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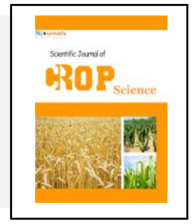

Original article

Mass and volume modeling of tomato based on physical characteristics

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A R T I C L E I N F O

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A B S T R A C T

There are instances in which it is desirable to determine relationship between various physical characteristics of vegetables and fruits. Although vegetables and fruits are often graded on the basis of size and projected area, it may be more economical to develop a machine which would grade by produce mass or volume. Therefore, relationships of mass and volume with other physical characteristics are needed. In this study, Market-King variety of tomato were selected and fruit dimensions and projected area were used to develop a number of models for predicting mass and volume of tomato. Three general models were established; Single and multiple variable regressions of tomato dimensions, single and multiple variable regressions of projected areas and modeling tomato mass and volume based on its measured volume and mass. Results revealed that for the first model that mass and volume can be best modeled on the basis of intermediate and minor diameters. Results for model #2 show that model based on 2nd projected area is a preferred model for mass and volume estimation. The third model which is based on ellipsoid volume can estimate tomato mass satisfactorily($R^2 = 0.98$). This study indicated that for estimating tomato mass the third model can give best results. On the other hand, for estimating tomato volume, the 2nd projected area can give best results.

Nomenclature

a - major diameter (mm)
b - intermediate diameter (mm)
c - minor diameter (mm)
CPA – criteria projected area (mm2)
GMD – geometric mean diameter (mm)
K_i – regression coefficient
M – mass (g)
M_m – measured mass (g)
S – surface area of fruit (cm2)
PA_1 – first projected area (mm2)
PA_2 – second projected area (mm2)
PA_3 – third projected area (mm2)
R^2 – coefficient of determination
V – volume (cm3)
V_m – measured volume (cm3)
V_{ellip} – volume of ellipsoid (cm3)
V_{obl} – volume of oblate spheroid (cm3)
π - constant (3.142)

1. Introduction

Tomato is an edible vegetable or fruit (Solanum Lycopersicon L.) that belongs to the Nightshade family (Smith, 1994). Its reported composition (fresh weight basis) is: water 94.5%, carbohydrates 3.9%, fiber 1.2%, fat 0.2%, protein 0.9%, sugar 2.6%. According to FAOSTAT, the world production of tomato in 2010 is estimated at 130,000,000 T (FAOSTAT, Crop statistics).

Physical properties of fruit are important for designing and fabricating equipment and structures for handling, transporting, processing and storage, and also for assessing quality. (Khoshnam et al., 2007). Fruits are often graded by size, but it may be more economical to develop a machine which grades by weight and density. In recent years, there has been interest in video-based dimensional sizing of agricultural products (Miller, 1990). Sizing by a weighting mechanism is recommended for the irregular shaped products (Khoshnam et al., 2007). Since mechanical sizing mechanisms react poorly, the video-based dimensional sizing method (of length, area and volume) can be used instead with tomato fruit. Predicting the mass and volume of tomato fruit by physical attributes reduces costs and increases of both weight and density sorting techniques.

In the case of both mass and volume modeling, Khanali et al. (2007) determined models for predicting mass and volume of the Iranian grown tangerine with some geometrical attributes. They reported that among the systems that sort oranges based on one dimension, the system that applies intermediate diameter is suitable with nonlinear relationship. Also mass and volume modeling, on the basis of actual fruit volume and one projected area, were identified as the best models.

Tabatabaeefar et al. (2000) modeled mass of the Iranian grown orange for its volume, dimensions, and projected areas. They reported that among the systems that stored oranges based on one dimension, the system that applies intermediate diameter is suitable with nonlinear relationship. Also, Naderi-Boldaji et al. (2008), Khoshnam et al. (2007), Lorestani and Tabatabaeefar (2006), Keramat Jahromi et al. (2007) and Tabatabaeefar and Rajabipour (2005) used this method for predicting mass of apricot, pomegranate and kiwi, bergamot and apple fruits, respectively.

No detailed studies concerning mass and volume modeling of the tomato has yet been performed. The aim of this study was to determine the most suitable model for predicting tomato fruit mass and volume by its physical attributes.

