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Some Physical Properties of Apple

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Abstract: Several physical properties as physical characteristics, mechanical, hydrodynamic and nutritional properties of two apple varieties (Redspar and Delbarstival), were determined and compared using Duncan's multiple ranges test. 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, true density and moisture content, were determined for both varieties. The coefficient of static friction on plastic, plywood and galvanized iron, flesh firmness, failure stress, modulus of elasticity were found. The terminal velocity, coming up time, bouncy and drag forces, as hydrodynamic properties and total dry matter, total soluble solid, pH and titratable acidity, as nutritional properties, were determined. It was concluded that most of properties of two apple varieties was statistically different at the one percent probability level.

Key words: Apple (redspar, delbarstival), harvest and post-harvest processing, terminal velocity

Introduction

In spite of 2.66 million tons of Iranian annual apple production, exportation of that is low (Anonymous, 2005). Loss of postharvest operation is considered heavy. That may cause less exportation. Physical characteristics of agricultural products are the most important parameters to determine the proper standards of design of grading, conveying, processing and packaging systems (Tabatabaeefar and Rajabipour, 2005). Among these physical characteristics, mass, volume and projected area are the most important ones in determining sizing systems (Khodabandehloo, 1999). 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.

Postharvest evaluation gives possibilities for delivering a high quality product and a basic understanding of apple texture is necessary for the development of technology for postharvest evaluations (Ioannides *et al.*, 2007). Mechanical properties of the tissue determine the susceptibility to mechanical damage that can occur during harvest, transport and storage and that eventually leads to a profound reduction in commercial value (Oey *et al.*, 2007). Mechanical properties such as failure stress and strain as well as modulus of elasticity can also be used to evaluate the behavior of the fruits mechanically under the static loading. Firmness or hardness is another important attribute of fruits and it is often used for fruit quality assessment (Vursavus *et al.*, 2006).

Hydrodynamic properties are very important characters in hydraulic transport and handling as well as hydraulic sorting of agricultural products. The velocity of mixture to transport agricultural products depends on terminal velocity of those and characters of channel (Mohsenin, 1986). To provide basic data essential for development of equipment for sorting and sizing apples needed to determine several properties of apple such as: Fruit density and terminal velocity of that (Matthews *et al.*, 1965; Dewey *et al.*, 1966). 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.

Information regarding chemical properties of fruit is crucial in processing it into different foods (Vursavus *et al.*, 2006). Fruit weight and dry matter can be used in order to determine the best time to harvest fruits. Considering postharvest operations of apples, some mechanical and nutritional properties of those are more important in both machinery and equipment design and also in controlling the actual process procedure. Therefore, in the current study, researchers investigated the mentioned properties of apple fruits, by comparing the two apple varieties, newly grown in Iran and then establishing a convenient reference table for apple mechanization and processing.

Materials and Methods

Two apple, Malus domestica Borkh, L., cultivars namely, Redspar and Delbarstival, new-planted varieties in Iran were randomly hand-picked in 2007 summer season from orchard located in Horticultural Research Center, Department, Faculty of Agriculture, University of Tehran.

Fig. 1: Apparatus for measuring static coefficient of friction.

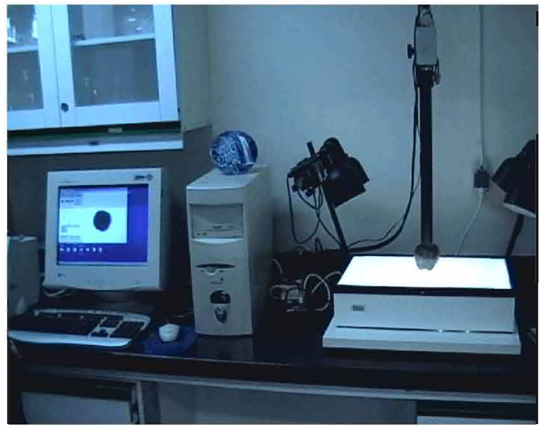

Fig. 2: Area Measurement System-Delta Tengland for measuring projected area of apples.

