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Study on some morphological and physical characteristics of tomato used in mass models to characterize best post harvesting options

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Abstract

Mass grading of vegetables provide useful insight into designing of sizing machine and reducing the packaging and transportation costs. In this research, tomato mass was correlated to different physical attributes using linear and nonlinear models into three different classifications: (1) single or multiple variable regressions of tomato dimensional characteristics, (2) single or multiple variable regression of tomato projected areas and (3) estimating tomato mass based on its volume. The results showed that mass modeling of tomato based on intermediate diameter and first projected areas are the most appropriate factors in the first and the second classifications, respectively. In third classification, the best model was obtained on the basis of the actual volume as M = 0.001 V + 1.498 with R^2 = 0.974, whereas corresponding values were 0.91 and 0.93 for assumed tomato shapes (oblate spheroid and ellipsoid), respectively. The best model for prediction of mass base on dimension was M = 0.206 b^2_19.61 b+558.1, R^2 = 0.916 and R.S.E. = 4.57. Which in economical and agronomical point of view, is suitable for grading and sizing systems.

Keywords: Tomato, Mass model, Physical properties, Grading; Projected areas.

Abbreviations: *a*- major, (the longest intercept); *b*- intermediate (the longest intercept normal to *a*); M-mass of fruit; GMD-Geometric mean diameter; P_A -first projected area; P_B -second projected area; P_C -third projectrd area; R-half of tickness S-surface area; T-thickness of fruit; Td-dropping time; V-volume of fruit; Vo-total volume; . V_{psp}-prolate spheroid; V_{ell}-ellipsoid; Φ-sphericity.

Introduction

To design and optimization a machine for handling, cleaning, conveying, and storing, the physical attributes and their relationships must be known (Mirzaee et al., 2008). The physical properties of tomato are important to design the equipment for processing, transportation, sorting, separation and storing. Designing such equipment without consideration of these properties may yield poor results. Therefore the determination and consideration of these properties have an important role (Taheri-Garavand et al., 2009). Among these physical properties, length, width, thickness, mass, volume, projected areas and center of gravity are the most important factors in sizing systems (Mohsenin, 1986). There are some situations in which it is desirable to determine relationships among physical attributes; for example, vegetables are often graded by size, but it may be more economical to develop a machine which grades by weight. Therefore, the relationship between weight and the major, minor and intermediate diameters is needed (Stroshine and Hamann, 1995). Determining relationships between mass and dimensions and projected areas may be useful and applicable (Stroshine and Hamann, 1995). In weight sizer machines, individual vegetables are carried by cups or trays that linked together in a conveyor and are individually supported by spring loaded mechanism. As the cups travel along the conveyor, the supports are engaged by triggering mechanisms, which allow the tray to dump if there is sufficient weight. Successive triggering mechanisms are set to dump the tray at lower weight. If the density of the vegetable is constant, the weight sizer sorts by volume. The sizing error will depend upon the correlation between weight and volume (Khoshnam et al., 2007). Beside, consumers prefer bright color vegetables with even weight and uniform shape. Mass grading of vegetable and fruit can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg et al., 1985). Tabatabaeefar et al. (2000) achieved models for predicting mass of Iranian orange for its dimensions, volumes and projected areas. These researchers stated that among the systems that stored oranges based on one dimension, the system that applies intermediate diameter is suitable with nonlinear relationship. Al-Maiman and Ahmad (2001) had analyzed pomegranate physical properties and obtained models to predict fruit weight from dimension, volume and surface pictures. Topuz et al. (2005) studied physical and nutritional properties of four mandarin genotypes of orange varieties. They reported dimension, volume, weight, surface picture, friction coefficient, porosity, and mass and fruit density in four mandarin genotypes. Among these physical characteristics, mass, volume, projected area are the most important factors in determining sizing systems (Mirzaee et al., 2009). Tabatabaeefar and Rajabipour (2005) recommended 11 models for predicting mass of apples based on geometrical attributes. Several models for predicting mass of kiwi based on physical attributes were determined and reported by Lorestani and Tabatabaeefar (2006). Also, Khoshnam et al. (2007) used this method for predicting the mass of pomegranate fruits. They suggested that there is a

Table 1. Assessed physical characteristics of the studied tomato.

