Agricultural Engineering Research Journal 10(1): 07-11, 2020
ISSN 2218-3906
© IDOSI Publications, 2020
DOI: 10.5829/idosi.aerj.2020.07.11

Mass Modeling of Plum Based on Geometrical Properties

Morteza Malekyarand

Imam Khomeini Higher Education Center, Agricultural Research,
Education and Extension Organization (AREEO), Karaj, Iran

Abstract: In this study, eighteen linear regression models for predicting plum mass based on some geometrical properties of plum such as major diameter (a), intermediate diameter (b), minor diameter (c), geometrical mean diameter (GMD), first projected area (PA_1), second projected area (PA_2), third projected area (PA_3), criteria area (CAE), estimated volume based on an ellipsoid assumed shape (V_{Ell}) and measured volume (V_M) were suggested. Models were divided into three main classifications, i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes). The statistical results of the study indicated that in order to predict plum mass based on outer dimensions, the mass model based on three diameters as $M = - 95.37 + 0.824\ a + 1.231\ b + 1.261\ c$ with $R^2 = 0.912$ may be recommended. Moreover, to predict plum mass based on projected areas, the mass model based on three projected areas as $M = - 22.10 + 1.141\ PA_1 + 1.148\ PA_2 + 2.479\ PA_3$ with $R^2 = 0.911$ may be suggested. Besides, to predict plum mass based on volumes, the mass model based on estimated volume as $M = 2.846 + 1.089\ V_{Ell}$ with $R^2 = 0.901$ may can be utilized. These models may be verified and used to design and develop sizing machines equipped with an image processing system.

Key words: Plum · Mass modeling · Geometrical properties · Linear regression models

INTRODUCTION

A plum (*Prunus domestica*) is a drupe fruit of the genus *Prunus*. The subgenus is distinguished from other subgenera (peaches, cherries, bird cherries, etc.) in the shoots having a terminal bud and solitary side buds (not clustered), the flowers in groups of one to five together on short stems and the fruit having a groove running down one side and a smooth stone (or pit). The commercially important plum trees are medium sized, usually pruned to 5-6 m height. The tree is of medium hardiness. Fruits are usually of medium size, between 1 to 3 inches in diameter, globose to oval. The flesh is firm, juicy and mealy. The fruit's peel is smooth, with a natural waxy surface that adheres to the flesh. The fruit has a single large seed. Plum fruit tastes sweet and/or tart; the skin may be particularly tart. It is juicy and can be eaten fresh or used in jam-making or other recipes. Plums come in a wide variety of colors and sizes. Some are much firmer-fleshed than others and some have yellow, white, green or red flesh, with equally varying skin color [1].

Plums are produced around the world and China is the world's largest producer. The ten largest producers of plums are China, Romania, USA, Serbia, Chile, France, Iran, Turkey, Italy and India. Iran products nearly about 269, 139 tons of plum and is ranked 7th in the world [2]. But, Iranian plums are not exported because of variability in size and shape and lack of suitable packaging [3].

Similar to other fruits, plum size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer fruits of equal size and shape [4, 5]. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [6]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [7]. Sorting manually is associated with high labor costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [8]. However, replacing human with a machine may still be questionable where the labor cost is comparable with the sorting equipment [9]. Studies on sorting in recent years have focused on automated sorting strategies and eliminating human efforts to provide more efficient and accurate sorting systems which improve the classification success or speed up the classification process [10, 11].

Corresponding Author: Morteza Malekyarand, Imam Khomeini Higher Education Center, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran

Physical and geometrical properties of products are the most important parameters in design of sorting systems. Among these properties, mass, outer dimensions, projected areas and volume are the most important ones in sizing systems [12]. The size of produce is frequently represented by its mass because it is relatively simple to measure. However, sorting based on some geometrical properties may provide a more efficient method than mass sorting. Moreover, the mass of produce can be easily estimated from geometrical properties if the mass model of the produce is known [13-17]. For these reasons, modeling of plum mass based on some geometrical properties may be useful and applicable. Therefore, the main objective of this research was to determine suitable mass model(s) based on some geometrical properties of plum.

