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Mass and volume modelling of tangerine (*Citrus reticulate*) fruit with some physical attributes

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A b s t r a c t. There are instances in which it is desirable to determine relationships among fruit physical attributes. For example, fruits are often graded on the basis of size and projected area, but it may be more economical to develop a machine which would grade by mass or volume. Therefore, the relationships between mass/volume (either mass or volume) and other physical attributes of fruit are needed. In this study three Iranian varieties of tangerine were selected and the various models for predicting mass/volume of tangerine from its dimensions, projected area, and volume/mass were established. The models were divided into three classifications: 1 – single and multiple variable regressions of tangerine dimensions, 2 – single and multiple variable regressions of projected areas, 3 – estimating tangerine mass/volume based on its volume/mass. The results revealed that mass and volume modelling on the basis of intermediate diameter, on any projected area, and the measured volume are the best models. Based on the results, mass and volume modelling, respectively on the basis of the actual volume and one projected area, were identified as the best models. The highest determination coefficient in all the models was obtained for volume modelling based on projected area as $R^2 = 0.97$. Finally, volume modelling from economical standpoint was recommended as the most reliable modelling.

K e y w o r d s: tangerine, physical attributes, mass/volume modelling, grading

INTRODUCTION

Annual citrus production in Iran is 3.5 mln t, which is ranked as 6th in the word (Lorestani and Tabatabaeefar, 2006). Iranian tangerines are not exported because of variability in size and shape and lack of proper packaging (Safwat, 1971). Consumers prefer fruits with equal weight and uniform shape. Mass grading of fruit can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg *et al*., 1985).

Based on the literature, the regression analysis was used by Chuma *et al*. (1982) to develop equations for predicting volume and surface area. They used logarithmic transformation to develop equations for wheat kernels at 15.7%. They suggested that the volume (V) was related to the surface area (S) by a linear regression relationship: V=1.10S+17.2. The surface areas of fruits are determined most frequently on the basis of their measured diameter or weight. Knowing the diameter or weight of a fruit, its surface area may be calculated using empirical equations, or read from an appropriate plot (Sitkei, 1986; Frechette and Zahradnik, 1968). Sizing by weighing mechanism is recommended for the irregular shape products (Stroshine and Hamann, 1994). Since electrical sizing mechanisms are expensive and mechanical sizing mechanisms react poorly, therefore, for citrus fruit *eg* tangerine, the dimensional method (of length, area, and volume) can be used. Determining the relationship among mass and dimensions and projected areas may be useful and applicable (Marvin *et al*., 1987; Stroshine and Hamann, 1994). In weight sizer machines, individual fruits are carried by cups or trays that may be linked together in a conveyor and are individually supported by a 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 fruit is constant, the weight sizer sorts by volume. The sizing error will depend upon the correlation between weight and volume (Stroshine and Hamann, 1994).

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In the case of mass modelling, Tabatabaeefar (2002) determined physical properties 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 potato with a high coefficient of determination. In another study, 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). They suggested that there is a very good relationship between mass and measured volume for all varieties of kiwi.

The objective of this research was to determine an optimum tangerine mass and volume model based on dimensions, surface area and volume/mass (either mass or volume) for three different Iranian varieties. This information can be used to design and develop sizing systems.

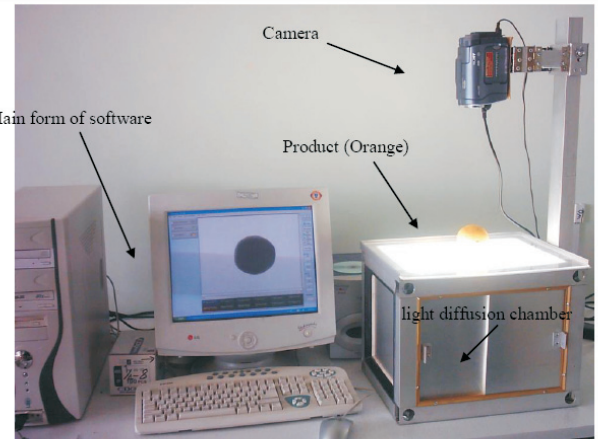

Fig. 1. Components of Win Area_UT_06 system (Keramat Jahromi *et al*., 2007)

