Physical Properties of Three Varieties of Tomato, a Comparative Study

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ABSTRACT

In this study, physical properties of three different cultivars of tomato were determined. For this purpose, twenty tomato fruits from each variety were selected randomly, packed in polyethylene and then stored at temperature of 4°C during the tests. A digital caliper with accuracy of 0.01 mm and a balance with accuracy of 0.001 g were used to measure the physical dimensions and the fruit mass, respectively. Water displacement method was used for determining of fruit volume. Terminal velocity was calculated by releasing the fruit into a water column. A digital camera was used to record the fruit movement in the water column. Fruit stiffness was determined using a Universal Testing Apparatus. To this end, a load cell of 50 kgf with accuracy of 0.01N was used to measure bio-yield point of tomato during the compression tests. Average values of fruit properties and standard deviation of parameters were calculated and compared. Results showed Riogrand variety has highest dimensions, mass, volume, packing coefficient and terminal velocity. Dimensional analysis technique was utilized to obtain a new model for prediction of terminal velocity. Therefore, after identifying the affecting parameters, pi-term groups were constructed and finally a dimensionless model incorporating the effect of all the independent pi–terms on the dependent one was derived and evaluated. Statistical analysis revealed RMSE, R2, MRD and MBE values for the modeling of terminal velocity were calculated as 0.02, 0.91, 0.10 and 0.01, respectively. Therefore, the derived dimensionless model could predict the terminal velocity of tomato, properly.

Keywords: Physical dimensions, terminal velocity, tomato stiffness, vegetable modeling

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INTRODUCTION

Tomato (*Solanum lycopersicum*) is a red fruit native to South American that transported to the other continents during Spain colonialism and today different varieties of tomato are planted across the world. Tomato is a rich source of vitamin C and lycopene and is categorized in the vegetable groups. This product can be used as a major ingredient of foods and salads as well as one of primary ingredients for preparation of sauce and paste hence this plant is a main contributor in household food basket. About three million hectares of farm land in the world has been allocated to cultivation of tomato (FAO, 2011). According to FAO (2011) reports, tomato is planted at 140000 hectares of farm land of Iran that about 5000 tons of tomato is harvested each year. Since large amounts of harvested tomato is used for production of tomato paste, sauce, juice and etc., thus identifying the physical and hydrodynamic properties of tomato is necessary for using in design, development and adjustments of grading and washing machinery. Among the fruit properties, physical dimensions, mass, volume and terminal velocity of tomato are most important in grading systems. Grading machines are classified into four different types: electrical, mechanical, infrared and hydrodynamic. Considering the drawback of the first three, the hydrodynamic grading method is of most interest. Grading by this method is based on fruit density.

In a research physical properties of four different varieties of orange were studied by Topuz *et al.* (2005). The physical properties included dimensions, volume and geometric mean diameter. They reported that diameter and length of W. Navel variety was higher than other orange varieties. They also found that both Alanya and Finike varieties had higher sphericity than the other varieties. In a similar research, physical properties of three varieties of orange were determined using image processing technique. They determined mass, volume, geometric mean diameter, sphericity, density, porosity and dimensions of the image of the fruit (Sharifi *et al.*, 2007). They found that the higher volume varieties of fruit have higher values of density.

Terminal velocity is a constant speed which a moving object can reach in a fluid. It is an important parameter in designing of pneumatic conveying systems (Tarighi *et al.*, 2010). Fruits of different size can be sorted based on their terminal velocities obtained when released into a column of a known fluid (having different density compared to fruit lot) (Jordan and Clark, 2004). In other words fruits can be sorted into different sizes when released in a fluid of specific density. In a research, a glass column filled with water was used to measure the terminal velocity of two different varieties of apple (Kheiralipour *et al.*, 2008). For this purpose, apples were released from water surface to fall in the water column and reached to the maximum depth within 5 seconds. Terminal velocity is a function of shape, volume and density of the fruit and fluid (Mirzaee *et al.*, 2009). Therefore, mathematical modeling of target parameters could be used to facilitate predicting of the value of these parameters (Zomorodian and Moradi, 2010). Mathematical models are classified into theoretical and empirical models. Dimensional analysis is an empirical approach which introduces a dimensionless model to explain the relations between dependent and independent dimensionless terms. This method is a beneficial tool for providing guidance in mathematical modeling and specially simulating the complex phenomena such as those involved in fluid sciences (Giuseppe, 2006; Gibbings, 2011).

