

Physical and mechanical properties of some Egyptian onion cultivars

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Abstract

Due to the lack of information about the physical and mechanical properties of onion in Egypt which are very importance to understand the behavior of the product during the post harvesting operations such as harvesting, transporting, sorting, grading, packaging and storage processes and also, it is necessary in processing operations such as cooling, drying and all heat and mass transfer processes, the main objective of this work was to study the physical and mechanical properties to form an improtant database for three of the most popular cultivars (Giza 6 (white), Beheri (red) and Giza 20 (yellow)) of onion in Egypt. These properties include: linear dimensions, shape index, geometric mean diameter, arithmetic mean diameter, frontal surface area, cross-sectional of area, volume, mass, density, static friction coefficient, rolling angle, crushing load and puncture resistance.

The equatorial and polar diameters ranged from 5.12 ± 0.33 to 6.20 ± 1.5 cm for all cultivars with coefficient of variation (CV) of 11–25%. Both of Beheri and Giza 20 onion bulbs were spherical in shape and the Giza 6 onion was an oval. The D_{gm} ranged from 5.48 to 5.98 cm, D_{am} ranged from 5.50 to 6.01 cm, $A_{f,s}$ ranged from 23.3 to 28.81 cm² and $A_{s,c}$ ranged from 23.96 to 29.52 cm² and mass ranged from 78.7 to 115.3 g for all onion cultivars. The volume ranged from 77.2 ± 25 to 108.8 ± 75 cm³ with CV of 33.4–69.7%. The density ranged from 1.04 ± 0.09 to 1.11 ± 0.15 g/cm³ with CV of 8.04–13.5%. The rolling angle ranged from 20° to 31° in the stable position and from 14° to 23° in the none-stable position. The highest values of rolling angles were obtained on the rubber surface followed by the plywood and the galvanized steel surfaces. The rolling angle increases with the onion bulb size (bs). The coefficient of friction (f) ranged from 0.67 to 1.34 for all three cultivars. The highest (f) was obtained on the plywood surface followed by the rubber and the galvanized steel surfaces. Crushing load increased with the onion bs and ranged from 443.3 to 819.7 N for Giza 6 (white onion), 341.4–980.7 N for Beheri (red onion) and from 400 to 780 N for Giza 20 (yellow onion). Penetration load also increased with the onion bs and ranged from 26.9 to 35.9, 26.1 to 43.0 and 27.6 to 45.5 N for same previous order.

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1. Introduction

Onion, *Allium cepa*, L., is considered as one of the most important crops in all countries. In Egypt, onion ranks fourth after cotton, rice, and citrus as an export crop. The total cultivated area was 36153 feddan (15184.3 ha) in 1999 and the total production was 305201 tons (CAPMS, 2000).

Exporting of agricultural products is one of the main goals of the current policy of the Egyptian Government, specially to Europe. To be able to achieve such target, it is vital to apply the proper post harvesting technologies for each crop. For onion bulbs, it has to be well sorted,

graded and backed. To achieve such operations, information about physical and mechanical properties for bulbs are required.

Knowledge of length, width, volume, surface area and weight of the product is necessary to (a) the design of sorting and grading machines (b) predicting amounts of surface applied chemicals and (c) describing heat and mass transfer during thermal processes and in quantification of bruise, abrasion and damage in handling process. The shape of some fruits is important in determining their suitability for processing as well as their retail value. Many researches were carried out on the physical and engineering properties of many agricultural products (Abd Alla, Radwan, & El-Hanfy, 1995; El-Raie, Hendawy, & Taib, 1996; Irvine, Jayas, White, & Britton, 1992; Korayem & Soliman, 1983; Kukulko, Jayas, White, & Britton, 1988; Mohsenin, 1970; Muir & Sinha, 1988).

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The information on size, density, and crushing strength are required for the development of grading system for barriers and for the pulpers (Gosh, 1969). The physical and mechanical properties such as size, friction angle, angle of repose, crushing strength and bulk density are important in the design of the handling system and grading (Chandrasekar & Viswanathan, 1999). Abd Alla et al. (1995) reported that the shape index and coefficient of contact surface had a high significant effect on the rupture force and broken percentage in milling process of rice grains.

