

PHYSICAL AND MECHANICAL PROPERTIES OF JOJOBA SEEDS

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ABSTRACT

A study was carried out to measure some of the most important physical and mechanical properties of freshly harvested jojoba seeds at initial moisture content of about 7 % \pm 1 (d.b). The studied physical properties included principal dimensions of jojoba seeds (length, width and thickness), geometric diameter, arithmetic diameter, shape index, seed volume, frontal area, arithmetic cross sectional area, surface area, surrounded surface area, sphericity, mass of 100 seeds, porosity, real density and bulk density (at loose and vibrated fill) . While the mechanical properties included, repose angle, seed hardness, shear force, crushing force and porosity of seeds. The obtained results showed that, the principal dimensions of jojoba seeds including length, width and thickness recorded values of (16.95, 13.13 and 11.78 mm) respectively. It was also recorded a volume of 1374.62 mm³, geometric diameter of 13.74 mm, arithmetic diameter of 13.95 mm, frontal area of 174.80 mm² and a sphericity of 81.19 % . The real density of jojoba seeds was 976.86 kg/m³. While, the bulk density recorded value of 602.10 and 630.33 kg/m³ under loosely and vibrated fill conditions respectively. The repose angle of jojoba seeds recorded a value of 29°, seed hardness of 153.19 N, shear force of 111.78 N at the longitudinal axis and 207.45 N at the transverse axis. The crushing forces of seeds were 302.95 and 295.25 N at the longitudinal and the transverse axis respectively. While, the recorded average of porosity was about 44.88 %. Mass of hundred seeds ranged from (99.15 to 109.20 g) with on average of 103.79 g.

INTRODUCTION

Oil seeds crops and their products are the most valuable agricultural crops in the world trade (Kadharmestan *et al.*, 1997). Sun flower, maize, soybean, and canola considered as the most important oilseed crops in Egypt. However during the last few years new seed crops such as jojoba has been introduced to the Egyptian agriculture as promising industrial crop (Ministry of Agriculture Statistics, 2007).

Jojoba [*Simmondsia chinensis*] belongs to the family simmondsiaceae is considered one of the new industrial oil seed crops. Selection over years has produced clones having potential seed yield of 3-4 ton per ha. Some of these clones are currently being planted in large areas in different countries (Melthorpe, 1998; and Tobares, *et al.*, 2004).

In Egypt the area planted with jojoba is over 762 fed. annually produce about 180 ton seeds and its plantations are concentrated in Ismailia and south Sinai governorates (Ministry of Agriculture Statistics, 2007). Regardless of the forecited economic benefits of jojoba plant products, planting jojoba shrubs in Egypt has a promising future specially because of its low water requirements and its high tolerance to salinity, as well as its ability to be planted in the new reclaimed lands or uncultivated ones . The

fruit of jojoba plant is a capsule of tan or brown color at maturation stage. It contains one to three dark brown seeds; at maturity, most of them vary in size and weight from 700 to 3500 seeds/kg, (Hogan *et al.*, 1980).

Oil crops such as Jojoba are processed into products derived by a partial removal of one of the major seed components, so it is important to understand the physical and mechanical characteristic of oil seeds that governing their response with the machines, processes, and handling operation which can be designed for maximum efficiency and highest quality of the end product. Meanwhile, the increasing economic important of oilseed crops together with complexity of modern technology for their production, handling, storage, processing, preservation, quality evaluation, distribution and marketing demands a better knowledge of the physical and mechanical properties of these materials (EL-Sahrigi, 1997; Matouk *et al.*, 2002) .

Many of research studies on physical and mechanical properties of the traditional oil seed crops such as maize, sunflower, soybeans, sesame, and canola have been conducted by Egyptian researchers (Owies, 1995; EL-Sahrigi, 1997; Matouk *et al.*, 2002; Tharwat, 2007). However limited studies were conducted on the new oil seed crops such as jojoba.

The main goal of the present study is to determine some of the most important physical and mechanical properties of jojoba seeds as a new and promising oil seed crop for Egyptian industry, beside the importance of these properties in the process of oil extraction.

MATERIALS AND METHODS

Materials:

Freshly harvested jojoba seeds used for the experimental work were harvested from the farm of jojoba trees (90 km from Cairo, Alex. desert road) at moisture content of about 7 % \pm 1 (d.b). The collected jojoba seeds were kept in plastic bags and stored temporarily in a freezer adjusted at temperature of (-5 °C) in order to suppress fungal growth and minimize quality changes.