Considering the fact that physical properties of common varieties of tomato are useful in designing and development of post–harvesting machinery and equipment, this study was devoted to determine physical characteristics of three tomato varieties in local market (Cherry, Orbana and Riogrand). A dimensionless equation was also developed to predict terminal velocity of common varieties in water.

MATERIALS AND METHODS

The main objective of this study is to determine the physical properties and terminal velocity of three 66 different cultivars of tomato. To this end, common tomato varieties (Cherry, Orbana and Riogrand) which are planted and consumed in Iran were used to do the experiments. Tomato samples were purchased from the local market and stored in polyethylene packages and kept in the refrigerator at 4°C to maintain moisture content. All the experiments were completed on one day. Initial moisture content of Riogrand, Orbana and Cherry tomato were 93.1%, 92.5% and 92% (w.b), respectively. In order to carry out the laboratory tests, twenty tomatoes from each variety were selected randomly. Mass and dimensions of the fruit were measured by a balance (A&D, Tokyo, Japan) and a caliper (Guanglu, Taizhou, China) respectively. Balance accuracy was 0.001g and caliper accuracy was 0.01mm. For measurement of the fruit volume, tomato was immersed into a graduated beaker filled with water. Volume of fruit is equal to the displaced water as recommended by Mohsenin (1986). Terminal velocity was measured by releasing the fruit in water column (Tarighi *et al.*, 2010). To determine the terminal velocity of tomato, a scaled glass column with 1 m height and

40 × 40 cm cross section filled with water. A digital camera of (Canon IXUS, 12.1 Mega pixels) with 30 frames per second was used to record the fruit movement from the releasing point to the top of the water column (Figure 1). Software of video to frame converter was used to convert video films to individual images. Camera capturing speed (30 fps) and relevant fruit fall were used to calculate tomato terminal velocity. For Riogrand cultivar that has lower density compared to water, a clamp with long handle was used to place the fruit at the bottom of the column. In a similar research, terminal velocity was measured for two different cultivar of apple which had lower density compared with water. They also used a clamp with long handle to place apples at the bottom of glass column (Kheiralipour *et al.*, 2008). In this research, each tomato was tested four times and the average values considered. The experiments were replicated for each variety of tomato.

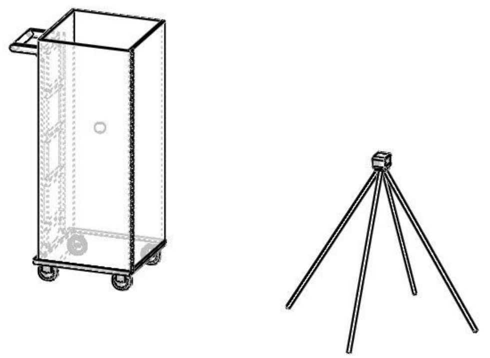

Figure 1 Water column and camera setting

In order to determine compression strength of tomato, compression test was conducted by a Universal Testing Machine (Instron, Santam-STM-20). A load cell of 50 kgf with accuracy of 0.01 N was installed on the apparatus to measure the compression force on the sample instantaneously. Compression force was applied by a flat plate of Texture Analyzer. Force-deformation curve was monitored as the output of the apparatus. The first point on the curve at which there occurs an increase in deformation with a decrease or no change of force was recorded as the bio-yield point of the fruit (Mohsenin, 1986).

