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Mass model of date fruit (cv. Mazafati) based on its physiological properties

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Abstract

The knowledge on existing relationship among the mass, length, width, thickness, volume and projected areas of fruits is useful for proper design of processing equipment especially grading machines. This study determined the basic physical properties of date fruit (Mazafati variety) during different ripening stages (Kimri, Khalal, Rutab and Tamr). The suitable model for predicting mass was the developed by fitting the measured physical properties with four models, including Linear, Quadratic, S-curve, and Power. The results of the study showed statistical significance among measured physical properties at the 1% probability level. According to the results obtained, the mass model based on actual volume was more accurate. However, measurement of dimension (s) and projected area (s) are far easier and reasonable than that of actual volume of date. To conclude, the mass model on the basis of length of date fruit is recommended: $M = 0.034L^2 - 1.878L+32.42$, $R^2 = 0.98$, SEE =0.005.

Introduction

Date fruit (*Pheonix dactylifera* L.) is one of the most productive fruits in the Middle Eastern countries. Based on FAO statistics, Iran with production of about 1.26 million tons of date fruits was in the second rank of the world in 2014 (Food and Agriculture Organization, 2014). More than 400 varieties of date fruit are cultivated in different regions of Iran, especially in southern regions (Anonymous, 2011). Almost 10% of Iranian date production belongs to Mazafati variety which is on demand as one of the best varieties due to its favorite taste and appearance as well as long shelf life. Consisting of about 30% of Iranian date exportation confirms also preference of Mazafati variety to consumers. (Mireei and Sadeghi, 2013). As well known, there are four distinct ripening stages almost for all varieties of date fruits which are termed as Kimri, Khalal , Rutab and Tamr, respectively (Imad and Abdul Wahab, 1995; Al-Shahib and Marshall, 2004; Sahari *et al*., 2007). Decreasing moisture content and increasing sugar content happens gradually while the date ripeness approaches to Tamr stage. From Kimri to Khalal stage, the size and acidity decreases when the color of Mazafati variety changes from green to red. The change in acidity continues from Rutab to Tamr stage while color transforms from brown to black. At the final stage of ripeness, Mazafati variety is soft and has a good storability. (Al-Shahib and Marshall, 2003).

Knowledge about physical properties of fruit e.g. mass, dimensions, projected areas and volume is necessary for developing appropriate processing technologies (Seyedabadi *et al*., 2011; Lorestani and Ghari, 2012). Especially, grading based on mass becomes increasingly important. Mass grading can reduce packaging and transportation costs, and may provide an optimum packaging configuration (Peleg, 1985). The relations among physical properties can therefore be useful for design of handling, sorting, processing and packaging systems (Khoshnam *et al.,* 2007).

Many valuable researches have been carried out about mass modeling of fruits based on their physical properties. Prediction of orange mass based upon dimensions, volume and surface areas was carried out by Tabatabaeefar *et al.* (2000) with 11 models. Lorestani and Tabatabaeefar (2006) achieved models for predicting mass of Iranian kiwi fruit by its dimensions, volumes, and projected areas. They found that the geometric mean diameter was more appropriate to estimate the mass of kiwi fruit. Naderi-Boldaji *et al.* (2008) investigated some physical properties of three Iranian apricot cultivars (Shams, Nakhjavan, and Jahangiri) and apricot mass was predicted by different physical characteristics with linear and nonlinear models. Seyedabadi *et al*. (2011) considered mass modeling of two major cultivars of Iranian cantaloupes (Tile Magasi and Tile Shahri) based on geometrical attributes.

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Literature review showed that there is no enough published work relating to the mass modeling of date fruits. Keramat Jahromi *et al.* (2008) investigated some physical properties of date (cv. Dairi). They determined dimensions and projected areas by using image processing technique. Also in another study, they investigated changes in physical properties of Zahedi variety of date fruit during three edible stages of ripening. Hence, the present study was carried out to determine the suitable model for predicting date fruit (Mazafati variety) mass during ripening by its physical attributes to be applicable in machine vision for grading systems and to form an important database for other researchers.