2. Materials and methods

A well-known variety of tomato (Market-King) was considered for this study. About 50 tomato fruits were obtained from an orchard of the Fars province in South of Iran. The mass of each tomato was measured by a digital balance with an accuracy of 0.001g. Its volume was measured by the water displacement method (Aydin and Musa Ozcan., 2005; Aydin and Musa Ozcan., 2007). Three mutually perpendicular axes: a – major (the longest intercept), b – intermediate (the longest intercept normal to a), and c – minor (the longest intercept normal to a, b) of each tomato were measured by image processing method. To avoid the shades, an illumination chamber was fabricated to produce indirect uniform lighting on samples (Figure 1). A NIKON COOLPIX P4 digital camera was mounted on top of the chamber at a distance of 30cm above the samples.

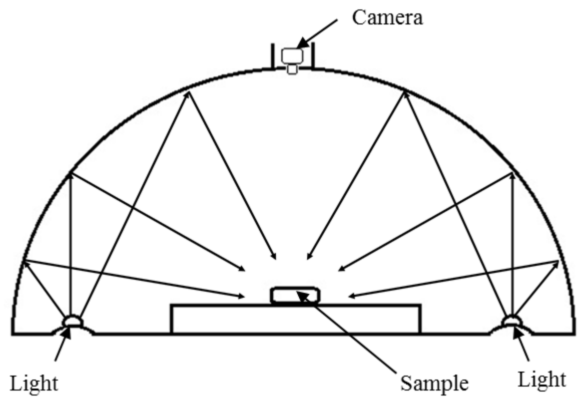

Fig. 1. Illumination chamber used in this study.

Geometric mean diameter, GMD, and sphericity were determined using the following equations (Mohsenin., 1986):

$$\mathrm{GMD} = \sqrt[3]{\mathrm{abc}} \qquad (1)$$

$$\mathrm{sphericity} = \frac{\mathrm{GMD}}{\mathrm{a}} \qquad (2)$$

Where three mutually perpendicular area are PA1, PA2, PA3, the average projected area (known as the criterion area, CPA, mm2) was determined from equation:

$$\mathrm{CPA} = \frac{(\mathrm{PA}_1 + \mathrm{PA}_2 + \mathrm{PA}_3)}{3} \qquad (3)$$

Microsoft EXCEL 2010, was used to analyze the data and to determine regression models between the parameters.

In order to estimate the tomato fruit mass and volume from its dimensions (length, area, and volume and mass), the following three classifications of models were considered:

Single or multiple variable regressions of tomato fruit dimension characteristics: major (a), intermediate (b) and minor (c) diameters.

Single or multiple variable regressions of tomato fruit projected areas: PA1, PA2 and PA3.

Single regression of tomato fruit volume: actual volume, volume of the fruit assumed as oblate spheroid and ellipsoid shapes.

In the first classification, mass and volume modeling was accomplished with respect to major, intermediate and minor diameters. The models obtained with three variables for predicting tomato fruit mass and volume were:

$$\mathrm{M} = \mathrm{k}_1\mathrm{a} + \mathrm{k}_2\mathrm{b} + \mathrm{k}_3\mathrm{c} + \mathrm{k}_4 \qquad (6)$$

$$\mathrm{V} = \mathrm{k}_1\mathrm{a} + \mathrm{k}_2\mathrm{b} + \mathrm{k}_3\mathrm{c} + \mathrm{k}_4 \qquad (7)$$

These models, can estimate mass and volume as a function of one, two and three dimensions.

In the second classification models, mass and volume of tomato fruit was established based on mutually perpendicular projected areas as follows:

$$M = k_1PA_1 + k_2PA_2 + k_3PA_3 + k_4 \quad 8)$$

$$V = k_1PA_1 + k_2PA_2 + k_3PA_3 + k_4 \quad 9)$$

In this classification, the mass and volume can be estimated as a function of one, two or three projected area(s).