Arithmetic, geometric and equivalent diameters were also calculated using equations of (1), (2) and (3), respectively (Mohsenin, 1986).

$$Da = (L+W+T)/3 \quad (1)$$

$$Dg = (LWT)^3 \quad (2)$$

$$De = \left[\frac{(W+T)^2}{4}\right]^{\frac{1}{3}} \quad (3)$$

Where: Da: arithmetic mean diameter (mm), Dg: Geometric mean diameter (mm), De: Equivalent mean diameter (mm), L: Length (mm), W: Width (mm), T: Thickness (mm). Sphericity, surface area, aspect ratio and packing coefficient of tomato were also calculated using equations of (4) to (7), respectively.

$$S = Dg/L \quad (4)$$

$$Sf = \pi(Dg)^2 \quad (5)$$

$$A = W/L \quad (6)$$

$$P = V/V_0 \quad (7)$$

Where: S: Sphericity, S_f: surface area (mm^2), A: Aspect ratio, P: Packing coefficient, V: volume of fruit (cm^3), V_0: volume of the box containing fruit (cm^3).

In order to obtain a new dimensionless model for prediction of terminal velocity, important parameters were identified (equation 8).

$$F (V, T, L, W, \rho w, \rho t, g) = 0 \quad (8)$$

Where; V: Terminal velocity (m/s), T: thickness of tomato (m), L: length of tomato (m), W: width of tomato (m), ρw: specific mass of tomato ($kg.m^{-3}$), ρt: specific mass of tomato ($kg.m^{-3}$), g: gravitational acceleration ($m.s^{-2}$).

Among the variables, three principle dimensions were recognized included: length, mass and time. Based on Buckingham theorem we must have four pi-terms (number of total variables minus number of principle dimensions) (Gibbings, 2011). Thus the variables were merged to obtain four pi-terms as follows:

$$\pi_1 = V/(Tg)0.5,\ \pi_2 = \rho t/\rho w,\ \pi_3 = L/T,\ \pi_4 = W/T \quad (9)$$

Where π1 is dependent pi-term and the others are independent.

Consequently, equation (8) can be rewritten as:

$$\pi_1 = f\,[\pi_2, \pi_3, \pi_4] \quad (10)$$

Experimental results were used to calculate the pi-term values and then graphs of logarithmic values of 123 dependent pi-term versus each independent pi-term were drawn (Figure 1 to 4). Regression analysis technique 124 was used to obtain best fitted equation for each curve. The following relationship has been proposed to 125 derive the final configuration of dimensionless model (Eric *et al.*, 2015):

$$\text{Log}(\pi_1) = A+B\,[(F_2(\pi_2)] + C\,[(F_3(\pi_3)] + D\,[F_4(\pi_3)] \quad (11)$$

Where; $F_2(\pi_2)$, $F_3(\pi_3)$ and $F_4(\pi_4)$ are the best fitted line equations between logarithmic values of dependent pi-term (π_1) and each independent pi-term. A, B, C and D are constants that must be determined. In order to compute the constants of A, B, C and D in equation (11), an optimizing algorithm was used to reach a minimum value of mean bias error (MBE) (Eric *et al.*, 2015):

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{V_{ex} - V_{pre}}{V_{ex}}\right| \quad (12)$$

Where; MBE: mean bias error, N: number of the experiments, V_{ex}: experimental terminal velocity, V_{pre}: predicted terminal velocity.

To obtain the new model for predicting the terminal velocity of tomato, 80% of the experimental data were used and the rest were used to validate the derived model.

To validate the goodness of the modeling, three statistical criteria namely MBE, RMSE1 and MRD2 were 139 calculated using equations of 12, 13 and 14, respectively:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{V_{ex} - V_{pre}}{V_{ex}}\right| \quad (13)$$

$$MRD = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\frac{V_{exp} - V_{pre}}{V_{exp}}\right)^2\right]^{0.5} \quad (14)$$

Where; N: number of the experiments, V_{ex}: experimental terminal velocity, V_{pre}: predicted terminal velocity.

RESULTS AND DISCUSSION

Different physical properties of three cultivars of tomato were determined and presented in the Table 1 to Table 3. It can be concluded from the Tables that the physical properties of Riogrand variety has highest values compared to other two varieties followed by Orbana and Cherry cultivars. Average terminal velocity of Riogrand, Orbana and Cherry varieties were measured to be 0.342, 0.108 and 0.076 $m.s^{-1}$, respectively. The results showed terminal velocity of tomato was increased with increase in fruit volume. 151 Terminal velocity of apricot fruit was determined in a similar research (Mirzaee *et al.*, 2009). The average terminal velocity of apricot for Nasiry, Ghavami and Rajabali varieties of apricot were as 0.17, 0.17 and 0.21 $m.s^{-1}$, respectively. They found that terminal velocity of apricot was increased with increase in fruit volume.