Maw, Hung, Tollner, Smittle, and Mullinix (1996) examined some physical and mechanical properties of Granex Grano onion variety. They concluded that the mean mass, surface area, volume, density and the overall mean equatorial and polar diameters were 98 g, 111 cm², 95 cm³, 1.1 g/cm³, 6.2 and 4.2 cm, respectively. They also found that the crushing and puncture forces were 26.4 N and 25.0 N, respectively.

Abdel-Ghaffar and Hindley (1984) tested four sizes (small, medium, large, and extra-large) of an Egyptian onion (Abo-Fatla variety). They found that the mean polar diameters were 40.45, 47.00, 47.94, and 52.40 mm and the mean equatorial diameters were 39.07, 50.03, 56.00, and 60.40 mm for the same previous order. The mean mass, bulb density and bulk density were 177 g, 0.976 g/cm³ and 0.586 g/cm³, respectively.

Eweida, Osman, Okaz, and Anous (1986) reported that the mean equatorial and polar diameters of onion bulbs were 74 and 52 mm, respectively for an Egyptian onion cultivar (Giza 6 Mohassan) and the mean volume was 187.6 cm³. They also reported that the degree of onion hardness (resistance to penetration) was 86.7 DN (Durometer Number) at harvest. Bulb hardness decreased gradually with storage period, to be 82.2, 77.9, and 72.4 DN at 2, 4, and 6 months of storage periods, respectively.

El-Khawaga (1999) estimated the rolling angle of orange fruits by using an inclined plane. The fruits are placed on the surface in two ways, in a stable position (with their bases) and in none-stable position and stated that the average value of rolling angle at stable position was 6.0° and 8.27°, for Washington and Balady cultivars, respectively. While, at unstable position, the corresponding values were 2.91° and 3.82°.

El-Raie, El Sahrighi, and Mosa (1998) estimated the coefficient of friction for orange cultivars and Egyptian lime on six different surfaces, namely, metal, wood, stainless steel, galvanized, fiber, and rubber. They found that the values of friction coefficients were ranged from 0.193 to 0.332 for orange cultivars and 0.231 to 0.331 for Egyptian lime variety, respectively.

Due to the lack of information about the physical and mechanical properties of onion in Egypt which are very importance to understand the behavior of the product during the post harvesting operations such as harvest-

ing, transporting, sorting, grading, packaging and storage processes and also, it is necessary in processing operations such as cooling, drying and all heat and mass transfer processes, the main objective of this work was to study the physical and mechanical properties to form an improtant database for three of the most popular cultivars (Giza 6 (white), Beheri (red) and Giza 20 (yellow)) of onion in Egypt. These properties include: linear dimensions, shape index, geometric mean diameter, arithmetic mean diameter, frontal surface area, cross-sectional of area, volume, mass, density, static friction coefficient, rolling angle, crushing load and puncture resistance.

2. Experimental procedures

Three of most popular onion cultivars (Giza 6, Beheri and Giza 20) were brought from the local Egyptian market. The moisture content values were 81.3 ± 2.44, 80.9 ± 2, and 79.7 ± 2.9% (w.b). for Giza 6 (white), Beheri (red) and Giza 20 (yellow onion), respectively. The bulbs were inspected and divided into three size categories {<4 cm (small), from 4 to 7 cm (medium) and >7 cm (large)}. These categories were used to measure the linear dimensions, mass, volume, density, coefficient of static friction, rolling angle, crushing load and resistance to penetration. The geometric and arithmetic diameters, frontal and cross-sectional of areas, shape index of the onion bulbs were also determined.

