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# Some physical and hydrodynamic properties of two varieties of apple (*Malus domestica* Borkh L.)

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A b s t r a c t. Several physical and hydrodynamic properties of two apple varieties (Redspar and Delbarstival), newly planted varieties in Iran, were determined and compared. These properties are necessary for the design of equipments for harvesting, processing, transporting, sorting, separating and packing. Some physical characteristics such as: average fruit length, width, thickness, the geometric, arithmetic and equivalent mean diameter, projected area, surface area, sphericity index, aspect ratio, fruit mass, volume and moisture content were studied. These values were different statistically at 1% level of significance for both cultivars. The terminal velocity, coming up time, bounce and drag forces for Redspar variety were 0.47 m $s^{-1}$, 2.33 s, 2.69 and 0.46 N, respectively. But in the case of Delbarstival variety, 0.42 m $s^{-1}$, 2.52 s, 1.40 and 0.24 N were as terminal velocity, coming up time, bounce and drag forces, respectively. The packaging coefficient was 0.62 and 0.53 for Redspar and Delbarstival varieties. The published comparison of data, which might be useful to engineering equipment design for the apple varieties, was generally found to be statistically different.

K e y w o r d s: apple, Redspar, Delbarstival, physical properties, hydrodynamic properties

## INTRODUCTION

Fruits are attractive and nutritional foods, because of their colour, shape, unique taste and smell, and rich in minerals, vitamins and other beneficial components (Cassano *et al*., 2003). The apple is a tree and its pomaceous fruit, of species *Malus domestica* Borkh in the rose family *Rosaceae*, is one of the most widely cultivated tree fruits. There are more than 7 500 known cultivars of apples (Dobrzański *et al*., 2006). In spite of 2.66 million tons of annual Iranian apple production, exportation of that is low (Anonymous, 2005). One of the most important problems preventing export from increasing is loss of post-harvest operations.

To design a machine for handling, cleaning, conveying and storage, the physical properties of agricultural products must be known. Physical characteristics of agricultural products are the most important parameters for determination of proper standards of design of grading, conveying, processing, and packaging systems (Tabatabaeefar, 2003; Tabatabaeefar and Rajabipour, 2005). Among these physical characteristics, mass, volume, projected area, and centre of gravity are the most important ones in determining sizing systems (Khodabandehloo, 1999; Peleg and Ramraj, 1975). Information regarding dimensional attributes is used in describing fruit shape which is often necessary in horticultural research for a range of differing purposes including cultivar descriptions in applications for plant variety rights or cultivar registers (Beyer *et al*., 2002; Schmidt *et al*., 1995). Quality differences in fruits can often be detected by differences in density. When fruits are transported hydraulically, the design fluid velocities are related to both density and shape. Volumes and projected area of fruits must be known for accurate modelling of heat and mass transfer during cooling and drying. Awareness of fruit surface area would be useful in determination of mass of the cuticular membrane per unit fruit surface area (Peschel *et al*., 2007). Determining a relationship between mass, dimensions and projected areas is useful and applicable in weight sizing (Wright *et al*., 1986).

Hydrodynamic properties are very important characters in hydraulic transport and handling as well as hydraulic sorting of agricultural products. Considering the following formula, Mohsenin (1986), the velocity of mixture to transport agricultural products depends on terminal velocity of those and on the characteristics of channel:

$$v_e = v_t \left(\frac{4}{d} R_h\right)^{\frac{1}{2}} , \quad (1)$$

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where: $v_e$ is velocity of mixture (m s$^{-1}$), $v_t$ is terminal velocity (m s$^{-1}$), $d$ is diameter of channel, and $R_h$ is hydraulic radius of channel. To provide basic data essential for the development of equipment for apple sorting and sizing it is needed to determine several properties of apple such as: fruit density and terminal velocity of that (Dewey *et al*., 1966; Matthews *et al*., 1965). Jordan and Clerk (2004) reported that 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 fruit density. Fruit with different terminal velocities will reach different depths after flowing a fixed distance in a flume and may be separated by suitably placed dividers.

## MATERIALS AND METHODS

Two apple cultivars, namely, Redspar and Delbarstival, new-planted varieties in Iran were randomly hand-picked in 2007 summer season from an orchard located at the Horticultural Research Centre, Faculty of Agriculture, University of Tehran. Both cultivars are late-season. Redspar is a red-colour variety with large size, while Delbarstival is a bi-colour (red and yellow) variety with medium size. They are very sweet and delicious in taste.

