Experimental modeling of orange settling depth in water

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Abstract: Settling depth of orange fruits and vegetables with the density lower than the density of water is an important hydrodynamic property important in hydraulic sorting and transporting. In this research, settling depth of orange fruit with regular shapes was experimentally modeled. The considered parameters in multivariate modeling were fruit characteristics, density, mass and volume, and dropping height of the fruits. The characteristics were determined by standard methods. The settling depth was determined by a water column and a digital camera. The models were obtained in MATLAB software. The best model was based on the density, volume and dropping height with coefficient of determination (R2) and mean squire error (MSE) of 0.89 and 4.67×10-7, respectively.

Keywords: Orange, Experimental Modeling, Settling Depth, Sorting, Physical Characteristics.

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1 Introduction

Orange, *Citrus cinensis*, L., is famous due to containing vitamin C, minerals, sugar, carotenoids, essential oil and flavonoids (Lee and Coates, 1999).

The first orange producer in the world is Brazil with 18.013 million ton, 2012. In the same year, Islamic Republic of Iran with annual production of 1.285 million ton was ranked as the third producer country (FAO, 2012).

Settling depth of fruits and vegetables in water, with the density lower than the density of water, is a depth that a target dropped from a height will reaches to the depth and returns to the water surface (Mohsenin, 1986).

Kheiralipour et al. 2014, theoretically modeled settling depth of fruits and vegetables with the density lower than the density of water, $\rho_f < \rho_w$, as following formula (Kheiralipour, 2014):

$$d = \frac{2d_0(\rho_f - \rho_a)V^{\frac{n+1}{3}}}{(\rho_w - \rho_f)V^{\frac{n+1}{3}} + K_6\mu_w^n\rho_w^{1-n}S_h\left(2gd_0\left(1-\frac{\rho_a}{\rho_f}\right)\right)^{\frac{2-n}{2}}} \quad (1)$$

Where d is settling depth of fruit, d_0 is dropping height, ρ_f is fruit density, ρ_a is air density, V is fruit volume, ρ_w is water density, μ_w is the static viscosity of water, S_h is fruit shape factor, g is acceleration of gravity and k_6 and n are constant factors. The more important effective parameters on settling depth of the fruits and vegetables are dropping height, density, mass and volume of them (Kheiralipour, 2014).

Previously, physical characteristics of orange was studied including, length, width, thickness, volume, mass, geometric mean diameter, projected area, surface area, sphericity, density, (Sharif et al., 2007) porosity, packing coefficient, optical properties (color), (Topuz et al, 2005), mechanical properties (static coefficient of friction and nutritional properties including water soluble dry matter, total dry matter, vitamin C, pH, reducing sugar, titratable acidity, sucrose and minerals (Topuz et al., 2005). But, in the literature, settling depth of a fruit or vegetable was not experimentally modeled. So, in this

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research, multivariate modeling of settling depth of orange fruit is conducted.

2 Materials and methods

2.1 Theory

Equation 2 were derived from Equation 1:

$$\frac{1}{d} = K_9 d_0^{-1} \rho_f^{-1} - K_7 d_0^{-1} + K_8 S_h d_0^{-n} \rho_f^{-1-n} V^{-\frac{n+1}{3}} \quad (2)$$

The volume in the Equation 2 can be replaced by fruit mass, m:

$$\frac{1}{d} = K_9 d_0^{-1} \rho_f^{-1} - K_7 d_0^{-1} + K_8 S_h d_0^{-n} \rho_f^{\frac{-2n-2}{3}} m^{-\frac{n+1}{3}} \quad (3)$$

So, descent depth of fruits and vegetables can be modeled using Equation 4 or Equation 5.

$$\frac{1}{d} = A d_0^{-1} \rho_f^{-1} + B S_h d_0^{C} \rho_f^{D} V^{E} + F d_0^{-1} + G \quad (4)$$

$$\frac{1}{d} = A d_0^{-1} \rho_f^{-1} + B S_h d_0^{C} \rho_f^{D} m^{E} + F d_0^{-1} + G \quad (5)$$

Where A, B, C, D, E, F and G are constant factors. G was added to the end of the Equations 4 and 5 as an error in experimental modeling. The difference of Equation 4 and Equation 5 is volume and mass, only.