In the third classification, to achieve models which can predict the tomato fruit mass on the basis of volume, three volume values were either measured or calculated. At first, actual volume Vm as stated earlier was measured, then the tomato fruit shape was assumed as a regular geometric shape, i.e. oblate spheroid (Vobl) and ellipsoid (Vellip) shapes, and their volume was thus calculated as:

$$V_{obl} = \frac{4}{3}\pi.\left(\frac{a}{2}\right).\left(\frac{b}{2}\right)^2 \quad (10)$$

$$V_{ellip} = \frac{4}{3}\pi.\left(\frac{a}{2}\right).\left(\frac{b}{2}\right).\left(\frac{c}{2}\right) \quad (11)$$

In this classification (applied only for mass modeling), the mass can be estimated as either a function of volume of supposed shape or the measured volume as given in following equations:

$$M = k_1V_{obl} + k_2 \quad (12)$$

$$M = k_1V_{ellip} + k_2 \quad (13)$$

$$M = k_1V_m + k_2 \quad (14)$$

3. Results

3.1. First classification models - length

Among the first classification, model 7, in which all three dimensions were considered, had a higher R2 value and lower SEE (Table 1 and 2). However, this model requires that all three diameters must be measured, which makes the sizing mechanism more complex and expensive. Among models 1, 2 and 3, model 2 had a higher R2 value and lower SEE. Therefore, in order to perform mass and volume modeling on the basis of length, model 2 and 3, among the three one-dimensional models, was selected as the best choice with intermediate and minor diameters as shown in Figures 2 (a and b respectively).

Table 1
Properties of tomato.

PROPERTIES	PARAMETERS	MIN	MAX	AVERAGE
Major Diameter (mm)	a	33.70	65.00	51.28
Intermediate Diameter (mm)	b	34.15	55.80	46.12
Minor Diameter (mm)	c	32.61	54.54	43.51
Equivalent Diameter	De	35.23	58.15	46.84
Mass (g)	M	25.579	105.950	58.332
Measured Volume (cm3)	Vm	16.5	104.25	54.86
Density (gr/cm3)	SD	0.47	1.55	1.087
Geometric Mean Diameter (mm)	GMD	35.22	58.15	46.82
Arithmetic Mean Diameter	Da	35.23	58.34	46.97
Surface Area (cm2)	S	38.94	106.18	69.67
Sphericity	φ	0.79	0.99	0.91
Aspect Ratio	Ra	0.72	1.00	0.90
Packing Coefficient	Packing coeff.	1.01	1.43	1.15

Table 2
Coefficient of determination (R2) and Standard error of estimate (SEE) of linear regression mass models for tomato.

No.	Models	R2	SEE
1	$\mathrm{M = k_1a + k_2}$	0.72	9.88
2	$\mathrm{M = k_1b + k_2}$	0.88	6.41
3	$\mathrm{M = k_1c + k_2}$	0.88	6.43
4	$\mathrm{M = k_1a + k_2b + k_3}$	0.92	5.32
5	$\mathrm{M = k_1a + k_2c + k_3}$	0.96	4.03
6	$\mathrm{M = k_1b + k_2c + k_3}$	0.91	5.46
7	$\mathrm{M = k_1a + k_2b + k_3c + k_4}$	0.96	3.85
8	$\mathrm{M = k_1PA_1 + k_2}$	0.91	5.22
9	$\mathrm{M = k_1PA_2 + k_2}$	0.97	3.36
10	$\mathrm{M = k_1PA_3 + k_2}$	0.93	4.77
11	$\mathrm{M = k_1PA_1 + k_2PA_2 + k_3}$	0.99	1.86
12	$\mathrm{M = k_1PA_1 + k_2PA_3 + k_3}$	0.99	2.02
13	$\mathrm{M = k_1PA_2 + k_2PA_3 + k_3}$	0.97	3.30
14	$\mathrm{M = k_1PA_1 + k_2PA_2 + k_3PA_3 + k_4}$	0.99	1.50
15	$\mathrm{M = k_1V_m + k_2}$	0.88	6.43
16	$\mathrm{M = k_1V_{obl} + k_2}$	0.96	3.92
17	$\mathrm{M = k_1V_{ellip} + k_2}$	0.98	2.64

The best equation for the calculation of mass and volume of tomato fruit based on intermediate and minor diameter was given in the non-linear form of equations (15) and (16).

$$\mathrm{M = 2.54 \times 10^{-3}b^3 - 0.26b^2 + 11.05b - 146} \qquad R2 = 0.91 \qquad (15)$$

$$\mathrm{V = 6.24 \times 10^{-3}c^3 - 0.7c^2 + 28.22c - 363} \qquad R2 = 0.79 \qquad (16)$$