2.1. Apparatus and procedure

2.1.1. Linear dimensions

There are two categories of onion bulb diameter: polar diameter and equatorial diameter. Polar diameter is the distance between the onion crown and the point of root attachment to the onion. Equatorial diameter is the maximum width of the onion in a plane perpendicular to the polar diameter. The equatorial diameter (D_e), polar diameter (D_p), and thickness (T), of each 15 bulbs from each variety were measured with a caliper reading to 0.01 mm. The geometric mean diameter (D_{gm}), arithmetic mean diameter (D_{am}), volume, frontal surface ($A_{f.s}$) and cross-sectional of areas ($A_{c.s}$) of the bulbs were calculated using the following relationships given by Mohsenin (1970), as follows:

Geometric mean diameter (D_{gm})

$$= (D_e D_p T)^{0.3333}, \text{ cm} \quad (1)$$

Arithmetic mean diameter (D_{am})

$$= \frac{(D_e + D_p + T)}{3}, \text{ cm} \quad (2)$$

$$\text{Frontal surface area } (A_{f.s}) = \frac{\pi}{4} EP, \text{ cm}^2 \quad (3)$$

Cross-sectional area ($A_{c,s}$)

$$= \frac{\pi (D_e + D_p + T)^2}{4 \cdot 9}, \text{ cm}^2 \quad (4)$$

2.1.2. Shape index

Shape index is used to evaluate the shape of onion bulbs and it is calculated according to the following equation (Abd Alla, 1993):

$$\text{Shape index} = \frac{D_e}{\sqrt{D_p * T}} \quad (5)$$

The onion bulb is considered an oval if the shape index >1.5, on the other hand, it is considered spherical if the shape index <1.5.

2.1.3. Surface area

Surface area is defined as the total area over the outside of the onion with the roots and tops removed. The surface area is measured by wrapping aluminum foil around the onion bulb and then cutting the foil away with scissors into thin strips sufficient to lay the foil flat. A planimeter was used to measure the area of the foil which represents the surface area of the onion concerned (Maw et al., 1996).

2.1.4. Moisture content

The moisture content of randomly selected onion bulbs from a 10 kg sample was determined according to ASAE standard (1984). Three samples of each variety bulbs were randomly selected and weighed on an electronic balance to a precision of 0.01 g.

2.1.5. Volume and density

The real density of samples was determined by the water displacement method. Fifteen bulbs of each sample were weighed and each one was dropped, separately into a 1000 ml measuring cylinder filled with distilled water up to 500 ml. The rise in water indicated the true volume of the bulbs. From the mass and the true volume of the bulbs, the real density was calculated. For each case, the determination was replicated five times and the mean was considered.

2.1.6. Rolling angle

To determine the rolling angle, the bulb to be tested was kept at the center of the working surface, (horizontal platform) in the most stable position (on their base) to prevent toppling over (top upwards). Then by rotating the handle at minimum speed, the platform was inclined until the bulb begins to roll. At this position, the turning of the handle was stopped and the angle of inclination of the platform was read by protractor. The platform was returned to the initial horizontal position for the next test. The next test was the same but in non-

stable position of the bulb (on their side). For each bulb the average of three angles of rolling were determined, for both the stable and non-stable positions (Buyanov & Voronyuk, 1985).

2.1.7. Coefficient of static friction

Coefficient of static friction is the ratio of the force required to slide the bulb over a surface divided by the normal force pressing the bulb against the surface. Coefficients of friction were determined for onion bulbs on three surfaces: rubber, galvanized steel and plywood. The material surface was fastened to tilting table. A frame made with a square wooden bars was placed on the surface. The frame was filled with bulbs. The table was tilted slowly manually until movement of the whole bulb mass. The coefficient of friction was the tangent of the slope angle of the table measured with a protractor (Oje & Ugbor, 1991).

2.1.8. Crushing load

Crushing implies the partial or complete destruction of onion. Onion was set upon a flat plate until the cross-head of a hand made apparatus was brought in contact with the onion and a compression force was applied by adding weights or loads until permanent (destruction) was caused and then the loads were recorded.

