Correlating the mass of walnut fruit to some physical characteristics

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Abstract: Physical characteristics of fruits and vegetables and their relationships are necessary for the design of some postharvest processing systems such as handling, sorting and packaging machines and reducing the processing costs. For proper design of grading systems, important relationships between the mass and other properties of fruits such as length, width, thickness, volumes and projected areas must be known. The aim of this research was to measure and present some physical properties of walnut fruits. In addition, walnut fruit mass was correlated to measured physical properties using linear, the Quadratic, S-curve and power models as three different classifications: (1) single variable regressions of walnut dimensional characteristics; (2) single variable regressions of walnut mass based on projected areas and (3) estimating the walnut mass based on its volumes. The results showed that mass modeling of walnut based on width and the second projected area were the most appropriate ones in the first and the second classifications, respectively. In the third classification, the Quadratic model based on the volume of the fruit assumed as ellipsoid shape (Vellip) with R2=0.976, was the best model as: M = 6.019 + 0.001Vellip - 3.067×10-9, R2=0.965. In the economical and agronomical point of view, suitable grading system of walnut mass was ascertained based on the second projected area as the Quadratic form: M = 7.663 – 0.002PA2 + 2.468×10-6PA22, R2=0.921.

Keywords: mass prediction, physical characteristics, walnut

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1 Introduction

Walnut (*Juglans regia* L.) is one of the oldest cultivated fruits in the world. Persian walnut production provides 11% of the world production (Ghafari et al., 2011). Walnut is rich in unsaturated fatty acids, proteins, vitamins, antioxidants and valuable minerals like phosphorus, potassium, sodium, magnesium and zinc (Figiel and Kita, 2008).

Knowledge about the physical properties of agricultural products and their relationships is necessary for the design of handling, sorting, processing and packaging systems. Among these properties, the dimensions, mass, volume and projected area are the most important ones in the design of grading system (Mohsenin, 1986). Consumers prefer fruits with equal weight and uniform shape. Mass grading of fruit can reduce packaging and transportation costs and may provide an optimum packaging configuration. Fruits are often classified based on the size, mass, volume and projected areas. Electrical sizing mechanisms are more complex and expensive. Mechanical sizing mechanisms work slowly. Therefore, it may be more economical to develop a machine, which grades fruits by their mass. Besides, using mass as the classification parameter is the most accurate method of automatic classification for more fruits. Therefore, the relationships between mass and length, width and projected areas can be useful and applicable (Khoshnam et al., 2007).

A number of studies have been conducted on the mass modeling of fruits based upon their physical properties. Tabatabaeefar et al. (2000) developed 11 models based upon dimensions, volumes and surface areas for mass predication of orange fruits. Al-Maiman and Ahmad (2002) studied the physical properties of

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pomegranate and developed models for predicting fruit mass while employing dimensions, volume and surface areas. A Quadratic model (*M*= $0.08c^2 + 4.74c + 5.14$, *R2=0.89*) to calculate the apple mass based on its minor diameter, was determined by Tabatabaeefar and Rajabipour (2005). Lorestani and Tabatabaeefar (2006) determined models for predicting mass of Iranian kiwi fruit by its dimensions, volumes, and projected areas. They reported that the intermediate diameter was more appropriate to estimate the mass of kiwi fruit. Khanali et al. (2005) determined similar mass models for tangerine fruit. Naderi-Boldaji et al. (2008) also determined models for predicting the mass of apricot. They found a nonlinear equation ($M= 0.0019c^{2.693}$, $R^2 = 0.96$) between apricot mass and its minor diameter. Some researchers (Kingsly et al., 2006; Fadavi et al., 2005) reported mass models for pomegranate fruit. Lorestani and Ghari (2012) concluded that the best model for predicting the mass of Fava bean among the dimensional models was linear based on width; and the best model for predicting the mass of Fava bean was based on third projected area perpendicular to L direction of Fava bean and it was Power form.

No detailed studies concerning mass modeling of walnut fruit were found. The aims of this study were to determine the most suitable model for predicting walnut mass by its physical attributes and specify some physical properties of walnut fruit to form an important database for other researches.