Samples of 40-50 fruits of each harvested variety were transferred to the laboratory in polyethylene bags to reduce water loss during transport. The initial moisture content of fruits was determined by using the oven dry method, at 77°C and 10 day, w.b. (Masoudi *et al*., 2004). The remaining material was kept in cold storage at 4ºC until use. All of the analyses were carried out at room temperature (RT), in the Biophysical laboratory and Biological laboratory of the University of Tehran, Karaj, Iran.

To determine the average size of the fruits, three linear dimensions, namely length, $L$, width, $W$, and thickness, $T$, were measured by using a digital caliper with accuracy of 0.01 mm, and fruit mass was determined with an electronic balance of 0.1 g accuracy. The diameters were calculated by considering Eqs (1), (2), and (3), respectively (Mohsenin, 1986):

$$D_g = (LDT)^{\frac{1}{3}} , \qquad (2)$$

$$D_p = \left[ L \frac{(W+T)^2}{4} \right]^{\frac{1}{3}}, \qquad (3)$$

$$D_a = \frac{(L+W+T)}{3} , \qquad (4)$$

where: $D_g$ – geometric diameter, $D_p$ – equivalent diameter, $D_a$ – arithmetic diameter (all in mm).

The sphericity, $S_p$ (%), defined as the ratio of surface area of a sphere having the same volume as that of fruit to the surface area of the fruit, was determined using the following formula (Mohsenin, 1986):

$$S_p = \frac{(LDT)^{\frac{1}{3}}}{L} . \qquad (5)$$

The surface area of the fruit was calculated by using the following formula (Mohsenin, 1986):

$$S = \pi (D_g)^2 , \qquad (6)$$

where: $S$ – surface area (mm$^2$).

The aspect ratio, $R_a$ was calculated by Omobuwajo *et al*. (1999):

$$R_a = \frac{W}{L} , \qquad (7)$$

where: $W$ – width (mm).

Volume and fruit density were determined by the water displacement method (Mohsenin, 1986). Projected area with two major axes of the apple was determined from images of the fruits taken by Area Measurement System-Delta Tengland (Fig. 1). Packing coefficient was defined by the ratio of the volume of fruit packed to the total, and calculated by the following formula (Topuz *et al*., 2004):

$$\lambda = \frac{V}{V_0} , \qquad (8)$$

where: $\lambda$ – packing coefficient, $V$ – true volume of fruits and $V_0$ – volume of the box.

To determine some hydrodynamic properties of apples, a glued Plexiglas column was constructed, with height – 1 200 mm and cross-section – 400 × 400 mm (Fig. 2). This column was optimal, with the fruit diameter approximately 20% of the tank diameter (Vanoni, 1975). The column was filled with tap water to a height of about 1 100 mm. Each fruit was placed on the bottom of the column, and any bubbles appearing on them were removed by rubbing. Fruit were then positioned flat *ie* with their largest two dimensions oriented horizontally on the bottom of the column. A digital camera, JVC with 25 frames per second, recorded

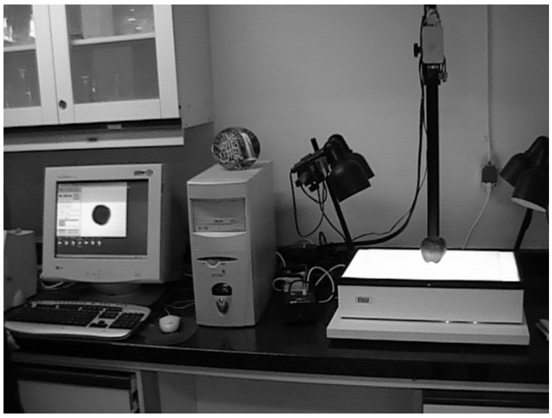

**Fig. 1.** Apparatus for measuring projected area of apples. Apple is positioned in the centre of horizontal plate, directionally, within the field of vision of the camera.

the movement of fruits from releasing point to the top of the water column, simultaneously (Fig. 3). Each fruit was tested three or four times. Video to frame software was used to convert the video film to individual images and, subsequently, to calculate coming up times and terminal velocities of fruits by knowing the fact that each picture takes 0.04 s.