2.2 Experiments

Tompson variety of orange was considered in this research. 20 specimens (Mohsenin, 1986) were randomly selected for experiments in Ilam University. Fruit mass was determined by Precisa electronic balance (Model: 3100c) with accuracy of 0.1 g. Volume and fruit density were determined by the water displacement method (Mohsenin, 1986).

A water column (35×35×90 cm^3) constructed by glass (8 mm thickness) was filled by water to a height of 80 cm. Each fruit was placed on a specific height (10, 25 and 50 cm) on top of the water surface, dropping height, so that the largest areas of them were parallel to the surface of the column. In order to determine settling depth of fruits, a digital camera, Sony with 25 frames per second, recorded the moving of fruits from the dropping height point to the end of the target's settling depth in water column. Each fruit was tested three times in each dropping height. In order to correctly determine the settling depth of the fruits, Video to Frame Software was used to change each video film to corresponding images.

2.3 Multivariate modeling

The obtained data were considered for modeling of settling depth of oranges considered the models developed by Equation 4 and Equation 5. The modeling was based on multivariate regression that done by a program coded in MATLAB Software.

In the present research, the projected area of fruits was not determined due to low coefficient of variety and consequently low effect on the terminal velocity [2 and 4]. So, the Equation 4 and Equation 5 can be changed to:

$$\frac{1}{d} = A d_0^{-1} \rho_f^{-1} + H d_0^{C} \rho_f^{D} V^{E} + F d_0^{-1} + G \quad (6)$$

$$\frac{1}{d} = A d_0^{-1} \rho_f^{-1} + H d_0^{C} \rho_f^{D} m^{E} + F d_0^{-1} + G \quad (7)$$

Where, H is a new constant factor instead of BS_h.

Also settling depth of orange fruits for dropping from heights of 10, 25 and 50 cm were compared by One-Way ANOVA in MATLAB software. The analysis was done using *anova1* syntax in the software.

3 Results and discussion

Some properties of the orange fruits were presented in Table 1. In this table, beside density, volume and mass, settling depth of the fruits when dropping from a height of 10 cm (SD10), 25 cm (SD25) and 50 cm (SD50) were listed.

Also mean of SD10, SD25 and SD50 were significantly different (1 %, probability level).

Table 1 Some physical properties of the orange fruits

	Minimum	Mean	Maximum	Standard Deviation	Coefficient of Variation
Density (g/cm^3)	0.85	0.94	0.98	0.03	0.03
Volume (cm^3)	84.82	150.55	272.22	58.69	0.39
Mass (g)	80.59	139.56	243.41	49.07	0.35
d10 (cm)	50.00	56.34	64.50	3.72	0.07
d25 (cm)	55.33	63.57	71.83	4.03	0.06
d50 (cm)	64.17	72.65	79.17	4.00	0.06

Settling depth of all experimented fruits was plotted in Figure 1. As shown in this figure, by increasing the dropping height from 10-50 cm, the settling depth increases. For example, settling depth of orange No. 9, the settling depth increased from 61.33 to 68.33 cm and 68.33 to 77.33 cm, when dropping height increased from 10 to 25 and 25 to 50 cm, respectively.