MATERIALS AND METHODS

Experimental Procedure: One of the most common commercial cultivars of plum in Iran, i.e. Golden Drop (Fig. 1) was considered for this study. One hundred randomly selected plums of various sizes were purchased from a local market. Plums were selected for freedom from defects by careful visual inspection, transferred to the laboratory and held at 5±1°C and 90±5 % relative humidity until experimental procedure. In order to obtain required parameters for determining mass models, the mass of each plum was measured to 0.1 g accuracy on a digital balance. By assuming the shape of plum as an ellipsoid, the outer dimensions of each plum, i.e. major diameter (a), intermediate diameter (b) and minor diameter (c) was measured to 0.1 cm accuracy by a digital caliper. The geometric mean diameter (GMD) of each plum was then calculated by equation 1.

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

Three projected areas of each plum, i.e. first projected area (PA_1), second projected area (PA_2) and third projected area (PA_3) was also calculated by using equation 2, 3 and 4, respectively. The average projected area known as criteria area (CAE) of each plum was then determined by equation 5.

$$PA_1 = \pi\, ab/4 \quad (2)$$
$$PA_2 = \pi\, ac/4 \quad (3)$$
$$PA_3 = \pi\, bc/4 \quad (4)$$
$$CAE = (PA_1+PA_2+PA_3)/3 \quad (5)$$

Fig. 1: Plum (Prunus domestica cv. Golden Drop)

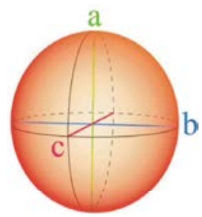

Fig. 2: The outer dimensions of a plum, i.e. major diameter (a), intermediate diameter (b) and minor diameter (c) by assuming the shape of plum as an ellipsoid

In addition, the volume of ellipsoid assumed shape (Fig. 2) or estimated volume of each plum (V_{Ell}) was calculated by using equation 6.

$$V_{ell} = \pi\, abc/6 \quad (6)$$

Table 1 shows mass and geometrical properties of the plums used to determine mass models.

Regression Model: A typical multiple-variable linear regression model is shown in equation 7:

$$Y = k_0 + k_1X_1 + k_2X_2 + \ldots + k_nX_n \quad (7)$$

where:

Y = Dependent variable, for example mass of plum

$X_1, X_2, \ldots, X_n$ = Independent variables, for example geometrical properties of plum

$k_0, k_1, k_2, \ldots, k_n$ = Regression coefficients

In order to estimate plum mass based on geometrical properties, eighteen linear regression models were suggested and all the data were subjected to linear regression analysis using the Microsoft Excel 2007 (Table 2). Models were divided into three main classifications, i.e. first classification (or outer dimensions), second classification (or projected areas) and third classification (or volumes).

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of mass and some geometrical properties of the 100 randomly selected plums used to determine mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	42.5	58.2	51.5	3.87	7.51
Major diameter (a), mm	39.3	45.0	41.9	1.29	3.07
Intermediate diameter (b), mm	42.7	47.9	45.5	1.17	2.57
Minor diameter (c), mm	41.5	46.8	44.7	1.21	2.72
Geometrical mean diameter (GMD), mm	41.3	46.0	44.0	1.11	2.52
First projected area (PA_1), cm^2	13.3	16.6	15.0	0.77	5.14
Second projected area (PA_2), cm^2	13.0	16.3	14.7	0.77	5.24
Third projected area (PA_3), cm^2	13.9	17.4	16.0	0.82	5.14
Criteria area (CAE), cm^2	13.4	16.6	15.2	0.77	5.03
Estimated volume (V_{Ell}), cm^3	36.9	51.0	44.7	3.37	7.54
Measured volume (V_M), cm^3	38.0	57.7	47.1	4.05	8.60

Table 2: Eighteen linear regression mass models and their relations in three classifications