2.1.9. Puncture or penetration load

Puncture load is the force required for pushing a probe into a product to a depth that causes irreversible crushing. It was given as an indicator of the mechanical strength of the onion to withstand mechanical harvesting and postharvest handling. A head of a flat-end probe (3.0 mm diameter) was used to measure the puncture resistance of the onion bulb. Onion bulbs were supported at such one angle, so as to enable the probe will be able to penetrate the onion through the shoulder of the onion (45° angle from the polar axis). Force required to penetrate the onion was taken when a complete penetration for all ranges was happened.

Statistical analysis was carried out according to Frennd and Lihell (1981). Analysis of variance for the data of Tables 4 and 5 was applied followed by LSD (at 0.05) to carry out the multiple comparison. Mean, standard deviation (SD) and coefficient of variation (CV) for the data of Tables 1–3, 6 and 7 were calculated.

3. Results and discussions

3.1. Physical properties

3.1.1. The equatorial and polar diameters, and shape index

Table 1 shows the mean values, SD and CV of the equatorial and polar diameters and shape index of bulbs

Table 1
The mean equatorial diameter, polar diameter and shape index for some onion cultivars

	Equatorial diameter (cm)	Polar diameter (cm)	Shape index
<i>Giza 6 (white)</i>			
Mean	5.54	5.91	1.97
SD	0.79	1.30	0.13
CV (%)	14.26	21.96	13.57
<i>Beheri (red)</i>			
Mean	5.75	6.20	0.96
SD	0.86	1.59	0.14
CV (%)	14.88	25.67	14.46
<i>Giza 20 (yellow)</i>			
Mean	5.17	5.71	0.92
SD	0.55	0.70	0.10
CV (%)	10.60	12.17	11.26

SD is the standard deviation.

CV is the coefficient of variation (%).

Table 2
Geometric mean diameter (D_{gm}), arithmetic mean diameter (D_{am}), frontal surface area ($A_{f,s}$), cross-sectional of area ($A_{c,s}$), and mass of some onion cultivars

	D_{gm} (cm)	D_{am} (cm)	$A_{f,s}$ (cm ²)	$A_{c,s}$ (cm ²)	Mass (g)
<i>Giza 6 (white)</i>					
Mean	5.72	5.74	26.29	26.68	91.96
SD	1.05	1.06	8.64	9.35	47.56
CV (%)	18.33	18.41	32.86	35.05	51.72
<i>Beheri (red)</i>					
Mean	5.98	6.01	28.81	29.52	115.29
SD	1.26	1.28	11.09	12.46	76.55
CV (%)	21.09	21.30	38.51	42.21	66.40
<i>Giza 20 (yellow)</i>					
Mean	5.48	5.50	23.33	23.96	78.68
SD	0.58	0.59	4.66	4.95	24.18
CV (%)	10.65	10.65	19.99	20.66	30.73

Table 3
The mean, SD, and CV of the volume and density of onion cultivars

	Volume (cm ³)			Density (g/cm ³)		
	Giza 6 (white)	Beheri (red)	Giza 20 (yellow)	Giza 6 (white)	Beheri (red)	Giza 20 (yellow)
Mean	88.20	108.80	77.20	1.09	1.11	1.04
SD	50.10	75.81	25.76	0.12	0.15	0.09
CV (%)	56.78	69.68	33.36	10.70	13.45	8.24

of three onion cultivars. It shows that the average equatorial and polar diameters were 5.54 ± 0.74 and 5.91 ± 1.3 cm for the white onion, 5.75 ± 0.86 and 6.20 ± 1.51 cm for the red onion and 5.17 ± 0.33 and 5.71 ± 0.7 cm for the yellow onion. The CV of the polar diameter value was higher than that of equatorial diameter for all cultivars.

The average of 1.97 ± 0.13 shape index was estimated for the white onion while it was 0.96 ± 0.14 for the red onion and 0.92 ± 0.10 for the yellow onion. It indicated that the onion bulbs of both Beheri and Giza 20 are a spherical in shape. On the other hand, the shape of the onion bulbs of Giza 6 can be regarded as an oval according to Abd Alla (1993).

