PROCESS ENGINEERING

SOME ENGINEERING PROPERTIES
OF COTTON SEEDS

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ABSTRACT

To design equipment for application in plantation, harvesting, ginning, transportation, storage, oil extraction and processing operations of cotton seeds, the knowledge of various engineering properties for cotton seeds. The study of experiments conducted on cotton seeds at 9.16 % moisture content on dry basis. The results showed that the average value of length, width, thickness, geometrical and arithmetic mean diameters, volume, sphericity, coefficient of contact surface and surface area of cotton seeds were 9.47, 5.57, 4.68, 6.27, 6.58 mm, 129.55 mm^3, 66.37 %, 50.32 % and 123.63 mm^2, respectively. While; the mean value of bulk and true densities, individual seed mass, one thousand seed, porosity and projected area were 0.457 and 1.051 g/cm^3, 0.115 g, 112.22 g, 56.39% and 39.91 mm^2, respectively. The study also revealed that the average value of repose angle was 36.22°. While; the lowest value of static friction coefficient for cotton seeds were on stainless steel sheet followed by galvanized iron, plywood and the highest on rubber were 0.320, 0.408, 0.482 and 0.583, respectively. The study also concluded that the mean value of rupture force and deformation ratio of cotton seeds were 76.88 N and 6.11 %. The mean values of terminal velocity and coefficient of drag were 9.34 m/s and 0.55, respectively. Also; the mean value of Reynolds number was 3536 so; the pattern of air flow is in the range of transitional flow.

1. INTRODUCTION

Cotton is cultivated in many parts of the world as a source of food (edible vegetable oil), fiber and feed (oil cake). Cotton seeds contains about 17-24% oil and 40-43% protein **(Ozarslan, 2002)**. **Zewdu and Solomon (2008)** told that the bulk density and porosity are crucial properties in the development of the aeration and drying systems as these properties affect the resistance to airflow of stored mass.

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Mohsenin (1986) mentioned that the physical properties of agricultural material such as; shape and size, volume, density, porosity and surface area are important and essential engineering data in many problems associated with design of machines or analysis of the behavior of the agricultural products in different processes.

Ozarslan (2002) measured physical properties of cotton seeds. The average length, width and thickness of cotton seeds ranged from 9.02 to 9.19, 4.70 to 4.86 and 4.25 to 4.45 mm, as the moisture content increased from 8.33 to 13.78 % (d.b.) respectively. In the same moisture range, studies on rewetted cotton seeds showed that the sphericity increased from 0.626 to 0.635, seed volume from 95.4 to 109.6 mm^3, thousand seed mass from 104.06 to 109.64 g and projected area from 35.89 to 40.14 mm^2. While; the bulk and true densities decreased from 642 to 610 and 1091 to 1000 kg/m^3 respectively.

Asadzadeh (2014) reported that the physical properties of cotton seeds were evaluated as a function of moisture content. The results showed that the average value of length, width, thickness, projected area, sphericity and thousand seed mass of seed ranged from 9.07 to 9.28, 4.87 to 5.5.02, 4.57 to 4.70 mm, 49.85 to 52.25 mm^2, 64.67 to 65.02 % and 99.09 to 107.52 g, as the moisture content increased from 7.17 to 13% d.b., respectively. While; the mean value of true density and porosity decreased from 1048.5 to 983.3 kg/m3 and 44.04 to 42.26 %, respectively.

Vasuki and Tajuddin (2015) examined some physical properties of cotton seeds. They found that the sphericity of seeds ranged from 0.636 to 0.687, thousand seed mass from 61.60 to 93.6 g, bulk density varied from 613 to 648 kg/m^3, the angle of repose varied from 19.2 to 26.3º and true density varied from 989 to 1000 kg/m^3.

The aim of this study was to investigate some engineering characteristics of the cotton seeds which affect designing and developing of precision planting, handling system, storage, ginning and separation machines.

2. MATERIALS AND METHODS

2.1. Materials

The experimental part of the present study was carried out in the Agricultural Products Process Engineering Laboratory at the Faculty of Agricultural Engineering Al-Azhar University, Egypt. The used cotton seeds (Giza 94) were provided by agricultural research center. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and fiber as well as immature, broken, and fuzzy seeds.

2.2. Physical properties of cotton seeds

Physical properties of cotton seeds were measured. The measured properties included moisture content, seed dimensions and related characteristics, individual seed mass, one thousand seed, bulk and true densities, porosity and projected area.

