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Some Physical and Mechanical Properties of Garlic

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Abstract

The physical parameter results showed that the garlic geometric and arithmetic mean diameters ranged from 2.53 to 4.93, and 2.53 to 5.02 cm, respectively according to the bulb size categories. The cloves' length, width and thickness were 1.92 to 2.91, 0.78 to 1.32, and 0.69 to 0.99 cm, respectively. The surface and cross-sectional of areas ranged from 53.31 to 136.4 and 29.1 to 128.4 cm2, respectively. The number of cloves ranged from 18 to 51/bulb according to the bulbs size categories. Bulk density, repose angle and coefficient of contact surface values ranged from 892 to 1007 kg/m3, 41.52 to 45.04º, and 0.91 to 1.12, respectively, according to the bulb size categories.

The chemical properties showed that the emptying (friction) angle ranged from 23.25 to 28.82º, where small bulbs recorded the highest values on the concrete surfaces, while the lowest values were recorded by the large bulbs on the iron surfaces. The friction coefficient decreased with increasing bulb size, where it was the highest (0.8) for the small bulbs on the concrete surfaces; on the other hand, the lowest values (0.36) were recorded for the large bulbs on the iron surfaces. The crushing load of the cloves ranged from 55.6 to 155.0 N, depending on the bulb size. The force required for loosening the cloves from the bulb ranged from 110 to 272 and 101 to 320 N on the horizontal and vertical positions of the bulbs.

KEYWORDS: garlic, physical, mechanical, properties

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1. INTRODUCTION

Garlic, *Allium sativum*, L., has been cultivated since ancient times all over the world especially in Asia. It ranks second in the Liliaceae family. Garlic has medicinal properties and it is an important ingredient of the most spice cooking around the world. Garlic as a spice is utilized in both fresh and dehydrated state in the food industry. It is dehydrated into different products such as flakes, slices and powder (Ahmad, 1996). Garlic is mainly consumed as a condiment in various prepared foods such as mayonnaise and tomato sauce, salad dressing, meat sausage and pickled products.

Garlic does not produce seeds, it must be propagated vegetatively with garlic cloves as the most common planting material. Yield, yield components and quality of garlic are affected by planting methods, cloves rates and size (Nourai, 1994 and Marijana, 1996).

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 (Irvine, Jayas, White and Britton, 1992; and El-Raie, Hendawy and Taib, 1996, Bahnasawy et al., 2004). 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 and Viswanathan, 1999). Abd Alla, Radwan and El-Hanfy (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

Haciseferogullari, Ozcan, Demir and Calisir (2005) studied some nutritional and technological properties of garlic. They concluded that the mean mass, mass weight of 1000 garlic segment, length of segment, diameter of whole garlic, geometric mean diameter, sphericity, projected area, volume, bulk density, porosity, and hardness of segments were 32.81g, 2383.8g, 27.24 mm, 46.51 mm, 15.15 mm, 0.559, 4.54 cm^2, 2245.64 mm^3, 478.75 kg/m^3, 54.61% and 13.78 N, respectively. Also, static and dynamic coefficient of friction of garlic segments on a galvanized sheet, an iron sheet and plywood were found as 0.352 to 0.416, 0.406 to 0.472, and 0.481 to 0.541, respectively.

Masoumi, Tabil and Akram (2003) reported that, the static friction against three surfaces (galvanized steel, Plexiglas and rubber), empty and filling angles of repose and terminal velocity of cloves were measured at a moisture content range from 34.9 to 56.7% wet basis. The maximum and minimum values of coefficient of friction were 74% for white garlic against rubber surface at moisture content of 56.7% and 26% for pink garlic against galvanized steel at 35.26% moisture content, respectively. The maximum value of filling angle of repose was 43.5º for the white garlic cloves at 55.7% moisture content while, the minimum value was 36.1º for pink garlic at 35.26% moisture content. The white garlic cloves had minimum value of terminal velocity (9.82 m/min) at 34.9% wb, and maximum corresponding value was 16.66 m/min at 56.7% wb for pink cloves.

