Models for predicting the mass of lime fruits by some engineering properties

Seyed-Hassan Miraei Ashtiani · Jalal Baradaran Motie · Bagher Emadi · Mohammad-Hosein Aghkhani

Revised: 1 September 2012 / Accepted: 18 September 2012 / Published online: 28 September 2012
© Association of Food Scientists & Technologists (India) 2012

Abstract Grading fruits based on mass is important in packaging and reduces the waste, also increases the marketing value of agricultural produce. The aim of this study was mass modeling of two major cultivars of Iranian limes based on engineering attributes. Models were classified into three: 1–Single and multiple variable regressions of lime mass and dimensional characteristics. 2–Single and multiple variable regressions of lime mass and projected areas. 3–Single regression of lime mass based on its actual volume and calculated volume assumed as ellipsoid and prolate spheroid shapes. All properties considered in the current study were found to be statistically significant ($p < 0.01$). The results indicated that mass modeling of lime based on minor diameter and first projected area are the most appropriate models in the first and the second classifications, respectively. In third classification, the best model was obtained on the basis of the prolate spheroid volume. It was finally concluded that the suitable grading system of lime mass is based on prolate spheroid volume.

Keywords Lime · Mass models · Physical property · Packing · Grading

Introduction

Citrus is recognized as one of the world's major fruit crops. It is produced in many countries all around the world with

tropical or subtropical climate (Anwar et al. 2008). Iran is ranked as the seventh producer of citrus, but the eighth in lime production in the world after India, Mexico, China, Argentina, Brazil, USA and Turkey. The total world production of citrus in 2007–2008 was 122.08 million tons, whereas in Iran it was 4.29 million tons with productivity level of $17.29 \text{ ton ha}^{-1}$. The annual lime production in Iran was 0.336 million tons with the share of 7.8 % of citrus production (FAO 2009).

To design and optimization a machine for various post harvesting operation such as cleaning, transportation, packaging and sorting of crops, the physical attributes and their relationships must be known (Adebowale et al. 2011; Ercisli et al. 2012). The knowledge of properties can also be used to calculate surface area and volume which are important during modeling of drying, aeration, heating and cooling systems (Kenghe et al. 2011). On the other hand, volume and its relationship with packing coefficient are very important because having any information about packing coefficient of fruits can led to efficient control of fruit quality (the price of agricultural produce is strongly depended on its availability and quality characteristics) during storing (Lorestani and Ghari 2012). Among the engineering properties of agricultural crops, dimensions, mass, volume, projected and surface areas have a special importance in sizing systems (Wright et al. 1986). As an instance, Lorestani and Ghari (2012) reported that grading of fruits by their size can be replaced with grading by their weight because it may be more economical. Grading fruit based on weight is important in packing and handling. The grading of raw products is mostly based on their weight. Consumers prefer fruits with equal weight and uniform shape. Mass grading of fruit can reduce packing and transportation costs, and also may provide an optimum packaging configuration (Peleg 1985). Sizing by weighing mechanism is recommended for the

S.-H. Miraei Ashtiani · J. Baradaran Motie · B. Emadi (✉) · M.-H. Aghkhani
Department of Agricultural Machinery, Faculty of Agriculture, Ferdowsi University of Mashhad,
P.O. Box 1163, Mashhad, Iran
e-mail: Emadi-b@ferdowsi.um.ac.ir

produce with an irregular shape (Stroshine and Hamann 1994). Since sizing mechanism is electrically expensive and mechanically works slowly (Tabatabaeefar and Rajabipour 2005) therefore, for citrus fruit *eg* lime, it may be more economical to develop a system which grades by weight. Besides, using mass as a sorting parameter is the most accurate method of automatic sorting for more fruits. Therefore, study the relationships among mass, dimensions and projected areas is essential (Stroshine and Hamann 1994).