2.2.1. Moisture content

The moisture content of cotton seeds can be determined by drying to constant weight in an oven at $105 \pm 1^{\circ}C$ according to (**AOAC, 2005**), moisture content can be calculated on dry basis as follows:

$$M.C = \frac{M_m}{M_d} \times 100 \quad \text{............} \ (1)$$

<u>Where:</u> M_m: Mass of moisture in sample, (g); and M_d: Mass of bone-dry sample, (g).

2.2.2. Principal dimensions of cotton seeds

A digital caliper with accuracy of 0.01 mm was used to measure the length (L), width (W) and thickness (T) for cotton seeds. The average length, width and thickness of one hundred seed were calculated.

2.2.2.1. Related characteristics of seeds principal dimensions:
a) Average diameters and volume

Geometric mean diameter (D_g), arithmetic mean diameter (D_a) and the calculated volume ($V_{cal.}$) of cotton seeds calculated using the following equations, according to (**Ghanem *et al*. 2017**):

$$D_g = (LWT)^{1/3} \quad \text{......} \ (2) \qquad D_a = (L + W + T)/3 \quad \text{......} \ (3)$$

$$V_{cal.} = \frac{\pi}{6}[LWT] \ ...... (4)$$

b) Sphericity

Movement of spherical seed is usually higher under gravity than non-spherical seeds. The sphericity of seeds (Ø) was calculated by using the following relationship **(Mohsenin, 1986)**:

$$\emptyset = \frac{(LWT)^{1/3}}{L} \times 100 \quad ....(5)$$

c) Coefficient of contact surface

Coefficient of contact surface (C.C) was calculated for seeds according to **(Abd Alla, 1995)**:

$$C.C = \frac{A_f - A_t}{A_f} \times 100 \ ....(6)$$

Where: A_f: Area of flat surface $= \frac{\pi}{4}(LW)$, mm^2; and

A_t: Area of transverse surface $= \frac{\pi}{4}(WT)$, mm^2.

d) Surface area

The surface area of seeds (A_s) depends on values of geometric mean diameter as in the following formula, according to **(Adejumo et al. 2015)**.

$$A_s = \pi D_g^2 \quad ....(7)$$

2.2.3. Bulk and true densities of seeds:

Bulk density of the seeds is used for seed storage structures designs. It was measured using a graduated flask having a volume of 25 cm^3. The graduated flask was filled with cotton seeds without compaction and then its weight was measured. The bulk density "ρ_b" (g/cm^3) was calculated as the following equation (8). The true density "ρ_t" (g/cm^3) was determined using a toluene (C_7H_8) displacement method with a known mass of seeds. It was calculated using the following equation **(Mohsenin, 1986)**.

$$\rho_b = \frac{M}{V_s} \ ....(8) \qquad \rho_t = \frac{M}{V_t} \ ....(9)$$

Where: M_s: Mass sample, (g); V_s: Volume of bulk sample, (cm^3); and
            V_t: Displaced volume of toluene,(cm^3).

The procedure was repeated ten times and the average bulk and true densities of the cotton seeds were reported.

2.2.4. Mass of seeds

The mass of single seed (M_i) was determined by randomly selecting one hundred seed of cotton and then weighing them one by one. A precision weighing balance having least count of 0.01 g was used. To determine the one thousand seed mass, three hundred seeds were selected and weighed, then divided to three groups, each group contains one hundred seed. The mass of thousand seed (M_t) was determined by multiplying the average mass of one hundred seeds by ten.

2.2.5. Porosity

Porosity affects the resistance to airflow through the bulk material bed and data on them are necessary in designing the drying process. The porosity of cotton seeds (ε) depends on values of bulk and true densities using the following equation according to, (**Mohsenin, 1986**).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots. (10)$$

Bulk density and true densities values obtained from previous experiments were used to calculate the porosity of the cotton seeds.

2.2.6. Projected area of cotton seed

To determine the projected area of cotton seeds (A_p), fifty seeds were randomly selected from cotton seeds and then scanned using a scanner to capture the image of seeds at natural flat position, then; the pictures of seeds were exported to SolidWorks, program to calculate the projected area of cotton seeds.

