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Modelling of apricot (*Prunus armeniaca L.*) terminal velocity in water

E. Mirzaee[1*], S. Rafiee[1], A. Keyhani[1], Z. Emam jom-eh [2], K. Kheiralipour [1] and A. .Tabatabaeefar [1]

[1]Deparment of Agricultural Machinery Engineering, Faculty of Biosystem Engineering, University of Tehran, Karaj, Iran.
[2]Department of Food Industry Engineering, Faculty of Biosystems Engineering, University of Tehran, Karaj, Iran.

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The possibility of using the terminal velocity of fruit through water as a means of hydro-sorting of apricot fruit was studied. In this study, the terminal velocity of three apricot varieties was determined experimentally using the water column method. Some effective characters of apricot on terminal velocity were determined using by standard methods. The best model for terminal velocity of *Ghavami*, *Nasiry* and *Rajabali* apricot varieties as a function of water and fruit densities, shape factor and fruit volume were modeled with determination coefficients of with 0.71, 0.71 and 0.73, respectively. The difference between fruit and water densities gave a major effect on terminal velocity of apricot varieties. On the other hand, the shape factor and the volume of fruit showed a small effect on the terminal velocity. It can be concluded that in an online sorting system; apricot fruits with approximately similar volume can be sorted on their densities.

Key words: terminal velocity, sorting, apricot, density

Introduction

Apricot (*Prunus armeniaca L.*) is classified under the *prunus* species of *prunoidae*, subfamily *Rosaceae*. This type of fruit is a cultivated type of *zerdali* (wild apricot) which is produced by inoculation (Ozbek, 1978). Apricot plays an important role in human nutrition, and can be used as a fresh, dried or processed fruit such as frozen apricot, jam, jelly, marmalade, pulp, juice, nectar, extrusion products etc. Moreover, apricot kernels are used in production of oils, cosmetics, active carbon and aroma perfume (Yildiz, 1994). Australia, France, Hungary, Iran, Italy, Morocco, Spain, Tunisia and Turkey are among

* Corresponding author. E. Mirzaee; e-mail:: mirzaee1364 @yahoo.com

the most important apricot producer countries. While some of the countries such as Hungary, Morocco, Iran and Tunisia are considered as fresh apricot exporters. The others, such as Australia and Turkey, are major dried apricot producers and exporters (USDA, 2004). Quality differences in apricot fruits can often be detected by differences in density. When apricot fruits are transported hydraulically, the design of fluid velocity is related to both density and shape (Peschel *et al*., 2007).Electrical sizing mechanisms are overly expensive and mechanical sizing mechanisms are slow to react (Tabatabeefar & Rajabipour, 2005). Also, fruit graders that employ near-infrared technologies, are expensive and more importantly, the calibrations and maintenance, they require tend to remain outside the skills of packing house staff (Jordan & Clerk, 2004).

Density, a good indicator of fruit dry matter thus becomes an interesting tool for fruit quality sorting because of its inherently lower cost and simpler operation(Richardson *et al*., 1997; Jordan *et al*., 2000). Sorting products based on density is not new, patents and publications for example, in the potato industry, extend from 1950s to the present day (Kunkel *et al*., 1952; Wilson &Lindsay, 1969; Bajema, 2001). Other products (e.g., citrus, blueberries and tomatoes) have also been sorted by flotation techniques for quality or defects (Perry & Perkins, 1968; Patzlaff, 1980).

According to Jordan and Clerk (2004), an approach to fruit sorting is to use the terminal velocity of fruit moving in a fluid that has a density above or below the target density. Fruit with different terminal velocities would reach different depths after flowing a fixed distance in a flume and may be separated by suitable placed dividers. This approach could use water as a sorting medium, which provides huge advantages in terms of the resulting low corrosion and disposal difficulties, and the fact that it does not need any density adjustment. Additionally, this approach allows purely mechanical setting of the separation threshold by adjusting the divider positions and no change in fluid density is required. Kheiralipour (2008), studied the terminal velocity of *Redespar* and *Delbarstival* apple varieties and reported that the apple was reached to its terminal velocity around 0.5 s after releasing and also most fruits showed little tendency to rotate and move in horizontal directions.