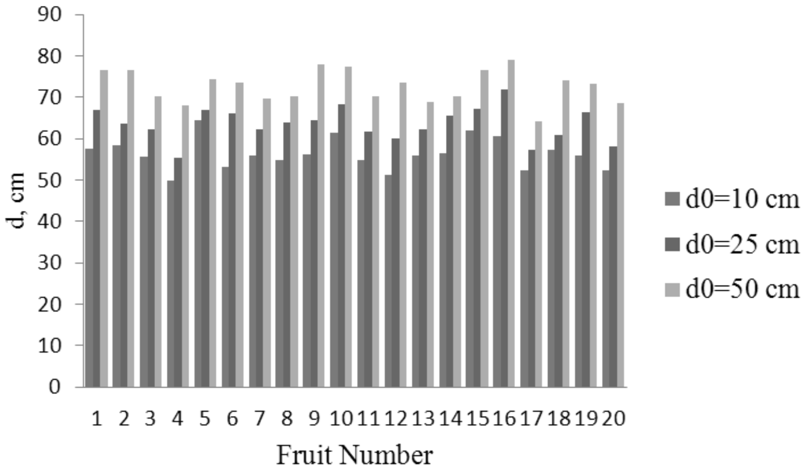

Figure 1 The settling depth of the orange fruits with different dropping heights. d is settling depth and d0 is dropping height

Settling depth of the specimens was individually plotted against density, volume and mass in Figure 2, Figure 3 and Figure 4, respectively.

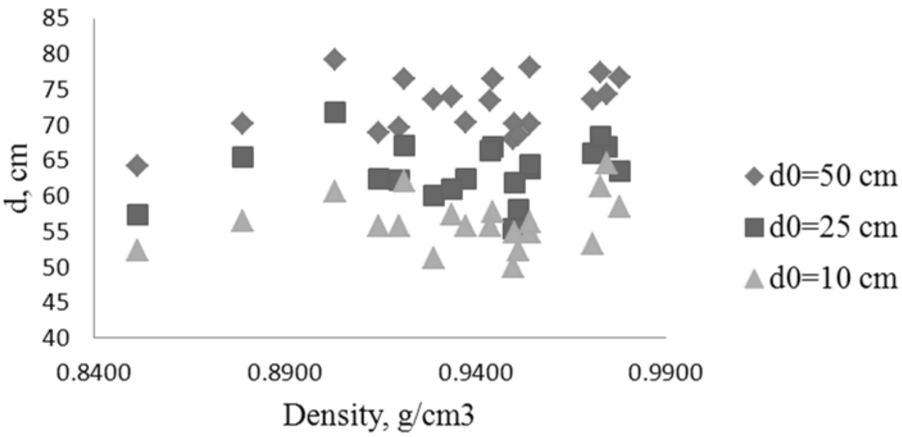

Figure 2 The settling depth of orang fruits versus their density. d is settling depth and d0 is dropping height

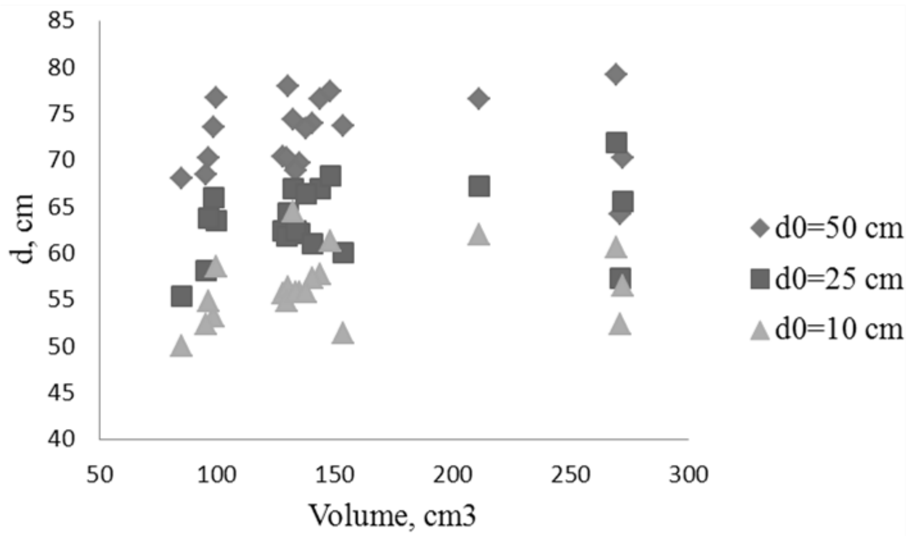

Figure 3 The settling depth of orang fruits versus their volume. d is settling depth and d0 is dropping height