The two cultivars are also late season. Redspar is red-color variety but Delbarstival is bicolor variety. They are very sweet and delicious in taste.

The 50 fruits were randomly harvested and transferred to the laboratory in polyethylene bags to reduce water loss during transport. The initial moisture content of fruits was determined by using dry oven method (AOAC, 1990). The remaining material was kept in cold storage in 4°C until use. All of the analyses were carried out at a room temperature, 25°C, in the Biophysical laboratory and Biological laboratory of university of Tehran, Karaj, Iran.

To determine the average size of the fruits three linear dimensions namely as length, width and thickness were measured by using a digital caliber with sensitively of 0.01 mm and fruit mass was determined with a electronic balance of 0.1 g sensitively. The geometric, Dg, equivalent, Dp and arithmetic mean diameter, Da, in mm was calculated by considering Eq. (1), Eq. (2) and Eq. (3), respectively (Mohsenin, 1986).

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

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

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

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

$$S_p = \frac{(LDT)^{\frac{1}{3}}}{L} \qquad (4)$$

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

$$S = \pi (d_g)^2 \qquad (5)$$

The aspect ratio (Ra) was calculated by (Omobouwajo *et al.,* 1999).

$$R_a = \frac{W}{L} \qquad (6)$$

Volume and fruit density were determined by the water displacement method (Mohsenin, 1986). Projected area with two major axis of the apple was determined from pictures of the fruits taken by Area Measurement System-Delta Tengland, Fig. 2. 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).

$$\lambda = \frac{V}{V_0} \qquad (7)$$

where V is true bulk of fruits and V_0 is bulk of the box. Mechanical properties of apples were evaluated using 20 cylindrical specimens of each variety, taken in radial direction with diameter as 14 mm and height as 18 mm and then Universal Testing Machine (Santam, MRT-5), as shown in Fig. 3. This machine has three main components, which are a stable forced and moving platform, a driving unit (A C electric motor, electronic variator and reduction unit) and a data acquisition (load cell, PC card and software) system (Vursavus and Ozguven, 2004). The machine was equipped with a load cell of 500 N at a compressive rate of 25 mm/min. Failure stress and strain of apples are expressed in terms of the change in compression force and compact area and deformation and initial length, respectively as (Vursavus *et al.,* 2006):

$$s_f = \frac{\Delta F}{\Delta A} \qquad (8)$$

$$e_f = \frac{d}{l_i} \qquad (9)$$

where σ_f, ΔF, ΔA, ε_f, d and l_i are designated as failure stress, failure force, cross section, failure strain, diameter and specimen length of fruits. Modulus of

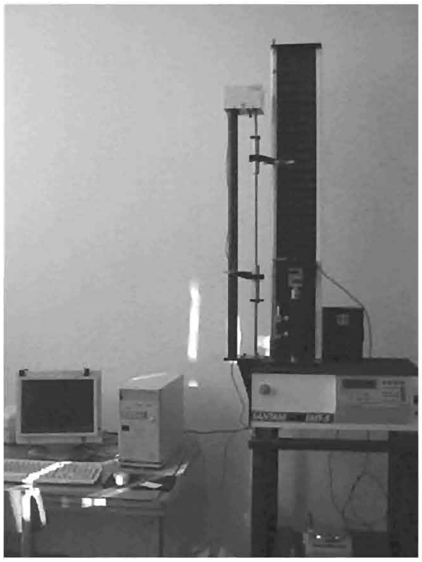

Fig.3. A Universal Testing Machine (Santam, MRT-5) for measuring mechanical properties of apples.

elasticity value (MPa) was calculated as the slope of the line from the origin (0:0) to 50% of failure point and failure energy was also considered as the total area in failure point (Mohsenin, 1986). Firmness was then calculated as the failure force dividing to the failure deformation. The coefficient of static friction was determined with respect to different surfaces: Plywood, compacted plastic and galvanized iron. A hollow metal cube (Fig. 1) open at both ends was filled with the fruits placed on adjustable titling surface such that the metal cube did not touches the surface. Then the surface was raised gradually until the filled cube just started to slide down (Razavi and Milani, 2006).