Terminal velocity at first appears to be a complex function of fruit shape, fruit size, both water and fruit temperature (not studied here) and density. The main objective in this study was to determine and test the terminal velocity of apricot in a water column to check if it can be used for sorting purposes.

Materials and method

The Iranian apricot cultivars consisted of *Ghavami*, *Nasiry* and *Rajabali* were obtained from orchard located in shahroud, Iran (170 km far from Semnan Province) in July 2008. The 25 fruits of each variety were tested in the Biophysical laboratory and Biological laboratory of the University of Tehran, Karaj, Iran. Fruit mass was determined with an electronic balance with 0.1 g sensitivity. Fruit volume and density were determined by the water displacement method (Mohsenin, 1986). Apricots' picture was taken by Area Measurement System Delta T-England apparatus shown in Fig. 1. Then, projected areas (A_P) were calculated by applying the software written in Visual Basic. A glued Plexiglas column was used with a height of 1,200 mm and a cross-section of 400 × 400 mm, as shown in Fig. 2. The column was constructed with a diameter five times more that that of the fruit (Vanoni, 1975). The column was filled with tap water to a height of about 1,100 mm (Kheiralipour, 2008).

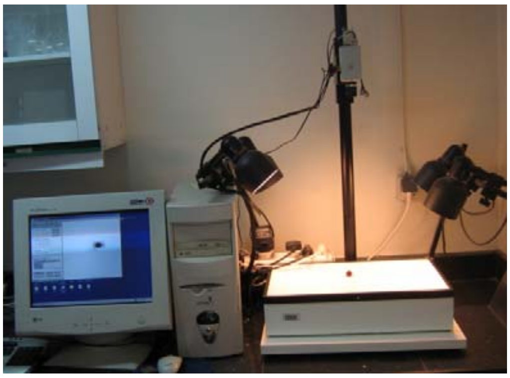

Fig.1. Apparatus for measuring projected area. Fruit is positioned in the center of horizontal plate, directionally, under the vision of camera**.**

Fig. 2. Water column and camera setting to the right side.

Each fruit was placed on the top of the column with hand and then released, and if any bubble appeared on them, it was removed by rubbing the fruit. Fruit was then positioned flat (i.e., with their largest two dimensions oriented horizontally) on the top of column. In order to determine the terminal velocity of the fruit, a digital camera, JVC (770) with 25 fps, recorded the moving of fruits from releasing point to the bottom of water column, simultaneously. Each fruit was tested three times. Subsequently, video to frame software was used to change video film to images in order to calculate terminal velocity of fruits by knowing the fact that each picture takes 0.04 s. Four images of a *Ghavami* apricot variety were selected at the time of 0.0, 0.52 and 1.52 seconds as shown in Fig. 3. Then, information on the trajectory of fruit moving through the water was plotted in a Microsoft Excel Worksheet. Terminal velocity of three varieties of apricot was modeled using SPSS, 15, software and considering KHAT 2 theory (Kheiralipour, 2008):

$$V_t = K\frac{\left(\rho_w - \rho_f\right)^{\left(\frac{1}{2-n}\right)} V^{\left(\frac{n+1}{3(2-n)}\right)}}{S_h^{\left(\frac{1}{2-n}\right)}} \qquad (1)$$

The above equation can be generalized as: (Kheiralipour, 2008):

$$V_t = A\left(\rho_w - \rho_f\right)^b V^c S_h^{-d} + E \qquad (2)$$

where parameters A, b, c, d and E are constant factors and take appropriate values. Parameter E is added to reducing errors, *Vt* is terminal velocity (m/s) , ρ_w is water density (kgm^{-3}), ρ_f is fruit density (kgm^{-3}), V is fruit volume (cm^3) and S_h is shape factor that is defined as : (Jordan and Clerk, 2004)

$$S_h = A_p/V^{2/3}$$

where: A_p = Projected area, (cm^2)

Notations: A_p = Projected area, (cm^2), V = Volume, (cm^3), ρ_f = Fruit density, (kgm^{-3}), S_h = Shape factor of fruits, ρ_w = Water density, (kgm^{-3}), V_t = Terminal velocity, (m/s,) n = Constant factor, A, b, c, d, E, k = curve fitting parameter

A: apricot at rest. B: apricot 0.52 s after releasing C: apricot 1.52 s after releasing

Fig.3. Actual images of apricot positions in water column; A: at rest; B: after 0.52 s; C: after 1.52 s.