MATERIALS AND METHODS

Three different common commercial varieties of Iranian tangerines were considered for this study. About 165 samples of tangerines were obtained from Agricultural Research, Education, and Extension Organization, from Citrus Research Institute placed in the North of Iran. The tangerines were picked up at random from their storage piles. Three different popular varieties sampled were Clementine, Onsho, and Page n =55. The mass of each tangerine was measured on a digital balance with an accuracy of 0.01 g. Its volume was measured by the water displacement method (Akar and Aydin, 2005; Aydin and Musa Ozcan, 2007). For this purpose, a tangerine was submerged into a known volume of water and the volume of water displaced was measured. Water temperature was kept at 25°C. Specific gravity of each tangerine was calculated by the mass of tangerines in air divided by the mass of displaced water.

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 tangerine were measured by Win Area-Ut-06 meter (Fig. 1) developed by Mirasheh (2006). Dimensional characteristics obtained from this device are based on image processing. 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; Keramat Jahromi *et al*., 2007).

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

$$\mathrm{GMD} = \sqrt[3]{abc}, \tag{1}$$

$$\text{sphericity} = \frac{\mathrm{GMD}}{a}. \tag{2}$$

Three mutually perpendicular areas, PA_1, PA_2, PA_3, were computed using Win Area-Ut-06 meter as stated above. The average area projected (known as the criterion area, A_c, cm^2) was determined from Eqs (1) and (2):

$$\text{Criteria areas (CPA)} = \frac{(PA_1 + PA_2 + PA_3)}{3}. \tag{3}$$

Spreadsheet software, Microsoft EXCEL 2003, was used to analyse the data and to determine regression models between the parameters. A typical linear multiple regression model is shown in Eq. (4):

$$Y = \mathrm{a} + b_1 X_1 + b_2 X_2 +,..., + b_n X_n, \tag{4}$$

where: Y – a dependent variable, for example mass, M; or volume (V); X_1, X_2, X_3,..., X_n – independent variables, for example physical dimensions; b_1, b_2,..., b_n – regression coefficients; a – constant of regression.

For example, mass is related to volume and can be estimated as a function of the measured volume as shown in Eq. (5):

$$M = \mathrm{a} + b_1 V. \tag{5}$$

In order to estimate the tangerine mass/volume from its dimensions (length, area, and volume/mass), the following three classifications of models were suggested.

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

2. Single or multiple variable regressions of tangerine projected areas: PA_1, PA_2 and PA_3.

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

From the above classifications, all three classifications were considered for mass modelling while the third classification was neglected in volume modelling. In other words, volume modelling based on mass was not done because the results of mass modelling based on volume and volume modelling based on mass are the same.

In the case of the first classification, mass/volume modelling was accomplished with respect to major, intermediate and major diameters. The model obtained with three variables for predicting tangerine mass/volume was:

$$M = k_1a+k_2b+k_3c+k_3, \qquad (6)$$

$$V = k_1a+k_2b+k_3c+k_3. \qquad (7)$$

In this classification, the mass/volume can be estimated as a function of one, two and three dimensions.

In the second classification models, mass/volume of tangerine was estimated based on mutually perpendicular projected areas as follows:

$$M= k_1PA_1+k_2PA_2+k_3PA_3+k_4, \qquad (8)$$

$$V= k_1PA_1+k_2PA_2+k_3PA_3+k_4. \qquad (9)$$

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

In the case of the third classification, to achieve models which can predict the tangerine mass on the basis of volume, three volume values were either measured or calculated. At first, actual volume V_m as stated earlier was measured, then the tangerine shape was assumed as a regular geometric shape *ie* oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes, and their volume was thus calculated as:

