

# Mass modelling of plum (*Prunus domestica* L.) fruit with some physical characteristics

F. Shahbazi and S. Rahmati

Lorestan University, Faculty of Agriculture, Department of Agricultural Machinery, 6818637751 Khoram Abad, Iran; shahbazi.f@lu.ac.ir

Received: 1 November 2012 / Accepted: 7 April 2013

© 2014 Wageningen Academic Publishers

## RESEARCH ARTICLE

### Abstract

Horticultural crops with similar weight and uniform shape are in high demand in terms of marketing value in the food sector. The knowledge on existing relationship between the mass, length, width, thickness, volume and projected areas of fruits is useful for proper design of grading machines. A part of this research was aimed to present some physical properties of plum fruit. In addition, in this study the mass of plum fruit was predicted using different physical characteristics in four models, including linear, quadratic, S-curve and power. According to the results, all properties considered in the current study were found to be statistically significant at the 1% probability level. The best and the worst models for predicting the mass of plum fruit were based on geometric mean diameter and length of the plum with determination coefficients of 0.803 and 0.125, respectively. At last, mass model of plum fruit based on first projected area from an economical standpoint is recommended.

**Keywords:** mass, modelling, physical characteristics, plum

### 1. Introduction

Plum (*Prunus domestica* L.) is the most taxonomically diverse of stone fruits and is adapted to a board range of climatic and edaphic factors (Ertekin *et al.*, 2006). Plum constitute the most numerous and diverse group of fruit tree species. The wide variety of plum, the distribution of the fruit through a wide area, and its adaptability to varying conditions make it, not only of great importance at present, but also for future development (Blazek, 2007).

Knowledge about 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 systems (Mohsenin, 1986). Fruits are often classified based on their 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 that 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 mass modelling of fruits based upon their physical properties. Tabatabaefar *et al.* (2000) found 11 models for the prediction of orange mass based upon dimensions, volume and surface areas. Al-Maiman and Ahmad (2002) studied the physical properties of pomegranate and found models of predicting fruit mass while employing dimensions, volume and surface areas. Tabatabaefar and Rajabipour (2005), determined a quadratic equation ( $M = 0.08c^2 + 4.74c + 5.14$ ;  $R^2=0.89$ ) to calculate apple mass based on its minor diameter. Lorestani and Tabatabaefar (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. Also Khanali *et al.* (2007) achieved models for tangerine. Naderi-Boldaji *et al.* (2008) also used this method 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 modelled the mass of pomegranate fruit

(Fadavi *et al.*, 2005; Kaya and Sozer, 2005; Kingsly *et al.*, 2006). Lorestani and Ghari (2012) concluded that the best linear model for predicting mass was based on width while the best predictive model was based on the third projected area perpendicular to the L direction of fava bean, and took a power form. No detailed studies concerning mass modelling of plum fruit have yet been performed. The aims of this study were to determine the most suitable models for predicting plum fruit mass by its physical attributes and to study some physical properties of Iranian plum fruit to form an important database for other investigators.

## 2. Materials and methods

Fresh harvested plum fruits in May 2012, of Siah Karaj cultivar obtained from Lorestan province Iran, were used in this study. In order to determine the physical properties, 150 plum fruits were randomly selected. Selected samples were healthy and free from any injuries. Samples of fruits were weighed and dried in an oven at a temperature of 78 °C for 48 hours then weight loss on drying to a final constant weight was recorded as moisture content (Ertekin *et al.*, 2006). Plum fruit mass ( $M$ ) was determined with an electronic balance (GM-600P; Lutron, Taipei, Taiwan) with 0.01 g accuracy. To determine the average size of the samples, three linear dimensions, namely length, width and thickness, were measured by using a digital calibre with 0.01 mm sensitivity (Figure 1). Actual volume ( $V_m$ ) was determined by the water displacement method (Mohsenin, 1986). The geometric mean diameter ( $D_g$ ) and surface areas ( $S$ ) were determined by using the following formulas (Mohsenin, 1986; Shahbazi, 2013), respectively:

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

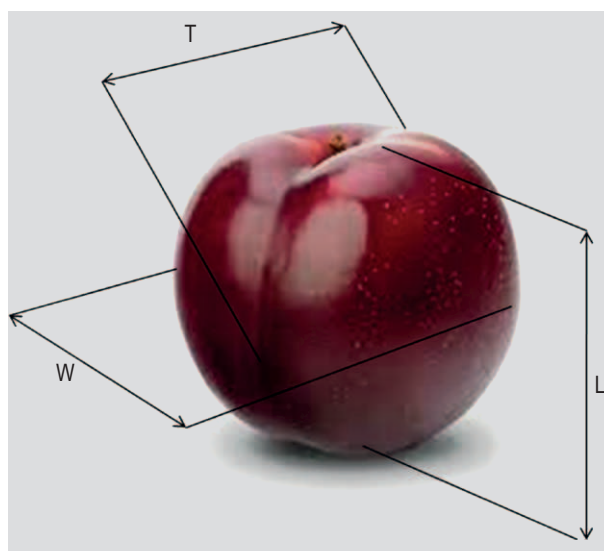


Figure 1. Dimensional characteristics of plum fruit (L = length; W = width; T = thickness).

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

Where  $L$  is length (mm),  $W$  is width (mm) and  $T$  is thickness of plum fruit (mm),  $S$  is surface area ( $\text{mm}^2$ ) and  $D_g$  is the geometric mean diameter (mm). In addition, the projected areas ( $PA_1$ ,  $PA_2$  and  $PA_3$ ) in three perpendicular directions of the fruit were measured by a  $\Delta T$  area-meter (model MK2; DELTA-T Device Ltd., Cambridge, UK) with 0.1  $\text{cm}^2$  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 the first, second and third projected areas ( $\text{mm}^2$ ).

In order to estimate mass models of plum fruits, the following models were considered:

Single variable regression of plum fruit mass based on plum fruit dimensional characteristics: length ( $L$ ), width ( $W$ ), thickness ( $T$ ), and geometric mean diameter ( $D_g$ ).

Single or multiple variable regressions of plum fruit mass based on projected areas ( $PA_1$ ,  $PA_2$  and  $PA_3$ ), surface area ( $S$ ) and criteria projected area (CPA).

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

In the case of the third classification, to achieve models, at first, the actual volume as stated earlier was measured. But because measuring of actual volume is time consuming, plum shape was assumed as a regular geometric shape, i.e. oblate spheroid ( $V_{osp}$ ) and ellipsoid ( $V_{ellip}$ ) shapes, and were calculated as follows (Lorestani *et al.*, 2012; Mohsenin, 1986):

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

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

In all cases, the results which were obtained from the experiments were fitted to linear, quadratic, S-curve and power models which are presented as the following equations, respectively (Lorestani and Ghari, 2012; Shahbazi and Rahmati, 2013a,b):

$$M = b_0 + b_1X \quad (6)$$

$$M = b_0 + b_1X + b_1X^2 \quad (7)$$

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

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

Where M is mass (g), X is the value of a parameter (independent parameter) for which we want to find its relationship with mass. And  $b_0$ ,  $b_1$ , and  $b_2$  are curve fitting parameters which are different in each equation. On evaluation of the goodness of fit is the value of the coefficient of determination. For regression equations in general, the nearer  $R^2$  is to 1.00, the better the fit (Stroshine, 1998). All of the models coefficients were analysed with F-test and t-test in SPSS software (version 15; SPSS Inc., Armonk, NY, USA).

### 3. Results and discussion

A summary of the physical properties of studied plum fruits are shown in Table 1. These properties were found at specific moisture contents about 81.13% wet basis. As shown 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 results, the mean values of properties which were studied in this research (length, width, thickness, geometric mean diameter, surface area, mass, first, second, third area, criteria projected area, measured volume, oblate spheroid volume and ellipsoid shapes volume) were 37.872 mm, 41.377 mm, 40.440 mm, 39.843 mm, 4,992.910 mm<sup>2</sup>, 37.819 g, 1,268.12 mm<sup>2</sup>, 1,179.73 mm<sup>2</sup>, 1,191.63 mm<sup>2</sup>, 1,213.11 mm<sup>2</sup>, 33,816.761 mm<sup>3</sup>, 34,060.922 mm<sup>3</sup> and 33,552.601 mm<sup>3</sup>, respectively.

### Mass modelling

Mass models and coefficient of determination ( $R^2$ ) that obtained from the data for plum fruits are shown in Table 2.