2 Materials and methods

Freshly harvested Persian walnut fruits, obtained from Lorestan province Iran, were used in this study. In order to determine the physical properties, 150 walnut fruits were randomly selected. Selected samples were healthy and free from any injuries. The moisture contents of the walnuts (shells) samples (taken from 10 nuts) in wet basis, were determined using an oven (three replicates) set at 105 ℃ for 24 h (Sharifian and Derafshi, 2008). The mass of each walnut fruit (*M*) was measured using a digital balance (GM-600P, Lurton, Taiwan) with 0.01 g accuracy. For each walnut fruit, three linear dimensions were measured by using a digital caliper with the accuracy of 0.01 mm, including major diameter (Length, *L*), intermediate diameter (Width, *W*) and minor diameter (Thickness, T) (Figure 1). Water displacement method was used for determining the fruits measured volume (V_m). Fruits geometric mean diameter (D_g) and surface area (*S*) were determined by using the following formulas (Mohsenin, 1986; Shahbazi, 2014), respectively:

$$D_g = (LWT)^{1/3} \quad (1)$$

$$S = \pi (D_g)^2 \quad (2)$$

where, *L* is length, mm; *W* is width, *T* is thickness of walnut fruit, mm; *S* is fruit surface are in mm^2; and D_g is geometric mean diameter, mm. In addition, fruit average projected areas perpendicular to dimensions (PA_1, PA_2 and PA_3) were measured by a ΔT are-meter, MK2 model device (DELTA-T Device Ltd., Cambridge, UK) with 0.1 cm^2 accuracy and then criteria projected area (CPA) was defined as follows (Mohsenin, 1986):

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3} \quad (3)$$

where, PA_1 (perpendicular to *L* direction of fruit), PA_2 (perpendicular to *T* direction of fruit) and PA_3 (perpendicular to *W* direction of fruit), are first, second and third projected areas, mm^2, respectively.

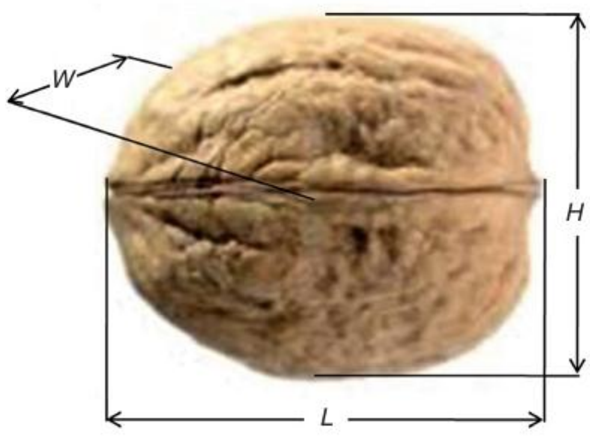

Figure 1 Characteristic dimensions of walnut

The following models were considered in the estimation of mass models for walnut fruits:

1) Single variable regression of walnut fruit mass based on fruit dimensional properties including length (*L*), width (*W*), thickness (*T*) and geometric mean diameter (D_g).

2) Single or multiple variable regression of walnut fruit mass based on fruit projected areas (PA_1, PA_2 and PA_3), surface area (*S*) and criteria projected are (*CPA*).

3) Single regression of walnut fruit mass based on measured volume (V_m), volume of the fruit assumed as oblate spheroid shape (V_{osp}) and volume of the fruit assumed as ellipsoid shape (V_{ellip}).

In the case of the third classification, to achieve models, which can predict the walnut fruit mass, based on volumes, three volume values were either measured or calculated. At first, measured volume (V_m) as stated earlier was measured and then the walnut fruit shape was assumed as a regular geometric shape, i.e. oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes, and their volume was thus calculated as (Shahbazi and Rahmati, 2014 a and b):

$$V_{osp} = \frac{4\pi}{3}(\frac{L}{2})(\frac{W}{2})^2 \quad (4)$$

$$V_{ellip} = \frac{4\pi}{3}(\frac{L}{2})(\frac{W}{2})(\frac{T}{2}) \quad (5)$$

Four models including: Linear, Quadratic, S-curve and Power models were used for mass predication of walnut fruits based on measured physical properties, as represented in the following expressions, respectively (Shahbazi and Rahmati, 2013 a and b):

$$M = b_0 + b_1 X \quad (6)$$

$$M = b_0 + b_1 X + b_2 X^2 \quad (7)$$

$$M = b_0 + \frac{b_1}{X} \quad (8)$$

$$M = b_0 X^{b_1} \quad (9)$$

Where, *M* is mass (g), *X* is the value of an independent (physical characteristics) parameter which wants to find its relationship with mass, and b_0, b_1, and b_2 are curve fitting parameters which are different in each equation. One evaluation of the goodness of fit is the value of the coefficient of determination (R^2). For regression equations in general, the nearer R^2 is to 1.00, the better the fit. SPSS 15, software was used to analyze the data and determine regression models between the physical characteristics.