3.1.2. Geometric mean diameter (D_{gm}), arithmetic mean diameter (D_{am}), frontal surface area ($A_{f,s}$), cross-sectional of area ($A_{c,s}$), and mass

Table 2 shows the mean values, SD and CV of the D_{gm} , D_{am} , $A_{f,s}$, $A_{c,s}$, and mass of the three cultivars of onion. The $A_{f,s}$ and $A_{c,s}$ were 26.9 ± 8.64 and 26.68 ± 9.35 cm² for the white onion while, they were 28.8 ± 11.09 and 29.52 ± 12.46 cm² for the red onion and 23.33 ± 4.66 and 23.96 ± 4.95 cm² for the yellow onion, respectively. It can be seen that the D_{gm} , and D_{am} were similar for all cultivars under study. The average mass values were 91.96 ± 47.56 , 115.29 ± 76.53 and 78.63 ± 24.18 g for Giza 6 (white onion), Beheri (red onion) and Giza 20 (yellow onion), respectively. The CV for the mass of the red onion was 66.4% and it was higher than both those of the white and the yellow onions which recorded 51.72% and 30.73%, respectively.

3.1.3. The volume and the real density

Table 3 shows the mean values, SD, and CV of the volume and the true density of three onion cultivars. The overall mean volumes were 83.2 ± 50.0 , 108.8 ± 75.8 and 77.2 ± 25.7 cm³ for Giza 6 (white), Beheri (red) and Giza 20 (yellow) cultivars, respectively. The average densities were 1.09 ± 0.116 , 1.11 ± 0.15 , and 1.04 ± 0.09 g/cm³ for the same previous order.

The CV values of the volume readings for red onion were higher than those of both white and yellow onion bulbs. The same trend was happened with the density values.

3.2. Mechanical properties

3.2.1. Rolling angle

Table 4 shows the average rolling angle in a stable (on their bases) and non-stable (on their sides) positions of three cultivars of onion (Giza 6, Beheri and Giza 20) on three different surfaces (rubber, plywood, and galvanized steel) for three sizes (small, medium and large). In a stable position, The highest rolling angle value (31.33°) was recorded for the large size of Giza 6 onion variety on the plywood surface, meanwhile the lowest rolling angle value (20.30°) was recorded for the small size of Giza 20 onion variety on the galvanized steel surface. In non-stable position, The highest rolling angle value (23.33°) was recorded for the medium size of Beheri onion variety on the rubber surface, and the lowest rolling angle value (14.33°) was recorded for the large

Table 4
Rolling angle for some onion varieties in a stable and non-stable positions

Onion varieties	Giza 6 (white)			Beheri (red)			Giza 20 (yellow)				
	Rubber	Galva. steel	Plywood	Rubber	Galva. steel	Plywood	Rubber	Galva. steel	Plywood		
<i>Rolling angle (°) in a stable position</i>											
Small	27.33 abc	22.67 cdef	22.67 cdef	28.67 abc	23.67 bcdef	18.0 fg	25.3 abcde	20.3 defg	22.67 cdef		
Medium	27.69 abc	23.33 cdef	24.67 abcde	29.00 abc	29.33 abc	25.67 abcde	27.6 abc	21.0 defg	22.33 cdef		
Large	30.67 a	24.67 abcde	31.33 a	31.30 a	29.3 abc	27.00 abc	29.67 ab	24.67 abcde	24.0 bcdef		
LSD at 0.05	6.02										
<i>Rolling angle (°) in non-stable position</i>											
Small	20.0 abc	17.33 def	19.0 bcd	22.33 ab	18.33 cde	14.67 efg	19.33 bcd	17.33 def	18.33 cde		
Medium	19.67 abc	21.0 abc	16.67 def	23.33 a	22.0 ab	14.67 efg	20.67 abc	17.33 def	19.0 bcd		
Large	20.33 abc	21.33 abc	17.33 def	21.33 abc	19.00 bcd	14.33 fg	21.00 abc	20.00 abc	17.00 def		
LSD at 0.05	3.70										
Cultivars	Mean	Surfaces	Mean	Sizes	Mean	Cultivars	Mean	Surfaces	Mean	Sizes	Mean
<i>The overall average of the rolling angle on a stable position</i>						<i>The overall average of the rolling angle on none-stable position</i>					
Giza 6	24.89	Rubber	23.70	Small	23.68	Giza 6	18.89	Rubber	18.52	Small	16.78
Beheri	26.11	Galva. steel	25.33	Medium	23.63	Beheri	19.19	Galva. steel	19.37	Medium	19.30
Giza 20	24.11	Plywood	26.07	Large	28.00	Giza 20	18.89	Plywood	19.07	Large	20.89
LSD at 0.05	6.02					3.70					