2.3. Mechanical properties of cotton seed:

2.3.1. Repose angle

The repose angle is the angle between the base and the slope of cone formed on a free vertical fall of the seeds mass to a horizontal plane. The slope of base of the seed flow structures is based on the average angle of

repose of seeds to ensure free flow of seeds. The dynamic angle of repose of seeds was measured by a hollow cylinder (80 mm diameter and 200 mm height) and a wooden table. The cylinder was placed on the wooden table. Then; it was filled with cotton seeds. The cylinder was raised slowly allowing the seeds to flow down to form a cone of seeds and then diameter and height of the seeds cone were measured and recorded. The repose angle was calculated as the following equation (11).

2.3.2. Static friction coefficient

The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on walls. Static friction coefficient of seeds was determined on four different materials namely; plywood (P_w), galvanized iron (G_i), rubber (R_b) and stainless steel (Ss). In order to determine coefficient of friction a sample was put on the surface with adjustable slope. When a sample started to move, the tangent of the slope angle calculate. The procedure was repeated ten times and the static friction coefficient for each replicate was calculated using the following equation:

$$\alpha = \tan^{-1}\left[\frac{2H}{D}\right] \ldots \ldots \ldots \ldots (11) \qquad \mu = \tan \beta \ \ldots \ldots \ldots \ldots (12)$$

Where: α: Repose angle, (degree); H: Height of the cone, (cm); D: Diameter of the cone, (cm). μ: Static friction coefficient; and β: Angle of friction, (degree).

2.3.3. Rupture force and deformation ratio

Rupture force (R_f) is implies the partial or complete destruction of seed. The rupture force and deformation ratio of seeds were measured by using a digital Universal Material Tester. The specifications of device were as follows: Model No: MT 2021, range of the measurement is 0 to 20 kN and its accuracy is 0.1 N. The used sample for measure the rupture force was 25 seed. Seed is set upon a flat plate until the crosshead of apparatus was brought in contact with the seed and a compression force was applied until permanent (destruction) was caused. The readings are recorded over a digital screen. The deformation ratio at rapture point (D_r) is the

longitudinal strain at rupture point and it was calculated by the following equation, according to (**Mousa *et. al.*, 2016**):

$$D_r = \frac{y}{d} \times 100 \ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (13)$$

Where: y: Deformation at rupture point "change in dimension", (mm); and d: Original dimension of seed, (mm).

2.4. Aerodynamic properties of cotton seed:
2.4.1. Terminal velocity and drag coefficient

The terminal velocities of cotton seeds were measured using the terminal velocity apparatus Fig.1 according to (**Awady and El-Sayed, 1994**). The apparatus consists of a rectangular tube constructed from transparent (plexi-glass) and connected with the outlet of the electric blower, two wire screens were fitted at the bottom and top of the transparent tube, an air-flow straightener was attached with the lower screen to improve flow uniformity throw the rectangular tube, a choke valve is built as the inlet of blower to control the air flow rate manually.
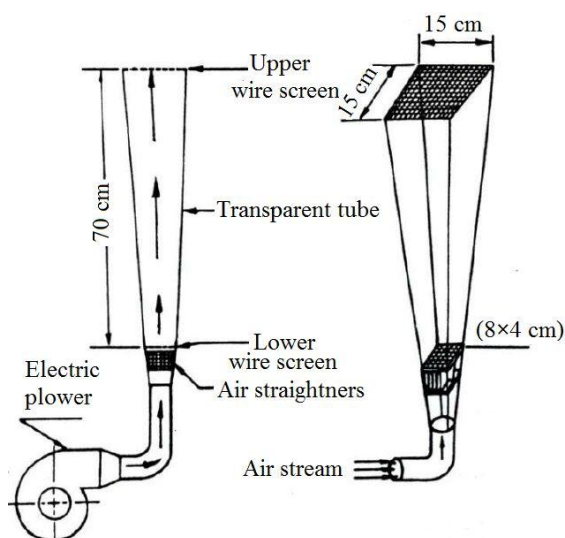
Fig. 1: Terminal air velocity setup (**Awady and El-sayed, 1994**).

The sample was placed on the lower screen. Terminal velocity can be obtained by measuring the air velocity required to suspend the particles in the vertical air stream. Air velocity was measured at the bottom of the tube by an anemometer. The air velocity changes according to changes in the cross-section of the tube. The value of the terminal velocity (V_t) "m/s" was calculated using the following equation:

$$V_t = \frac{Q}{A} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (14)$$

Where: Q: Air flow rate, (m^3/s); and A: Cross-section area of the tube, (m^2).