Also in another research, the terminal velocity of nectarine was measured to be 0.11 $m.s^{-1}$ (Terighi *et al.*, 2010). The average value of bio-yield point of Riogrand, Orbana and Cherry was 63.6, 36.5 and 7.29 N, respectively. The results showed Riogrand cultivar has highest value of bio-yield point compared to other varieties followed by Orbana and Cherry cultivars. Packing coefficient was also calculated for three cultivars of tomatoes. The results showed the packing coefficient of Riogrand, Orbana and Cherry cultivars were to be 0.645, 0.46 and 0.523, respectively. In the similar research, packing coefficient of nectarine fruit 160 was reported to be 0.65 (Tarighi *et al.*, 2010).

Table 1 Physical properties of Riogrand tomato

Measured parameters	Mean ± Standard deviation	Minimum	Maximum
Length (mm)	65.40 ± 3.34	60.81	71.27
Width (mm)	63.72 ± 4.16	58.74	71.25
Thickness (mm)	56.12 ± 4.22	48.44	62.30
Geometric mean diameter (mm)	61.58 ± 3.53	57.99	68.14
Arithmetic mean diameter (mm)	61.75 ± 3.50	58.06	68.27
Equivalent mean diameter (mm)	61.68 ± 3.52	58.027	68.24
Sphericity	0.940 ± 0.026	0.889	0.97
Surface area (mm^3)	11,947.2 ± 1,389.6	10,559.8	14,578.61
Aspect ratio	0.974 ± 0.025	0.917	0.999
Fruit mass (g)	138.19 ± 21.09	114.01	177.056
Fruit density (kg/m^3)	914.17 ± 38.22	851.55	988.87
Fruit volume (cm^3)	150.91 ± 20.31	125	195
Packing coefficient	0.645 ± 0.039	0.572	0.718
Terminal velocity (m/s)	0.342 ± 0.130	0.180851	0.66875
Bio–yield point (N)	63.61 ± 18.70	30.13	101.62

Table 2 Physical properties of Orbana tomato

Measured parameters	Mean ± Standard deviation	Minimum	Maximum
Length (mm)	43.760 ± 3.098	38.47	48.71
Width (mm)	40.41 ± 3.45	36.64	48.39
Thickness (mm)	39.43 ± 3.44	35.5	46.27
Geometric mean diameter (mm)	41.14 ± 3.48	37.32	47.77
Arithmetic mean diameter (mm)	41.19 ± 3.47	37.34	47.79
Equivalent mean diameter (mm)	41.14 ± 3.48	37.34	47.78
Sphericity	0.940 ± 0.028	0.85	0.98
Surface area (mm^2)	5,347.021 ± 936.430	4,374.065	7,167.678
Aspect ratio	0.9230 ± 0.0434	0.8	0.99
Fruit mass(g)	40.68 ± 9.70	31.79	64.59
Fruit density (kg/m^3)	1,251.924 ± 68.205	1,113.655	1,343.64
Fruit volume (cm^3)	33.00 ± 9.96	25	58
Packing coefficient	0.460 ± 0.034	0.423	0.531
Terminal velocity (m/s)	0.1080 ± 0.0235	0.0769	0.1511
Bio–yield point (N)	36.46 ± 14.19	14.14	62.28

