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Modelling the mass of kiwi fruit by geometrical attributes

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A b s t r a c t. The determination of mathematical models for predicting the mass of kiwi fruits from their dimensions and projected areas was done. The research was conducted on 200 observations of two Iranian varieties of kiwi fruit (Abbott and Hayward). The physical characteristics measured included mass, volume, dimensions and projected areas perpendicular to major diameters. Maximum, mean, minimum values, standard deviation, coefficient of variation, bulk density (BD), geometric mean diameter (GM), and percent sphericity (SPH) of all of the parameters were determined. Models were divided into three classifications: 1 – single and multiple variable regression models of kiwi fruit dimensions (dimension models), 2 – single and multiple variable regression models of projected areas (projected area models), 3 – estimation of kiwi fruit shape, ellipsoid or spheroid based on volume (models based on volume). Among single variable models, 1st classification, second diameter model of kiwi fruit had maximum coefficient of determination, $R^2 = 0.78$ for all observations. Among the second classification, mass models of projected areas had a nonlinear relationship with $R^2 = 0.97$. Third classification models had the highest performance followed by the second classification and, respectively, the first, with R^2 approaching unity.

K e y w o r d s: kiwi fruit, mass models, dimensions, physical properties, geometrical attributes

INTRODUCTION

Annual citrus production in Iran is 3.5 million tones, which is ranked as 6th in the world (Ministry of Agriculture, Iran, 1998). The physical configurations of most agricultural products are of utmost importance in the design of handling, sorting, processing, and packaging systems. Among the physical attributes of agricultural materials, dimensions, mass, volume, projected areas and surface areas have always been of special importance to the engineer (Tabatabaeefar and Rajabipour, 2005; Wright *et al*., 1986; Safwat and Moustafa, 1971).With respect to the economical importance of kiwi fruit and its need for a grading process, for overcoming the world markets and decreasing product losses, investigation and development in the field of selection or designing of the most suitable machine for sizing of kiwi fruit is necessary. Sizing by weight mechanism for products with irregular shape is recommended (Stroshine and Hamann, 1994). Electrical sizing mechanisms are expensive, and mechanical sizing mechanism work slowly, therefore, dimensions method (length, area and volume) can be used for kiwi fruit. Determination of relationship between mass with dimensions and projected areas may be useful and applicable (Pitts *et al*., 1987, Stroshine and Hamann, 1994).

The objective of this study is to determine the most suitable model for predicting kiwi fruit mass by its geometrical attributes. This information can be used in the design and development of sizing mechanisms.

MATERIALS AND METHODS

Two different Iranian varieties of kiwi fruits sampled were Abbott (n=100) and Hayward (n=100), from the northern region of the country, with a total of 200 observations.

Physical attributes

The mass of each kiwi fruit was measured to 0.1 g accuracy on a digital balance. Its volume was obtained by volume of water displaced. A kiwi fruit was submerged into a known volume of water and then the volume of water displaced was measured. Water temperature was kept at 25°C. Bulk density of each kiwi fruit was calculated by the

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mass of kiwi fruit in air divided by the mass of the displaced water. Three mutually perpendicular axes: a – the longest intercept, b – the longest intercept normal to a, c – the longest intercept normal to a and b, of kiwi fruit were measured to 0.05 mm by a micrometer (caliper), when it was laid on a flat surface and assumd its natural rest position (Pitts *et al.*, 1987). Three mutually perpendicular areas, PA, PB, PC were measured to 0.1 cm^2 accuracy by aΔT area-meter, MK2 model, by positioning each kiwi fruit in the diameter directions; the mean of these three projected areas was suggested as a criterion for a sizing machine (Peleg, 1985). Geometric mean diameter (GM), was determined from the cubic roots of the three diameters, $(abc)^{1/3}$, and percent sphericity (SPH) was equal to the geometric mean diameter divided by the longest diameter x 100, (GM/a) x 100. The surface area (SA) is the surface of the skin of kiwi fruit was peeled by knife and laid on aΔT area-meter, MK2 model (Mohsenin, 1986).