Equipments, Measurements and Test Procedure:

Before each experiment, jojoba samples were taken out from the freezer and left at room temperature until the initial temperature of the seeds approached a level (at or around) that of the ambient temperature.

Measuring of physical and mechanical properties of jojoba seeds were carried out according to the following procedure.

Physical Properties

Physical properties of jojoba seeds included seed principal dimensions and related characteristics, mass of 100 seeds, the projection area, bulk and true density and porosity.

a - Moisture content of Jojoba seeds:

The oven drying method was used for determining moisture content of seeds. Five grams of jojoba seeds were crushed and then placed inside the oven at 130 \pm 2 °C until a constant weight was reached (based on Preliminary study on the crop), and then kept in a desecrator at the room temperature. The dried samples were weighed again using an electronic

digital balance and the moisture content of seeds was calculated in dry bases.

b - Seed dimensions:

A digital caliper model (Mitutoyo DAG-500, Japan) shown in figure (1) with accuracy of 0.01 mm, was used to measure the principal dimensions of jojoba seeds length (L), width (W) and thickness (T) in millimeters and the average Length, width and thickness of 100 seeds were considered.



Figure (1): Digital vernier caliber

C - Related characteristics of jojoba seeds:

1- Geometric mean diameter (D_g):

The geometric mean diameter of jojoba seeds was calculated using the following equation (Mohsenin, 1984).

$$D_g = (LWT_h)^{1/3}, \text{ mm} \dots\dots\dots(1)$$

2- Arithmetic mean diameter (D_a):

The arithmetic diameter of jojoba seeds was calculated using the following equation (Mohsenin, 1984).

$$D_a = (L+W+T_h) / 3, \text{ mm} \dots\dots\dots (2)$$

3- Seed volume (V_{cal})

The calculated volume of seeds could be obtained from the following equation (Mohsenin, 1984).

$$V_{cal} = (\pi/6) LWT_h \dots\dots\dots (3)$$

4- Sphericity (S):

The sphericity percent of jojoba seeds was calculated from the following equation (Mohsenin, 1984).

$$s = [(LWT_h)^{1/3} / L] \times (100) \dots\dots\dots (4)$$

where, 0 < s ≤ 100 %.

5- Frontal area (A_f):

The frontal area of jojoba seed was calculated using the following formula (Mohsenin, 1984).

$$A_f = (\pi/4)LW, \text{ mm}^2 \dots\dots\dots (5)$$

6- Cross sectional area (A_t):

The cross sectional area of jojoba seed was calculated using the following formula (Mohsenin, 1984).

$$A_t = (\pi/4)[(L+W+T_h) / 3]^2, \text{ mm}^2 \dots\dots\dots (6)$$

7- Surface area (A_s):

The surface area of jojoba seeds was calculated using the following formula (Deshpande *et al.*, 1993).

$$A_s = \pi D_{g2}, \text{ mm}^2 \dots\dots\dots (7)$$

8- Surrounded surface area (A_{ss})

The surrounded surface area was calculated from the following equation (El Raie *et al.*, 1996).

$$A_{ss} = (\pi/2) (L + D_g) (D_g), \text{ mm}^2 \dots\dots\dots (8)$$

9- Aspect ratios (R₁, R₂, R₃)

Three aspect ratios based on axial dimensions of seeds were developed as follows, (Tharwat, 2007).

$$R_1 = (L / W), \text{ decimal} \dots\dots\dots (9)$$

$$R_2 = (L / T_h), \text{ decimal} \dots\dots\dots (10)$$

$$R_3 = (W / T_h), \text{ decimal} \dots\dots\dots (11)$$

10- Shape index of seeds (k)

Seeds shape index (k) was calculated using the measured values of the principal dimensions of seeds and was used to describe shape of seeds using the following equation, (Tharwat, 2007).

$$K = L / (W.T_h)^{0.5}, \text{ decimal} \dots\dots\dots (12)$$

d- Mass of 100 seeds:

The mass of 100 seeds was determined using an electronic digital balance model (MFD-K 1000920, Japan) with maximum reading of 200 g and accuracy of 0.01 g. To determine the 100 seed mass, 10 samples of each of 100 seeds were weighted and the average of them was considered.

e- Real density:

The real density of jojoba seeds was calculated by dividing the weight of individual seed by its volume using toluene displacement methods as follows:

$$R_d = W_e / V \dots\dots\dots(13)$$

Where,

R_d = Real density of the individual seed, g/cm³.