Materials and Methods

Sample preparation

Mazafati date fruits from each four stages of ripening namely Kimri, Khalal, Rutab and Tamr were harvested in July-August 2012 from two different orchards in Bam, Kerman province, Iran. After each harvest, fruits were stored at 20°C and used 10 days (Mireei *et al.*, 2010). A total of 100 samples were tested in this study from all bunches, and the external features of the four stages are exemplified in Figure 1, in which the numbers in the parentheses indicate the number of samples for which physical properties measurements were done at each stage.

Gravimetrical properties

Fruit mass was determined using a precision electronic balance with an accuracy of 0.001 g. Fruit volumes were measured by the water displacement method. Fruits were weighed in air and allowed to float in water. Fruits were lowered with a needle into a beaker containing water and the volume of water displaced by fruit was recorded (Mireei *et al.*, 2010; Seyedabadi *et al.*, 2011; Lorestani and Ghari, 2012). Finally, fruit densities (g cm^{-3}) were calculated by using the following equation (Mohsenin, 1986):

$$\rho_f = \frac{M_a}{M_a - M_w}\rho_w \quad (1)$$

where ρf and ρw are the fruit and water density (g cm^{-3}); Ma and Mw are the mass of fruit in air and water, respectively.

Geometrical properties

To determine the size and shape of the samples, three linear dimensions namely as length (L), width (W) and thickness (T) were measurement by using a digital caliper with an accuracy of ±0.01 mm.

Geometric mean diameter, D_g (mm); sphericity, φ;

Figure 1. Example images of Mazafati variety of Date fruit samples at different ripeness stages

and surface areas, S (mm^2); were determined by using the following formulas, respectively (Mohsenin, 1986; Khodabakhshian *et al.*, 2010; Lorestani and Ghari, 2012):

$$D_g = (LWT)^{1/3} \quad (2)$$

$$\phi = D_g / L \quad (3)$$

$$S = \pi D_g^2 \quad (4)$$

where L is length of date fruit (mm), W is width of date fruit (mm); T is thickness of date fruit (mm).

To determine the volume, three volume values were measured or calculated. First, actual volume (V_m) was measured, and then the fruit date shape was assumed as a regular geometric shape, that is, oblate spheroid (V_{obl}) and prolate spheroid (V_{pro}). Therefore the volume was estimated as follows as reported by Mohsenin (1986), Seyedabadi *et al.* (2011) and Shahbazi and Rahmati (2013):

$$V_{obl} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2 \quad (5)$$

$$V_{pro} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \quad (6)$$

Projected areas of date fruit (PA_1, projected area normal to the length; PA_2, projected area normal to the wide, and PA_3, projected area normal to thickness) were determined based on the image processing method using a digital camera (SONY DSC-W35). The sample areas were computed using the Photoshop cs5 program. The criteria projected area (CPA) was estimated as suggested by Mohsenin (1986):

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3} \quad (7)$$

This method has been used and reported by several researchers (Mireei *et al.*, 2010; Seyedabadi *et al.*, 2011).

Model development

In order to estimate the date fruit mass from the measured dimensions, projected areas, volume and surface area, the following four classes of models were studied.

1. Univariate regression of date fruit mass based

on dimensions: length (L), width (W), thickness (T), and geometric mean diameter *(D_g)*.

2. Univariate regression of date fruit mass based on date fruit projected areas and criteria projected area (CPA).

3. Univariate regression of date fruit mass based on volumes: actual volume (V_m), volume of the fruit assumed as prolate spheroid (V_{pro}) and oblate shapes (V_{obl}).