3 Results and discussion

3.1 Physical properties of walnut fruit

A summary of the physical properties of studied walnut fruits are shown in Table 1. These properties were found at specific moisture contents of 8.13% (w.b). As can be seen in Table 1, the effects of all properties, on the mass of walnut fruit, were found to be statistically significant at 1% probability level. The mean values of measured physical properties of studied walnut fruits include: length (*L*), width (*W*), thickness (*T*), geometric mean diameter (D_g), surface area (*S*), mass (*M*), first projected area (AP_1), second projected area (AP_2), third projected area (AP_3), criteria projected area (*CPA*), measured volume (V_m), oblate spheroid volume (V_{osp}) and ellipsoid shapes volume (V_{ellip}) were 31.19 mm, 30.52 mm, 29.26 mm, 30.27 mm, 2890.51 mm^2, 10.04 g, 586.69 mm^2, 656.23 mm^2, 646.23 mm^2, 629.71 mm^2, 13307.69 mm^3, 15503.16 mm^3 and 14718.76 mm^3, respectively (Table 1).

3.2 Mass modelling

Table 2 shows the obtained models and their coefficient of determination (R^2) for mass predication of walnut fruits based on the measured physical properties. The results of the F-test and T-test in SPSS 15 software showed that all the coefficients of the models were significant at the 1% probability level.

Table 1 Some physical properties of walnut fruit

Properties	Values			Significant level
	Average	Maximum	Minimum	
L /mm	31.19	39.10	27.38	P<0.01
W /mm	30.52	36.01	25.54	P<0.01
T /mm	29.26	32.60	25.74	P<0.01
D_g /mm	30.27	35.64	26.81	P<0.01
S /mm^2	2891	3990	2256	P<0.01
M /g	10.04	11.89	8.98	P<0.01
AP_1 /mm^2	586.69	841.21	354.02	P<0.01
AP_2 /mm^2	656.23	972.12	509.11	P<0.01
AP_3 /mm^2	646.23	901.31	463.12	P<0.01
CPA /mm^2	629.71	897.66	453.62	P<0.01
V_m /mm^3	13308	18001	10010	P<0.01
V_{osp} /mm^3	15503	26519	9347	P<0.01
V_{ellip} /mm^3	14719	23705	10079	P<0.01

3.2.1 Modelling based on dimensions

The results of mass (M) modelling of walnut fruit based on dimensional characteristics including length (L), width (W) thickness (T) and geometric mean diameter (D_g), showed that Quadratic model to calculate mass of walnut fruit based on geometric mean diameter, had the highest R^2 among the others as:

$$M = 3.667 + 0.091D_g + 0.004D_g^2 \qquad R^2=0.978 \qquad (10)$$

However, measurement of three diameters of walnut fruit is needed for calculating the geometric mean diameter (D_g) to use this model, which makes the sizing mechanism more tedious and expensive. Among three dimensions including length (L), width (W) and thickness (T), Quadratic model, which expresses the width (W) as independent variable, had the highest R^2 among the others (Table 2). Therefore, the mass (M) model of walnut fruit based on width is given as Quadratic form:

$$M = 12.516 - 0.376\,W + 0.010W^2 \qquad R^2=0.782 \qquad (11)$$

In addition, the Quadratic model can predict the relationships between the mass with length (L) and thickness (T) with R^2 values of 0.686 and 0.409, respectively (Table 2). Therefore, mass modelling of walnut fruit based on width is recommended. Similar model (nonlinear) suggested by Tabatabaeefar et al. (2000) for mass predication of orange fruit mass based on fruit width too. Their recommended model was: M= $0.069b^2$-2.95b-39.15, R^2=0.97. In addition, eleven models for predicting mass of apples based on geometrical attributes were recommended by Tabatabaeefar and Rajabipour (2005). They recommended an equation for calculating apple mass based on minor diameter as M= $0.08c^2$-4.74c+5.14, R^2=0.89. Ghabel et al. (2010) recommended a nonlinear model for onion mass determination based on length as $M = 0.035a^2 - 1.64a + 36.137$, R^2=0.96.