$$V_{osp} = 4/3\pi\ (a/2)\ (b/2)^2, \qquad (10)$$

$$V_{ellip} = 4/3\pi\ (a/2)\ (b/2)\ (c/2). \qquad (11)$$

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

$$M = k_1V_{osp} + k_2\ , \qquad (12)$$

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

$$M = k_1V_m + k_2\ . \qquad (14)$$

RESULTS AND DISCUSSION

First classification models, lengths

Among the first classification models Nos 1, 2, 3, and 4, shown in Tables 1 and 2, model 4, in which all three dimensions were considered, had a higher R^2 value and its regression standard error (R.S.E) was also low for all the three varieties. However, all three diameters must be measured for the model 4, which makes the sizing mechanism more complex and expensive. Among the models 1, 2, and 3, model 2 had a higher R^2 value and lower R.S.E. for all the varieties. Therefore, in order to perform mass/volume modelling on the basis of length, model 2, among the three one dimensional models, was selected as the best choice with intermediate diameter as independent variable as shown in Figs 2 and 3.

For all the varieties, the best equation for the calculation of mass/volume of tangerine based on the intermediate diameter was given in non-linear form of Eqs (15) and (16).

$$M = 0.07b^2 - 3.78b + 73.80 \qquad R^2= 0.83, \quad (15)$$

$$V = 0.05b^2 - 2.02b + 20.85 \qquad R^2= 0.91. \quad (16)$$

Similar results concerning mass modelling of orange fruit were reported by Tabatabeefar *et al*. (2000). They suggested that the mass modelling of orange based on intermediate diameter is the most appropriate model among the three one-dimensional models. The expression recommended by them was as:

$$M= 0.069b^2 - 2.95b - 39.15, \qquad R^2 = 0.97. \qquad (17)$$

With comparison of the above equations and their R^2, it is obvious that if sorting tends to be based on tangerine length, volume modelling is more reasonable.

Second classification models, areas

For both mass and volume modelling, among the second classification models 5, 6, 7, and 8, shown in Tables 1 and 2, the model 8 for all the varieties had a higher R^2 value and lower R.S.E.; model 8 needs to have all three projected areas taken for each one tangerine.

In the case of mass modelling, among the models 5, 6, and 7, model 6 for the varieties of Clementine and Page, and model 5 for Onsho had a higher R^2 value and lower regression standard error, R.S.E. Therefore, model 6 among the models 5, 6, 7 is chosen for the varieties of Clementine and Page and model 5 is chosen for the variety of Onsho.

T a b l e 1. Coefficient of determination (R^2) and regression standard error (R.S.E) for linear regression mass models for three Iranian varieties of tangerine fruits and the total observations

No.	Models	Parameter	Clementine	Onsho	Page	Total of observations
1	$M = k_1a+k_2$	R^2	0.93	0.90	0.95	0.81
		R.S.E.	3.48	3.82	4.34	8.97
2	$M = k_1b+k_2$	R^2	0.95	0.92	0.96	0.82
		R.S.E.	2.90	3.33	3.86	8.78
3	$M = k_1c+k_2$	R^2	0.71	0.55	0.84	0.60
		R.S.E.	7.20	8.01	7.48	13.05
4	$M = k_1a+k_2b+k_3c+k_4$	R^2	0.97	0.95	0.98	0.88
		R.S.E.	2.40	2.84	2.48	7.10
5	$M = k_1PA_1+k_2$	R^2	0.94	0.94	0.98	0.86
		R.S.E.	3.25	2.93	2.60	7.70
6	$M = k_1PA_2+k_2$	R^2	0.96	0.93	0.98	0.88
		R.S.E.	2.62	3.26	2.40	7.25
7	$M = k_1PA_3+k_2$	R^2	0.96	0.93	0.97	0.82
		R.S.E.	2.67	3.25	3.10	8.68
8	$\mathrm{M} = k_1PA_1+k_2PA_2+k_3PA_3+k_4$	R^2	0.98	0.96	0.99	0.89
		R.S.E.	1.97	2.38	1.46	6.80
9	$M = k_1V+k_2$	R^2	0.98	0.97	0.99	0.96
		R.S.E.	1.87	2.15	1.46	4.08
10	$M = k_1V_{osp}+k_2$	R^2	0.95	0.92	0.97	0.89
		R.S.E.	3.06	3.49	3.37	6.98
11	$M = k_1V_{ell}+k_2$	R^2	0.96	0.93	0.98	0.83
		R.S.E.	2.72	3.17	2.36	8.55