W_e = Weight of seed, g.

V = Volume of seed, cm³.

f- Bulk density:

At loose fill condition:

Bulk density at loose seeds fill condition was determined by filling a known container volume with the seeds from a height of 150 cm at constant rate (Matouk, *et al.*, 2004), then the weight of seeds bulk was determined (3.25 kg) and the bulk density was calculated as shown in equation (14).

$$\text{Bulk density of seeds} = W / V_b \dots\dots\dots (14)$$

Where:

W =Weight of seeds bulk, kg.

V_b = Volume of seeds bulk, m³.

At vibrated fill condition:

Seeds bulk density at vibrated fill condition was determined by filling the same container with seeds under vibration using a laboratory seeds shaker figure (2) for two minutes. The bulk density of jojoba seeds was then calculated according equation (14).



Figure (2): Bulk density meter with shaker.

g- Porosity of jojoba seeds:

Porosity of jojoba seeds was determined as a percentage of volume of inters - seed space into the volume of seeds bulk using porosity measuring device shown in figure (3). The apparatus was development by (Mohsenin, 1984) and fabricated according to (Matouk, *et al.*, 2002).

The apparatus consists of two identical stainless-steel tanks sealed by compressed rubber covers. The first tank was connected to an air compressor, pressure reducer and control valves (1). The second tank was filled with seeds sample and connected to the control valve (2) and (3). A precise manometer was fixed to the main pipe for detecting the air pressure during different stages of measurement. Figure (3) shows the apparatus used for measuring seeds porosity.

Jojoba seeds were filled in tank (2) before closing both of valves (2 and 3). The air was supplied in tank (1), when a suitable manometer displacement was achieved, valve (1) was closed and the steady state pressure (p_1) was recorded. After that, valve (2) was opened keeping valves (1 and 3) closed. A steady state manometer reading (p_2) was recorded then, the porosity of jojoba seeds was found by the following formula:

$$P = (P_1 - P_2) / p_2 \dots\dots\dots (15)$$

Where,

- P = porosity of seeds, %
- P_1 = steady state pressure inside tank (1), bar
- P_2 = steady state pressure in both tank (1) and (2) together, bar

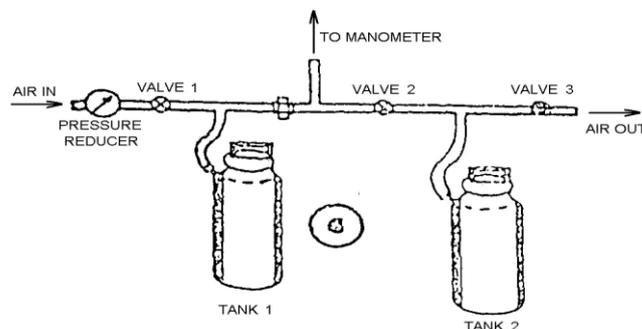


Figure (3): laboratory apparatus used for measuring jojoba seeds porosity.

2.2.2. Mechanical Properties:

a- Seeds repose angle:

Angle of repose apparatus designed by (Matouk, *et. al.*, 2006 a) was used for the experimental work. The apparatus consists of a wooden box with inner dimensions of 18 x 18 x 20 cm, three transparent plastic sided (left, right and front sides), where the front side is sliding up and down. Wooden parallelogram with a base fixed in the protractor was used to measure the angle between the base and the inclined of the formed cone due to a free side fall of the seeds as shown in figure (4).

In this test each seeds sample was taken randomly and then poured in the wooden box of the apparatus until completely filling the box (1.25 kg). The surface of the box is carefully leveled and the transparent sliding side is quickly taken up to give a chance for the seeds to flow down under natural slope forming an inclined angle between the box side and the horizontal surface of the table.



Figure (4): Repose angle meter.

b- Hardness, shear and crushing force of seeds:

Hardness, shear and crushing force meter model (FGN-50, USA) with an accuracy of 0.01 N, and a digital LCD was used for measuring seed hardness, shear and crushing force as follows.

1 - Seed hardness:

For measuring seed hardness, a seed was pressed by the conical end of the meter, while the digital reading was increased with the increasing of the pressure on the seed until it has been cracked.

At this point the displayed reading means seed hardness described by (Matouk, *et al.*, 2006 b). It should be mentioned here that each tested sample was represented by 10 seeds and only one reading was recorded for each seed.