4. Univariate regression of date fruit mass based on surface area.

In all cases, the results of the experiments were fitted to Linear, Quadratic, S-curve, and Power models which are presented as following equations, respectively:

$$M = k_0 + k_1 X \tag{8}$$

$$M = k_0 + k_1 X + k_2 X^2 \tag{9}$$

$$Ln(M) = k_0 + \frac{k_1}{X} \tag{10}$$

$$M = k_0 X^{K_1} \tag{11}$$

where M is predicted mass (g), X is the measured value of physical characteristics, and k_0, k_1 and k_2 are curve-fitting constants. Coefficient of determination (R^2) and standard error of estimate (SEE) was used to evaluate the regression models. It is evident that models which have the higher value of R^2 anld lowest SEE represent a better estimation (Stroshine, 1998; Seyedabadi *et al*., 2011; Shahbazi and Rahmati, 2013).

Data analysis

SPSS 16.0 software was used to analyze data and determine regression models among the physical attributes.

Results and Discussion

Physical properties of date fruit

The average values of physical properties for Mazafati date fruit were statistically significant at 1% probability level as shown in Table 1. According to the obtained results, the mean values of many properties which were studied in this research (L, W, T, M, V_m, V_{pro}, V_{obl}, D_g and S) have an increasing trend from Kimri to Khalal stage then followed a decreasing trend, as the minimum value of these properties were obtained in Tamr stage. The density had a contrary trend. The mean projected area increased until Rutab stage, and then had a minimum in Tamr stage. The average sphericity decreased during ripening period. The same results were found by Keramat Jahromi

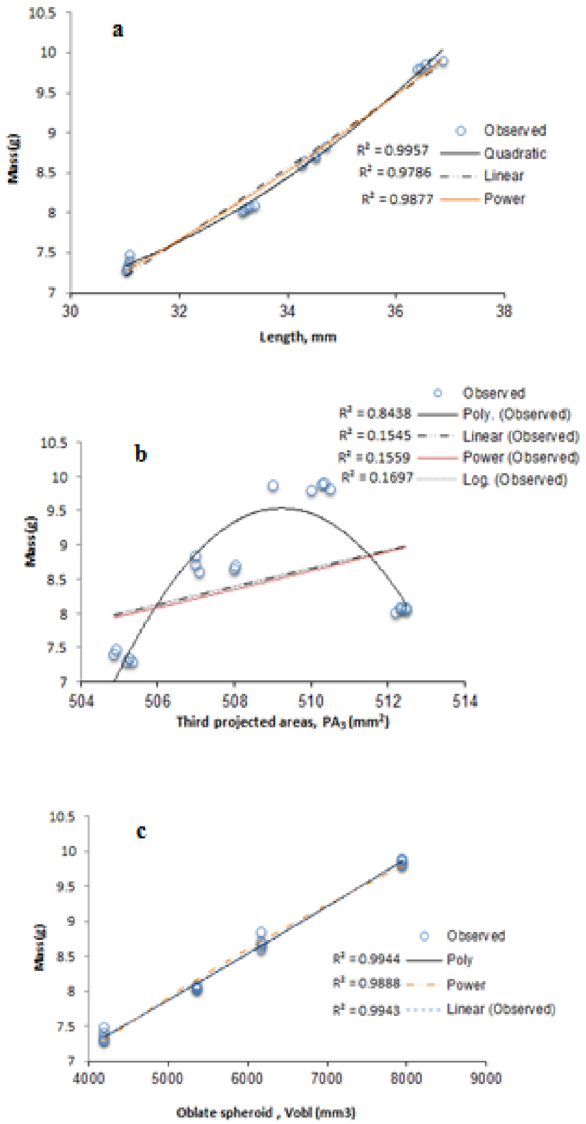

Figure 2. Linear and nonlinear models for total observations based on a) date fruit length, b) n fruit's third projected areas (PA_3) and c) fruit's volume of assumed oblate spheroid shape

et al. (2008). They investigated changes in physical properties of date (cv. Shahani) during three edible stages of ripening.