When a particle is suspended into a turbulent stream of air, equilibrium is achieved between its weight and the drag force, the drag coefficient (C_d) of seed was calculated by the following equation according to (**Awady and El- sayed, 1994**):

$$C_d = \frac{2M.g}{V_t^2 . \rho_a . A_p} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (15)$$

Where: M: Mass of seed, (kg); g: Acceleration of gravity, (9.81 m/s²); V_t: Air terminal velocity, (m/s); ρ_a: Air density (1.2 kg/m³); and A_p: Projected area of seed, (m²).

2.4.2. Reynolds number

Reynolds number (R_n) "dimensionless" was calculated by the following equation (**Mohsenin, 1986**).

$$R_n = \frac{\rho_a . V_t . D_g}{\mu} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (16)$$

Where: D_g: Geometric mean diameter, (m);   and   μ: Dynamic viscosity of air, $(18 \times 10^{-6}$ kg/m.s).

The laminar flow is at $R_n \leq 2100$, transitional flow at $2100 < R_n < 4000$ and turbulent flow is at $R_n \geq 4000$.

3. RESULTS AND DISCUSSIONS

All experiments of physical, mechanical and aerodynamic properties were carried out under the average moisture content of 9.16 ± 0.57 % d.b.

3.1. Physical properties

Based on the experiments conducted in the laboratory for each mentioned property of cotton seeds, the results are as follows:

3.1.1. Seeds principal dimensions

The principal dimensions of cotton seeds were taken with the help of a digital caliper. The average value of length was 9.47 ± 0.65 mm, varying in range from 8.12 to 10.48 mm, whilst; the mean values of width and

thickness were 5.57 ± 0.33 and 4.68 ± 0.31 mm which ranged from 4.92 to 6.45 and 4.02 to 5.19 mm, respectively, as shown in Table 1.

Table 1: Physical properties (seeds principal dimensions and related characteristics of principal dimensions) of cotton seeds

Parameter	Symb.	Range		Mean ± SD	CV, (%)
		Min.	Max.		
Moisture content, (d.b)	M.C	8.19	9.78	9.16 ± 0.57	6.27
Principal dimensions, (mm)	L	8.12	10.48	9.47 ± 0.65	6.85
	W	4.92	6.45	5.57 ± 0.33	5.52
	T	4.02	5.19	4.68 ± 0.31	6.56
Average diameter, (mm)	D_g	5.66	6.86	6.27 ± 0.25	3.93
	D_a	5.98	7.20	6.58 ± 0.27	4.16
Calculated volume, (mm^3)	$V_{cal.}$	94.81	169.08	129.55 ± 15.29	11.80
Sphericity, (%)	Ø	58.80	75.77	66.37 ± 3.55	5.35
Coefficient of contact surface, (%)	C.C	40.02	60.94	50.32 ± 4.72	9.38
Surface area, (mm^2)	A_s	100.55	147.87	123.63 ± 9.71	7.86

3.1.1.1.Related characteristics of principal dimensions of cotton seeds
1) Average diameters and volume
From Table 1 the mean value of geometric mean diameter was 6.27 ± 0.25 mm and it varied in range from 5.66 to 6.86 mm. While; the mean value of arithmetic mean diameter was 6.58 ± 0.27 mm which ranged between 5.98 to 7.20 mm. Also; the mean value of calculated volume was 129 ± 15.29 mm^3 and it varied in range from 94.81 to 169.08 mm^3.

2) Sphericity
As shown in Table 1 the mean sphericity of the seeds was recorded as 66.37 ± 3.55 %, which ranged between 58.80 % and 75.77%. This characteristic is considered to be helpful for separation and grading machines.

3) Coefficient of contact surface and surface area
According Table 1 the value of coefficient of contact surface ranged from 40.02 to 60.94 % with an average value of 50.32 ± 4.72%. Meanwhile; the

average value of surface area was found to be 123.63 ± 9.71 mm^2, which ranged from 100.55 to 147.87 mm^2.

3.1.2. Bulk and true densities

The average value of bulk density of the seeds was 0.457 ± 0.02 g/cm^3, ranging from 0.435 to 0.491 g/cm^3. While; the mean true density of the seeds was recorded as 1.051 ± 0.06 g/cm^3, which ranged between 0.990 and 1.148 g/cm^3, according Table 2.