El-Gayar and Bahnas (2005) reported that, the mean values of sphericity and roundness of garlic cloves were 0.43 and 0.19 for the Sidth-40 variety, while they were 0.62 and 0.40 for Baladi variety. The mean weight of Sidth-40 and Baladi cloves were 2.46 and 1.90 g, respectively. The mean length, width and thickness of both varieties ranged from 22.9 to 28.7, 14.13 to 14.5, 9.0 to 13.13 mm. The surface area and bulk density values ranged from 186.27-253.6 mm^2, and 0.92-0.99 g/cm^3, respectively, for both variety cloves. The mean values of sliding friction coefficient of the cloves ranged from 0.50 to 0.56, 0.47 to 0.50, and 0.33 to 0.40 against stainless steel, galvanized steel and plywood, respectively, for both varieties. The mean values of repose angle and hardness for the cloves ranged from 42.65 to 44.15 º and 17.13 to 18.23 N, respectively, for both variety cloves.

Lack of basic engineering properties of this planting material is an identified problem in the development of new methods of sowing of garlic crop, development of new equipment for processing and control strategies for crop storage. So that, the main objective of this work was to study some physical and mechanical properties of garlic. These properties include: linear dimensions, shape index, geometric mean diameter, arithmetic mean diameter, frontal surface area, cross-sectional of area, volume, mass, bulk density, static friction coefficient, rolling angle, crushing load and force required to loosening the cloves from the whole bulb.

2. Materials and methods

2.1 Materials:

The garlic bulbs (Egyptian Baladi variety) were brought from the local market after harvesting with the same maturity stage, then inspected and graded into three categories according to the Egyptian Organization of Controlling the Export Standard, {< 4 cm (small), from 4 to 6 cm (medium) and > 6cm (large)}. These categories were used to measure and determine the physical and mechanical properties.

2.2 Methods:

2.2.1 Physical properties:

- Linear Dimensions:

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

$$\text{Geometric mean diameter } (D_{gm}) = (D_e D_p T)^{0.333}, \quad \text{cm} \tag{1}$$

$$\text{Arithmetic mean diameter } (D_{am}) = \frac{(D_e + D_p + T)}{3}, \text{ cm} \tag{2}$$

$$\text{Surface area (SA)} = \frac{\pi}{4} D_e D_p, \text{ cm}^2 \tag{3}$$

$$\text{Cross - sectional area (CSA)} = \frac{\pi}{4} \frac{(D_e + D_p + T)^2}{3}, \text{ cm}^2 \tag{4}$$

- Shape Index:

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

$$\text{Shape Index} = \frac{D_e}{\sqrt{D_p * T}} \tag{5}$$

The garlic 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.

- Surface Area:

Surface area is defined as the total area over the outside of the garlic with the roots and tops removed. The surface area is measured by wrapping aluminum foil around the garlic 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 garlic concerned.

- Volume and Density:

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

2.2.2 Mechanical properties:

- Friction angle:

To determine the friction 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. For each bulb the average of three angles of friction were determined (Buyanov and Voronytik, 1985).

- 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 garlic bulbs on three surfaces: concrete, galvanized steel and plywood. The material surface was fastened to tilting table. A frame made with 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 and Ugbor, 1991).

- Crushing load:

Crushing implies the partial or complete destruction of cloves. Clove was sat upon a flat plate until the cross-head of a hand made apparatus was brought in contact with the clove and a compression force was applied by adding weights or loads until permanent (destruction) was caused and then the loads were recorded (Maw et al., 1996).

- The Force required for loosening the cloves from the whole bulb:

The Force required for loosening the cloves from the whole bulb was determined by placing the whole bulb upon a flat plate until the cross-head of a hand made apparatus was brought in contact with the bulb and a compression force was applied by adding weights or loads until loosening the all cloves from the bulb was occurred and then the loads were recorded.

Statistical analysis was carried out according to Frennd and Lihell (1981). Analysis of variance for the data of tables 1 to 8 was applied followed by LSD (at 0.05) to carry out the multiple comparison.