Classification	Model No.	Model	Relation
Outer dimensions	1	$M = k_0 + k_1\ a$	$M = -45.50 + 2.316\ a$
	2	$M = k_0 + k_1\ b$	$M = -86.05 + 3.025\ b$
	3	$M = k_0 + k_1\ c$	$M = -77.88 + 2.893\ c$
	4	$M = k_0 + k_1\ GMD$	$M = -94.25 + 3.313\ GMD$
	5	$M = k_0 + k_1\ a + k_2\ b$	$M = -93.93 + 0.896\ a + 2.373\ b$
	6	$M = k_0 + k_1\ a + k_2\ c$	$M = -89.40 + 0.977\ a + 2.236\ c$
	7	$M = k_0 + k_1\ b + k_2\ c$	$M = -88.40 + 1.666\ b + 1.435\ c$
	8	$M = k_0 + k_1\ a + k_2\ b + k_3\ c$	$M = -95.37 + 0.824\ a + 1.231\ b + 1.261\ c$
Projected areas	9	$M = k_0 + k_1\ PA_1$	$M = -17.37 + 4.601\ PA_1$
	10	$M = k_0 + k_1\ PA_2$	$M = -16.54 + 4.622\ PA_2$
	11	$M = k_0 + k_1\ PA_3$	$M = -18.71 + 4.393\ PA_3$
	12	$M = k_0 + k_1\ CAE$	$M = -21.56 + 4.799\ CAE$
	13	$M = k_0 + k_1\ PA_1 + k_2\ PA_2$	$M = -17.56 + 1.626\ PA_1 + 3.038\ PA_2$
	14	$M = k_0 + k_1\ PA_1 + k_2\ PA_3$	$M = -22.33 + 2.112\ PA_1 + 2.642\ PA_3$
	15	$M = k_0 + k_1\ PA_2 + k_2\ PA_3$	$M = -21.47 + 2.216\ PA_2 + 2.525\ PA_3$
	16	$M = k_0 + k_1\ PA_1 + k_2\ PA_3 + k_3\ PA_3$	$M = -22.10 + 1.141\ PA_1 + 1.148\ PA_2 + 2.479\ PA_3$
Volumes	17	$M = k_0 + k_1\ V_{Ell}$	$M = 2.846 + 1.089\ V_{Ell}$
	18	$M = k_0 + k_1\ V_M$	$M = 12.46 + 0.829\ V_M$

RESULTS AND DISCUSSION

The p-value of independent variable(s) and coefficient of determination (R^2) of the linear regression models are shown in Table 3.

First Classification Models (Outer Dimensions): In this classification plum mass can be predicted using linear regression models No. 1-8 (Table 2). As indicated in Table 3, among the first classification models, model No. 8 had the highest R^2 value (0.912). Also, the p-value of independent variables (a, b and c) was 9.63E-10, 3.75 E-06 and 5.30E-07, respectively. Based on the statistical results model No. 8 was selected as the best model of first classification models. Model No. 8 is given in equation 8.

$$M = - 95.37 + 0.824\ a + 1.231\ b + 1.261\ c \qquad (8)$$

Second Classification Models (Projected Areas): In this classification plum mass can be predicted using linear regression models No. 9-16 (Table 2). As demonstrated in Table 3, among the second classification models, model No. 16 had the highest R^2 value (0.911). Moreover, the p-value of independent variables (PA_1, PA_2 and PA_3) was 0.113250, 0.129671 and 1.63E-11, respectively. Again, based on the statistical results model No. 16 was chosen as the best model of second classification models. Model No. 16 is given in equation 9.

$$M = - 22.10 + 1.141\ PA_1 + 1.148\ PA_2 + 2.479\ PA_3 \qquad (9)$$

Third Classification Models (Volumes): In this classification plum mass can be predicted using linear regression models No. 17 and 18 (Table 2). As measuring the volume of an irregularly shaped object (plum) using

Table 3: The p-value of independent variable(s) and coefficient of determination (R^2) of the linear regression models

	p-value										
Model No.	a	b	c	GMD	PA_1	PA_2	PA_3	CAE	V_{Ell}	V_M	R^2
1	5.76E-21	---	---	---	---	---	---	---	---	---	0.595
2	---	3.51E-40	---	---	---	---	---	---	---	---	0.835
3	---	---	4.19E-39	---	---	---	---	---	---	---	0.827
4	---	---	---	9.86E-52	---	---	---	---	---	---	0.904
5	2.97E-09	2.22E-28	---	---	---	---	---	---	---	---	0.886
6	3.48E-11	---	3.26E-29	---	---	---	---	---	---	---	0.890
7	---	1.41E-07	1.77E-06	---	---	---	---	---	---	---	0.870
8	9.63E-10	3.75E-06	5.30E-07	---	---	---	---	---	---	---	0.912
9	---	---	---	---	8.25E-41	---	---	---	---	---	0.840
10	---	---	---	---	---	1.71E-42	---	---	---	---	0.852
11	---	---	---	---	---	---	2.92E-45	---	---	---	0.870
12	---	---	---	---	---	---	---	1.09E-51	---	---	0.904
13	---	---	---	---	0.073004	0.000995	---	---	---	---	0.857
14	---	---	---	---	4.96E-09	---	1.66E-13	---	---	---	0.909
15	---	---	---	---	---	5.53E-09	9.03E-12	---	---	---	0.909
16	---	---	---	---	0.113250	0.129671	1.63E-11	---	---	---	0.911
17	---	---	---	---	---	---	---	---	5.32E-51	---	0.901
18	---	---	---	---	---	---	---	---	---	1.34E-31	0.754

water displacement method is often difficult, model No. 17 was primarily preferred. Moreover, as demonstrated in Table 3, between the third classification models, model No. 17 had higher R^2 value (0.901) and lower p-value (5.32E-51) of independent variable (V_{Ell}). Once more, based on the statistical results model No. 17 was chosen as the best model of third classification models. Model No. 17 is given in equation 10.