Table 3 Physical properties of Cherry tomato

Measured parameters	Mean ± Standard deviation	Minimum	Maximum
Length (mm)	24.202 ± 2.490	20.51	29.11
Width (mm)	19.47 ± 1.32	16.9	21.74
Thickness (mm)	18.42 ± 1.37	16.4	20.45
Geometric mean diameter (mm)	20.54 ± 1.55	18.54	23.48
Arithmetic mean diameter (mm)	20.69 ± 1.58	18.61	23.77
Equivalent mean diameter (mm)	20.544 ± 1.544	18.56	23.48
Sphericity	0.85 ± 0.04	0.77	0.92
Surface area (mm^2)	1,331.85 ± 202.35	1,079.74	1,730.85
Aspect ratio	0.810 ± 0.067	0.69	0.92
Fruit mass (g)	5.39 ± 1.13	4.17	7.65
Fruit density (kg/m^3)	1,175.116 ± 59.510	1,068.97	1,275.98
Fruit volume (cm^3)	4.61 ± 1.05	3.3	6.8
Packing coefficient	0.523 ± 0.03	0.51	0.55
Terminal velocity (m/s)	0.0760 ± 0.0075	0.062	0.087
Bio-yield point (N)	7.29 ± 2.59	2.9	13.07

Mathematical Modeling of Terminal Velocity of Tomato Plant

Dimensional analysis technique was adopted to create a new model for predicting the terminal 163 velocity of tomato. For this purpose, affecting parameters were identified and dependent pi-term and 164 independent pi-terms were established. Logarithmic relation between each independent pi-term and 165 dependent one is shown in Figure 2 to Figure 4. Regression analysis was used to obtain the best line equation for the 166 each curve (equations 15 to 17).

$$\text{Log}(\pi_1) = -3.0946\ \text{Log}(\pi_2) - 0.4878,\ R^2 = 0.987 \quad (15)$$

$$\text{Log}(\pi_1) = -2.1984\ \text{Log}(\pi_3) - 0.5431,\ R^2 = 0.8 \quad (16)$$

$$\text{Log}(\pi_1) = -35.075\ \text{Log}(\pi_4) + 0.0199,\ R^2 = 0.94 \quad (17)$$

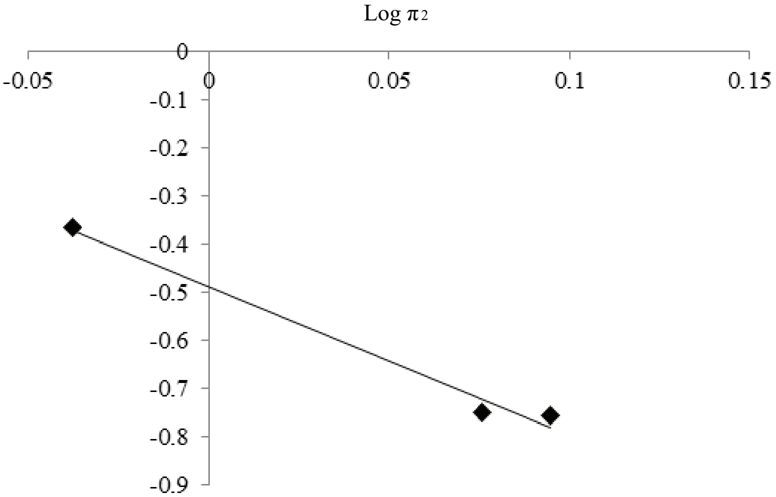

Figure 2 Variations of log (π_1) versus log (π_2)

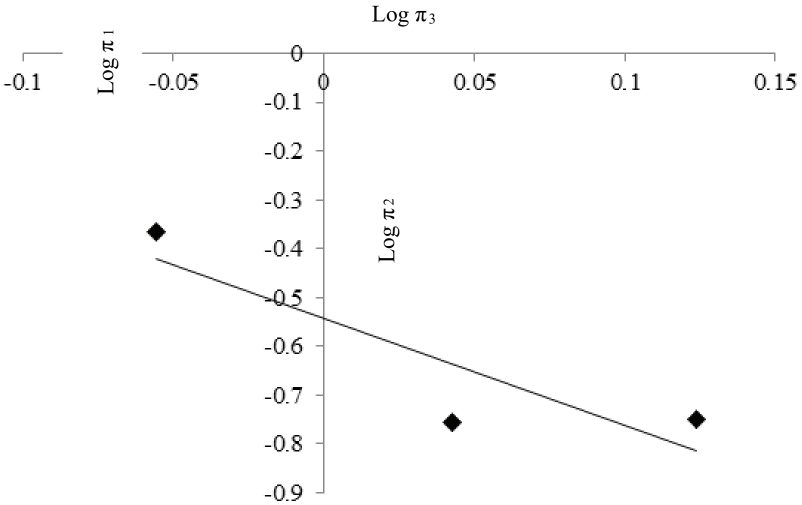

Figure 3 Variations of log (π_1) versus log (π_3)