2 - Seed shear force and shear stress:

Shear force was measured at both longitudinal and transverse axis. The conical end of the meter was changed to shearing edge (straight sharp edge), as shown in figure (5) and the previously mentioned procedure was used for measuring shear force at both seed axis.



Figure (5): Digital hardness and shear force gauge.

The average of 10 reading of shear force at the longitudinal axis was used for calculating shear stress at this axis using the following equation:

$$S_L = F_L / A_L \dots\dots\dots (16)$$

Where:

S_L : shear stress at seed longitudinal axis

F_L : shear force at seed longitudinal axis

A_L : cross section area of shear at seed longitudinal axis

The value of A_L for jojoba seed could be calculated using the following relationship:

$$A_L = (\pi / 4) . L . T_h \dots\dots\dots (17)$$

Also, the average of 10 reading shear force at transverse axis was used for calculating the shear stress at this axis using the following equation:

$$S_w = F_w / A_w \dots\dots\dots (18)$$

Where,

S_w : shear stress at seed transverse axis

F_w : shear force at seed transverse axis

A_w : cross section area of shear at seed transverse axis

The value of A_w for jojoba seed could be calculated using the following relationship:

$$A_w = (\pi / 4) . W . T_h \dots\dots\dots (19)$$

3 - Seed crushing force

Crushing force as a very important characteristic in oil extraction process was measured at both longitudinal and transverse axis. The conical end of the meter was changed to flat edge, and following the same procedure of hardness measurement.

RESULTS AND DISCUSSION

Physical properties of jojoba seeds:

Determinations of the main principal dimensions of jojoba seeds are very important for describing their technological characteristics and effectiveness in many respects. The dimensions of jojoba seeds (length, width and thickness) shape index, seed volume, frontal area, sphericity, mass of 100 seeds, real density and bulk density were measured and presented in tables (1).

Table (1): Physical properties of jojoba seeds:

Characteristics	Unit	Number of replication	Mean value	Max. value	Min. value	Standard deviation
Length	mm	100	16.95	18.82	13.52	0.91
Width	mm	100	13.13	14.67	10.84	0.87
Thickness	mm	100	11.78	13.30	9.08	0.74
Volume	mm ³	100	1374.62	1711.11	945.92	160.73
Geometric diameter	mm	100	13.74	14.80	12.15	0.55
Arithmetic Diameter	mm	100	13.95	14.95	12.43	0.53
Frontal area	mm ²	100	174.80	203.49	135.63	15.01
Arithmetic cross sectional area	mm ²	100	153.14	175.62	121.28	11.43
Sphericity	%	100	81.19	95.72	67.88	4.32
Shape index	decimal	100	1.37	1.78	1.06	0.11
Surface area	mm ²	100	593.82	688.11	463.68	46.72
Surrounded surface area	mm ²	100	663.04	758.40	533.39	48.71
Porosity	%	3	44.88	0.50	0.42	0.03
R1	decimal	100	1.30	1.67	1.02	0.11
R2	decimal	100	1.45	2.04	1.11	0.14
R3	decimal	100	1.12	1.31	1.00	0.08
Mass of 100 seeds	g	100	103.80	109.20	99.15	3.12
Real density	kg/m ³	5	976.86	989.35	841.33	61.89
Bulk density at loose seed fill	kg/m ³	5	602.10	629.07	564.94	33.16
Bulk density at vibrated seed fill	kg/m ³	5	630.33	644.16	615.87	11.31

As shown in (table 1), the principal dimensions of jojoba seeds length, width and thickness recorded values of (16.95, 13.13 and 11.78 mm) respectively.

Meanwhile, the volume of seeds recorded a mean value of (1374.62 mm³), geometric diameter of (13.74 mm), arithmetic diameter of (13.95 mm), frontal area of (174.80 mm²), and arithmetic cross sectional area of (153.14 mm²).

In (table 1) the sphericity of seeds and ranged from (67.88 to 95.72 %) with a mean value of 81.19 %, This results indicate that , jojoba seeds is quite close to the shape of a sphere which means that a sieving or separation machine with circular holes is suitable for separation process of jojoba seeds.

During unloading the seeds will roll a way too far from intended unloading spot.

On the other hands, the Porosity of seeds recorded a mean value of (44.88 %), shape index of (1.37), surface area of (593.82 mm²) and surrounded surface area of (663.04 mm²). Also, the average real density of jojoba seeds was 976.86 kg/m³ and the average values of bulk density which consider important for handling process were 602.10 and 630.33 kg/m³ at loosely and vibrated fill conditions respectively.