T a b l e 2. Coefficient of determination (R^2) and regression standard error (R.S.E) for linear regression volume models for three Iranian varieties of tangerine fruits and the total observations

No.	Models	Parameter	Clementine	Onsho	Page	Total of observations
1	$V = k_1a+k_2$	R^2	0.95	0.91	0.95	0.90
		R.S.E.	3.66	4.39	4.25	6.54
2	$V = k_1b+k_2$	R^2	0.96	0.94	0.96	0.91
		R.S.E.	3.48	3.57	4.02	6.31
3	$V = k_1c+k_2$	R^2	0.74	0.57	0.82	0.63
		R.S.E.	8.46	9.46	8.27	12.55
4	$V = k_1a+k_2b+k_3c+k_4$	R^2	0.98	0.97	0.98	0.96
		R.S.E.	2.14	2.70	2.71	4.04
5	$V = k_1PA_1+k_2$	R^2	0.97	0.97	0.98	0.93
		R.S.E.	2.89	2.61	2.84	5.40
6	$V = k_1PA_2+k_2$	R^2	0.98	0.96	0.98	0.94
		R.S.E.	2.45	3.06	2.66	4.88
7	$V = k_1PA_3+k_2$	R^2	0.97	0.94	0.98	0.92
		R.S.E.	2.92	3.49	2.77	5.99
8	$\mathrm{V} = k_1PA_1+k_2PA_2+k_3PA_3+k_4$	R^2	0.99	0.97	0.99	0.97
		R.S.E.	1.16	1.72	1.24	3.39
9	$V = k_1M+k_2$	R^2	0.98	0.97	0.99	0.96
		R.S.E.	2.33	2.62	1.53	4.06

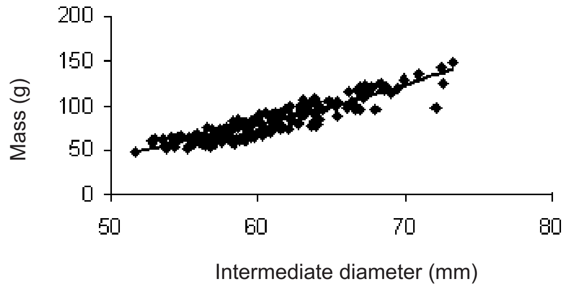

Fig. 2. Mass model of tangerine based on intermediate diameter.

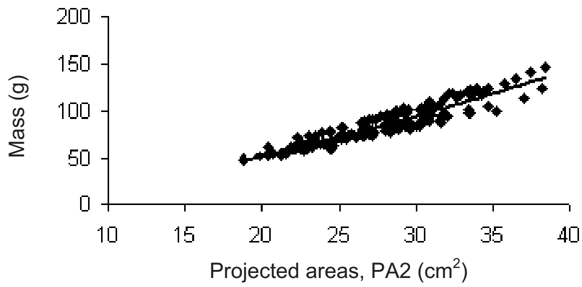

Fig. 4. Overall mass model of tangerine versus the projected areas.

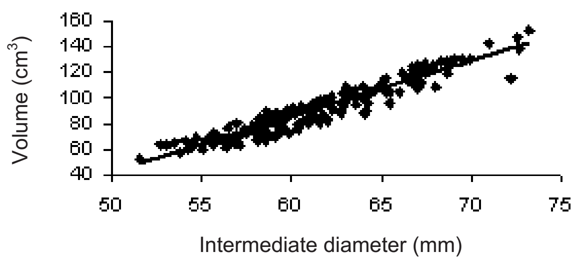

Fig. 3. Volume model of tangerine based on intermediate diameter.