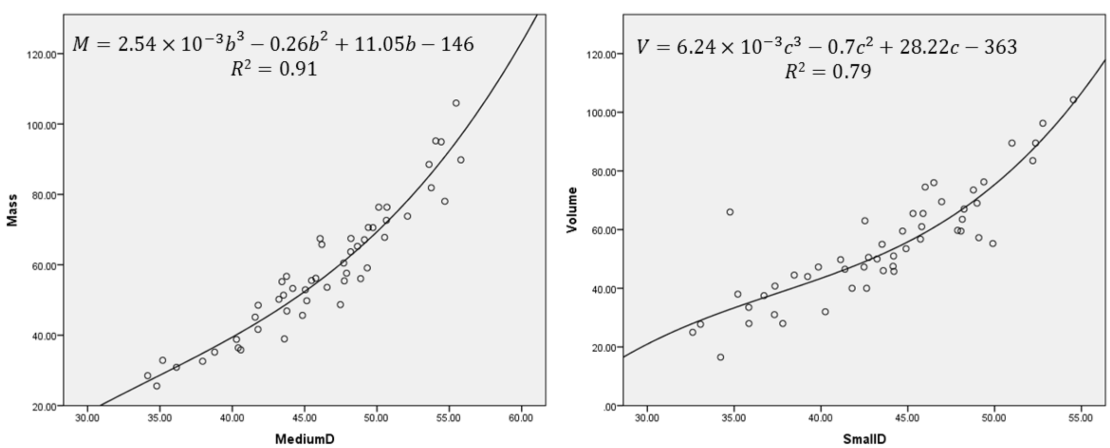

Fig. 2. (a) Mass model of tomato based on intermediate diameter & (b) Volume model of tomato based on minor diameter.

3.2. Second classification models – area

For both mass and volume modeling, among the second classification models, as shown in Table 1 and 2, model 14, showed a higher R2 value and lower SEE. Among models 8-13, model 11 was chosen.

The overall mass and volume models based on three projected areas (model 14) are given in equations (17) and (18), respectively.

$$\mathrm{M = 0.016PA_1 + 0.015PA_2 + 0.011PA_3 - 27.59} \qquad R2 = 0.99 \qquad (17)$$

$$V = 0.011PA_1 + 0.016PA_2 + 0.016PA_3 - 35 \qquad R2 = 0.96 \qquad (18)$$

The mass and volume model of overall tomato fruit based on the 2nd projection area as shown in Figures 3 (a and b), was given as a non-linear form of equations (19) and (20).

$$M = 2.42 \times 10^{-6}PA_2^2 + 0.03PA_2 - 15.94 \qquad R2 = 0.97 \qquad (19)$$

$$V = 8.91 \times 10^{-6}PA_2^2 + 1.53 \times 10^{-3}PA_2 + 15.78 \qquad R2 = 0.87 \qquad (20)$$

Each one of the three projection areas can be used to estimate the tomato mass. There is a need to have three cameras, in order to take all the projection areas and have one R2 value close to unity; therefore, a model using only one projection area, possibly model 9, can be used.

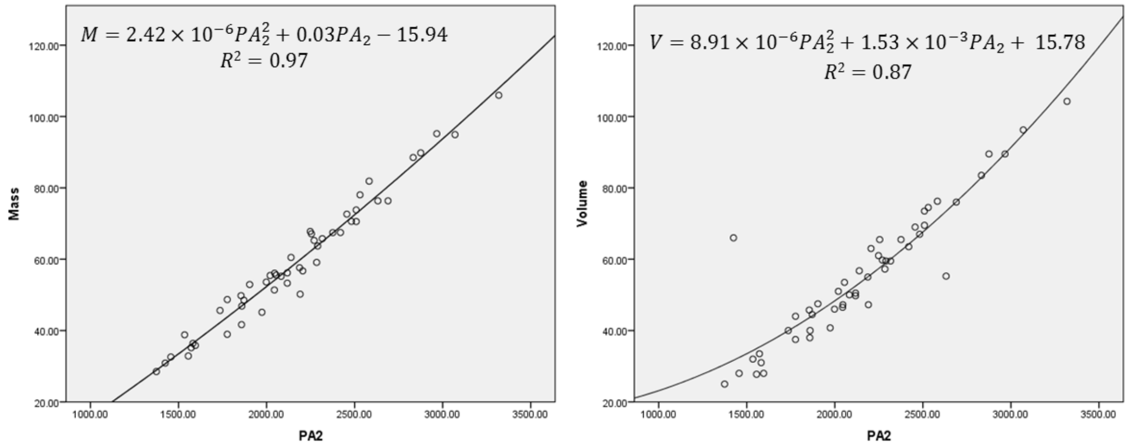

Fig. 3. (a) Mass model of tomato versus second projected area & (b) Volume model of all tomato versus second projected area.