The table also shows that, the average jojoba mass was 1.03 g compared with 0.068 g for sunflower, 0.181 g for soybean and 0.003 g for canola as determined by (Tharwet, 2007). Thus, the jojoba seed has a bigger mass, that indicate higher percentage of oil in comparison with the previously mentions seeds.

Meanwhile, the three aspect ratios of jojoba seeds recorded mean values of (1.30, 1.45, 1.12) for (R₁, R₂ and R₃) respectively.

Figure (6) illustrates the frequency distribution curves of seed dimensions at moisture content of (7±1%) (d.b). As shown in the figure a trend towards a normal distribution was detected for all dimensions. This means that 85 % of jojoba seeds had lengths between 15 and 17 mm, 93 % had width between 12 and 14 mm and 97 % had thickness between 10 and 12 mm.

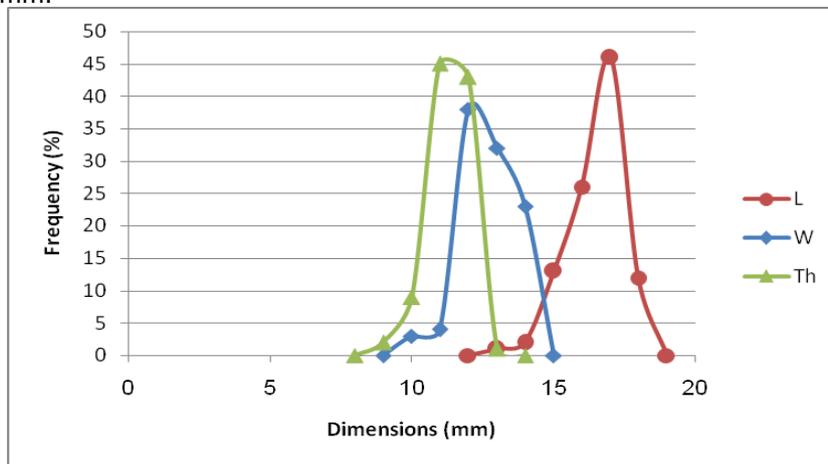


Fig (6): Frequency distribution curves for dimensions of jojoba seeds at (7±1 %) (d.b).

General expressions shown in (table 2) were used to describe the relationships between the average principal dimensions of jojoba seeds at (7 ± 1 %) (d.b.) moisture content as follow:

The coefficient of determination shows that the width, thickness, volume, geometric diameter, arithmetic diameter, frontal Area, arithmetic cross sectional area, surface area, surrounded surface area, sphericity, shape index and mass of one seed are highly correlated to each other

Table (2): General expressions describing the relationships between the length and the physical properties of jojoba seeds.

Characteristics	Symbol	Equation	Coefficient of determination, (R^2)
Width	W	$L = 1.289 W$	0.9872
Thickness	T_h	$L = 1.4368 T_h$	0.9837
Volume	V	$L = 0.0123 V$	0.9487
Geometric diameter	d_g	$L = 1.2331 d_g$	0.9944
Arithmetic diameter	d_a	$L = 1.2142 d_a$	0.9958
Frontal Area	A_f	$L = 0.0968 A_f$	0.9838
Arithmetic cross sectional area	A_t	$L = 0.1105 A_t$	0.9826
Surface area	A_s	$L = 0.0285 A_s$	0.9773
Surrounded surface area	A_{ss}	$L = 0.0255 A_{ss}$	0.9869
Sphericity	S	$L = 0.2086 S$	0.9925
Shape index	K	$L = 12.371 K$	0.9826
Mass of one seed	M	$L = 16.32 M$	0.9940

* L (Length of seed).

Mechanical properties of jojoba seeds:

Repose angle, seed hardness, shear force, and crushing force of seeds were measured and presented in table (3).

Table (3): Mechanical properties of jojoba seeds.

Characteristics	Unit	Number of replications	Mean value	Max. value	Min value	Standard Deviation (S.D)
Repose angle	Degree	5	29.00	29.00	29.00	0.00
Seed hardness	N	10	153.19	158.60	150.20	2.62
Shear force at the longitudinal axis	N	10	111.78	146.70	78.10	29.67
Shear force at the transverse axis	N	10	207.45	254.30	165.40	29.47
Crushing force at the longitudinal axis	N	10	302.95	385.40	202.90	58.43
Crushing force at the transverse axis	N	10	295.25	367.60	266.30	32.29

As shown in table (3), jojoba seeds repose angle, which considered as one of the mechanical properties needed for design of material handling system and storage facilities recorded a mean value of 29^0 .