3. RESULTS AND DISCUSSIONS

3.1. Physical Properties

3.1.1 The Geometric mean diameter, arithmetic mean diameter and shape index:

Table (1) shows the mean (mean±SD) values, SE and CV of the geometric mean diameter, arithmetic mean diameter and shape index of the garlic bulbs. It shows that the average the geometric and arithmetic mean diameters were 2.53 ±0.45 and 2.53 ± 0.3 cm for the small size of garlic bulbs, while, they were 3.86 ± 0.25 and 3.91 ± 0.35 cm for the medium size of garlic bulbs and 4.93 ± 0.45 and 5.02 ± 0.58 cm for the large size of garlic bulbs. The CV of the geometric diameter, arithmetic diameter and shape index values of the small bulb sizes were higher than those of for medium and large sizes.

The average of 1.36±0.32 shape index was estimated for the small garlic bulb, while it was 1.38 ± 0.12 for the medium size of garlic bulbs and 1.50 ± 0.10 for the large size of garlic bulbs. It indicated that the garlic bulbs of all sizes are a spherical in shape according to Abd-Alla (1993). Shape index is very important in designing sorting and grading machines, also it is used in peeling machines.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the geometric and arithmetic diameters as well as shape index as affected by the size of garlic bulb are presented in Table 1. The analysis indicated that the differences between the average geometric and arithmetic diameters of the various bulb sizes were significant. While the differences between the shape index values were none significant.

3.1.2. The length, width and thickness of garlic cloves.

Table (2**)** shows the length, width and thickness of different sizes of garlic cloves, it can be seen that the cloves length ranged from 1.92 to 2.91 cm with coefficient of variation range from 11.98 to 17.18% depending on the bulb size. The average of 0.78 ± 0.11 cm cloves width was measured for the small garlic bulb, while it was 0.93 ± 0.0.31 cm for the medium size of garlic bulbs and 1.32 ±

0.37 for the large size of garlic bulbs. The cloves thickness values were 0.69 ± 0.09, 0.0.73 ± 0.22, and 0.99 ± 0.28 cm for the small, medium and large size of garlic bulbs. Fig. 1 shows the frequency distribution of the linear dimensions of the garlic cloves.

Table 1 : The geometric, arithmetic mean diameters and shape index for garlic bulbs (n=15).

	Geometric mean diameter (cm)	Arithmetic mean diameter (cm)	Shape index
Small size			
Mean	2.53a	2.53a	1.36a
SE	0.12	0.08	0.08
CV,%	19.48	10.23	23.53
Medium size			
Mean	3.86b	3.91b	1.38a
SE	0.07	0.09	0.03
CV,%	7.20	7.32	8.70
Large size			
Mean	4.93c	5.02c	1.50a
SE	0.12	0.15	0.03
CV,%	10.37	9.11	6.80

Means followed by the same letters are none significant.
SE is the standard Error
CV is the coefficient of variation, %.
n is the number of samples

Table 2 : The length, width and thickness of garlic cloves.

	Length (cm)	Width (cm)	Thickness (cm)
		Small size	
Mean	1.92a	0.78a	0.69a
SE	0.06	0.03	0.02
CV,%	11.98	14.10	13.04
		Medium size	
Mean	2.41b	0.93b	0.73a
SE	0.10	0.08	0.06
CV,%	16.18	33.33	30.14
		Large size	
Mean	2.91c	1.32c	0.99b
SE	0.13	0.10	0.07
CV,%	17.18	28.03	28.28

Means followed by the same letters are none significant.