Regression models (linear, non-linear, single and multiple variables)

Spreadsheet software, Microsoft Excel 98 (1998) and SPSS Software (1999) were used to analyze the data and to determine regression models between the parameters of either linear or polynomial form.

In order to estimate a kiwi fruit's mass from measured dimensions (length, projected area, and volume), the following three categories of models were suggested.

1. Regression models of mass with major (a), intermediate (b), minor (c) and all three diameters were applied. A total of four models were determined. A model with the highest coefficient of determination, R^2, and the least R.S.E. was selected.

2. Regression models of mass with each projected area (PA, PB, PC) and all three projected areas were determined. A total of four models were determined. A model with the highest coefficient of determination, R^2, and the least R.S.E. was presented.

3. Regression models of mass with kiwi fruit volume (spheroid (SPH), oblate spheroid shape) and measured volume (V). A total of 11 models for all three categories were determined. A model with the highest coefficient of determination, R^2, and the least R.S.E. was presened.

For the first category, the independent variables were one, two or three mutually perpendicular diameters:

$$M = k_1 a + k_2 b + k_3 c + k_4, \quad (1)$$

where: M – mass of kiwi fruit (g); a, b, c – the longest, median and the smallest diameters, respectively (mm); k_i – regression coefficients. In this category, the mass can be estimated as a function of one, two or three projected areas.

For the second category, the independent variables were three mutually perpendicular projected areas:

$$M = k_1 PA + k_2 PB + k_3 PC \quad (2)$$

where: PA, PB, PC – projected areas in diameter directions (cm^2). Mass was related to the volume calculated from an assumed shape. For the third category, the mass can be estimated as a function of the volume:

$$M = k_1 V_{PSP} + k_2 \quad (3)$$

$$M = k_1 V_{ell} + k_2 \quad (4)$$

$$M = k_1 V + k_2 \quad (5)$$

where:

V_{PSP} – volume of prolate spheroid (cm^3) = $\frac{4\pi}{3}\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)^2$,

V_{ell} = volume of ellipsoid (cm^3) = $\frac{4\pi}{3}\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)\left(\frac{c}{2}\right)$.

RESULTS AND DISCUSSION

Physical properties

The physical attributes of two Iranian varieties of kiwi fruits (Abbott, Hayward), such as maximum, mean, and minimum diameters, mass, volume, bulk density, geometric mean and percent sphericity of mixed two different varieties of kiwi fruits are shown in Table 1. The Hayward variety had the highest values for dimensions, mass, and volume, while the Abbott variety had the smallest.

The mean bulk density of the mixed varieties was 1.07 g cm^{-3}. The highest bulk density, BD, 1.08 g cm^{-3}, belonged to the Abbott variety with 9.54% coefficient of variation. The smallest bulk density belonged to the Hayward variety, at 1.07 g cm^{-3} with 6.32% coefficient of variation.

Evaluation of regression models

A total of 11 regression models in three different categories were classified. Coefficient of determination (R^2), regression standard error (R.S.E.), and models obtained from the data for two Iranian varieties of kiwi fruits are shown in Table 2. All of the model coefficients were analysed with F-test and t-test, where all of them were significant at α =5%.