Character	Minimum	Mean	Maximum	Standard deviation
Major diameter (mm)	53.28	58.868	64.94	3.37
Intermediate diameter (mm)	46.4	54.151	58.65	3.53
Minor diameter (mm)	45.1	51.812	57.8	3.33
Geometric mean diameter (mm)	48.87	54.83	60.7	2.88
Mass (g)	91.01	99.80	111.63	10.33
Volume (cm^3)	68	107.417	146	20.04
Surface area (mm^2)	7499.6	9467.3	11582.9	74.11
Sphericity (%)	84.46	93.25	98.69	2.78
True density (g/cm^3)	0.82	0.914	0.998	0.042
P_A (mm^2)	3047.7	3786.4	4873.8	54.8
P_B (mm^2)	3012.3	3776.4	4866.5	76.4
P_C (mm^2)	2934.3	3713.7	4849.3	86.2
Volume of ellipsoid(cm^3)	61.087	86.986	117.250	13.753
Volume of oblate spheroid (cm^3)	62.77	91.11	122.77	15.78

Table 2. Linear regression mass models, coefficient of determination (R^2) values and regression standard error (R.S.E) in tomato (cv. *Rio grande*).

No.	Models	factor	
1	$M = k_1a + k_2$	R^2	0.56
		R.S.E.	11.15
2	$M= k_1b + k_2$	R^2	0.837
		R.S.E.	4.57
3	$M= k_1c + k_2$	R^2	0.58
		R.S.E.	10.88
4	$M= k_1a + k_2b + k_3$	R^2	0.91
		R.S.E.	5.26
5	$M= k_1a + k_2c + k_3$	R^2	0.90
		R.S.E.	5.47
6	$M= k_1b + k_2c + k_3$	R^2	0.86
		R.S.E.	6.44
7	$M= k_1a + k_2b + k_3c + k_4$	R^2	0.94
		R.S.E.	4.53
8	$M = k_1P_A + k_2$	R^2	0.94
		R.S.E.	3.87
9	$M = k_1P_B + k_2$	R^2	0.91
		R.S.E.	4.82
10	$M = k_1P_C + k_2$	R^2	0.90
		R.S.E.	5.02
11	$M = k_1P_A + k_2P_B + k_3P_C + k_4$	R^2	0.95
		R.S.E.	3.42
12	$M = k_1V + k_2$	R^2	0.974
		R.S.E.	3.39
13	$M = k_1Vosp + k_2$	R^2	0.91
		R.S.E.	5.39
14	$M = k_1Vellip + k_2$	R^2	0.93
		R.S.E.	4.66

very good relationship between mass and measured volume for all varieties of kiwi. Ebrahimi et al. (2009) studied morphological and physical characteristics of Iranian walnuts and mass modeling of walnut. Moreover, they reported that among grading system based on dimensions in walnut (first classification), minor diameter model with nonlinear relation was the best and could be considered as a good model for economical and horticultural designing systems. To our knowledge, detailed measurements concerning mass modeling of tomato have not been published. Therefore, the objective of this research was to determine an optimum tomato mass model based on its physical attributes. This information provides useful insights into design of harvesting, processing, sorting, separating and packing equipments for tomato.

Materials and methods

Samples Preparation

This research was conducted on Rio Grande variety obtained from agriculture research farm of Tehran University in Karaj during August–September, 2009. Thus has a semi-arid (375 mm rainfall yearly) climate. Hundred tomato fruits were selected for this study.

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*) and also projected areas, were determined by image processing method. In order to obtain dimensions and projected areas, using area measurement system Delta-T, (Delta-T Devices)

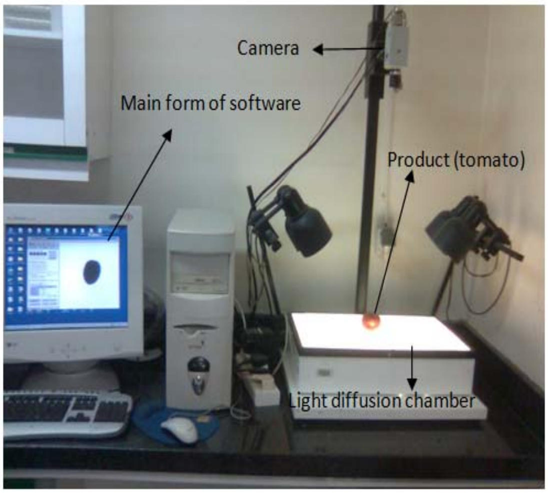

Fig 1. Apparatus for measuring projected area of tomato. (areameter Delta T, England).