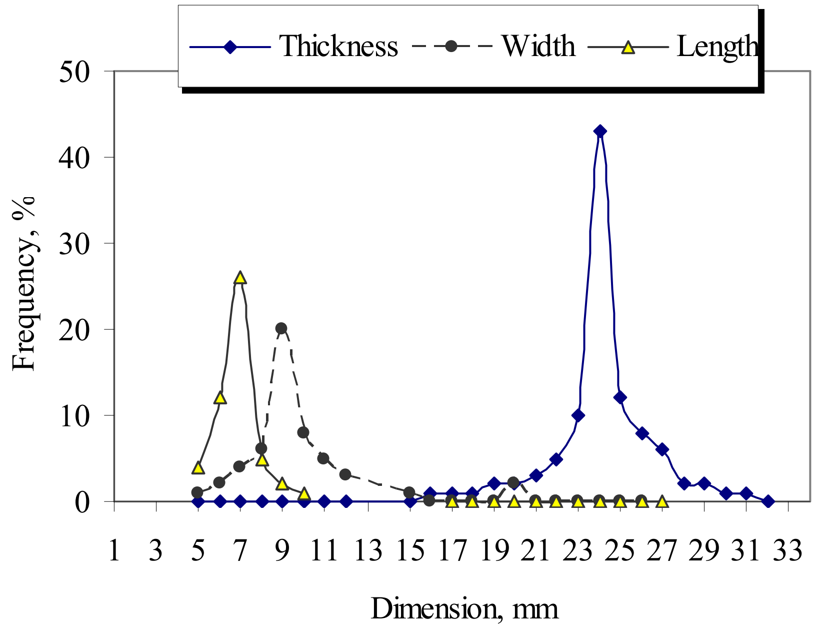

Figure 1. The frequency distribution curves for linear dimensions of the garlic cloves.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the length, width and thickness of the garlic cloves are presented in Table (2). The analysis indicated that the differences between the average lengths and widths of the garlic cloves of the various clove sizes were significant. While the differences between the average thickness of both small and medium sizes were none significant.

3.1.3 Surface area, cross-sectional of area, volume, number of cloves/bulb, bulb mass, and ratio of cloves mass to the whole mass of bulb.

Table (3) shows the mean values of the surface area, cross-sectional of area, volume, bulk density, number of cloves/bulb, bulb and clove masses, ratio of cloves mass to the whole mass of bulb and the cross-sectional of area of cloves.

The surface and cross-sectional of areas were 53.31±8.85 and 29.10±5.75 cm^2 for the small size of garlic bulbs, while, they were 82.89±11.87 and 72.10±10.11 cm^2 for the medium size and 136.37±17.71 and 128.35±22.23 cm^2 for the large size, respectively. Those kinds of areas are very useful in determination of heat transfer during heating and cooling processes.

Table 3: The mean of surface area, cross-sectional of area, volume, number of cloves/bulb, bulb mass, and ratio of cloves mass to the whole mass of bulb.

	Bulb size		
	Small	Medium	Large
Surface area (cm^2)	53.31±8.85a	82.89±11.87b	136.37±17.71c
Cross-sectional of area (cm^2)	29.10±5.75a	72.10±10.11b	128.35±22.23c
Volume (cm^3)	16.60±4.97a	36.90±6.76b	84.70±6.67c
Mass of whole bulb (g)	16.72±3.78a	36.68±6.31b	75.53±11.12c
Bulk Density (kg/m^3)	1007±0.76c	994±0.93b	892±1.67a
Number of cloves/bulb	17.8±4.34a	37.4±5.52b	50.7±14.64c
Clove mass (g)	0.67±0.23a	1.12±0.76b	2.40±1.28c
Cloves mass /total bulb mass (%)	94.20±2.70a	94.40±1.50a	93.90±1.50a
Cross-sectional of clove area (cm^2)	0.44±0.10a	0.58±0.30a	1.07±0.44b

Means followed by the same letters are none significant.

The average volume values were 16.60±4.97, 36.68±6.31 and 84.70±6.67cm^3 for the small, medium and large size of garlic bulbs, respectively. The mean values of bulb mass were 16.72±3.78, 36.68±6.31 and 75.53±11.12 g for the small, medium and large size of garlic bulbs, respectively. The bulk density decreased with increasing the garlic bulb size, it decreases from 1007±0.76 kg/m^3 for the small size to 994±0.93 and 892±1.67 kg/m^3 for the medium and large garlic bulb sizes, respectively. The number of cloves/bulb increases with increasing the bulb size, where, the mean values were 17.8±4.34, 37.4±5.52, and 50.7±14.64 for the small, medium and large size of garlic bulbs, respectively. These properties are very important in designing the storage rooms, hoppers of planting machines and capacity of the transportation tools.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the surface area, cross-sectional of area, volume, number of cloves/bulb, bulb mass, and ratio of cloves mass to the whole mass of bulb are presented in Table (3). The analysis indicated that the differences between the average the surface area, bulb cross-sectional of area, volume, bulk density, number of cloves/bulb, bulb and clove masses, and ratio of cloves mass to the whole bulb mass of the various garlic bulb sizes were significant. While the differences between the average ratios of cloves mass to the whole bulb mass of all bulb sizes were none significant. The differences between the average cloves cross-sectional of area of both small and medium sizes were none significant.

