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Mass modeling of kumquat fruit (cv. Nagami) with some physical attributes

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Abstract

Mass grading of vegetables and fruits can reduce packaging and transportation costs, and also may provide an optimum packaging configuration. Grading of fruit based on its weight is important and grading is based on weight nearly in all cases of agricultural products. In addition, consumers prefer vegetables and fruits with uniform weight and shape. So, we should find relationship between mass and dimensions or projected areas of fruits to choose fruits with uniform weight and shape only by measuring mass of them. Therefore, in this study models for predicting mass of kumquat by its dimensions and projected areas were identified. Models were divided into three classifications: Single and multiple variable regressions of kumquat dimensions (1st classification), Single and multiple variable regressions of projected areas (2nd classification) and estimation of kumquat shape; ellipsoid or spheroid based on volume (3rd classification). Third classification models had the highest performance followed by 2nd and 1st classifications respectively, with R^2 close to unity. Among single variable models, the mass model versus spheroid volume was power and had maximum coefficient of determination as $M= k_1 V_{psp}{}^m$ and R^2=0.99.

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Introduction

Kumquat (cv. Nagami) is a citrus fruit and has an edible skin (Fig.1). It is the most well known of the sort fortunella which is closely related to Citrus. Nagami variety has an oblong shape and bright orange color. Its origin is Indochina but nowadays it is available in other places such as north of Iran.

There are some situations that are desirable to determine relationships among physical attributes; For example, vegetables and fruits are often graded by size, but it may be more economical to develop a machine which grades the fruits by weight (Ghabel *et al.*, 2010). Therefore, the relationship between weight and the major, minor and intermediate diameters is needed. Determining relationships between mass and dimensions and projected areas may be useful and applicable. In weight sorter machines, each fruit is carried by cups or trays that linked together in a conveyor that each one supported by spring loaded mechanism. As the cups travel along the conveyor, the supports are engaged by triggering mechanisms, which allow the tray to dump if there is sufficient weight. If the density of the fruits is constant, the weight sorter grades by volume. The sizing error will depend upon the correlation between weight and volume (Khoshnam *et al.*, 2007). In addition, consumers prefer vegetables and fruits with uniform weight and shape. Mass grading of vegetables and fruits can reduce packaging and transportation costs, and also may provide an optimum packaging configuration.

In the related to mass modeling, Topuz *et al.*, (Topuz *et al.*, 2005) studied physical and nutritional properties of four mandarin genotypes of orange varieties. They reported dimension, volume, weight, surface picture, friction coefficient, porosity, mass and density of four mandarin genotypes. In another study, Tabatabaeefar and Rajabipour (Tabatabaeefar and Rajabipour, 2005) recommended 11 models for predicting mass of apples based on geometrical attributes. Several models for predicting mass of kiwi based on physical attributes were determined and reported by Lorestani and Tabatabaeefar (Lorestani and Tabatabaeefar, 2006). Also, Khoshnam *et al.* (Khoshnam *et al.*, 2007) used this method for predicting the mass of pomegranate fruits. They suggested that there is a good relationship between mass and measured volume for all varieties of kiwi.

No detailed studies concerning mass modeling of kumquat have been performed up to now. The objective of this research is determining an optimum kumquat mass model based on its physical attributes. This information will be used to design and develop sorting systems.

Materials and methods

From the northern region of Iran 50 Kumquat (var. Nagami) fruits prepared. The mass ,M, of each kumquat fruit was measured to 0.01 g accuracy on a digital balance. Its volume ,V, was obtained by volume of water displaced. A kumquat 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. Density ,D, of each kumquat fruit was calculated by the mass of kumquat fruit in air divided by its volume. 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 kumquat fruit were measured to 0.01 mm by a caliper. The three important characteristics were measured include maximum (PC), mean (PB) and minimum (P_C) projected areas (perpendicular to thickness, width and length respectively) (Akar and Aydin, 2005).