In the case of mass modeling, Naderi-Boldaji et al. (2008) determined models for predicting mass of Iranian grown apricot from its dimensions, projected areas and volumes; they found a nonlinear equation between mass and its minor diameter. Also, Hassan-Beygi et al. (2010) and Seyedabadi et al. (2011) used this method for predicting the mass of saffron and cantaloupe, respectively. The physical properties of different seeds and fruits have been determined by the other researchers; Zerun wheat (Işıklı et al. 2012), rice (Mohapatra and Bal 2011), berberis fruit (Işıklı and Yılmaz 2011), mahua (Patel et al. 2011), millet (Balasubramanian and Viswanathan 2010), olive fruit (Kılıçkan and Güner 2008), tangerine (Khanali et al. 2007), pear (Wang 2004), sunflower seeds (Gupta and Das 1997) and soybean (Kulkarni et al. 1993). Most of the lime fruit processing methods are still traditional. Hence, it is necessary to make a comprehensive study on the physical properties and their relationships of lime fruit to develop appropriate technologies for its processing. The main objectives of the current study were to determine the most suitable model for predicting lime mass by its engineering properties and investigating the detailed physical properties of two cultivars of Iranian lime (Jahromi and Khoshei). This information could be used to design and development of sorting and the other required equipments for lime mechanization.

Materials and methods

Sample preparation Two exportable limes called Jahromi and Khoshei were procured from the lime orchards of Jahrom township (longitude: 53°33'E and latitude: 28°30'N) during 2011. The number of fruits obtained from the aforementioned cultivars was 60 for each cultivar. They were directly transferred, individually, on the same day to the Biophysical and Biological laboratory of Ferdowsi University of Mashhad (longitude: 59°38'E and latitude: 36°16'N), Iran. The best conditions for keeping lime are temperature ranging from 10–12 °C and relative humidity of 85–95 % (Jomori et al. 2003). For ignoring the effect of environmental parameters, the samples were kept in these conditions for 24 h. The cut parts of the fruits were weighed and dried in an oven at a temperature of 80 °C for 74 h and then the weight lost on drying to reach the final content weight was recorded as

moisture content (AOAC 1984). Average of three replications was noted and reported as moisture content of the samples.

Determination of physical properties The physical properties including size, geometric mean diameter, mass, volume, true density, bulk density, porosity, surface area and projected area were studied. Linear dimensions and projected areas were determined by image processing technique. For each lime fruit, three linear dimensions were measured, which are (a) major (longest intercept), (b) intermediate (longest intercept normal to 'a'), and (c) minor (longest intercept normal to 'a' and 'b') by applying ImageJ 1.46d software. Then projected areas (PA₁, PA₂ and PA₃) in three perpendicular directions of lime using aforementioned program were determined. A Sony DSC-W35 digital camera was fixed at certain height and at the center of captured area to take the digital images. The camera was placed vertically at the distance of 60 cm from the samples. The area of approximately 25×30 cm was captured in each photo. In order to calibrate length in mm, a caliper with intervals of 1 mm was placed beside the groups of limes. Photos were transmitted to a computer. Digital images were then processed in the software and the desired needs were determined. Through three normal images of the fruit, it was possible to determine the required diameters as well as projected areas perpendicular to these dimensions. Dimensions of lime, namely a, b, and c; and PA₁, PA₂ and PA₃ as projected areas are perpendicular to a, b and c, respectively. The mass (M) of each lime was measured using an electronic balance with accuracy of 0.01 g. The actual volume (V_m) and true density (ρ_t) were determined by the water displacement technique. A rod was used to immerse lime in the water because of lighter weight of lime than water (Mohsenin 1986). Water temperature was kept at 25 °C. The packing coefficient (λ) was calculated by using the formula given by Topuz et al. (2005) as follows:

$$\lambda = \frac{V_m}{V_0} \quad (1)$$

where, V_m is the volume of fruit present in the box (cm³) and V₀ is the volume of the box (cm³).

The average projected areas named as criteria projected area (CPA), Geometric mean diameter (D_g), sphericity (Ø) and surface area (S) were calculated according to Naderi-Boldaji et al. (2008). The bulk density (ρ_b) was determined using the mass and volume relationship (Mohsenin 1986) by filling an empty plastic container of predetermined volume and mass. The fruits were left to fall from a constant height (15 cm). The fruit bulk density value is the ratio of mass to volume of the container. The porosity (ε) was defined as the ratio of the intergranular void volume and the volume of the bulk fruit. Porosity was determined using an expression as described by Işıklı et al. (2012). To determine the volume,

the fruit was assumed as ellipsoid and prolate spheroid. Therefore, the volume was estimated by using the following relationships (Mohsenin 1986).

$$V_{\text{ellip}} = \frac{\pi}{6}abc \quad (2)$$

$$V_{\text{PSP}} = \frac{\pi}{6}ab^2 \quad (3)$$

Regression models The following classifications of models were considered in order to estimate the lime mass from its dimensions, volume and projected areas.