England, were determined (Fig. 1). This method has been used and reported by Mirasheh (2006). Captured images from a camera are transmitted to a computer card which works as an analogue to digital converter. Digital images are then processed in the software and the desired user needs are determined. Through three normal images of the fruit, this device is capable of determining the required diameters as well as projected areas perpendicular to these dimensions. Total error for those objects that take up 5% of the camera field is less than 2%. This method has been used and reported by several researchers (Rafiee et al., 2006; Khoshnam et al., 2007; Keramat Jahromi et al., 2007).

Physical properties

a, b, and c are designated as perpendicular dimensions of tomato namely length (major diameter), width (intermediate diameter) and thickness (minor diameter) and P_A, P_B, and P_C are denoted as the first, second, and third projected areas taken along these three mutual perpendicular axes.Mass (g) of individual tomato was determined by using an electronic balance with an accuracy of 0.0l g.The actual volume of pomegranate was determined by the water displacement method (Aydine and Ozcan, 2007). Randomly selected tomato was placed with a metal sponge sinker into a measuring cylinder containing known water volume such that the fruit did not float during immersion in water; weight of water displaced by the tomato was recorded. The volume of each tomato was calculated by following equation (Mohsenin, 1986).

$$\text{Actual volume (cm}^3\text{)} = \frac{W}{\gamma} \qquad (1)$$

where W and γ were considered as weight of displaced water and weight density of water, respectively.The bulk density was measured using the mass–volume relationship by filling an empty plastic container of predetermined volume and weight, the tomato was placed inside the container from a constant height, and weight (Fraser et al., 1978).

Geometric mean diameter (GMD), surface area (S) and sphericity (ϕ) were calculated as suggested by Mohsenin (1986):

$$\text{GMD} = \sqrt[3]{abc} \qquad (2)$$

$$S = \pi(GMD)^2 \qquad (3)$$

$$\phi = \frac{GMD}{a} \qquad (4)$$

Spreadsheet software, Microsoft Excel 2007 and SPSS 9.0 Software were used to analyze the data and to determine regression models between the studied parameters.In order to estimate the tomato mass from the measured dimensions, projected areas and volume, the following three categories of models were considered. 1. Single or multiple variable regressions of tomato dimensional characteristics: length (a), width (b) and thickness. 2. Single or multiple variable regressions of tomato projected areas: PA, PB and PC. 3. Single regression of tomato volumes: actual volume, volume of the tomato assumed as oblate spheroid and ellipsoid shapes. In the case of first classification, mass modeling was accomplished with respect to length, width and thickness. Model obtained with three variables for predicting of tomato mass was:

$$M = k_1a + k_2b + k_3c + k_4 \qquad (5)$$

In this classification, the mass can be estimated as a function of one, two and three dimension(s). In second classification models, mass modeling of tomato was estimated based on mutually perpendicular projected areas as following:

$$M = k_1P_A + k_2P_B + k_3P_C + k_4 \qquad (6)$$

In this classification, the mass can be estimated as a function of one, two or three projected area(s), too. In the case of third classification, to achieve the models which can predict walnut mass on the basis of volumes, three volume values were measured or calculated. At first, actual volume (V_m) as stated earlier was measured then the nut shape was assumed as a regularly geometrical shape, i.e. prolate spheroid (V_{psp}) and ellipsoid (V_{ell}) shapes and thus their volume (cm^3) were calculated as:

$$V_{psp} = \frac{4\pi}{3}\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)^2 \qquad (7)$$

$$V_{ell} = \frac{4\pi}{3}\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)\left(\frac{c}{2}\right) \qquad (8)$$

In this classification (applied only for mass modeling), the mass can be estimated as either a function of volume of supposed shapes or the determined actual volume as represented in following expressions:

$$M = k_1V_{osp} + k_2 \qquad (9)$$

$$M = k_1V_{ell} + k_2 \qquad (10)$$

$$M = k_1V_m + k_2 \qquad (11)$$

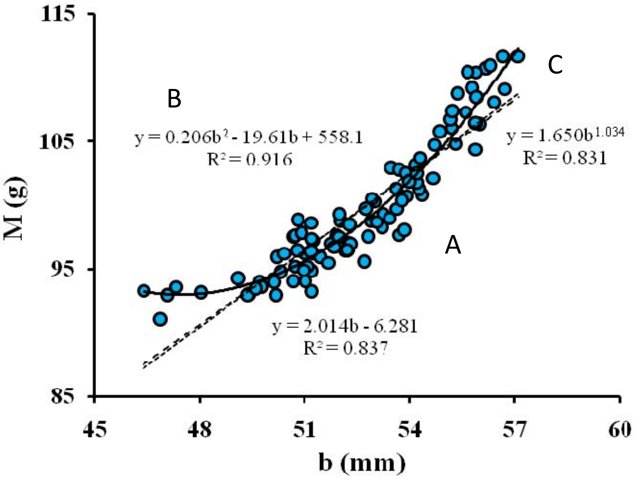

Fig 2. Tomato mass model based on intermediate diameter. A: liner regression, B: polynomial regression, C: exponential regression

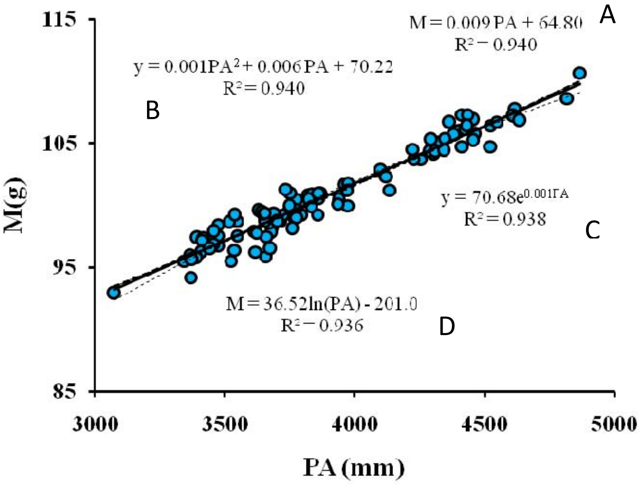

Fig 3. Tomato mass model based on one projected area. A: liner regression, B: polynomial regression, C: exponential regression, D: logarithmic regression

Packages of statistical programs, available on both main frame and personal computers, can perform such regression analysis. Many spreadsheet programs also can perform multiple regressions. When evaluating the usefulness of such regression analyses, it is necessary to know how well the data fit the model. One measure of the goodness of fit is the value of the coefficient of determination which is usually designated as R^2. For regression equations in general, the nearer R^2 is to 1.00, the better the fit (Stroshine and Hamann, 1995). If values of k_i exactly predict the mass, then R^2 would be equal to 1.00. Win-Area-Ut-06 software was used to analyze data and determine regression models between the physical properties.

Results and discussion

A summary of the results of determined physical properties of tomato (cv. *Rio grande*) including the average value, maximum, minimum and standard deviation of each measurement is presented in Table 1. Also, a total of 14 regression models in three different categories were classified. Coefficient of determination (R^2), regression standard error (R.S.E.), and models obtained from the data for the studied tomato based on the selected independent variables are presented in Table 2.

First classification models, dimensions

Among the first classification model Numbers. 1– 7, given in Table 2, model 7 had the highest R^2 and the lowest R.S.E. while for this model, measurement of three diameters is needed, which make the sizing mechanism more complex and expensive. Moreover, among the model Numbers. 1–3, model number 3 among the one dimensional models was selected as the best tomato mass model with intermediate diameter (Fig. 2). For dimensional models, this model had the highest R^2 value and regression standard error was also the lowest. Therefore, model 3 obtained based on the intermediate diameter (b) is recommended. Tabatabeefar et al. (2000) and Khanali et al. (2007) reported similar results concerning mass modeling for orange and tangerine fruit, respectively. They suggested that the mass modeling of orange based on intermediate diameter is the most appropriate model among the three one-dimensional models. Lorestani and Tabatabaeefar (2006) determined models for predicting mass of kiwi fruit based on physical characteristics. They also recommended an equation to calculate kiwi fruit mass based on intermediate diameter as $M = 2.93b - 64.15$, $R^2 = 0.78$. However, 11 models for predicting mass of apple verities based on geometrical attributes were recommended by Tabatabaeefar and Rajabipour (2005). They recommended an equation calculating apple mass on the basis of minor diameter (c) as $M = 0.08c^2 - 4.74c + 5.14$, $R^2 = 0.89$. It another research, Khoshnam et al. (2007) reported suitable equation based on minor diameter for predicting the mass of pomegranate fruit as $M = 7.320c - 376.1$, $R^2 = 0.91$. The mass model of tomato based on the model 7 (whole diameters) is given in Eq. (12).