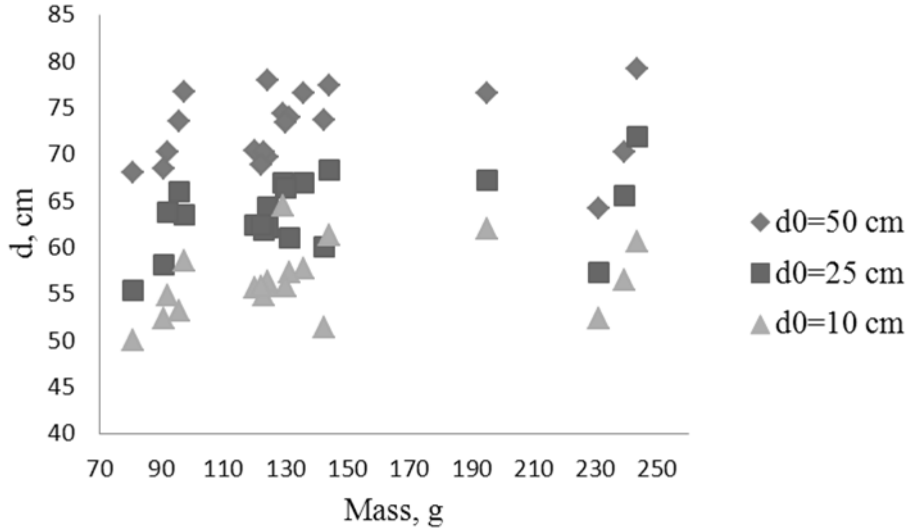

Figure 4 The settling depth of orang fruits versus their mass. d is settling depth and d0 is dropping height

As seen in this figures, the settling depth, dropped in any height, increased by increasing of mass, volume and density of the fruits,

Multivariate models of settling depth of the oranges, based on Equation 6 and 7, were shown in Table 2, Table 3, and Table 4 for dropping height of 10, 25 and 50 cm, respectively. For the models, coefficient of determination (R^2) and mean squire error (MSE) was obtained by the coded program.

Table 2 Multivariate models of the settling depth of orange with dropping height of 10 cm

Model No.	Model	MSE	R^2
1	$\frac{1}{d}=0.0095\rho_f^{-1}+0.0036$	1.23×10^{-6}	0.03
2	$\frac{1}{d}=9.183e7V^{-5.4928}+0.0174$	6.90×10^{-3}	0.16
3	$\frac{1}{d}=2.235e7m^{-4.701}+0.0173$	6.90×10^{-3}	0.19
4	$\frac{1}{d}=0.126\rho_f^{-0.3851}V^{-.0414}-0.0874$	4.43×10^{-7}	0.65
5	$\frac{1}{d}=0.514\rho_f^{-0.073}m^{-0.009}-0.4764$	4.46×10^{-7}	0.65
6	$\frac{1}{d}=0.2609\rho_f^{-1}-0.3472\rho_f^{-0.6256}V^{0.0114}+0.1221$	4.50×10^{-7}	0.65
7	$\frac{1}{d}=0.0545\rho_f^{-1}-0.7825\rho_f^{-0.0285}m^{0.0054}+0.7647$	4.51×10^{-7}	0.66

In Table 2, model No. 1, 2 and 3 with R^2=0.03, 0.16 and 0.19, shows that fruit density, volume and mass cannot individually model the settling depth of the fruits dropped from 10 cm height. Also other model with a coefficient determination of 0.65-0.66 cannot strongly predict the settling depth with 10 cm dropping height.