**Table 1. Some physical properties of plum fruit.**

Physical properties	Value			Significant level
	Average	Maximum	Minimum	
L (mm)	37.872	42.36	34.04	$P < 0.01$
W (mm)	21.099	26.46	18.86	$P < 0.01$
T (mm)	22.430	26.98	19.62	$P < 0.01$
$D_g$ (mm)	22.063	25.72	19.96	$P < 0.01$
S (mm <sup>2</sup> )	1,533.899	2,078.23	1,251.63	$P < 0.01$
M (g)	6.543	9.64	5.16	$P < 0.01$
PA <sub>1</sub> (mm <sup>2</sup> )	318.221	459.38	234.12	$P < 0.01$
PA <sub>2</sub> (mm <sup>2</sup> )	360.39	519.31	288.12	$P < 0.01$
PA <sub>3</sub> (mm <sup>2</sup> )	328.12	407.12	277.98	$P < 0.01$
CPA (mm <sup>2</sup> )	335.39	459.33	270.11	$P < 0.01$
V <sub>m</sub> (mm <sup>3</sup> )	6,627.391	7,750.13	5,750.19	$P < 0.01$
V <sub>osp</sub> (mm <sup>3</sup> )	5,376.091	8,984.18	3,574.19	$P < 0.01$
V <sub>ellip</sub> (mm <sup>3</sup> )	5,681.173	8,910.96	4,164.84	$P < 0.01$

CPA = criteria projected area;  $D_g$  = geometric mean diameter; L = length; M = mass; PA<sub>1</sub>, PA<sub>2</sub>, PA<sub>3</sub> = first, second, third projected area; S = surface areas; T = thickness; V<sub>m</sub> = measured volume; V<sub>osp</sub> = oblate spheroid volume; V<sub>ellip</sub> = ellipsoid shapes volume; W = width.

**Table 2. The best models for predicting the mass (g) of plum fruit with some physical characteristics.**

Independent variable	Best fitted model	Constant parameters of model			$R^2$
		$b_0$	$b_1$	$b_2$	
L (mm)	quadratic	-191.26	11.271	-0.137	0.125
W (mm)	quadratic	148.101	-7.199	0.109	0.741
T (mm)	linear	-53.559	2.260	-	0.684
$D_g$ (mm)	quadratic	228.255	-12.604	0.196	0.803
PA <sub>1</sub> (mm <sup>2</sup> )	quadratic	135.319	-0.188	$8.671 \times 10^{-5}$	0.649
PA <sub>2</sub> (mm <sup>2</sup> )	linear	-4.925	0.036	-	0.622
PA <sub>3</sub> (mm <sup>2</sup> )	quadratic	-13.862	0.054	$-8.56 \times 10^{-5}$	0.528
CPA (mm <sup>2</sup> )	quadratic	15.806	-0.006	$1.989 \times 10^{-5}$	0.750
S (mm <sup>2</sup> )	quadratic	37.027	-0.12	$2.381 \times 10^{-6}$	0.801
V <sub>m</sub> (mm <sup>3</sup> )	quadratic	5.755	0.001	$7.181 \times 10^{-9}$	0.762
V <sub>osp</sub> (mm <sup>3</sup> )	linear	1.555	0.001	-	0.792
	quadratic	6.314	0.001	$3.982 \times 10^{-9}$	0.792
V <sub>ellip</sub> (mm <sup>3</sup> )	quadratic	8.744	0.001	$8.743 \times 10^{-9}$	0.616

CPA = criteria projected area;  $D_g$  = geometric mean diameter; L = length; M = mass; PA<sub>1</sub>, PA<sub>2</sub>, PA<sub>3</sub> = first, second, third projected area;  $R^2$  = coefficient of determination; S = surface areas; T = thickness; V<sub>m</sub> = measured volume; V<sub>osp</sub> = oblate spheroid volume; V<sub>ellip</sub> = ellipsoid shapes volume; W = width.