$$M = 2.846 + 1.089\ V_{Ell} \qquad (10)$$

CONCLUSIONS

To predict plum mass based on outer dimensions, the mass model based on three diameters as $M = - 95.37 + 0.824\ a + 1.231\ b + 1.261\ c$ with $R^2 = 0.912$ may be recommended. Moreover, to predict plum mass based on projected areas, the mass model based on three projected areas as $M = - 22.10 + 1.141\ PA_1 + 1.148\ PA_2 + 2.479\ PA_3$ with $R^2 = 0.911$ may be suggested. Besides, to predict plum mass based on volumes, the mass model based on estimated volume as $M = 2.846 + 1.089\ V_{ell}$ with $R^2 = 0.901$ may can be utilized. These models may be verified and used to design and develop sizing machines equipped with an image processing system.

REFERENCES

1. Anonymous, 2013. Plum. From Wikipedia, the free encyclopedia. Available at http://en.wikipedia.org/wiki/Plum. Retrieved April 29, 2013.
2. FAO Statistical Yearbook, 2010. Food and Agriculture Organization of the United Nations.
3. Statistical Yearbook, 2010. Iranian Ministry of Agriculture, Iran.
4. Rashidi, M. and K. Seyfi, 2007. Classification of fruit shape in cantaloupe using the analysis of geometrical attributes. World Appl. Sci. J., 3(6): 735-740.
5. Rashidi, M. and M. Gholami, 2008. Classification of fruit shape in kiwifruit using the analysis of geometrical attributes. Am-Euras. J. Agric. & Environ. Sci., 3(2): 258-263.
6. Sadrnia, H., A. Rajabipour, A. Jafary, A. Javadi and Y. Mostofi, 2007. Classification and analysis of fruit shapes in long type watermelon using image processing. Int. J. Agric. Biol., 9: 68-70.
7. Wilhelm, L.R., D.A. Suter and G.H. Brusewitz, 2005. Physical Properties of Food Materials. Food and Process Engineering Technology. ASAE, St. Joseph, Michigan, USA.
8. Wen, Z. and Y. Tao, 1999. Building a rule-based machine-vision system for defect inspection on apple sorting and packing lines. Expert Systems with Application, 16: 307-713.
9. Kavdir, I. and D.E. Guyer, 2004. Comparison of artificial neural networks and statistical classifiers in apple sorting using textural features. Biosys. Eng., 89: 331-344.
10. Kleynen, O., V. Leemans and M.F. Destain, 2003. Selection of the most effective wavelength bands for 'Jonagold' apple sorting. Postharvest Biol. Technol., 30: 221-232.

11. Polder, G., G.W.A.M. Van Der Heijden and I.T. Young, 2003. Tomato sorting using independent component analysis on spectral images. Real-Time Imaging, 9: 253-259.
12. Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers. New York. USA.
13. Khanali, M., M. Ghasemi Varnamkhasti, A. Tabatabaeefar and H. Mobli, 2007. Mass and volume modeling of tangerine (*Citrus reticulate*) fruit with some physical attributes. Int. Agrophysics, 21: 329-334.
14. Rashidi, M. and K. Seyfi, 2008. Modeling of kiwifruit mass based on outer dimensions and projected areas. Am-Euras. J. Agric. & Environ. Sci., 3(1): 26-29.
15. Taheri-Garavand, A. and A. Nassiri, 2010. Study on some morphological and physical characteristics of sweet lemon used in mass models. Int. J. Environ. Sci., 1: 580-590.
16. Rashidi, M. and M. Gholami, 2011. Modeling of apricot mass based on some geometrical attributes. Middle-East J. Sci. Res., 7(6): 959-963.
17. Rashidi, M. and M. Gholami, 2011. Modeling of nectarine mass based on some geometrical properties. Am-Euras. J. Agric. & Environ. Sci., 10(4): 621-625.