Mass modeling based on dimensions

The results of mass modeling in the univariate variable classification models based on dimensions revealed that the Quadratic model based on length (L) and thickness (T) had the highest R^2 value among the others. On the other hand, the model based on length showed lower SEE value. Therefore, the model which expresses the length as independent variable was selected as the best choice and was introduced for sizing mechanisms ($M=0.03L^2-1.87L+32.42$, $R^2=0.98$). Figure 2a shows linear and nonlinear mass models for total observations based on date

Table 1. Mean values of some physical properties of date fruit (Mazafati variety) during ripening (Standard deviations of the mean values are shown in parenthesis)

Characteristics	Different ripeness stages				Significant Level
	Kimri	Khalal	Rutab	Tamr	p<0.01
Moisture content (%)	84(1.5)	52(2.25)	43(2.5)	20(3.5)	p<0.01
Dimensions (mm)					
Length	34.45(2.25)	36.58 (2.12)	33.25(2.01)	31.05(1.15)	p<0.01
Width	17.52(1.02)	19.42 (1.25)	18.02 (1.08)	18.25(1.12)	p<0.01
Thickness	16.80(0.95)	18.45(1.05)	15.32 (0.92)	14.25(0.85)	p<0.01
Mass (g)	8.69(0.85)	9.86(0.56)	8.06(0.74)	7.36(0.85)	p<0.01
Volume (cm^3)					
V_m	5102.73(95.1)	6619.92(98.2)	4393.08(90.8)	3468.05(80.1)	p<0.01
V_{pro}	5804.36(80.6)	7467.27 (92.8)	50.37.98(91.3)	3944.58(96.5)	p<0.01
V_{obl}	6174.85(86.2)	7943.90(95.4)	5359.56(90.2)	4196.34(89.5)	p<0.01
Geometric mean diameter (mm)	21.36(1.11)	23.90(1.85)	20.82(1.52)	19.78(1.22)	p<0.01
Sphericity	0.65(0.02)	0.63(0.02)	0.60(0.01)	0.58(0.02)	p<0.01
Density (g/cm^3)	1.71(0.07)	1.38(0.11)	1.83(0.04)	2.12(0.03)	p<0.01
Surface area (mm^2)	1433.35(95.1)	1794.51(120.3)	1297.17(85.1)	1108.03(80.5)	p<0.01
Projected area (mm^2)					
PA_1	310.52 (20.12)	315.38(25.85)	319.45(30.24)	305.24(21.78)	p<0.01
PA_2	487.56(30.25)	490.68(32.47)	493.92(40.23)	480.22(21.52)	p<0.01
PA_3	507.04(40.14)	510.24(27.65)	512.57(35.18)	505.10(34.21)	p<0.01
CPA	435.04(30.17)	438.76(28.65)	441.98(35.22)	430.19(25.84)	p<0.01

fruit length. Similar model (on the basis of length) was suggested by Keramat Jahromi *et al.* (2008) for mass predication of date fruit (Zahedi variety) mass based on fruit dimensions. Their recommended model was M =0.3783L-5.8761, R^2=0.7. Also similar model (nonlinear) was suggested by Tabatabaeefar *et al.* (2000) for mass predication of orange fruit mass based on fruit width. In addition, 11 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 geometric mean diameter as M = 0.08c^2- 4.74c+5.14, R^2 = 0.89. Ghabel *et al.* (2010) found a nonlinear model for onion mass determination based on length as M = 0.035a^2-1.64a + 36.137, R^2 = 0.96. Another research showed that apricot mass model obtained based on the geometric mean diameter (M= 2.6649c−66.412, R^2= 0.954) was obtained (Naderi-Boldaji *et al.*, 2008).

Mass modeling based on projected areas

Among the investigated classification models based on projected areas (models shown in Table 2), the model that is based on PA3 had the highest value of R2 and the lowest value of SSE (M=-0.143 PA_3^2+145.5PA_3-37047, R^2 = 0.84, SEE =2.15). With using this model for grading the date fruit, it is not necessary to specifying and applying all three projected areas. Therefore, the speed of the processing will be increased and the costs of sorting and grading will be decreased. Despite many researchers found the mass models on three projected areas had the highest value of R^2 and the lowest value of SSE, but they proposed univariate mass models based on projected areas (Seyedabadi *et al.*, 2011; Lorestani and Ghari, 2012; Shahbazi and Rahmati, 2013). They stated that the mass models on three projected areas makes the grading mechanisms more tedious and expensive. Figure 2b shows linear and nonlinear mass models for total observations based on date fruit's third projected areas (PA3). By comparing the obtained estimates, the quadratic model was recommended for sizing mechanisms (M=-0.143 PA_3^2+145.5 PA_3-37047, R^2 = 0.84, SEE =2.15).