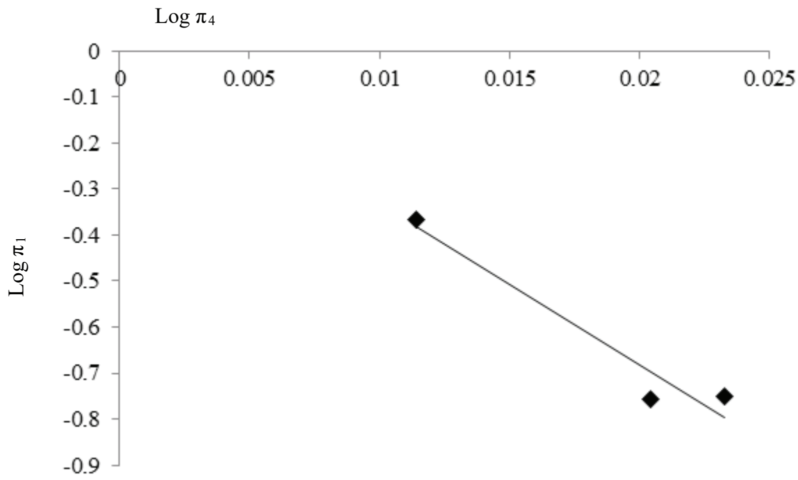

Figure 4 Variations of log (π_1) versus log (π_4)

The final equation for prediction of terminal velocity is as equation (18):

$$Log(\pi_1)=A+B[-3.095log(\pi_2)-0.4878]+C[-2.198log(\pi_3)-0.5431]+D[-35.075log(\pi_4)+0.0199] \quad (18)$$

Where: A: 0.017, B: 0.710, C: 0.187, D: 0.236. (Figure 5) shows the correlation between experimental and predicted data.

The RMSE, R^2, MRD and MBE values for the modeling of terminal velocity were calculated as 0.02, 0.91, 0.10 and 0.01, respectively. The obtained values show relatively good agreements between the predicted and the experimental terminal velocity of tomato. Therefore, the derived model can be used to predict terminal velocity of these three varieties of tomato.

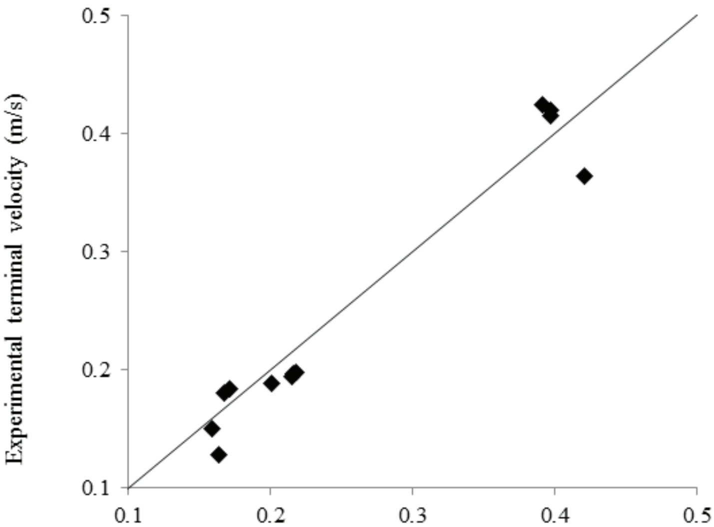

Figure 5 Comparison of experimental and predicted terminal velocity values of tomato

CONCLUSIONS

Physical dimensions, mass, volume, density and terminal velocity of three tomato varieties were obtained. A dimensionless model for predicting terminal velocity of tomato was also developed and validated. The validation results showed good agreement between the experimental and predicted values of terminal velocities.

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