1. Single or multiple variable regressions of dimensional characteristics: major diameter (a), intermediate diameter (b), minor diameter (c) and whole three diameters. Model obtained with three variables for predicting of lime mass as follows:

$$M = f(a, b, c) \quad (4)$$

2. Single or multiple variable regressions of projected areas: PA_1 - PA_3 and all three projected areas as given below:

$$M = f(PA_1, PA_2, PA_3) \quad (5)$$

3. Single regression of volumes: actual volume (V_m), volume of the fruit assumed as ellipsoid (V_{ellip}) and prolate spheroid (V_{psp}) shapes. In this category, the mass can be estimated as either a function of volume of supposed shapes or the measured actual volume as represented in the following expressions:

$$M = f(V_m) \quad (6)$$

$$M = f(V_{\text{ellip}}) \quad (7)$$

$$M = f(V_{\text{psp}}) \quad (8)$$

In the above classifications, mass of the lime was modeled with respect to independent variable, i.e. major diameter, intermediate diameter, minor diameter, PA_1 , PA_2 , PA_3 , V_m , V_{ellip} and V_{psp} with the general form of linear and nonlinear (logarithmic, power and quadratic) equations.

Statistical analysis Spreadsheet software, Microsoft Excel 2007 and SPSS version 16.0 program were used to analyze

the data and to determine regression models between the parameters of either linear or nonlinear form. Coefficient of determination (R^2) and standard error of estimate (SEE) were used to evaluate the regression models. It is evident that models which have the higher value of R^2 and the lower value of SEE represent a better estimation.

Results and discussion

Physical properties of lime A summary of physical properties of the lime fruit has been represented in Table 1. These properties were found at specific fruit moisture contents of cultivars (Jahromi and Khoshei) at 87.92 % and 83.36 % wet basis, respectively. Water is an important component in most fruits and determines their perish ability. As seen in Table 1, all properties which were considered in the current study were found to be statistically significant at 1 % probability level. According to the obtained results, mean values of many engineering properties which were studied in this research for jahromi cultivar were significantly greater than for Khoshei cultivar. According to the results of the dimensional properties of two lime cultivars, for Jahromi cultivar the average major, intermediate and minor diameters were respectively 43.18, 39.40 and 38.74 mm, whereas the corresponding values for Khoshei cultivar were 35.80, 31.15 and 30.51 mm. These dimensions can be used in designing machine components and their parameters. For instance, they may be helpful in estimating the number of fruits to be packed at a time. As observed from Table 1, the obtained mass values differed considerably among the tested cultivars. The latter property values were 34.51 and 17.69 g for Jahromi and Khoshei, respectively. The difference in mass is due to the smaller dimensions and lower water content of Khoshei cultivar. This property may be useful in the separation and transportation of the fruits by hydrodynamic means. The values of average volumes including actual, ellipsoid and prolate spheroid shapes were found for Jahromi cultivar as 32.93, 34.63 and 35.20 cm^3 , respectively while these values were 18.23, 18.41 and 18.80 cm^3 for Khoshei cultivar. Considering the latter result, it is clear that a large number of Khoshei fruits could be packed in the predetermined volume compared with the other cultivar. The average value of packing coefficient for Jahromi was less than that for Khoshie. Because of that, the packing coefficient increased with decrease of fruit volume. Packing coefficient of Jahromi and Khoshei varieties were found to be 0.45 and 0.59, respectively. Having any data about packing coefficient could result in efficient control of fruit quality during

Table 1 Some engineering properties of two Iranian cultivars of lime fruit (Jahromi and Khoshei)