Mass modeling based on volume

In this classification group (Three last models in Table 2), the R^2 and SSE values of linear mass model based on Vm and Vpro were higher and lower, respectively. So the linear mass model based on V_m is favorable and volume of assumed shape of oblate is acceptable while the model based on prolate spheroid wasn't acceptable. Therefore, linear mass models based on V_m and V_{pro} were supposed for predicting

Table 2. The best models for prediction the mass of of date fruit (Mazafati variety) during ripening with some physical characteristics

Dependent parameter	Independent parameters	The best model	Constant parameters K_0	K_1	K_2	R^2	Standard error of estimate (SSE)
M (g)	L (mm)	Quadratic	32.42	-1.87	0.03	0.98	0.05
M (g)	W (mm)	Quadratic	624.08	-67.32	1.84	0.95	0.12
M (g)	T (mm)	Quadratic	5.49	-0.21	0.02	0.99	0.07
M (g)	PA_1 (mm^2)	Quadratic	-3221.1	20.61	-0.03	0.43	10.52
M (g)	PA_2 (mm^2)	Quadratic	-7086.2	29.06	-0.03	0.41	12.24
M (g)	PA_3 (mm^2)	Quadratic	-37047	145.53	-0.14	0.84	2.15
M (g)	CPA (mm^2)	Quadratic	-8609.7	39.44	-0.04	0.80	5.12
M (g)	V_m (mm^3)	Linear	4.5871	0.01	-	0.99	0.04
M (g)	V_{pro} (mm^3)	Quadratic	7.602	1.76	-0.47	0.75	1.05
M (g)	V_{obl} (mm^3)	Linear	4.51	0.01	-	0.99	0.04

cantaloupe mass. Since volume of assumed oblate spheroid shape has high value for R^2 and because measuring actual volume is time consuming, it was preferred to model the mass of date fruit based on the volume of assumed oblate spheroid shape ($M = 0.007V_{obl} + 4.5083$, $R^2 = 0.99$). Keramat Jahromi *et al.* (2008) suggested mass model based on actual volume (V_m) and prolate spheroid as best model for sizing mechanism of Zahedi variety of date fruit. Figure 2c shows linear and nonlinear mass models for total observations based on the volume of assumed oblate spheroid shape. According to the results obtained in this study and comparing mass equations with their R^2 and SSE, it is indicated that mass modeling based on actual volume is more accurate while measurement of dimension (s) and projected area (s) are far easier and reasonable than that of actual volume of date. Lorestani and Tabatabaeefar (2006) concluded that the linear regression models of kiwi fruits have higher R^2 than nonlinear models for them and are economical models for application.

Conclusion

Some physical properties and their relationships of mass of date fruit during ripening are presented in this study. All the measured physical properties of studied date fruit were statistically significant at 1% probability level. The best model for date fruit mass predication among the dimensional properties was Quadratic form based on length (L) of fruit. The mass model recommended for sizing date fruit based on the third projected area was also as Quadratic form. The model to predict the mass of date fruit based on the estimated volume of date fruit (oblate spheroid shape) was found to be most appropriate for sorting systems. According to the results obtained in this study and comparing mass equations with their R^2 and SSE, it is indicated that mass modeling based on actual volume is more accurate while measurement of dimension (s) and projected area (s) are far easier and reasonable than that of actual volume of date. At last, on the basis of obtained results, mass model of date fruit based on the length is recommended for designing and development of grading systems. At the end, it is recommended that other properties of date fruit such as thermal, mechanical, and nutritional characteristics are to be studied and changes of these properties are to be examined as a function of moisture content and ripening stages.

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