To determine some hydrodynamic properties of apples, a glued Plexiglas column was constructed, height = 1200 mm and cross-section = 400 × 400 mm, shown in Fig. 4. This column was optimal, fruit diameter approximately 20% of tank diameter (Vanoni, 1975). The column was filled with tap water to a height of about 1100 mm. Each fruit was placed in the bottom of column and any bubbles appearing on them were removed by rubbing. Fruit were then positioned flat (i.e., with their largest two dimensions oriented horizontally) in the bottom of column. A digital camera, JVC with 25 frames per second, recorded the moving of fruits from releasing point to the top of water column, simultaneously. Each fruit was tested three or four times. Video to Frame software were used to change video film to pictures and subsequently to calculate Coming up times and terminal velocities of fruits by knowing the fact that each picture takes 0.04 s.

a

b

c

d

Fig. 4: The position of apple in water column a: at the rest, b: after 0.5 s, c: after 1 s and d: after 1.5 s.

Bouncy (F_b) and drag (F_d) are forces for and against moving of fruits in water defined by following formula, respectively:

$$F_d = C_d A_p \frac{p_f v^2}{2} \qquad (10)$$

Where C_d, drag coefficient, is a function of fruit velocity and can be modeled well at low velocity using Stokes' law (Crowe *et al.,* 2001). Thus:

$$C_d = \frac{24}{N_R} \quad \text{For } N_R < 1 \qquad (11)$$

$$N_R = \frac{Vd}{\upsilon} \qquad (12)$$

$$F_b = p_f V g \qquad (13)$$

where N_R is Reynolds number, v is the dynamic viscosity of water, g is gravity force, V is the velocity, d is the diameter, p_f is the true density and is the volume of fruit.

The nutritional composition of the apple fruit juices were studied as explained following: Total dry matter was determined according to AOAC (1990). The total titratable acidity was determined by titration with sodium hydroxide (0.1 N) and expressed as a % of malic acid. The pH value was measured using a Macroprocessor pH meter (iHANNA pH211, Made in Italy). Total soluble solids (TSS) were measured as ^{0}Brix a Neerveld 14-B22550, GETI (Belgium) refractometer.

All data were statistically analyzed using the analysis of variance (ANOVA) test and means were compared using Duncan's multiple ranges test.

Results and Discussion

A summary of the physical characteristic, mechanical, hydrodynamic and nutritional properties of Redspar and Delbarstival cultivars is shown in Table 1. The moisture contents were 82.80 and 81.16% for Redspar and Delbarstival apples, respectively. According to this results of the dimensional Properties of two apple cultivars; the mean fruit length was 75.28 mm, fruit width was 84.12 mm and thickness was 80.64 mm for Redspar variety, whereas these values were 58.31 mm and 67.17 mm 65.04mm for Delbarstival variety. Tabatabaeefar and Rajabipour, 2005 studied on two different common commercial export varieties of Iranian grown apples (Red Delicious and Golden Delicious) from four different regions. They concluded 73, 70 and 67 mm as the mean fruit length, width and thickness for these varieties. The geometric, D_g, equivalent, D_p and arithmetic mean diameter, D_a, of Redspar and Delbarstival apples resulted in different means as 79.90, 80.01, 79.92 mm and 63.38, 63.51, 63.38 mm, respectively. The surface area and projected area of the apple varieties were found to be statistically different. When the fruit mass in this study was compared with previous studies, the mean mass of the Redspar (229.65 kg) fruits was greater than that of the mixed varieties of Red Delicious and Golden Delicious, 165 kg (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 cm^3 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 cm^3 - 424.2 cm^3) in 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.