3.2.2 Modelling based on areas

Among the investigated models based on projected areas (PA_1, PA_2, PA_3 and CPA), Quadratic model of the criteria projected area (CPA), as is shown in Table 2, had the highest value of R^2=0.984 as:

$$M = 6.479 + 0.005CPA + 1.493\times10^{-6}CPA^2 \qquad R^2=0.984 \qquad (12)$$

However, if this model use for grading of walnut fruits, all the three projected areas of fruit will be required. Therefore, the speed of the processing will be decreased and the costs of sorting and grading will be increased. It is evident that one of the projected areas must be selected. Among the PA_1, PA_2 and PA_3 projected areas, the Quadratic model of PA_2 was preferred because of the highest value of R^2=0.921 as:

$$M = 7.663 - 0.002PA_2 + 2.468\times10^{-6}PA_2^2 \quad R^2=0.921 \qquad (13)$$

For mass prediction of the walnut fruit based on surface area, the best models were Linear and Quadratic with R^2=0.976 as:

$$M = 5.058 - 0.002S \qquad R^2=0.976 \qquad (14)$$

$$M = 4.656 + 0.002S - 4.491\times10^{-8}S^2 \quad R^2=0.976 \qquad (15)$$

However, measurement of three dimensions of walnut fruit is needed for geometric mean diameter (D_g) and surface area (S) to use these models, which makes the grading mechanisms more tedious and expensive (Table 2).

3.2.3 Modelling based on volumes

According to the results, for mass prediction of the walnut fruit based on volumes (V_m, V_{osp} and V_{ellip}), as is shown in Table 2, the Quadratic model based on the volume of the fruit assumed as ellipsoid shape (V_{ellip}) with R^2=0.976, was the best model as:

$$M = 6.019 + 0.001V_{ellip} - 3.067\times10^{-9} \quad R^2=0.976 \qquad (16)$$

According to the results obtained in this study, the quadratic models could predict the relationships between the mass and some physical properties of walnut fruits with proper values of coefficient of determination. Finally, the quadratic model based of the second projected area (AP_2) for mass predication of walnut fruits is suggested because it needs one camera, as the main part of the grading systems and it is applicable and is an economic method.

Table 2 The models for mass prediction of walnut fruit with some physical characteristics

Dependent variable	Independent variable	Best fitted model	Constant parameters			R^2
			b_0	b_1	b_2	
M (g)	L /mm	quadratic	6.329	0.063	0.002	0.686
M (g)	W /mm	quadratic	12.516	-0.376	0.010	0.782
M (g)	T /mm	S-curve	3.095	-23.071	-	0.409
M (g)	D_g /mm	quadratic	3.667	0.091	0.004	0.978
M (g)	PA_1 /mm^2	linear	7.409	0.004	-	0.449
M (g)	PA_2 /mm^2	quadratic	7.663	0.002	2.468×10^{-6}	0.921
M (g)	PA_3 /mm^2	S-curve	2.627	-201.733	-	0.704
M (g)	CPA /mm^2	quadratic	6.497	0.005	1.493×10^{-6}	0.984
M (g)	S /mm^2	linear	5.058	0.002	-	0.976
		quadratic	4.656	0.002	-4.491×10^{-8}	0.976
M (g)	V_m /mm^3	quadratic	8.186	-5.194×10^{-5}	-6.367×10^{-9}	0.648
M (g)	V_{osp} /mm^3	quadratic	7.161	0.0001	-1.426×10^{-9}	0.921
M (g)	V_{ellip} /mm^3	quadratic	6.019	0.0001	-3.067×10^{-9}	0.976

4 Conclusions

In this study, some physical properties of walnut fruits and their correlation with fruit mass were presented. Correlations of the all considered properties were significant at the 0.01 level. The best model for walnut fruits mass predication among the dimensional properties was Quadratic form based on width (W) of fruit as: $M = 12.516 - 0.376 W + 0.010W^2$, R^2=0.782. The best model for mass prediction of walnut fruit based on three projected areas was Quadratic form based on second projected area (perpendicular to T direction of walnut) as: $M = 7.663 - 0.002PA_2 + 2.468\times10^{-6}PA_2^2$, R^2=0.921. Quadratic model based on the volume of the fruit assumed as ellipsoid shape (V_{ellip}) with R^2=0.976, was the best model for prediction of the mass of walnut fruit based on volumes as: $M = 6.019 + 0.001V_{ellip} - 3.067\times10^{-9}$, R^2=0.965.

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