3.2. Mechanical Properties

3.2.1 Repose angle (RA) and coefficient of contact surface (CCS) of garlic bulbs:

When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area, and coefficient of friction of the material. Material with a low angle of repose forms flatter piles than material with a high angle of repose. In other words, the angle of repose is the angle a pile forms with the ground. This property is sometimes used in the design of equipment for the processing of particulate solids. For example, it may be used to design an appropriate hopper or silo to store the material. It can also be used to size a conveyor belt for transporting the material. It can also be used in determining whether or not a slope will likely collapse; the talus slope is derived from angle of repose and represents the steepest slope a pile of granular material will take. This angle of repose is also crucial in determining the correct calculus of stability in vessels. Table (4) shows the mean, SE and CV of repose angle and coefficient of contact surface of garlic bulbs of three different sizes (small, medium and large).

Table 4: Repose angle and coefficient of surface contact of garlic bulbs.

	Repose angle	CCS
	Small size	
Mean	45.04a	0.91a
SE	0.28	0.13
CV,%	1.08	23.93
	Medium size	
Mean	43.42b	1.02a
SE	0.51	0.06
CV, %	2.02	9.52
	Large size	
Mean	41.52c	1.12a
SE	1.36	0.06
CV,%	5.66	7.00

Means followed by the same letters are none significant.

The results indicate that the repose angle decreases with increasing the bulb size, where it was 45.04±0.49º for the small size bulb, which decreased to 43.42±0.88 and 41.52±2.35º for the medium and large sizes, respectively. Also, the CV of the repose angle data increased with increasing the bulb size. This trend was in agreement with the results obtained by Masoumi et al. (2003).

Regression analysis was carried out to find a relationship between the repose angle and bulb size (bs). The following form was the most suitable to describe this relationship with high coefficient of determination:

$$RA = 47.73 - 0.088\,(bs) \qquad R^2 = 0.99 \qquad (6)$$

Where bs : is the bulb size (ranged from 2-7cm)

Concerning the coefficient of contact surface, the results in Table 4 indicate that the coefficient of contact surface increases with increasing the bulb size, where it was 0.91±0.22 for the small size bulb, which increased to 1.02±0.10 and 1.12±0.10 for the medium and large sizes, respectively. It can be noticed that, the CV of the coefficient of contact surface data decreased with increasing the bulb size, where, the small size recorded the highest value (23.93%), while, the medium and large sizes had 9.52 and 7.00% CV. The coefficient of contact surface is very important for designing the surfaces of handling, peeling and crushing machines.

Regression analysis was carried out to find a relationship between the coefficient of contact surface and bulb size (bs). The following form was the most suitable to describe this relationship:

$$CCS = 0.76 + 0.052\ (bs) \qquad R^2 = 0.99 \qquad (7)$$

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the repose angle and coefficient of contact surface of garlic bulbs of three different sizes (small, medium and large) are presented in Table (4). The analysis indicated that the differences between the repose angle of garlic bulbs of three different sizes (small, medium and large) were significant. While the differences between the average coefficients of contact surface of all sizes were none significant.

3.2.2 The friction angle:

Table (5) shows the mean values of friction angle of three sizes (small, medium, and large) of garlic bulbs on three surfaces (concrete, galvanized steel and plywood).

Table 5: The friction angle of different sizes of garlic bulbs on different surfaces.

	Galvanized steel	Plywood	Concrete
		Small size	
Mean	23.37c	28.85e	38.49g
SE	1.24	0.56	0.81
CV,%	9.20	3.33	3.65
		Medium size	
Mean	22.66b	27.26d	31.87f
SE	0.94	0.63	0.38
CV,%	7.21	3.98	2.03
		Large size	
Mean	20.03a	23.25c	30.86f
SE	0.14	0.53	0.99
CV,%	1.21	3.91	5.38

Means followed by the same letters are none significant.