Property	Jahromi			Khoshei		
	Max	Min	Mean±SD	Max	Min	Mean±SD
Major diameter (<i>a</i>), mm	54.19	37.82	43.18±3.13	46.71	29.62	35.80±4.31
Intermediate diameter (<i>b</i>), mm	43.68	36.17	39.40±1.65	39.92	25.75	31.15±3.32
Minor diameter (<i>c</i>), mm	43.59	35.55	38.74±1.67	39.04	25.25	30.51±3.19
Geometric mean diameter (<i>D_g</i>), mm	45.55	37.82	40.37±1.69	40.95	27.67	32.39±3.46
Sphericity (<i>Φ</i>), %	98.57	82.75	93.75±4.39	98.73	81.53	90.67±3.64
Mass (<i>M</i>), g	48.20	27.21	34.51±4.04	33.07	10.19	17.69±6.26
Actual volume (<i>V_m</i>), cm ³	46.69	26.19	32.93±4.03	36.79	10.46	18.23±6.62
Ellipsoid volume (<i>V_{ellip}</i>), cm ³	49.49	28.34	34.63±4.57	35.95	11.09	18.41±6.26
Prolate spheroid volume (<i>V_{psp}</i>), cm ³	49.59	28.71	35.20±4.51	36.76	11.12	18.80±6.41
True density (<i>ρ_t</i>), g/cm ³	1.07	1.02	1.05±0.01	0.99	0.89	0.97±0.02
Bulk density (<i>ρ_b</i>), g/cm ³	0.55	0.52	0.53±0.07	0.51	0.46	0.49±0.04
Porosity (<i>ε</i>), %	55.99	52.93	54.89±0.90	54.65	50.01	52.70±0.62
Surface area (<i>S</i>), mm ²	6518.55	4494.76	5128.70±439.56	5267.21	2405.56	3332.85±734.33
Packaging coefficient (<i>λ</i>)	0.48	0.43	0.45±0.02	0.61	0.58	0.59±0.03
First projected area (<i>PA₁</i>), mm ²	1515.56	988.36	1215.16±107.17	1343.30	546.89	794.14±183.97
Second projected area (<i>PA₂</i>), mm ²	1686.97	1124.13	1309.77±119.77	1470.12	601.12	902.23±224.69
Third projected area (<i>PA₃</i>), mm ²	1699.82	1131.83	1333.42±117.50	1514.12	617.72	918.82±228.41
Criteria projected area (<i>CPA</i>), mm ²	1634.12	1082.69	1286.12±108.98	1442.51	588.58	871.73±211.28

± SD are standard deviations

Values are means of twenty replicates for bulk density, porosity and packaging coefficient, and sixty for others

storage. The highest values of *PA₁*, *PA₂* and *PA₃* for Jahromi cultivar were found to be 1215.16, 1309.77 and 1333.42 mm², respectively, whereas Khoshei variety revealed values of 794.14, 902.23 and 918.82 mm², respectively for similar parameter. The observed difference for the projected area was due to the different values of dimensional characteristics. The values of the projected areas may be used for design and development of grading equipment that work based on machine vision technique. The shapes of both lime cultivars were shown to be ellipsoid with minimum probable error from measured volume. These data will have a potential usage in harvest, classification, transportation, processing, packaging and other processes related to lime fruits.

First classification models, dimensions Linear regression models based on the selected independent variables are shown in Table 2. All of the models coefficients were analyzed, where, all of them were significant at 1 % probability level. Among the first classification model (Nos. 1–4), shown in Table 2, model 4, in which all three dimensions were considered, had the highest *R*² value and lowest SEE for each cultivar and total observations. However, the three diameters must be measured

for the model 4, while making a sizing mechanism is tedious and expensive. Among the model No. 1–3, model 3 for Jahromi cultivar, models 2 and 3 for Khoshei cultivar and also model 3 for total of observations showed the highest *R*² value. Therefore, model 3 which is obtained based on the minor diameter (*c*) is recommended. Thus, model number 3 among the one dimensional models was selected as the best lime mass model with minor diameter as illustrated in Fig. 1 (a).

The mass model of lime (for two cultivars) based on the model 4 (whole diameters) is described by following equation:

$$M = 0.455a + 0.607b + 0.970c - 46.990; \quad (9)$$

$$R^2 = 0.98; SEE = 1.32$$

By comparing linear, quadratic, power and logarithmic models, the best model based on single dimension can be suggested as follow:

$$M = 0.005c^{2.408}; R^2 = 0.83; SEE = 0.047(\text{Jahromi}) \quad (10)$$

$$M = 0.078b^2 - 3.218b + 40.802; R^2 = 0.95; \quad (11)$$

$$SEE = 1.44(\text{Khoshei})$$

Table 2 Coefficient of determination (R^2) and standard error of estimate (SEE) for linear regression models of mass (M) for two Iranian cultivars of lime fruit (Jahromi, Khoshei) and the total observations