### Modelling based on dimensions

The results of mass modelling of plum fruit based on dimensional characteristics including length, width thickness and geometric mean diameter, showed that the quadratic model to calculate mass of plum fruit based on geometric mean diameter, had the highest  $R^2$  among the others as:

$$M = 228.255 - 12.604D_g + 0.196D_g^2 \quad R^2=0.803 \quad (10)$$

However, measurement of three diameters of plum 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, width and thickness, quadratic model which expresses the width ( $W$ ) as independent variable had the highest  $R^2$  among the others (Table 2). Therefore, the mass model of plum fruit based on length is given as quadratic form:

$$M = 53.929 - 4.794W + 0.119W^2 \quad R^2=0.741 \quad (11)$$

In addition, the quadratic model can predict the relationships between the mass with length and thickness with  $R^2$  values of 0.125 and 0.584, respectively. Therefore, mass modelling of plum fruit based on width is recommended. Tabatabaefar *et al.* (2000) suggested a nonlinear model for orange mass based on fruit width too. Their recommended model was with the following values:  $M = 0.069b^2 - 2.95b - 39.15$ ,  $R^2=0.97$ . Eleven models for predicting mass of apples based on geometrical attributes were recommended by Tabatabaefar and Rajabipour (2005). They recommended an equation calculating apple mass on the basis of 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 based on length as:  $M = 0.035a^2 - 1.64a + 36.137$ ,  $R^2 = 0.96$ .

### Modelling based on areas

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

$$M = 15.806 - 0.006CPA + 1.989 \times 10^{-5} CPA^2 \quad R^2=0.750 \quad (12)$$

But, if this model was used for the classification of fruits in grading system, all three projected areas will be required for plum fruit. Therefore, the costs of sorting and grading will be increased while the speed of system will be decreased. Then it is evident that one of projected areas must be selected. Among the  $PA_1$ ,  $PA_2$  and  $PA_3$  areas, the quadratic model of  $PA_1$  was preferred because of the highest value of  $R^2$ :

$$M = 135.319 - 0.188PA_1 + 8.761 \times 10^{-5} PA_1^2 \quad R^2=0.649 \quad (13)$$

For the prediction of the mass of the plum fruit based on surface area the best model was the quadratic with  $R^2 = 0.801$ :

$$M = 37.027 - 0.12S + 2.381 \times 10^{-6} S^2; \quad R^2=0.801 \quad (14)$$

However, measurement of three defamations of plum fruit is needed for calculating the geometric mean diameter ( $D_g$ ) and then calculating surface areas ( $S$ ) to use this model, which makes the sizing mechanism more tedious and expensive.

### Modelling based on volumes

According to the results, for the prediction of the mass of the plum fruit based on volumes ( $V_m$ ,  $V_{osp}$  and  $V_{ellip}$ ), shown in Table 2, linear and quadratic models based on volume of assumed oblate spheroid ( $V_{osp}$ ) with  $R^2 = 0.792$ , were the best models as:

$$M = 1.555 + 0.001V_{osp} \quad R^2=0.792 \quad (15)$$

$$M = 8.744 + 0.001V_{osp} + 8.774 \times 10^{-9} V_{osp}^2 \quad R^2=0.792 \quad (16)$$

According to the results obtained in this study, the quadratic model could predict the relationships among the mass and some physical properties of plum fruit with proper value for determination coefficient. So we suggest the quadratic model based on first projected area ( $PA_1$ ) for predicting the mass of plum fruit because we need one camera and it is applicable and economical method.

## 4. Conclusions

Some physical properties and their relationships of mass of plum fruit are presented in this study. From this study it can be concluded that:

- All properties considered in the current study were found to be statistically significant at the 1% probability level.
- The results showed that mass modelling of plum fruit based on width was the most appropriate ones in the first classification:  $M = 53.929 - 4.794W + 0.119W^2$ ,  $R^2=0.741$ .
- In the second classification, the best model was obtained as Quadratic form based on the first projected area which perpendicular to L direction of plum.
- In the third classification, the best models were obtained based on the oblate volume as  $M = 1.555 + 0.001V_{osp}$  and  $M = 8.744 + 0.001V_{osp} + 8.774 \times 10^{-9} V_{osp}^2$  with  $R^2=0.792$ .
- At last, mass model based on the first projected area from an economic standpoint is recommended.

This information can be used in the design and development of sizing mechanisms and other post-harvest processing

machines. At last, it is recommended that other properties of plum such as thermal, mechanical, and nutritional characteristics to be studied and changes of these properties are to be examined as a function of moisture content and ripening phases.