Geometric mean diameter, GMD, was determined by using the following equation (Jalilian Tabar *et al.*, 2012):

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

Where, GMD is mean geometrical diameter (mm), a, is the main (longest) diameter (mm), b, is the intermediate diameter (mm) and c, is the longest diameter perpendicular to a and b (mm) Sphericity (%) calculates by following equation (Mohsenin, 1986):

$$Sphericity = \frac{GMD}{a} \times 100 \quad \text{(Eq.2)}$$

The water content of fruits was determined by keeping them in an oven for 24 h in 130 (°C). Water content of fruit derives from (Eq.3).

$$\%\ \text{w.c. (w.b.)} = \frac{M - M_0}{M_0} \quad \text{(Eq.3).}$$

Where M and M_0 are last and initial (before placed in the oven) mass of fruit (Jaliliantabar *et al.*, 2012).
Regression models (linear, non-linear, single and multiple variables).

Spreadsheet software, Microsoft Excel and SPSS Software were used in the analyzing data and determining regression models between the parameters of either linear or polynomial form.

In order to estimate mass of kumquat fruit 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) and minor (c), and also all three diameters were applied (Lorestani *et al.*, 2012).
2. Regression models of mass with each projected area (P_a, P_b, and P_c) and all three projected areas were determined.
3. Regression models of mass with measured volume (V) were determined.

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

$$M = k_1a + k_2b + k_3c + k_4 \quad \text{(Eq.4)}$$

Where: M is mass of the kumquat (g); a, b, c are the longest, median and the smallest diameters respectively (mm); k_i is regression coefficients. In this category, the mass can be estimated as a function of one, two or three diameters.

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

$$M = k_1PA + k_2PB + k_3PC + k_4 \quad \text{(Eq.5)}$$

Where: P_A, PB, PC are projected areas in a diameter directions (mm^2).

For the third category, the mass can be estimated as a function of the volume:

$$M=k_1V_{psp}+k_2 \quad \text{(Eq.6)}$$

$$M=k_1V_{ell}+k_2 \quad \text{(Eq.7)}$$

$$M = k_1V + k_2 \quad \text{(Eq.8)}$$

Where:

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

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

When evaluating the usefulness of such regression analyses, it is necessary to know how well the data fit the model. One measure of the goodness of fit is the value of the coefficient of determination which is usually designated as R^2. In general, for regression equations, the best R^2 is closer to 1.00. If values of ki exactly predict the mass, then R^2 will be equal to 1.00.

Results and discussion

Physical properties

Experiments were carried out at moisture content of 82.6 % (w.b.). The physical properties of Kumquat (var. Nagami) such as major, minor, and intermediate diameter, mass, volume, specific gravity, geometric mean diameter and sphericity of Kumquats are shown in table 1.

The average major, intermediate, and minor diameters for kumquat fruits were 39.46, 25.67 and 25.13 (mm), respectively. The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials, as discussed by Mohsenin (Mohsenin, 1986).

The GDM, with an average value of 29.40, varied between 35.90 and 20.91(mm). Average sphericity was obtained as 74.54%. As shown in Table 1, the volume of kumquat fruit varied from 5 (ml) to 20 (ml), with an average value of 12.30 (ml). True density ranged from 0.98 to 1.33 gml^{-3}, with mean of 1.16 gml^{-3}. These show that the value of true density of kumquat fruit was higher than density of water, so this fruit not float on water and can not be transport with it.

Post harvest gravimetrical properties of kumquat fruit such as length, width, thickness, geometrical mean diameter, sphericity and surface area was lower than orange (Sahraroo *et al.*, 2008 and Sharifi M, 2007). Thus, these show that the kumquat fruit is one of the smallest fruit in the citrus family.

Table 1. Physical attributes of Nagami variety of Kumquat.