Drag, $F_d$, and bounce, $F_b$, are forces for and against the movement of fruits in water, as defined by the following formula, respectively:

$$F_d = C_d A_p \frac{\rho_f v^2}{2}, \quad (9)$$

where: $F_d$ – drag force (N), $A_p$ – projected area (cm$^2$), $\rho_f$ – true density (kg m$^{-3}$), $v$ – the velocity, $C_d$ – drag coefficient, is a function of fruit velocity and can be modelled well at low velocity using Stokes' law (Crowe *et al*., 2001). Thus:

**Fig. 2.** Water column for determination of hydrodynamic properties. An apple on the bottom of the water column, prepared to be released.

**Fig. 3.** Water column and camera setting to the side.

$$C_d = \frac{24}{N_R} \quad \text{for} \quad N_R < 1, \quad (10)$$

$$N_R = \frac{v_d}{\nu}, \quad (11)$$

and

$$F_b = \rho_f V_g, \quad (12)$$

where: $F_b$ – bounce force (N), $N_R$ – Reynolds' number, $\nu$ – dynamic viscosity of water, $g$ – gravity force, $d$ – diameter.

All data were subjected to statistical analysis using the analysis of variance (ANOVA) test, and means were compared using Duncan's multiple range tests.

## RESULTS AND DISCUSSION

A summary of the physical and hydrodynamic properties of Redspar and Delbarstival cultivars is shown in Table 1. The moisture contents were 82.8 and 81.16%, w.b., for Redspar and Delbarstival apples, respectively. According to the results of the dimensional properties of two apple cultivars, for Redspar variety the mean fruit length, width, and thickness were respectively 75.28, 84.12, and 80.64 mm, whereas the corresponding values for the Delbarstival variety were 58.31, 67.17, and 65.04 mm. Tabatabaeefar and Rajabipour, 2005, studied two different common commercial export varieties of Iranian grown apples (Red Delicious and Golden Delicious) from four different regions. They obtained 73, 70, and 67 mm as the mean fruit length, width and thickness for these varieties, with means of 71.83 and 71.57 mm, respectively. It can be said that Redspar cultivar has big size and Delbarstival has small size. The geometric, $D_g$, equivalent, $D_p$, and arithmetic mean diameter, $D_a$, of Redspar and Delbarstival apples were different, at 79.9, 80.01, 79.92 mm for Redspar variety and 63.38, 63.51, 63.38 mm for Delbarstival variety, respectively. The surface area and projected area of the apple varieties were characterised by 35% differences. When the fruit mass in this study was compared with previous studies, the mean mass of the Redspar (229.65 g) fruits was greater than that of the mixed varieties of Red Delicious and Golden Delicious, 165 g (Tabatabaeefar and Rajabipour, 2005). The true density of Redspar and Delbarstival cultivars varied from 837.68 to 827.91 kg m$^{-3}$. The packaging coefficient and volume were 0.62, 0.53 and 275.15 and 143.19 cm$^3$ for Redspar and Delbarstival varieties, against Topuz *et al*. (2004), the packing coefficient increased with decreased fruit volume. This result is due to extended volume values for Redspar variety (138.5-424.2 cm$^3$), on the other hand the small fruits filled the vacancy among big fruits. In spite of significant differences between all parameters of two varieties, aspect ratio and sphericity were not significantly different.

Terminal velocity of Redspar and Delbarstival cultivars was found to be 0.47 and 0.42 m s$^{-1}$. Siimilar researches were conducted by Matthews *et al*. (1965), and Dewey *et al*.