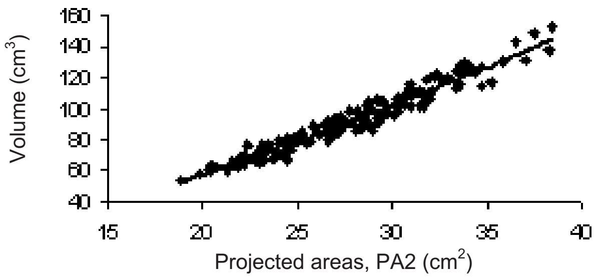

Fig. 5. Overall volume model of all tangerines versus the projected areas.

Similarly, with regard to Table 2, it can be concluded that among the models 5, 6, and 7, model 6 is the best model regarding volume modelling for all the varieties.

The overall mass model based on three projected areas (model 8) for all the varieties was given in Eqs (18) and (19).

$$M = 0.66\, PA_1 + 2.52\, PA_2 + 1.47\, PA_3 - 47.13 \quad R^2 = 0.89, \tag{18}$$

$$V = 1.17\, PA_1 + 1.71\, PA_2 + 1.96\, PA_3 - 46.37 \quad R^2 = 0.97. \tag{19}$$

The mass/volume model of overall tangerines based on the 2nd projection area as shown in Figs 4 and 5, was given as non-linear form of Eqs (20) and (21).

$$M = 0.64\, (PA_2)^{1.47} \qquad R^2 = 0.89, \tag{20}$$

$$V = 1.15\, (PA_2)^{1.33} \qquad R^2 = 0.99. \tag{21}$$

Considering the Eqs (18) to (21), volume modelling is more suitable than mass modelling because of higher R^2.

Each one of the three projection areas can be used to estimate the mass. There is a need to have three cameras, in order to take all the projection areas and have one R^2 value close to unity or even lower than R^2 for just one projection area; therefore, a model using only one projection area, possibly model 6 can be used.

Third classification models, volume

This classification was only used for mass modelling because the obtained results were the same. Among the models in third classification (models 9, 10, 11), the R^2 for model 9 was higher and R.S.E. was lower.

Among the models 10 and 11, the model 10 for all the varieties had a higher R^2 value and lower R.S.E. Therefore, model 10 was suggested for predicting tangerine mass. The mass model of overall tangerines based on the measured volume as shown in Fig. 6, was given as a linear form of Eq. (19):

$$M = 0.99\, V - 5.52 \qquad R^2 = 0.96. \tag{22}$$

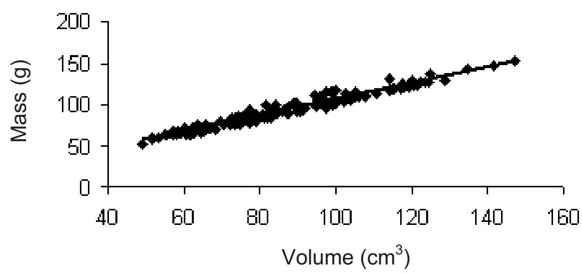

Fig. 6. Mass model of tangerine based on volumes.

Considering Eqs (15), (18), (20), and (22) it can be concluded that the best model for mass modelling of tangerine is the model based on the measured volume *ie* model 15, while model 14 is the best model for volume modelling. Since measurement of one projected area is far easier than that of actual volume of tangerine, therefore, volume modelling of tangerine seems to be more convenient and economical.

CONCLUSIONS

1. The recommended equation for calculation of tangerine mass/volume based on intermediate diameter was of a non-linear form:

$$M = 0.07b^2 - 3.78b + 73.80 \qquad R^2 = 0.83,$$

$$V = 0.05b^2 - 2.02b + 20.85 \qquad R^2 = 0.91.$$

2. The recommended mass/ volume model for sizing the tangerines based on any one projected area was of a non-linear form:

$$M = 0.64\,(PA_2)^{1.47} \qquad R^2 = 0.89,$$

$$V = 1.15\,(PA_2)^{1.33} \qquad R^2 = 0.99.$$

3. There was a very good relationship between mass and measured volume of tangerines for all varieties with R^2 in the order of 0.96.

4. Mass and volume modelling, respectively on the basis of the actual volume and one projected area, were identified as the best models.

5. From the economical point of view, volume modelling was discerned as the most convenient modelling.

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