Statistical values	a (mm)	b (mm)	c (mm)	M (g)	V (ml)	D (g/ml)	GM (mm)	SPH (%)	PA (mm^2)	PB (mm^2)	PC (mm^2)
Ave.	39.46	25.67	25.13	14.27	12.30	1.16	29.40	74.54	539.22	809.40	859.26
Max.	48.71	30.92	30.86	24.81	20.00	1.33	35.90	82.96	817.79	1162.22	1252.22
Min.	27.91	17.83	16.96	4.90	5.00	0.98	20.91	65.87	221.35	434.14	356.84
SD	3.75	2.81	2.78	3.93	3.30	0.08	2.95	3.52	147.58	153.15	177.37
CV(%)	9.49	10.95	11.07	27.52	26.80	6.69	10.03	4.73	27.37	18.92	20.64

a, b, c - diameters; M - mass; V - volume; B - density; GM - geometric mean diameter; SPH - sphericity; PA, PB, PC- projected areas.

Table 2. Coefficient of determination (R^2) and linear regression models for Nagami variety of kumquat.

No.	Models	R^2
1	$M= k_1a + k_2$	0.76
2	$M= k_1b + k_2$	0.92
3	$M= k_1c + k_2$	0.91
4	$M= k_1a + k_2b+ k_3c+ k_4$	0.96
5	$M= k_1PA + k_2$	0.82
6	$M= k_1PB + k_2$	0.88
7	$M= k_1PC + k_2$	0.91
8	$M= k_1PA + k_2PB+ k_3PC+ k_4$	0.93
9	$M= k_1V + k_2$	0.95
10	$M= k_1V_{psp} + k_2$	0.98
11	$M= k_1V_{ell} + k_2$	0.97

Evaluation of regression models

A total of 9 regression models in three different categories have been classified (Tables 2, 3, 4). Coefficient of determination (R^2) and models that obtained from the data for Iranian variety of Kumquats are shown in table 2. All of the models coefficients were analyzed with F-test and t-test by SPSS Software, where, all of them were significant at α=5%.

Table 3. Coefficient of determination (R^2) and polynomial regression models for Nagami variety of Kumquat.

No.	Models	R^2
1	$M= k_1a^2 + k_2a +k_3$	0.77
2	$M= k_1b^2 + k_2b +k_3$	0.95
3	$M= k_1c^2 + k_2c +k_3$	0.93
4	$M= k_1 PA^2 + k_2 PA +k_3$	0.83
5	$M= k_1 PB^2 + k_2 PB +k_3$	0.88
6	$M= k_1 PC^2 + k_2 PC +k_3$	0.92
7	$M= k_1 V^2 + k_2 V +k_3$	0.95
8	$M= k_1 V_{psp}^2 + k_2 V_{psp} +k_3$	0.98
9	$M= k_1 V_{ell}^2 + k_2 V_{ell} +k_3$	0.97

First category models: dimensions

Among the first category models (nos. 1, 2, 3, 4), model number 4 had the higher R^2, while, for this model, measurement of three diameters are needed.

$$M = 0.330a + 0.947b + 0.048c - 24.238 \quad ; R^2 = 0.96$$

Among the models (nos. 1, 2, 3), model number 2 for total of observations, had higher R^2 than the other models. Therefore, model number 3 that was obtained based on the intermediate diameter (c) is recommended. Thus, sorting of Kumquats based on the intermediate diameter is suitable.

Second category models

projected area

Among the linear regression projected area models (nos. 5, 6, 7, 8), model number 8 for Nagami variety of Kumquats had higher R^2 than the other models. Since this model requires measurement of three projected areas, it is not economical.

$$M = 0.007\ PA + 0.006\ PB + 0.011\ PC - 3.699$$

Among the other models (nos. 5, 6, 7), model number 7 had higher R^2; is recommending for sizing of Kumquats, at least one camera is needed.

Fig. 1. Nagami kumquat fruit.