First category models, length

Among the first category models (Nos 1, 2, 3, 4), model number 4 had the highest R^2 and the lowest R.S.E., while for this model, measurement of three diameters is needed. Among the models Nos 1, 2, 3, model number 1 for each variety and model number two for total of observations, had

T a b l e 1. Physical attributes of two Iranian varieties of kiwi fruits (Hayward, Abbott)

Variety	Statistical values	Parameters											
		a (mm)	b (mm)	c (mm)	M (g)	V (cm^3)	BD (g cm^{-3})	GM (mm)	SPH (%)	PA (cm^2)	PB (cm^2)	PC (cm^2)	SA (cm^2)
Hayward	Mean	61.08	46.91	42.26	72.64	68.47	1.07	49.40	81	17.89	23.30	25.58	59.25
	Max.	74.60	63.40	50.10	115.9	113.0	1.38	58.11	99	26.00	32.00	39.00	84.00
	Min.	35.70	31.00	30.15	23.10	23.00	0.90	34.99	72	8.00	11.00	12.00	29.00
	Stdev.	8.08	6.50	4.43	22.92	22.28	0.07	5.64	5	4.23	5.36	6.41	14.45
	CV (%)	13.23	13.85	10.48	31.55	32.53	6.32	11.42	6.28	23.62	23	25.04	24.39
Abbott	Mean	61.55	40.06	35.35	53.71	50.24	1.08	44.16	73	13.04	19.66	21.96	49.51
	Max.	87.65	60.80	43.30	96.60	90.00	1.51	55.30	89	23.00	33.00	37.00	82.00
	Min.	35.15	28.35	26.10	16.20	16.33	0.81	30.56	62	6.00	8.00	9.00	24.00
	Stdev.	14.52	7.07	3.92	23.67	22.53	0.10	6.96	8	3.96	6.85	8.30	15.20
	CV (%)	23.59	17.64	11.09	44.07	44.85	9.54	15.77	11	30.34	34.82	37.80	30.70
Total observations	Mean	61.32	43.49	38.81	63.17	59.36	1.07	46.78	0.77	15.47	21.48	23.77	54.38
	Max.	87.65	63.40	50.10	115.9	113.0	1.51	58.11	0.99	26.00	33.00	39.00	84.00
	Min.	35.15	28.35	26.10	16.20	16.33	0.81	30.56	0.62	6.00	8.00	9.00	24.00
	Stdev.	11.72	7.59	5.42	25.10	24.14	0.09	6.84	0.08	4.75	6.40	7.61	15.58
	CV (%)	19.12	17.45	13.98	39.73	40.67	8.12	14.63	10.10	30.73	29.79	32.04	28.64

a, b, c – diameters; M – mass; V – volume; BD – bulk density; GM – geometric mean diameter; SPH – sphericity; PA, PB, PC – projected areas; SA – surface area.

Table 2. Coefficient of determination (R^2) and regression standard error (R.S.E.) for linear regression models for two Iranian varieties of kiwi fruits (Hayward, Abbott) and the total observations

No.	Models	Hayward		Abbott		Total of observations	
		R^2	R.S.E.	R^2	R.S.E.	R^2	R.S.E.
1	$M= k_1a + k_2$	0.849	8.92	0.844	9.35	0.663	14.57
2	$M= k_1b + k_2$	0.772	10.95	0.724	12.43	0.783	11.70
3	$M= k_1c + k_2$	0.744	11.61	0.803	10.51	0.749	12.58
4	$M= k_1a + k_2b+ k_3c+ k_4$	0.969	4.02	0.978	3.49	0.965	4.72
5	$M= k_1PA + k_2$	0.876	8.06	0.950	5.30	0.907	7.66
6	$M= k_1PB + k_2$	0.947	5.29	0.917	6.82	0.919	7.13
7	$M= k_1PC + k_2$	0.849	8.92	0.983	3.05	0.952	5.48
8	$M= k_1PA + k_2PB+ k_3PC+ k_4$	0.979	3.36	0.990	2.33	0.977	3.77
9	$M= k_1V + k_2$	0.976	3.54	0.981	3.27	0.982	3.41
10	$M= k_1V_{psp} + k_2$	0.883	7.83	0.910	7.10	0.902	7.84
11	$M= k_1V_{ell} + k_2$	0.955	4.86	0.987	2.70	0.976	3.92

higher R^2 and lower R.S.E. than the other models. Therefore, model number 1, obtained based on the longest diameter (a), is recommended. Thus, sizing of kiwi fruits based on the longest diameter is recommended.