## References

- Al-Maiman, S. and Ahmad, D., 2002. Changes in physical and chemical properties during pomegranate (*Punica granatum* L.) fruit maturation. *Journal of Food Chemistry* 76: 437-441.
- Blazek, J.A., 2007. Survey of the genetic resources used in plum breeding. *Acta Horticulture* 734: 31-45.
- Ertekin, C., Gozlekci, S., Kabas, O., Sonmez, S. and Akinci I., 2006. Some physical, pomological and nutritional properties of two plum (*Prunus domestica* L.) cultivars. *Journal of Food Engineering* 75: 508-514.
- Fadavi, A., Barzegar, M., Azizi, M.H. and Bayat, M., 2005. Note. Physicochemical composition of ten pomegranate cultivars (*Punica granatum* L.) grown in Iran. *Food Science and Technology International* 11: 113-119.
- Ghabel, R., Rajabipour, A., Ghasemi-Varnamkhasti, M. and Oveisi, M., 2010. Modeling the mass of Iranian export onion (*Allium cepa* L.) varieties using some physical characteristics. *Research in Agricultural engineering* 56: 33-40.
- Kaya, A. and Sozer, N., 2005. Rheological behavior of sour pomegranate juice concentrates (*Punica granatum* L.). *International Journal of Food Science and Technology* 40: 223-227.
- Khanali, M., Ghasemi Varnamkhasti, M., Tabatabaeefar, A. and Mobli, H., 2007. Mass and volume modelling of tangerine (*Citrus reticulata*) fruit with some physical attributes. *International Agrophysics* 21: 329-334.
- Khoshnam, F., Tabatabaeefar, A., Varnamkhasti, M.G. and Borghei, A., 2007. Mass modeling of pomegranate (*Punica granatum* L.) fruit with some physical characteristics. *Scientia Horticulturae* 114: 21-26.
- Kingsly, A.R.P., Singh, D.B., Manikantan, M.R. and Jain, R.K., 2006. Moisture dependent physical properties of dried pomegranate seeds (*Anardana*). *Journal of Food Engineering* 75: 492-496.
- Lorestani, A.N. and Ghari, M., 2012. Mass modeling of fava bean (*Vicia faba* L.) with some physical characteristics. *Scientia Horticulturae* 133: 6-9.
- Lorestani, A.N. and Tabatabaeefar, A., 2006. Modeling the mass of kiwi fruit by geometrical attributes. *International Agrophysics* 20: 135-139.
- Lorestani, A.N., Jaliliantabar, F. and Gholami, R., 2012. Mass modeling of caper (*Capparis spinosa*) with some engineering properties. *Quality Assurance and Safety of Crops & Foods* 4: e38-e42.
- Mohsenin, N.N., 1986. Physical properties of plant and animal materials (revised 2<sup>nd</sup> Ed.). Gordon and Breach Science Publications, New York, NY, USA.
- Naderi-Boldaji, M., Fattahi, R., Ghasemi-Varnamkhasti, M., Tabatabaeefar, A. and Jannatizadeh, A., 2008. Models for predicting the mass of apricot fruits by geometrical attributes (cv. Shams, Nakhjavan, and Jahangiri). *Scientia Horticulturae* 118: 293-298.
- Shahbazi, F. and Rahmati, S., 2013a. Mass modeling of sweet cherry (*Prunus avium* L.) fruit with some physical characteristics. *Food and Nutrition Sciences* 4: 1-5.
- Shahbazi, F. and Rahmati, S., 2013b. Mass modeling of fig (*Ficus carica* L.) fruit with some physical characteristics. *Food Science and Nutrition* 1: 125-129.
- Shahbazi, F., 2013. Effective conditions for extracting higher quality kernels from walnuts. *Quality Assurance and Safety of Crops & Foods* 5: 199-206.
- Stroshine, R., 1998. Physical properties of agricultural materials and food products. Course Manual. Purdue University, West Lafayette, IN, USA.
- Tabatabaeefar, A. and Rajabipour, A., 2005. Modeling the mass of apples by geometrical attributes. *Scientia Horticulturae* 105: 373-382.
- Tabatabaeefar, A., Vefagh-Nematolahee, A. and Rajabipour, A., 2000. Modeling of orange mass based on dimensions. *Journal of Agricultural Science and Technology* 2: 299-305.