Table 2: Physical properties (density, mass, porosity and projected area)

Parameter	Symb.	Range		Mean ± SD	CV, (%)
		Min.	Max.		
Density, (g/cm^3)	ρ_b	0.435	0.491	0.457 ± 0.02	4.27
	ρ_t	0.990	1.148	1.051 ± 0.06	5.62
Mass, (g)	M_i	0.071	0.153	0.115 ± 0.02	16.00
	M_t	109.60	115.40	112.22 ± 2.44	2.18
Porosity, (%)	ε	53.85	60.18	56.39 ± 2.38	4.23
Projected area, (mm^2)	A_P	38.12	43.88	39.91 ± 1.93	4.84

3.1.3. Mass of cotton seeds

Table 2 showed that the values of individual seeds masses varied from 0.071 to 0.153 g with an average value of 0.115 ± 0.02 g. Whereas; the average mass of one thousand seeds varied from 109.60 to 115.40 g with an average value of 112.22 ± 2.44 g.

3.1.4. Porosity and projected area

From Table 2 the mean values of porosity and projected area were 56.39 ± 2.38 % and 39.91 ± 1.93 mm^2, these values ranged from 53.85 to 60.18% and 38.12 to 43.88 mm^2, respectively. These characteristics are also beneficial for separation and grading machines.

3.2. Mechanical properties

3.2.1. Repose angle

The average value of repose angle was found to be $36.22 \pm 2.39°$ which ranged from 32.21° to 38.31°, as shown in Table 3. This characteristic can

be utilized to assess the optimum side's inclination of seed hopper in ginning machines, silos and storage containers to allow an easily sliding.

Table 3: Mechanical properties of cotton seeds.

Parameter	Symb.	Range		Mean ± SD	CV, (%)
		Min.	Max.		
Repose angle, (degree)	α	32.21	38.31	36.22 ± 2.39	6.59
Static friction coefficient	P_w	0.410	0.560	0.482 ± 0.05	11.00
	G_i	0.360	0.455	0.408 ± 0.03	8.38
	R_b	0.525	0.671	0.583 ± 0.04	7.63
	S_s	0.240	0.375	0.320 ± 0.04	13.99
Rupture force, (N)	R_f	60.80	91.40	76.88 ± 10.32	13.43
Deformation ratio, (%)	D_r	4.10	7.73	6.11 ± 1.15	18.77

3.2.2. Static friction coefficient

According to Table 3 the lowest values of static friction coefficient were on stainless steel sheet followed by galvanized iron, plywood and the highest on rubber (0.320, 0.408, 0.482 and 0.583), respectively. This is due to the smoother and more polished surface of stainless steel sheet and galvanized iron than the other tested surfaces. As shown in Fig. 1.
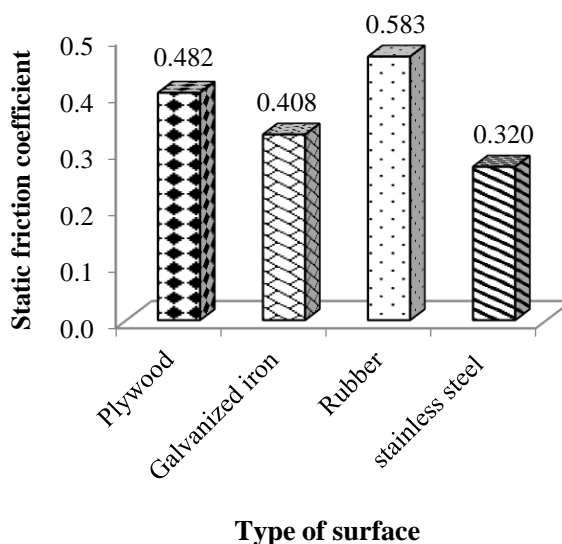

Fig. 1: Static friction coefficient for cotton seeds on different material surfaces

3.2.3. Rupture force and deformation ratio

The results showed that the mean values of rupture force and deformation ratio of cotton seeds were found to be 76.88 ± 10.32 and 6.11 ± 1.15% which

ranged from 60.80 to 91.40 N and 4.10 to 7.73 %, as shown in Table 3 .This characteristic is beneficial for extract oil from cotton seeds.

3.3. Aerodynamic properties

3.3.1. Terminal velocity and drag coefficient

The results showed that the values of terminal velocity and coefficient of drag for seeds varied from 8.28 to 10.54 m/s and 0.42 to 0.69 with average values of 9.34 ± 0.58 m/s and 0.55 ± 0.07, with coefficient of variation as 6.26% and 12.49% respectively, These characteristics can be utilized in designing air screen, cleaning and grading equipment.