Results and discussion

The model was optimized by adjusting various combinations of the five parameters to maximize the determination coefficients. A number of models were tested, and the results are summarized in Tables 1-3 for for *Ghavami*, *Nasiry* and *Rajabali* apricot varieties, respectively. For *Ghavami* apricot variety the effectiveness of all parameters including shape factor, volume, and water and fruit densities for determining the terminal velocity is shown in model 1 with R^2 of 0.71.

$$V_t = 0.035(\rho_w - \rho_f)^{0.371} V^{-0.017} S_h^{0.020} - 0.246 \quad R^2 = 0.71$$

Table.1. Different models developed with different parameters and corresponding determination coefficients for *Ghavami* apricot variety.

Model	A	b	c	d	E	R^2
1	0.035	0.371	-0.017	0.020	-0.246	0.71
2	0.001	0.845	-0.041	0.047	0.000	0.71
3	0.037	0.362	-0.018	0.000	-0.241	0.71
4	0.043	0.349	0.000	0.025	-0.294	0.70
5	0.061	0.308	0.000	0.000	-0.332	0.70

Deleting parameter E in model 2, showed no decreasing in the determination coefficients. By eliminating shape factor in model 3, the determination coefficient was not decreased. By eliminating the volume in model 4 and both shape factor and the volume in model 5, little reduction in R^2 were observed. From these models, it can be seen that the most effective parameter on the terminal velocity of *Ghavami* apricot variety is density.

Nasiry apricot variety, the effectiveness of all parameters including shape factor, volume, and water and fruit densities for determining the terminal velocity are shown in model 1 with R^2 of 0.71.

$$V_t = 0.815(\rho_w - \rho_f)^{0.188} V^{-0.002} s_h^{-0.002} - 2.818 \qquad R^2 = 0.71$$

Table.2. Different models developed with different parameters and corresponding determination coefficients for *Nasiry* apricot variety.

Model	A	b	c	d	E	R^2
1	0.815	0.188	-0.002	-0.002	-2.818	0.71
2	1.303	2.376	-0.047	-0.284	0.000	0.71
3	0.182	0.327	-0.003	0.000	-1.568	0.71
4	0.150	0.344	0.000	-0.004	-1.471	0.70
5	0.158	0.341	0.000	0.000	-1.511	0.70

Table.3. Different models developed with different parameters and corresponding determination coefficients for *Rajabali* apricot variety.

Model	**A**	**b**	**c**	**d**	**E**	**R^2**
1	0.270	0.210	-0.016	0.836	-0.871	0.73
2	0.001	1.081	-0.070	0.447	0.000	0.73
3	0.303	0.174	-0.244	0.000	-0.726	0.73
4	0.010	0.558	0.000	0.257	-0.295	0.72
5	0.005	0.594	0.000	0.000	-0.131	0.71

Deleting parameter E in model 2, the determination coefficients was not decreased. It can be seen that the most effective parameter on the terminal velocity of *Nasiry* apricot variety on its terminal velocity like *Ghavami* apricot variety is density.

Rajabali apricot variety the effectiveness of all parameters including shape factor, volume, and water and fruit densities for determining the terminal velocity are shown in model 1 with R^2 of 0.73.

$$V_t = 0.27(\rho_w - \rho_f)^{0.21} V^{-0.016} S_h^{0.836} -0.871 \qquad R^2 = 0.73$$

From these models, like *Ghavami* and *Nasiry* apricot varieties, it can be seen that the most effective parameter on the terminal velocity of *Rajabali* apricot variety on terminal velocity is density.

Conclusion

The best model for terminal velocity of *Ghavami*, *Nasiry* and *Rajabali* apricot varieties found to be in the form of Eq. 2 as a function of water and fruit densities, shape factor and fruits' volume. It can be concluded that differences between water and fruit densities of three apricot varieties were found to be the most effective on their terminal velocity. Apricot fruits with approximately constant volume can be sorted on their densities. This is due to the fact that fruits with approximately constant volume and different densities have different terminal velocities and can be separated.

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