$$M = 3.602a + 4.285b + 3.719c - 343.46,$$
$$R^2 = 0.94,\ \text{R.S.E.} = 4.53 \qquad (12)$$

For studied tomato, the best equation to calculate mass of tomato based on the intermediate diameter is given in nonlinear (polynomial) as below:

$$M = 0.206\, b^2 - 19.61\, b + 558.1,$$
$$R^2 = 0.916,\ \text{R.S.E.} = 4.2 \qquad (13)$$

Second classification model, projected areas

Among the linear regression projected area models (Number. 8–11), model number 11, shown in Table 2, for studied tomato had higher R^2, and lower R.S.E. than the other models. The overall mass model based on three projected areas (model 11) for total of observations is given in Eq. (14) as:

$$M = 0.01\, P_A + 0.01\, P_B + 0.01\, P_C - 178.18,$$
$$R^2 = 0.95,\ \text{R.S.E.} = 3.42 \qquad (14)$$

The overall mass model of tomato based on the one projected area as shown in Figure. 3, was given as linear and nonlinear (polynomial) forms in following equation:

$$M = 0.001PA^2 + 0.006\, PA + 70.22$$
$$R^2 = 0.94,\ \text{R.S.E.} = 3.85 \qquad (15)$$
$$M = 0.009\, PA + 64.80$$
$$R^2 = 0.94,\ \text{R.S.E.} = 3.87 \qquad (16)$$

Also, the mass model recommended for sizing pomegranate fruits based on any one projected area was reported by Khoshnam et al. (2007) as:

$M = 1.29\ (PA)^{1.28}$
$R^2 = 0.96$

Nevertheless, each one of the three projected areas can be applied to determine the mass. There is a need to have three cameras, in order to take all the projected areas and have one R^2 value close to unit or even lower than R^2 for just one projected area. Thus, model using only one projected area, possibly model 8 can be used.

Third classification models, volume

Among the models in third classification (models 12–14), the R^2 for model 12 had maximum value and minimum R.S.E. Among the models 13 and 14, the model 14 for the tomato had the highest R^2 value and the lowest R.S.E. Therefore, model 14 was recommended for predicting tomato mass. The mass model of overall tomato based on measured volume is given as linear form of Eq. (17).

$M = 0.001\ V + 1.498$
$R^2 = 0.974$, R.S.E. = 3.39 (17)

In an experiment conducted by Khoshnam et al. (2007), the mass model of overall pomegranates based on measured volume was reported as:

$M = 0.96\ V + 4.20$
$R^2 = 0.99$

Furthermore, Tabatabaeefar (2002) measured physical characteristics of common varieties of Iranian grown potatoes. Relationships among physical attributes were determined and a high correlation was found between mass and volume of mixed potatoes with a high coefficient of determination as:

$M = 0.93\ V - 0.6$
$R^2 = 0.994$

Measuring of actual volume is time consuming task, therefore, mass modeling based on it is not reasonable; consequently it seems suitable to mass modeling of tomato be accomplished based on volume of assumed ellipsoid shape (Table 2).

Conclusion

1. The recommended equation to calculate tomato mass based on intermediate diameter (model 2 was the best) is as nonlinear form:

   $M = 0.206\ b^2 - 19.61\ b + 558.1,$
   $R^2 = 0.916$, R.S.E. = 4.57

2. The mass model recommended for sizing tomatoes based on one projected area (model 8 is suitable) are linear and nonlinear forms:

   $M = 0.001PA^2 + 0.006\ PA + 70.22$
   $R^2 = 0.94$
   $M = 0.009\ PA + 64.80$
   $R^2 = 0.94$

3. There was a very good relationship between mass and measured volume of tomatoes for all cultivars with R^2 as 0.974 (highest R^2 value among all the models).
4. The model which predicts mass of tomato based on estimated volume, the shape of tomato considered as ellipsoid volume was found to be the most appropriate (model 14 is recommended).
5. Finally, mass model No. 2 from economical standpoint is recommended.

It can be point out those physical attributes of the studied tomato can be a subject of interest to agricultural scientist for farm machinery engineers for efficiently equipment design for tomato postharvest operations. Also, the best models obtained are important information in sorting and sizing the tested tomato based on their weight.

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