The results indicate that the friction angle decreased with increasing the bulb size at all surfaces under study. The friction angle values ranged from 20.03 to 23.37º on the galvanized steel surface, whereas, it ranged from 23.25 to 28.85 and 30.86-38.49º on the plywood and concrete surfaces, respectively. It could be noticed that the values of friction angles recorded on the concrete surface were higher significantly than those obtained on both galvanized and plywood surfaces for all bulb sizes, which it maybe to the roughness of the concrete surface which is higher than both galvanized and plywood surfaces. The CV of the friction angle data decreased with increasing the bulb size, where, the small size recorded the highest value (9.20%) on the galvanized steel surface, while, the minimum value (1.21%) was recorded for the large size on the galvanized surface.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the friction angle at different surface and garlic bulbs sizes (small, medium and large) are presented in Table (5). The analysis indicated that the differences between the friction angle of garlic bulbs of three different sizes (small, medium and large) were significant. The lowest friction angle significantly (20.03º) was recorded for the large size of bulb at the galvanized steel surface, while the highest angle significantly (38.49º) was recorded for the small bulb size at the concrete surface.

Regression analysis was carried out to find a relationship between the friction angle (FA) and bulb size (bs) on different surfaces. The following forms were the best fit for these relationships:

$$FA = 26.20 - 0.84\,(bs) \qquad R^2 = 0.90 \qquad \text{(galvanized steel surface)} \tag{8}$$
$$FA = 33.45 - 1.40\,(bs) \qquad R^2 = 0.99 \qquad \text{(plywood surface)} \tag{9}$$
$$FA = 43.28 - 1.91\,(bs) \qquad R^2 = 0.99 \qquad \text{(concrete surface)} \tag{10}$$

3.2.3 Coefficient of Static Friction:

Table (6) shows the mean values of coefficient of static friction of three sizes (small, medium, and large) of garlic bulbs on three surfaces (concrete, galvanized steel and plywood). The results indicate that the coefficient of static friction decreased with increasing the bulb size on all surfaces. The coefficient of static friction values ranged from 0.36 to 0.43 on the galvanized steel surface, whereas, it ranged from 0.43 to 0.55 and 0.52 to 0.80 on the plywood and concrete surfaces, respectively.

It could be noticed that the values of coefficient of static friction recorded on the concrete surface were higher than those obtained on both galvanized and plywood surfaces for all bulb sizes, which it maybe owed to the roughness of the concrete surface which is higher than both galvanized and plywood surfaces. The CV of the coefficient of static friction data was the highest value (10.32%) on the galvanized steel surface for the small bulb size, while, the minimum value

(1.32%) was recorded for the large size on the same surface. This trend of these results was in agreement with that obtained by Haciseferogullar et al. (2005). This property is very useful in the product movements during the processing.

Table 6: The coefficient of static friction of three sizes of garlic bulbs on different surfaces.

	Galvanized steel	Plywood	Concrete
Small size			
Mean	0.43b	0.55c	0.80e
SE	0.03	0.01	0.02
CV,%	10.32	3.95	4.96
Medium size			
Mean	0.42b	0.52c	0.62d
SE	0.020	0.010	0.001
CV,%	8.07	4.62	2.51
Large size			
Mean	0.36b	0.43b	0.52c
SE	0.003	0.011	0.024
CV,%	1.32	4.39	6.63

Means followed by the same letters are none significant.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the coefficient of static friction at different surface and garlic bulbs sizes (small, medium and large) are presented in Table (6). The analysis indicated that the lowest coefficient of static friction significantly (0.36) was recorded for the large size of bulb at the galvanized steel surface, while the highest coefficient of static friction significantly (0.80) was recorded for the small bulb size at the concrete surface.

Regression analysis was carried out to find a relationship between the coefficient of static friction (CSF) and bulb size (bs) on different surfaces. The best fits for the data were as follows:

$CSF = 0.32 + 0.018\ (bs)$ $R^2 = 0.85$ (galvanized steel surface) (11)
$CSF = 0.35 + 0.030\ (bs)$ $R^2 = 0.92$ (plywood surface) (12)
$CSF = 0.30 + 0.070\ (bs)$ $R^2 = 0.97$ (concrete surface) (13)

3.2.4. The crushing load of the garlic cloves:

Table (7) shows the mean values, SE and CV of the crushing load of three sizes of garlic cloves. The results show that the crushing load increased with the increasing of cloves size. The average crushing load values were 55.60±17, 83.40±10.6 and 155.00±22.6 N for the small, medium and large sizes of garlic cloves, respectively. The CV of the crushing load data was the highest (30.6%) for the small size garlic cloves, while it was the lowest (12.7%) for the medium size of garlic cloves. The results indicate that the force required for crushing the large size cloves was 3 times what the small size cloves had.