As seen in Table 1, all the failure properties such as stress, strain and energy and modulus of elasticity were found to have statistically significant difference at the 1% probability level. The mean values of the failure stress and strain for the Redspar variety were 0.43 MPa and 0.20 mm/mm, respectively. This values were greater than those of Delbarstival variety that were 0.24 MPa and 0.15 mm/mm, respectively. Similar study was undertaken and reported by Masoudi, Tabatabaeefar, Borghei and Shahbake (2004) for Red Delicious (0.13 MPa and 0.07 mm/mm), Golden Delicious (0.28 MPa and 0.13 mm/mm) and Grani Smith (0.34 MPa and 0.11 mm/mm). Failure energy values of variety resulted in different means 127.59 and 51.06 N.mm. Also, the Redspar had more module of elasticity (2.53 MPa) than that of Delbarstival (1.77MPa) and according to Masoudi *et al.* (2004), Red Delicious (1.53) and Golden Delicious (1.92 MPa) but less than that of the Grani Smith (2.84 MPa). The firmness parameter for each apple variety was found to have different means as 18.55 N/mm for Redspar and 14.15 N/mm for Delbarstival. The coefficient of static friction for Redspar and Delbarstival fruits was determined on the compacted plastic, plywood and galvanized iron. These coefficient values varied from 0.28 to 0.31 and 0.34 to 0.44, respectively. On the plywood surface, the coefficient of static friction of the Redspar and Delbarstival was not very different (0.31 and 0.34, respectively). This value for the Redspar fruits was found to be 0.31 on the galvanized iron that was less than that of Delbarstival as 0.37. The coefficient of static friction of the Redspar fruits, with a mean of 0.28 was significantly smaller than that of the Delbarstival. Considering above information on Redspar and Delbarstival apples, can be concluded that Redspar variety is more endurable than Delbarstival variety under static loads. The depth of boxes includes Redspar apples are more than that of Delbarstival apples, according to Sitkei, 1986, damage increases with increasing in depth of packaging boxes.

Terminal velocity of Redspar and Delbarstival cultivars was found to be 0.47 and 0.42 m/s. The similar

Table 1: Several physical characteristics and mechanical, hydrodynamic and nutritional properties of two apple varieties

Property	Redspar Max	Redspar Min	Redspar Mean	Delbarstival Max	Delbarstival Min	Delbarstival Mean	Significant level
L	88.03	57.13	74.78±8.2	66.66	50.98	58.31±4.09	**
W	101.27	66.98	83.80±7.57	77.13	50.55	67±4.37	**
T	95.61	62.6	80.37±7.05	72.35	58.85	65.04±3.77	**
D_g	94.15	62.94	79.54±7.32	70.57	57.01	63.38±3.89	**
D_p	94.17	62.96	79.55±7.32	70.57	57.01	63.39±3.89	**
D_a	94.36	63.1	79.65±7.30	70.64	57.11	63.51±3.89	**
S_p	1.13	0.99	1.07±0.04	1.14	1.02	1.09±0.03	**
S	278.33	124.4	200.29±35.42	156.39	102.05	126.59±15.54	**
A_p	83.16	36.63	59.73±10.84	49.15	30.86	38.95±5.04	**
R^a	1.24	0.99	1.12±0.06	1.23	1.07	1.15±0.04	**
M_f	347	119.1	228.72±54.34	159.6	87.6	118.43±20.97	**
ρ_t	882.88	811.49	837±34.29	868.74	795.02	827.91±13.45	ns
M	85.21	81.1	82.80±1.17	86.4	79.55	81.84±2.37	**
λ	0.65	0.6	0.62±0.03	0.55	0.52	0.53±0.01	**
V_t	0.76	0.33	0.47±0.07	0.49	0.35	0.42±0.04	**
T_c	3.2	1.6	2.33±0.32	2.88	2.24	2.52±0.16	**
F_d	0.76	0.18	0.46±0.14	0.36	0.16	0.24±0.05	**
F_b	4.16	1.36	2.69±0.67	1.92	1.04	1.40±0.26	**
Φ_p	0.31	0.31	0.31±0.00	0.33	0.35	0.34±0.01	**
Φ_g	0.3	0.32	0.31±0.00	0.41	0.34	0.37±0.04	ns
Φ_c	0.27	0.29	0.28±0.00	0.47	0.41	0.44±0.03	**
σ_f	0.55	0.33	0.43±0.05	0.36	0.16	0.24±0.06	**
δ_f	0.29	0.16	0.20±0.03	0.19	0.1	0.15±0.03	**
E	3.69	1.87	2.53±0.47	4.44	0.98	1.77±0.79	**
E_f	192.47	85.29	127.59±26	80.25	25.4	51.06±17.2	**
F_i	23.94	11.18	18.55±3.5	22.83	8.41	14.15±3.80	**
D_m	18.9	14.75	17.2±1.17	20.45	13.6	18.6±2.37	**
PH	4.3	3.74	3.91±0.14	3.93	3.46	3.61±0.16	**
T_c	0.034	0.017	0.025±0.01	0.05	0.03	0.041±0.01	**
TSS	13.2	8.4	10.73±1.5	15.1	9.5	12.54±2.23	ns