3.3. Third classification models - volume

This classification was only used for mass modeling because the obtained results were the same. Among the models in the third classification (models 15, 16, 17), the R2 for model 17 was higher and SEE was lower.

Therefore, model 17 was suggested for predicting tomato mass. The mass model of overall tomato fruit based on the ellipsoid volume as shown in Figure 4, was given as a linear form of equation (21).

$$M = 1.01V_{ellip} + 1.95 \qquad R2 = 0.98 \qquad (21)$$

Considering equations (15) to (21) it can be concluded that the best model for mass modeling of tomato fruit is the model based on the measured volume i.e. model 17 (equation 21), while equation 20 is the best model for volume modeling. Measurement of one projected area is far easier than that of the ellipsoid volume of tomato fruit, so volume modeling of tomato fruit seems to be more convenient and economical.

4. Conclusions

1. The recommended equation for the calculation of tomato fruit mass and volume based on intermediate and minor diameter was of a non-linear form:

$$M = 2.54 \times 10^{-3}b^3 - 0.26b^2 + 11.05b - 146 \qquad (R2 = 0.91)$$

$$V = 6.24 \times 10^{-3}c^3 - 0.7c^2 + 28.22c - 363 \qquad (R2 = 0.79)$$

2. The recommended mass and volume models for sizing the tomato fruit based on 2nd projected area was similarly of a non-linear form:

$$M = 2.42 \times 10^{-6}PA_2^2 + 0.03PA_2 - 15.94 \qquad (R2 = 0.97)$$

$$V = 8.91 \times 10^{-6}PA_2^2 + 1.53 \times 10^{-3}PA_2 + 15.78 \qquad (R2 = 0.87)$$

3. There was a very good relationship between mass and ellipsoid volume of tomato fruit with R2 in the order of 0.98.

4. For estimating mass and volume model based on the ellipsoid volume and the projected area model, were identified as the best models, respectively.

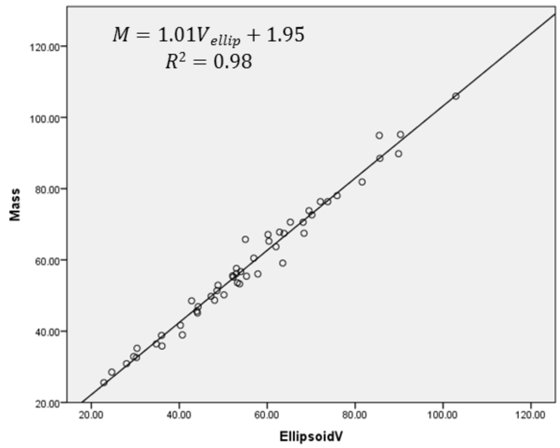

Fig. 4. Mass model of tomato based on ellipsoid volume.

The relationship among mass/volume and dimensional parameters of tomato are shown in Tables 3.

Table 3
Coefficient of determination (R2) and Standard error of estimate (SEE) of linear regression volume models for tomato.

No.	Models	R2	SEE
1	$V = k_1a + k_2$	0.65	11.44
2	$V = k_1b + k_2$	0.74	9.77
3	$V = k_1c + k_2$	0.75	9.65
4	$V = k_1a + k_2b + k_3$	0.79	8.91
5	$V = k_1a + k_2c + k_3$	0.83	8.12
6	$V = k_1b + k_2c + k_3$	0.76	9.24
7	$V = k_1a + k_2b + k_3c + k_4$	0.83	8.16
8	$V = k_1PA_1 + k_2$	0.84	7.21
9	$V = k_1PA_2 + k_2$	0.85	7.21
10	$V = k_1PA_3 + k_2$	0.84	7.41
11	$V = k_1PA_1 + k_2PA_2 + k_3$	0.95	4.03
12	$V = k_1PA_1 + k_2PA_3 + k_3$	0.95	3.97
13	$V = k_1PA_2 + k_2PA_3 + k_3$	0.86	7.08
14	$V = k_1PA_1 + k_2PA_2 + k_3PA_3 + k_4$	0.96	3.73
15	$V = k_1M_m + k_2$	0.88	6.61

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