Table 7: The mean values, SE and CV of the crushing force of garlic cloves.

Cloves Size	Crushing Load (N)		
	Mean	SE	CV, %
Small	55.60a	9.83	30.60
Medium	83.40b	6.13	12.70
Large	155.00c	13.07	14.60

Means followed by the same letters are none significant.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the crushing load of different garlic bulbs sizes (small, medium and large) are presented in Table (7). The analysis indicated that the differences between the average crushing loads of garlic bulbs of three different sizes were significant.

Regression analysis was used to obtain an equation to describe the relationship between the crushing force (CF) and the garlic cloves size (cs). The best fit for the data was:

$$CF = 100.55\ (cs) + 144.66 \qquad R^2 = 0.94 \qquad (14)$$

Where: cs is the clove size (1.9 to 2.9 cm)

3.2.5. Force required for loosening the garlic cloves from the whole bulb:

Table (8) shows the average, SE and CV of the force required for loosening the garlic cloves from the whole bulb on the horizontal and vertical positions. The results show that the force required for loosening the cloves from the whole bulb increases with increasing the bulb size on both horizontal and vertical positions, where, it ranged from 110±20.4 to 272±25.8 N on the horizontal position depending on the bulb size with coefficient of variation from 6.94-18.4%. This force ranged from 101±9.36 to 320±62.20 N on the vertical position with coefficient of variation from 6.94-18.4%. It is worthy to notice that the force required for loosening the cloves from the whole bulb on the vertical position for the large size is higher than that on the horizontal position for the same size, which maybe due to the presence of woody formation in the middle of the bulb which in turn increased the force required for loosening the cloves from the whole bulb on this position.

Table 8: Force required for loosening the garlic cloves from the whole bulb.

Sizes		Horizontal Position	Vertical Position
		Force (N)	
Small	Mean	110.00b	101.00a
	SE	11.79	5.41
	CV,%	18.40	9.29
Medium	Mean	189.00d	181.00c
	SE	7.57	1.73
	CV,%	6.94	1.66
Large	Mean	272.0e	320.00f
	SE	14.91	35.95
	CV,%	9.49	19.50

Means followed by the same letters are none significant.

Statistical analyses were performed on the experimental data to evaluate the significance of the differences in the force required for loosening the garlic cloves from the whole bulb on the horizontal and vertical positions of different garlic bulbs sizes (small, medium and large) are presented in Table (8). The analysis indicated that the differences between the average force required for loosening the garlic cloves from the whole bulb on the horizontal and vertical positions of garlic bulbs of three different sizes were significant. Where, the small size recorded the lowest value of force significantly (101 N) at the vertical position, while the large size of bulb gave the highest value of force required significantly (320 N) at the same position.

Regression analysis was used to obtain equation to describe the relationship between the force required for loosening the garlic cloves from the whole bulb (FL) and the garlic bulb size (bs). The bulb size ranged from 2 to 7 cm. The best fit for the data on the horizontal and vertical positions were:

$FL_1 = 40.5\ (bs) - 12.17 \quad (R^2 = 0.99)$ on the horizontal position (15)

$FL_2 = 54.75\ (bs) - 73.08 \quad (R^2 = 0.98)$ on the vertical position (16)

4. CONCLUSIONS

Recently, there has been a general recognition of the need to determine the physical and mechanical properties of the agricultural products. This is due to the problems that have been caused the developed mechanization and the application of engineering principles to agricultural production, processing, handling and automation. The properties of these products must be described in concise engineering terms which an engineer can utilize effectively in the design of specific machine and its operation, and the analysis of the behavior of these products in the handling of the material. In this present study, some physical and mechanical properties of the whole garlic bulbs and cloves were either measured or calculated. Empirical equations for the relationship between some properties and their sizes were obtained. Also, this work provides useful knowledge that help in designing peeling, and cutting machines; storage rooms and heating and cooling operation. It helps in designing the planting machines and the different component of handling unites during processing.

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