -1.49 g and 1.59 g (Fig. 7). As a result, the apricot mass values predicted by model No. 17 may be 1.54 g lower or higher than the apricot mass values measured by digital balance. The average percentage difference for the apricot mass values predicted by model No. 17 and measured by digital balance was 3.9%.

CONCLUSIONS

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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