size of the same onion variety but on the plywood surface.

Generally, the rolling angle on stable position was higher than that on the non-stable position where, it ranged from 20.30° to 31.33° on the stable position and 14.33–23.33° on the non-stable position, this trend was in agreement with that obtained by El-Khawaga (1999).

The results of the analysis of variance performed on the rolling angle data on both stable and none-stable positions of the onion cultivars with different sizes which obtained at the various surfaces. In stable position, the analysis indicated that the differences between the average rolling angles for various cultivars at various surfaces and different sizes were none significant. In the non-stable position, the analysis indicated that the differences between the average rolling angles for various cultivars at the various surfaces were none significant, while, the differences between the average rolling angles recorded for different sizes were significant at 0.05 level.

3.2.2. Coefficient of friction

Table 5 shows the mean values of static friction of three cultivars and three sizes (small, medium, and large) of onion bulbs on three surfaces (rubber, galvanized steel, and plywood). The results show that, coefficient of friction values ranged from 0.85 to 1.02, 0.67 to 1.34 and 0.85 to 1.15 for the white, red and yellow onions, re-

spectively. The highest coefficient of friction was obtained by the plywood followed by rubber and galvanized steel surface for all onion size and cultivars. This trend of these results is in agreement with that obtained by Helmy (1995) and Saif and Bahnasawy (2002).

The results of variance analysis performed on the coefficient of friction data of the onion cultivars with different sizes which obtained at the various surfaces indicated that the differences between the average coefficients of friction for the onion cultivars and different sizes were non-significant, while, the differences between the average coefficients of friction recorded on different surfaces were significant.

3.2.3. Crushing load

Table 6 shows the mean values, SD and CV of the crushing load of three onion sizes and cultivars. The results show that the crushing load increase with the increase of onion bulb size (bs) for all cultivars. For all sizes of white onion, the average crushing load was ranged from 443.3 to 819.7 N. This range was from 341.4 to 980.7 N for the red onion and from 400 to 780 N for the yellow onion.

Regression analysis was used to obtain an equation to describe the relationship between the crushing load (CL) and the onion bulb size (bs). The bs ranged from 2 to

Table 5
Coefficient of friction for some onion varieties

Onion varieties	Giza 6 (white)			Beheri (red)			Giza 20 (yellow)		
	Rubber	Galva. steel	Plywood	Rubber	Galva. steel	Plywood	Rubber	Galva. steel	Plywood
Small	1.02 df	0.92 ef	1.05 cd	1.3 bc	1.01 df	1.34 bc	1.08 cd	0.99 df	1.15 c
Medium	0.92 ef	0.86 ef	0.95 def	1.01 df	0.99 df	1.04 df	0.90 ef	0.86 ef	0.94 def
Large	0.88 ef	0.85 ef	0.90 ef	0.69 fg	0.67 fg	0.71 fg	0.88 ef	0.85 ef	0.90 ef
LSD at 0.05 0.17									
Cultivars	Mean	Surfaces	Mean	Sizes	Mean				
<i>The overall average of the coefficient of friction</i>									
Giza 6	0.97	Rubber	1.11	Small	0.99				
Beheri	0.92	Galva. steel	0.92	Medium	0.88				
Giza 20	0.94	Plywood	0.81	Large	0.96				
LSD at 0.05 0.17									

Means followed by the same letters are none significant.