No.	Models	Parameter	Jahromi	Khoshei	Total of observations
Category 1					
1	$M=k_1a+k_2$	R^2	0.42	0.87	0.85
		SEE	3.12	2.27	3.92
2	$M=k_1b+k_2$	R^2	0.74	0.93	0.96
		SEE	2.09	1.73	1.93
3	$M=k_1c+k_2$	R^2	0.82	0.93	0.97
		SEE	1.75	1.73	1.77
4	$M=k_1a+k_2b+k_3c+k_4$	R^2	0.96	0.97	0.98
		SEE	0.90	1.14	1.32
Category 2					
5	$M=k_1PA_1+k_2$	R^2	0.75	0.97	0.97
		SEE	2.07	1.11	1.75
6	$M=k_1PA_2+k_2$	R^2	0.89	0.98	0.95
		SEE	1.39	0.85	2.16
7	$M=k_1PA_3+k_2$	R^2	0.88	0.98	0.95
		SEE	1.40	0.83	2.14
8	$M=k_1PA_1+k_2PA_2+k_3PA_3+k_4$	R^2	0.94	0.99	0.98
		SEE	1.06	0.68	1.50
Category 3					
9	$M=k_1V_m+k_2$	R^2	0.99	0.99	0.99
		SEE	0.38	0.49	1.02
10	$M=k_1V_{ellip}+k_2$	R^2	0.93	0.98	0.99
		SEE	1.12	0.97	1.15
11	$M=k_1V_{psp}+k_2$	R^2	0.93	0.98	0.99
		SEE	1.10	0.95	1.11

The total number of observations was 120

k_1 , k_2 , k_3 and k_4 are coefficients or constant values, a , b and c are lime dimensions, PA_i is the projected area, V_m , V_{ellip} and V_{psp} are the actual volume, assumed ellipsoid volume and assumed prolate spheroid volume respectively.

For the entire regions, the best equation to calculate mass based on the minor diameter of the lime is given in linear form as below:

$$M = 2.017c - 43.868; R^2 = 0.97; \quad (12)$$

$$SEE = 1.77(\text{Total of observations})$$

Research review carried out by the authors revealed that eleven models for predicting mass of apples based on geometrical attributes were recommended by Tabatabaefar and Rajabipour (2005). They reported that although the mass of apples could be predicted accurately with a three-dimension model, they recommended a one variable quadratic model based on minor diameter for its simplicity and applicability. Lorestani and Tabatabaefar (2006) determined models for predicting mass of kiwi fruit based on physical attributes. They recommended a linear equation to approximate the mass of kiwi fruit by intermediate diameter, though a model based on three diameters showed a higher R^2 and lower RSE values. Also Naderi-Boldaji et al. (2008) reported a power equation based on minor diameter for predicting the mass of apricot.

Second classification models, projected areas Among the second classification model Nos. 5–8, shown in Table 2, the model 8 for two cultivars had maximum R^2 value and minimum SEE. The overall mass model based on three projected areas (model 8) for total of observations is given as below:

$$M = 0.026PA_1 + 0.025PA_2 - 0.013PA_3 - 12.788; \quad (13)$$

$$R^2 = 0.98; SEE = 1.50$$

Each one of the three projected areas can be used to estimate the mass. However, models with multiple variables make the sizing mechanism more complex and expensive. So we recommend the mass model based on single projected area for prediction, because we need one camera and it is applicable and more economical method. Therefore, among the models 5, 6 and 7, based on one projected area, the model 6 for Jahromi cultivar, model 7 for Khoshei cultivar and also model 5 for total of observations had highest R^2 and lowest SEE than the other models. The comparison between projected area and predicted mass of limes

Fig. 1 Linear models for total observations based on: (a) minor diameter, (b) first projected area, (c) volume of assumed prolate spheroid shape

applying first projected area (Model 5 in Table 2) is shown in Fig. 1 (b). So the first projected area can probably be recommended as the best choice for the sizing mechanism.