**T a b l e 1.** Several physical and hydrodynamic properties of the two apple varieties

| Parameters | Redspar | | | Delbarstival | | | Significance level |
|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | Max | Min | Mean | |
| Length (mm) | 88.03 | 57.13 | 74.78±8.2 | 66.66 | 50.98 | 58.31±4.09 | * |
| Width (mm) | 101.27 | 66.98 | 83.80±7.57 | 77.13 | 50.55 | 67±4.37 | * |
| Thickness (mm) | 95.61 | 62.60 | 80.37±7.05 | 72.35 | 58.85 | 65.04±3.77 | * |
| Geometric mean diameter (mm) | 94.15 | 62.94 | 79.54±7.32 | 70.57 | 57.01 | 63.38±3.89 | * |
| Equivalent diameter (mm) | 94.17 | 62.96 | 79.55±7.32 | 70.57 | 57.01 | 63.39±3.89 | * |
| Arithmetic diameter (mm) | 94.36 | 63.10 | 79.65±7.30 | 70.64 | 57.11 | 63.51±3.89 | * |
| Sphericity (%) | 1.13 | 0.99 | 1.07±0.04 | 1.14 | 1.02 | 1.09±0.03 | * |
| Surface area ($mm^2$) | 278.33 | 124.40 | 200.29±35.42 | 156.39 | 102.05 | 126.59±15.54 | * |
| Project area ($cm^2$) | 83.16 | 36.63 | 59.73±10.84 | 49.15 | 30.86 | 38.95±5.04 | * |
| Aspect ration | 1.24 | 0.99 | 1.12±0.06 | 1.23 | 1.07 | 1.15±0.04 | * |
| Mass of fruit (g) | 347.00 | 119.10 | 229.65±54.34 | 159.60 | 87.60 | 118.43±20.97 | * |
| True density (kg $m^{-3}$) | 882.88 | 811.49 | 837±34.29 | 868.74 | 795.02 | 827.91±13.45 | ns |
| Moisture content (%) | 85.25 | 81.1 | 82.80±1.17 | 86.40 | 79.55 | 81.84±2.37 | * |
| Packing coefficient | 0.65 | 0.60 | 0.62±0.03 | 0.55 | 0.52 | 0.53±0.01 | * |
| Terminal velocity (m $s^{-1}$) | 0.76 | 0.33 | 0.47±0.07 | 0.49 | 0.35 | 0.42±0.04 | * |
| Coming up time (s) | 3.20 | 1.60 | 2.33±0.32 | 2.88 | 2.24 | 2.52±0.16 | * |
| Drag force (N) | 0.76 | 0.18 | 0.46±0.14 | 0.36 | 0.16 | 0.24±0.05 | * |
| Bouncy force (N) | 4.16 | 1.36 | 2.69±0.67 | 1.92 | 1.04 | 1.40±0.26 | * |

*1% significant level, ns – no significant.

(1966). They obtained 0.61 and 0.53 m $s^{-1}$ as coming up terminal velocity, 74.68 and 72.14 mm as geometric mean diameter, 760 and 820 kg $m^{-3}$ as true density of Jonathan and Granny Smith apple cultivars. In comparison, terminal velocity of these cultivars, with considering other characters, can be concluded to increase with decrease of true density and increase of geometric mean diameter. For Delbarstival and Redspar cultivars the effective factor on terminal velocity was geometric mean diameter, because of little difference in true density (which varied from 827.91 to 837 kg $m^{-3}$) compared with the difference in geometric mean diameter (from 79.54 to 63.38 mm). As seen in Table 1, Redspar and Delbarstival cultivars had 2.33 and 2.52 s as coming up time. Logically, it would be concluded that with decreasing terminal velocity the coming up time of apples increased. Finally, the drag and bounce force were 2.69 and 0.46 N for the Redspar variety, and 1.4 and 0.24 N for Delbarstival, respectively. These data can be used in modelling of terminal velocity and coming up time of apples, because to reach the terminal velocity the drag and bounce forces must be in balance with the weight of apples.

## CONCLUSIONS

1. For Redspar cultivar, length, width and thickness values were larger than those of Delbarstival cultivar, by 22, 20, and 19%, respectively. Comparing these results with the previous study, it is concluded that Redspar cultivar is generally bigger than Delbarstival cultivar.

2. It was observed that surface area and projected area values of Redspar cultivar are greater than those values of Delbarstival cultivar, while the sphericity and aspect ratio values of the Redspar cultivar are lower than that those values for other cultivars, by 1.9 and 2.7%, respectively.

3. The packing coefficient of Redspar cultivar was 15% bigger than that of Delbarstival cultivar. This result is due to wide range of values (138.5-424.2 $cm^3$) of the volume of Redspar cultivar.

4. These data are valuable for packing task of apples. The mass values of both cultivars had a 48% difference, but there were no significant differences between the true densities of the cultivars studied.

5. The terminal velocity value of Redspar cultivar was 11% greater, but the rising time was 8% less than that of the Delbarstival cultivar.

6. There was a 48% difference between drag and bounce force values of the two cultivars. This is due to the difference in fruit mass between the cultivars.

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