Table 3 Multivariate models of the settling depth of orange with dropping height of 25 cm

Model No.	Model	MSE	R^2
1	$\frac{1}{d}=0.005\rho_f^{-1}+0.0101$	9.59×10^{-7}	0.03
2	$\frac{1}{d}=2.755\mathrm{e}6\mathrm{V}^{-4.751}+0.0154$	7.20×10^{-3}	0.15
3	$\frac{1}{d}=3.2e5m^{-4.299}+0.0153$	7.20×10^{-3}	0.19
4	$\frac{1}{d}=0.976\rho_f^{-13.0151}V^{-1.3547}+0.0129$	3.13×10^{-7}	0.68
5	$\frac{1}{d}=0.0467\rho_f^{-1.6412}m^{-0.1966}-0.0041$	3.24×10^{-7}	0.67
6	$\frac{1}{d}=3.445\rho_f^{-1}-3.6165\rho_f^{-0.9427}V^{0.001}+0.204$	6.40×10^{-7}	0.70
7	$\frac{1}{d}=3.5704\rho_f^{-1}-3.7416\rho_f^{-0.9457}m^{0.001}+0.2037$	4.16×10^{-7}	0.70

Models No. 1, 2 and 3 in Table 3, are same as those in Table 1. Although, the determination coefficients of other models are not high, but they are higher than corresponding values in Table 2.

Table 4 Multivariate models of the settling depth of orange with dropping height of 50 cm

Model No.	Model	MSE	R^2
1	$\frac{1}{d}=0.0095\rho_f^{-1}+0.0036$	4.41×10^{-7}	0.22
2	$\frac{1}{d}=3.16e9V^{-6.505}+0.0137$	1.60×10^{-3}	0.02
3	$\frac{1}{d}=2.5e7m^{-5.472}+0.0136$	7.60×10^{-3}	0.03
4	$\frac{1}{d}=2.5729\rho_f^{-21.1302}V^{-1.7989}+0.0123$	1.17×10^{-7}	0.79
5	$\frac{1}{d}=2.55727\rho_f^{-19.3311}m^{-1.7989}+0.0123$	1.35×10^{-7}	0.76
6	$\frac{1}{d}=2.551\rho_f^{-1}-2.7721\rho_f^{-912}V^{0.0009}+0.2464$	1.28×10^{-7}	0.81
7	$\frac{1}{d}=4.5295\rho_f^{-1}-4.7417\rho_f^{-0.9509}m^{0.0005}+0.2374$	4.5478×10^{-7}	0.81

Also, Models No. 1, 2 and 3 in Table 4 have low determination coefficient same as corresponding values in Table 1 and 2. The other models show that settling depth of orange dropped from height of 50 can be better modeled.

Settling depth of orange fruits was modeled again in Table 5, also based on Equation 10 and Equation 11. But, dropping height was considered in the models.

Table 5 Final multivariate models of settling depth of orange

Model No.	Model	MSE	R^2
1	$\frac{1}{d}=-0.7265d_0^{-1}\rho_f^{-1}+0.0029d_0^{0.5019}\rho_f^{-0.7197}V^{-0.0155}+2.4266d_0^{-1}-0.033$	3.90×10^{-7}	0.89
2	$\frac{1}{d}=-0.7266d_0^{-1}\rho_f^{-1}+0.0029d_0^{0.5019}\rho_f^{-0.7046}m^{-0.0155}+2.4264d_0^{-1}-0.033$	4.67×10^{-7}	0.89

As can be seen in Table 5, the coefficient of determination of the two models is same and equal to 0.89. But, as mean squire error of the model No. 1 (3.90×10^{-7}) is lower than that of model No. 2 (4.67×10^{-7}), there can be told that volume and density of orange can model the settling depth better than mass and density.

Also, these models have higher coefficient of determination compare with the model in Table 2, Table 3 and Table 4. This fact show that, for modeling of the settling depth of orange there is better to consider dropping height for modeling, beside density and volume.

4 Conclusions

Some physical characteristics, density, volume and mass of orange, Tompson variety, were determined. The settling depth of the dropped from different height of 10, 25 and 50 cm were determined using a water column and a camera. The settling depth was experimentally modeled based on the determined parameters. Based on the best model, R^2=0.89 and MSE=4.67×10^{-7}, the most useful parameters on orange settling depth were dropping height, density and volume of the fruits.

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