Table 6
Crushing load for onion cultivars

Sizes	Onion cultivars	Crushing load (N)		
		Giza 6 (white)	Beheri (red)	Giza 20 (yellow)
Small	Mean	443.30	341.40	400.00
	SD	3.10	4.57	2.50
	CV (%)	6.97	13.38	10.50
Medium	Mean	676.7	803.3	678.7
	SD	3.31	4.20	0.67
	CV (%)	4.89	5.23	0.98
Large	Mean	819.70	980.70	780.00
	SD	8.41	2.10	4.10
	CV (%)	10.26	2.14	5.24

8 cm. The best fit for the data of the overall average of the three cultivars were:

$$CL = 271.50 \ln(bs) + 243.05 \quad (R^2 = 0.99) \quad (6)$$

3.2.4. Penetration load

Table 7 shows the mean values, SD, and CV of the penetration load for three onion sizes and cultivars. There were no significant differences between the cultivars in the resistance to penetration. The lowest penetration load was recorded for the white onion cultivars (26.9 N) whereas, the highest value was recorded for the yellow onion (45 N). This may be due to there was no hard scale on the white onion compared with the red and the yellow onions.

Regression analysis was used to obtain equation to describe the relationship between the penetration load (PL) and the onion bs (bs). The bs ranged from 2 to 8 cm. The best fit for the data of the overall average of the three cultivars were:

$$PL = 11.03 \ln(bs) + 19.87 \quad (R^2 = 0.98) \quad (7)$$

Table 7
Penetration load for onion some cultivars

Onion cultivars		Penetration load (N)		
		Giza 6	Beheri	Giza 20
Small	Mean	26.90	26.10	27.60
	SD	0.49	0.47	0.40
	CV (%)	18.29	12.09	14.35
Medium	Mean	33.50	38.60	42.90
	SD	0.27	0.71	0.69
	CV (%)	8.06	19.77	16.11
Large	Mean	35.90	43.00	45.00
	SD	0.44	0.56	0.51
	CV (%)	12.31	13.14	11.60

4. Conclusions

This work focuses on some physical and mechanical properties of three common cultivars of the onion bulbs in Egypt. The physical properties were equatorial and polar diameters, shape index, volume, density, mass and surface area. The mechanical properties were the rolling angle, coefficient of friction, crushing load, and penetration resistance. The following conclusions could be made:

- The equatorial and polar diameters ranged from 5.12 ± 0.33 to 6.20 ± 1.5 cm for all cultivars with CV ranged from 11% to 25%.
- Both of red and yellow onion bulbs were spherical in shape while the white onion was regarded as an oval.
- The geometric mean diameter (D_{gm}) ranged from 5.48 to 5.98 cm, the arithmetic mean diameter (D_{am}) ranged from 5.50 to 6.01 cm, frontal surface area ($A_{f,s}$) ranged from 23.3 to 28.81 cm² and the cross-sectional of area ($A_{s,c}$) ranged from 23.96 to 29.52 cm² and mass ranged from 78.7 to 115.39 for all onion cultivars.

- The volume ranged from 77.2 ± 25 to 108.8 ± 75 cm³ with CV ranged from 33.4% to 69.7% for all cultivars.
- The density ranged from 1.04 ± 0.09 to 1.11 ± 0.15 g/cm³ with CV ranged from 8.04% to 13.5% for all cultivars.
- The rolling angle ranged from 20° to 31° for a stable position and from 14° to 23° for non-stable position for all cultivars. The highest values of rolling angle were offered by the rubber surface followed by plywood and galvanized steel surfaces.
- The coefficient of friction (f) ranged from 0.67 to 1.34 for all onion cultivars. The highest (f) was offered by plywood surface followed by rubber and the galvanized steel surfaces.
- Crushing load increased with the increasing of onion bs. It was ranged from 443.3 to 819.7 N for white onion, 341.4–980.7 N for red onion and from 400 to 780 N for the yellow onion.
- Penetration load increased with the increasing of onion bulb size. It was ranged from 26.9 to 35.9 N for white onion, 26.1–43.0 N for red onion and from 27.6 to 45.5 N for the yellow onion.

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