Third category models

volume

Among the linear regression based on volume (nos. 9, 10, 11), model number 10 that is based on volume of prolate spheroid, had high R^2. Therefore, this model for sorting of Kumquats is recommended.

$$M = 0.002\ V_{PSP} + 0.315.$$

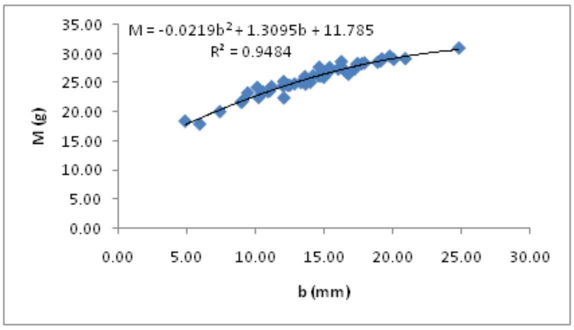

Fig. 2. kumquat mass model based on intermediate diameter.

In order to consider models for total of observations, similar models were obtained, that are shown in table 2. Nonlinear regression models (polynomial and power) are also shown in table 3 and table 4, respectively. These models were used for comparison to linear regression models. We concluded that the linear regression models have higher R^2 than the other models and are economical models for application.

Table 4. Coefficient of determination (R2) and power regression models for Nagami variety of Kumquat.

No.	Models	R^2
1	$M= k_1 a^m$	0.79
2	$M= k_1 b^m$	0.95
3	$M= k_1 c^m$	0.94
4	$M= k_1 PA^m$	0.83
5	$M= k_1 PB^m$	0.89
6	$M= k_1 PC^m$	0.92
7	$M= k_1 V^m$	0.96
8	$M= k_1 V_{psp}^m$	0.99
9	$M= k_1 V_{ell}^m$	0.98

Among the dimensional linear regression models, the model that is based on the intermediate diameter (b), and among the projected areas linear models, the model that is based on projected area normal to the smallest diameter; (PC), and among the other linear regression models, the model that is based on spheroid volume (V), had higher R^2 and are recommended for sorting of Kumquat.

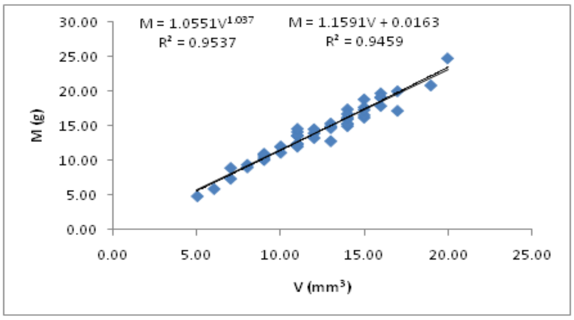

Fig. 3. kumquat mass model based on volume.

Tabatabeefar *et al.* (Tabatabaeefar *et al.*, 2000) reported similar results concerning mass modeling for orange. They suggested that the mass modeling of orange based on intermediate diameter is the most appropriate model among the dimensional models. Lorestani and Tabatabaeefar (Lorestani and Tabatabaeefar, 2006) determined models for predicting mass of kiwi fruit based on physical characteristics. They also recommended an equation to calculate kiwi fruit mass based on intermediate diameter as $M = 2.93b - 64.15$, $R^2 = 0.78$.

Conclusion

It can be point out those physical attributes of the studied kumquats can be a subject of interest to agricultural scientist for farm machinery engineers for kumquat postharvest operations. Also, the best obtained models are important information in sorting and sizing the kumquats based on their weight and volume.

1. The recommended equation to calculate kumquat mass is based on the intermediate diameter, as shown in Fig.2:

$M = -0.0219b^2 + 1.3095b + 11.785 \quad R^2 = 0.95$

2. The mass model recommended for sizing of Kumquats is based on biggest projected area and power form:

$M = 0.0024PC^{1.2817}, \quad R^2 = 0.92$

3. There was very good relationship between mass and measured volume of kumquats with $R^2 = 0.96$, as shown in Fig.3:

$M = 1.0551\ V^m + 1.0370$, $R^2 = 0.96$ and $M = 0.0163V - 1.1591$, $R^2 = 0.95$.

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