3.3.2. Reynolds number

The mean value of Reynolds number was 3536 ± 221 ranging from 3135 to 3991 with coefficient of variation as 6.26%. The results showed that the pattern of air flow is in the range of transitional flow.

CONCLUSIONS

The study of experiments conducted on cotton seeds at 9.16 % moisture content on dry basis revealed the following conclusions:

- The mean values of length, width, thickness, geometrical and arithmetic mean diameter were 9.47, 5.57, 4.68, 6.27 and 6.58 mm, respectively. Also; the average values of volume, sphericity, coefficient of contact surface and surface area were 129.55 mm^3, 66.37%, 50.32% and 123.63mm^2, respectively.

- The study also concluded that the mean values of bulk and true densities of cotton seeds were 0.457 and 1.051 g/cm^3, respectively. In addition to that the average values of individual seed mass and one thousand seed were 0.115 and 112.22 g, respectively. Also; the mean values of porosity and projected area were 56.39 % and 39.91 mm^2, respectively.

- The average value of repose angle was 36.22°. While; the lowest values of static friction coefficient for cotton seeds were on stainless steel followed by galvanized iron, plywood and the highest on rubber were 0.320, 0.408, 0.482 and 0.583 respectively. The study also concluded that the mean values of rupture force and deformation ratio of seeds was 76.88 N and 6.11% respectively.

- The mean values of terminal velocity and coefficient of drag were 9.34 m/s and 0.55 respectively. While; the mean value of Reynolds number was 3536 so; the pattern of air flow is in the range of transitional flow.

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<u>الملخص العربي</u>

بعض الخصائص الهندسية لبذور القطن

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يعد القطن ملك محاصيل الألياف ومن أهم المحاصيل التجارية التي تزرع في بلدان كثيرة من العالم وفى مصر يعتبر القطن محصول تصدير رئيسى. يستخدم القطن كمصدر للغذاء (الزيوت النباتية الصالحة للأكل المستخلصه من البذور) والألياف والأعلاف (كُسب الزيت).

وكان تصنيع الآلات الزراعية وخاصة آلات ما بعد الحصاد مثل آلات الحلج والتنظيف تحتاج إلى توفير بيانات عن الخصائص الهندسية للمنتج لكي تساعد في تصميم أجزاء الآلة.

ولتحقيق هذا الهدف تم دراسة الخواص الطبيعية والميكانيكية والأيروديناميكية المتعلقة ببذور القطن وذلك عند محتوي رطوبي 9,16 ٪ على أساس جاف.

ويمكن تلخيص النتائج كما يلي:

<u>أولاً: الخصائص الطبيعية:</u> كان متوسط كل من الطول، العرض، السمك، القطر الهندسي، القطر الحسابي، الحجم، والكروية، معامل التلامس السطحى والمساحة السطحية لبذور القطن 9,47 ، 5,57 ، 4,68 ، 6,27 ، 6,58 مم ، 129,55 مم³ ، 66,37% ، 50,32% و 123,63مم² على التوالي. أيضاً، كان متوسط كل من الكثافة الظاهرية، الكثافة الحقيقية، كتلة البذرة الواحدة، كتلة الألف بذرة، المسامية والمساحة المسقطة لبذور القطن 0,457 ، 1,051 جرام/سم³ ، 0,115 ، 112,22 جرام ، 56,39% ، 39,91 مم² على التوالي.

<u>ثانياً: الخصائص الميكانيكية:</u> حيث بلغ متوسط كلاً من زاوية الراحة للبذور وكذلك القوة اللازمة لكسر البذرة ونسبة تشوة البذور 36,22 درجة، 76,88 نيوتن و 6,11 % على التوالي. كما وجد أيضاً أن أقل قيمة لمعامل الإحتكاك الإستاتيكي لبذور القطن كانت 0,320 لسطح الإستانلس ستيل (صلب مقاوم للصدأ) يليها سطح الصاج المجلفن 0,408 وسطح الخشب 0,482 بينما كانت أعلى قيمة 0,583 لسطح الجلد.

<u>ثالثاً: الخصائص الأيروديناميكية:</u> وجد أن متوسط قيمة كلاً من السرعة الحرجة ومعامل الجرف 9,34 م/ث و 0,55 على التوالى، بينما وجد أن متوسط رقم رينولد 3536 وبالتالى تقع فى نطاق سريان الهواء الإنتقالى.

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