By comparing linear and nonlinear models, for two cultivars, the best equation to calculate mass of lime based on one projected area can be suggested as:

$$M = 0.032PA_2 - 7.084; R^2 = 0.89; SEE = 1.39(\text{Jahromi}) \quad (14)$$

$$M = 0.027PA_3 - 7.395; R^2 = 0.98; SEE = 0.83(\text{Khoshei}) \quad (15)$$

$$M = 0.001(PA_1)^{1.552}; R^2 = 0.98; \quad (16)$$

$$SEE = 0.06(\text{Total of observations})$$

In relation to mass modeling of other fruits, similar result was reported by Khoshnam et al. (2007). They suggested the mass modeling of pomegranate based on the one projected area with power form. Lorestani and Tabatabaeefar (2006) recommended a power function to estimate the kiwi fruit mass by third projected area. Seyedabadi et al. (2011) also suggested a power regression equation to estimate the mass of cantaloupes based on the third projected area.

Third classification model, volume In this classification group (models 9–11, as shown in Table 2), the R^2 and SEE values of model 9 were highest and lowest, respectively for each cultivar and total observations. Measuring of actual volume was time consuming and noneconomic. Models 10 and 11 were almost similar in R^2 and SEE; therefore, model 11 which needs to measure only two diameters, rather than three, was suggested. Figure 1 (c) shows linear mass model for total observations based on the volume of assumed prolate spheroid shape. By comparing the all resulted estimations, the linear model for both cultivars and total observations can be introduced for grading mechanisms. The mass model of overall limes based on measured volume is given as linear form:

$$M = 1.073V_m - 1.574; R^2 = 0.99; SEE = 1.02 \quad (17)$$

The mass models based on volume for Jahromi and Khoshei cultivars are given as below:

$$M = 0.865V_{psp} + 4.073; R^2 = 0.93; SEE = 1.10(\text{Jahromi}) \quad (18)$$

$$M = 0.964V_{psp} - 0.573; R^2 = 0.98; SEE = 0.95(\text{Khoshei}) \quad (19)$$

Finally, for prediction of the mass of the lime based on volume the best model was:

$$M = 1.002V_{psp} - 1.094; R^2 = 0.99; \quad (20)$$

$$SEE = 1.11(\text{Total of observations})$$

Khoshnam et al. (2007) also reported the linear equation with a high coefficient of determination for the mass modeling of pomegranate based on the actual volume. Naderi-Boldaji et al. (2008) suggested a power regression equation to predict the mass of apricot as a function of V_{ellip} . Hassan-Beygi et al. (2010) found a linear model for predicting the mass of saffron crocus corm by ellipsoid volume.

Conclusion

Some physical properties and their relationships with mass for Jahromi and Khoshei lime cultivars were introduced in this study. The mean values of properties such as minor diameter, intermediate diameter, major diameter, geometric mean diameter, mass, volume, true density, surface area, bulk density, porosity and projected area for Jahromi cultivar were greater than that for the Khoshei cultivar. The density value of Jahromi lime was above one g cm^{-3} so it sank in the water while Khoshei lime had density value below one g cm^{-3} and remained float in the water. The recommended equation to calculate lime mass based on minor diameter (model 3 was the best) was as linear form: $M=2.017c-43.868$; $R^2=0.97$ and the mass model recommended for sizing limes based on first projected area was a nonlinear form as $M=0.001(\text{PA}_1)^{1.552}$, $R^2=0.98$. There was a good relationship between the mass and measured volume of lime for both cultivars with the higher coefficient of determination value but the model to predict the mass of lime based on the estimated volume (prolate spheroid shape) was found to be most appropriate for sorting systems: $M=1.002V_{\text{psp}}-1.094$, $R^2=0.99$, $\text{SEE}=1.11$.