** Significant (1% level) ns: Nonsignificant

researches were conducted by Matthews *et al.,* 1965; Dewey *et al.,* 1966. They concluded 0.61 and 0.53 m/s 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 Grani Smith apple cultivars. In comparison terminal velocity of these cultivars, with considering other characters, can be concluded that terminal velocity increased with decreasing of true density and increasing of geometric mean diameter. For Delbarstival and Redspar cultivars the effective factor on terminal velocity was geometric mean diameter, because of little deference in true density (varied from 827.91 to 837kg/m^3) compare with deference in geometric mean diameter (varied 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, would be concluded that with decreasing terminal velocity, the coming up time of apples increased. Finally, the drag and bouncy force were 2.69 N and 0.46 N for Redspar variety and 1.40 N and 0.24 N for Delbarstival variety, respectively.

The values of all the chemical properties of apple juices were statistically different with respect to the varieties. Also, the cultivar of Redspar has the smaller dry matter (17.2 %) than Delbarstival (18.12 %). In the case of the TSS, as shown in Table 1, there were non significant differences between the studied cultivars. For Delbarstival variety, the average value of the TSS was 12.54 whereas 10.73 obtained for Redspar variety, but Ragni and Berardinelli, 2001, reported this value as 14.3, 13.7, 14.3 and 12.9 for Golden Delicious, Stark Delicious, Grani Smith and Rome Beauty, respectively. The juice of Redspar cultivar also represented the higher ratio of pH, 3.91, compared with Delbarstival, 3.61. Eventually, titrable acidity value found for Delbarstival variety in this experiment was 0.034 that was higher than 0.021 for Redspar variety.

Conclusion: Some engineering properties of Redspar and Delbarstival varieties which may be useful in designing much of the equipment used for harvest and post-harvest processing were studied in this paper. Authors concluded that all studied properties of two apple varieties were found to be statistically different at the probability level (1%), except for true density, static coefficient of friction on galvanized iron surface and TSS, This paper concludes with information on engineering properties of Redspar and Delbarstival varieties which may be useful in designing much of the equipment used for postharvest processing.

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Notations: L = length, mm, Φ_g = on galvanized iron surface, W = width, mm, Φ_c = on compressed plastic surface, T = thickness, mm, Φ_p = on plywood surface, D_g, = geometric mean diameter, mm, σ_f = Failure stress, kPa, D_p = equivalent diameter, mm, δ_f = Failure strain, mm/mm, D_a = arithmetic diameter, mm, E = Elasticity module, kPa, S_p = sphericity, %, E_f = Failure energy, kPa, S = surface area, mm^2, F_l = Firmness, N/mm, A_p = Projected area, cm^2, V_t = Terminal velocity, m/s, M_f = Mass of fruit, g, C_r = Coming up time, s, V = volume, mm^3, F_d = Drag force, N, ρ_t = true density, kgm^{-3}, F_b = Bouncy force, N, M = moisture content, % , D_m = Dry matter, %, λ = Packing coefficient, T_c = Titratable acidity, Φ = static coefficient of friction, TSS, Total soluble solid ^{o}Brix.