Second category models, projected area

Among the linear regression projected area models (Nos 5, 6, 7, 8), model number 8 for two Iranian varieties of kiwi fruits had higher R^2, and lower R.S.E. than the other models. Since this model requires measurement of three projected areas, it is not economical. Among the other models (5, 6, 7), model number 6 for Hayward variety and model number 7 for Abbott variety had higher R^2, and lower R.S.E.; in recommending one of these models for sizing of kiwi fruits, at least one camera is needed.

Third category models, volume

Among the linear regression based on volume (Nos 9, 10, 11), model number 9 is based on measured volume. Model number 11 had a higher combination of R^2; and lower R.S.E. Therefore, this model for sizing of kiwi fruits is recommended.

In order to consider models for the total of observations (variety is ignored), similar models were obtained, that are shown in Table 2. Nonlinear regression models (polynomial and power) are also shown in Tables 3 and 4, respectively. These models were used only for comparison with linear regression models. We concluded that the linear regression models have higher R^2 and lower R.S.E. than these models, and are economical models for application.

Table 3. Coefficient of determination (R^2) and regression standard error (R.S.E.) for polynomial regression models for the total of observations of both varieties combined

No.	Models	Total of observations	
		R^2	R.S.E.
1	$M= k_1a^2 + k_2a + k_3$	0.693	13.92
2	$M= k_1b^2 + k_2b + k_3$	0.806	11.05
3	$M= k_1c^2 + k_2c + k_3$	0.754	12.44
4	$M= k_1 PA^2 + k_2 PA + k_3$	0.913	7.41
5	$M= k_1 PB^2 + k_2 PB + k_3$	0.919	7.15
6	$M= k_1 PC^2 + k_2 PC + k_3$	0.952	5.48
7	$M= k_1 V^2 + k_2 V +k_3$	0.982	3.41
8	$M= k_1 V_{psp}^2 + k_2 V_{psp} + k_3$	0.941	6.12
9	$M= k_1 V_{ell}^2 + k_2 V_{ell} + k_3$	0.977	3.83

Among the linear regression dimensions models, the model that is based on median diameter (b), and among the linear projected area models, the model that is based on projected area normal to c (PC), and among the other models, the model that is based on measured volume (V), had higher R^2, and lower R.S.E., that are recommended for sizing of kiwi fruit.

T a b l e 4. Coefficient of determination (R^2) and regression standard error (R.S.E.) for power regression models for the total of observations of both varieties combined

No.	Models	Total of observations	
		R^2	R.S.E.
1	$M= k_1a^m$	0.747	0.23
2	$M= k_1b^m$	0.800	0.21
3	$M= k_1c^m$	0.773	0.22
4	$M= k_1\ PA^m$	0.921	0.13
5	$M= k_1\ PB^m$	0.952	0.10
6	$M= k_1\ PC^m$	0.972	0.08
7	$M= k_1\ V^m$	0.974	0.07
8	$M= k_1\ V_{psp}{}^m$	0.953	0.10
9	$M= k_1\ V_{ell}{}^m$	0.984	0.06

CONCLUSIONS

1. The recommended equation to calculate kiwi fruit mass based on intermediate diameter, as best shown in Eq. (6), is of linear form:

$$M = 2.93b - 64.15, \quad R^2 = 0.78, \quad R.S.E. = 11.70. \quad (6)$$

2. The mass model recommended for sizing kiwi fruits based on any on e projected area, as in Eq. (7), is of power form:

$$M = 1.098PC^{1.273}, \quad R^2 = 0.97, \quad R.S.E. = 0.08. \quad (7)$$

3. There was very good relationship between mass and measured volume of kiwi fruits for all varieties with R^2 in the order of 0.98:

$$M = 1.03V + 2.03, \quad R^2 = 0.98, \quad R.S.E. = 3.41. \quad (8)$$

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