References

- Adebowale AA, Sanni LO, Owo HO, Karim OR (2011) Effect of variety and moisture content on some engineering properties of paddy rice. *J Food Sci Technol* 48(5):551–559
- Anwar F, Naseer R, Bhangar MI, Ashraf S, Farah NT, Adekunle AF (2008) Physico-chemical characteristics of citrus seeds and seed oils from Pakistan. *J Am Oil Chem Soc* 85(4):321–330
- AOAC (1984) Official methods of analysis, 14th edn. Association of Official Analytical Chemists, Arlington
- Balasubramanian S, Viswanathan R (2010) Influence of moisture content on physical properties of minor millets. *J Food Sci Technol* 47(3):279–284
- Ercisli S, Sayinci B, Kara M, Yildiz C, Ozturk I (2012) Determination of size and shape features of walnut (*Juglans regia* L.) cultivars using image processing. *Sci Hortic* 133:47–55
- FAO (2009) Food and agricultural organization statistical database. <http://faostat.fao.org/site/339/default.aspx>. Accessed 23 November 2011
- Gupta RK, Das SK (1997) Physical properties of sunflowers seeds. *J Agric Eng Res* 66:1–8
- Hassan-Beygi SR, Ghanbarian D, Farahmand M (2010) Prediction of saffron crocus corm mass by geometrical attributes. *Sci Hortic* 124:109–115
- Işıklı ND, Yılmaz İ (2011) Some physical properties of sun-dried Berberis fruit. *J Food Sci Technol*. doi:10.1007/s13197-011-0469-y
- Işıklı ND, Şenol B, Çoksöyler N (2012) Some physical and mechanical properties of roasted Zerun wheat. *J Food Sci Technol*. doi:10.1007/s13197-012-0704-1
- Jomori MLL, Kluge RA, Jacomino AP (2003) Cold storage of Tahiti lime treated with 1-methylcyclopropene. *Sci Agricola* 60(4):785–788
- Kenghe RN, Nimkar PM, Shirkole SS (2011) Moisture dependent physical properties of lathyrus. *J Food Sci Technol*. doi:10.1007/s13197-011-0428-7
- Khanali M, Ghasemi Varnamkhasti M, Tabatabaefar A, Mobli H (2007) Mass and volume modeling of tangerine (*Citrus reticulata*) fruit with some physical attributes. *Int Agrophys* 21(4):329–334
- Khoshnam F, Tabatabaefar A, Ghasemi-Varnamkhasti M, Borghei A (2007) Mass modeling of pomegranate (*Punica granatum* L) fruit with some physical characteristics. *Sci Hortic* 114:21–26
- Kılıçkan A, Güner M (2008) Physical properties and mechanical behavior of olive fruits (*Olea europaea* L.) under compression loading. *J Food Eng* 87:222–228
- Kulkarni SD, Bhole NG, Sawarkar SK (1993) Spatial dimensions of soybeans and their dependence on grain moisture conditions. *J Food Sci Technol* 30(5):335–338
- Lorestani AN, Ghari M (2012) Mass modeling of Fava bean (*vicia faba* L.) with some physical characteristics. *Sci Hortic* 133:6–9
- Lorestani AN, Tabatabaefar A (2006) Modelling the mass of kiwi fruit by geometrical attributes. *Int Agrophys* 20(2):135–139
- Mohapatra D, Bal S (2011) Physical properties of *Indica* rice in relation to some novel mechanical properties indicating grain characteristics. *Food Bioprocess Technol*. doi:10.1007/s11947-011-0539-1
- Mohsenin NN (1986) Physical properties of plant and animal materials, 2nd edn. Gordon and Breach Science Publication, New York
- Naderi-Boldaji M, Fattahi R, Ghasemi-Varnamkhasti M, Tabatabaefar A, Jannatizadeh A (2008) Models for predicting the mass of apricot fruits by geometrical attributes (cv. Shams, Nakhjavan, and Jahangiri). *Sci Hortic* 118:293–298
- Patel M, Pradhan RC, Naik SN (2011) Physical properties of fresh mahua. *Int Agrophys* 25(3):303–306
- Peleg K (1985) Produce handling, packaging and distribution. AVI Publication, pp 20–90
- Seyedabadi E, Khojastehpour M, Sadrnia H, Saiedirad MH (2011) Mass modeling of cantaloupe based on geometric attributes: a case study for Tile Magasi and Tile Shahri. *Sci Hortic* 130:54–59
- Stroshine R, Hamann DD (1994) Physical properties of agricultural materials and food products. Course manual, Purdue Univ, USA
- Tabatabaefar A, Rajabipour A (2005) Modeling the mass of apples by geometrical attributes. *Sci Hortic* 105:373–382
- Topuz A, Topakci M, Canakci M, Akinci I, Ozdemir F (2005) Physical and nutritional properties of four orange varieties. *J Food Eng* 66:519–523
- Wang J (2004) Mechanical properties of pear as a function of location and orientation. *Int Food Prop* 7:155–164
- Wright ME, Tappan JH, Sister FE (1986) The size and shape of typical sweet potatoes. *Trans ASAE* 29:678–682