Seed hardness, shear force at the longitudinal and transverse axis and the crushing force of seeds at the longitudinal and the transverse axis which are also considered important properties in designing vertical storage systems and in pressing process during oil extraction. As shown in table (3), the above mentioned properties recorded mean values of 153.19 N, 111.78 N, 207.45 N, 302.95 N and 295.25 N respectively.

CONCLUSIONS

The results of the studied physical and mechanical properties of jojoba seeds can be summarized as follows:

- 1- The dimensions of jojoba seeds including length, width and thickness recorded values of (16.95, 13.13 and 11.78 mm) respectively.
- 2- Jojoba seed recorded volume of (1374.62 mm³), geometric diameter of (13.74 mm), arithmetic diameter of (13.95 mm), frontal area of (174.80 mm²), arithmetic cross sectional area of (153.14 mm²), and a sphericity of (81.19 %).
- 3 - The porosity of seeds recorded a mean value of (44.88 %), shape index of (1.37), surface area of (593.82 mm²) and surrounded surface area of (663.04 mm²).
- 4- The average real density of jojoba seeds was 976.86 kg/m³. While, the average values of bulk density were 602.10 and 630.33 kg/m³ under loosely and vibrated fill conditions respectively.
- 5- The average repose angle of jojoba seeds recorded a value of 29°, seed hardness of 153.19 N, shear force of 111.78 N at the longitudinal axis and 207.45 N at the transverse axis.
- 6- The crushing forces of jojoba seeds were 302.95 and 295.25 N at the longitudinal and the transverse axis respectively. While, the recorded average of seeds porosity was about 44.88 %.
- 7- Weight of hundred seeds ranged from (99.15 to 109.20 g) with an average was 103.70 g.

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الخصائص الطبيعية والميكانيكية لحبوب الجوجوبا

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** قسم هندسة تصنيع و تداول المنتجات الزراعية , معهد بحوث الهندسة الزراعية .

- أجريت هذه الدراسة لقياس وحساب بعض الخصائص الطبيعية والميكانيكية لبذور الجوجوبا وشملت حجم وشكل البذرة، وزن المنه حبه، حجم وكثافة البذور، المسامية، زاوية التكوين للبذور، صلابة البذور، إجهاد القص وقوة الجرش وذلك عند محتوى رطوبى للبذور (7 ± 1%) على أساس جاف وكانت النتائج المتحصل عليها كما يلي:
- 1- أبعاد الجوجوبا والتي تشمل الطول والعرض والسمك سجلت القيم 16.95 و 13.13 و 11.78 (مم) على التوالي.
 - 2- حجم بذور الجوجوبا سجلت قيم (1374.62 مم³) والقطر الهندسى (13.74 مم) والقطر الحسابى (13.95 مم) والمساحة الأمامية للجوجوبا (174,80 مم²) وكانت مساحة المقطع (153.14 مم²) والكرويه (81.19%) مما يعنى اقترابها من الشكل الكروى.
 - 3- متوسط المسامية سجلت (44.88%) ومعامل الشكل كان (1.37) وكانت المساحة السطحية (593.82 مم³) ومساحة السطح المحيطية (663.04 مم³).
 - 4- كان متوسط الكثافة الحقيقية لبذور الجوجوبا (976.86 كجم / م³) بينما كانت متوسط قيم الكثافة الظاهرية (602.10 و 630.33 كجم / م³) تحت نظامى الملىء الحر و الملىء تحت إهتزاز على التوالي.
 - 5- متوسط زاوية التكوين لبذور الجوجوبا هى (29 درجة) وصلابه البذور (153.19 نيوتن) وقوة القص للبذور على المحور الطولى (111.78 نيوتن) وعلى المحور العرضى (207.45 نيوتن).
 - 6- قوة الجرش لبذور الجوجوبا (302.95 و 295.25 نيوتن) على المحورين الطولى والعرضى على الترتيب. كما كان متوسط المساميه للبذور (44.88%).
 - 7- تراوح وزن المائه حبه لبذور الجوجوبا بين (99.15 إلى 109.20 جرام) بمتوسط (103.79 جرام).

قام بتحكيم البحث

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