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Original article

Engineering Properties of Wheat and Corn Under Libya Conditions

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ABSTRACT

Background and aims. *Cereal grains are biological materials and as such have certain unique characteristics. The knowledge about the physical and mechanical properties of cereal grains is crucial for machine design, operational efficiency, and handling. Aerodynamic properties of solid materials have long been used to convey and separate seeds and grains during post-harvest operations. The experimental work was carried out during the year 2023 at the Agricultural Engineering Department, Faculty of Agriculture, Omar Al-Mokhtar University, Al-Beyda, Libya. The main objective of this research to determine and measurements of engineering properties including the physical, mechanical and aero-dynamic properties of wheat and corn beans grains under Libya conditions subjected to design the operating machines.* ***Methods.*** *The experimental work was carried out through 2023 at the Agricultural Engineering Department, Faculty of Agriculture, Omar Al-Mokhtar University, Al-Beyda, Libya, to verify the engineering properties of different seeds. Samples of wheat and corn grains were selected randomly (average of 100 grain crop) and cleaned by hand grains dimensions were tested under a moisture level of 8 %. The average of physical, mechanical and aerodynamic properties was determined for each studied grain.* ***Results.*** *It is clear that the value of geometric mean diameter recorded largest value of corn followed by wheat were 7.75 and 4.25 mm, respectively. The projected area of wheat and corn grains were 18.72, 82.09 mm2, respectively. Whereas, the porosity of wheat and corn were 42.09 and 32.36 %, respectively. The average angle of repose was largest of wheat followed by corn grains were 27.60 and 20.4^{o} C, respectively. While, the coefficient of fraction largest of corn followed by wheat grains as 24.81 and 19.41 respectively. The terminal velocity, was largest of wheat followed by corn grains were 7.80 and 15.02 m/s, respectively. On the otherwise, the drag coefficient largest of corn and wheat grains of 0.30 and 0.61, respectively. Also, the Renold's number largest of corn followed by wheat of 9592.03 and 2378.94, respectively.* ***Conclusion.*** *The results from these experiments on wheat and corn grains at 12 and 14 % moisture conducted the content dry basis revealed. The results showed that the pattern of air flow is in the range of turbulent flow. The develop designs to improve product quality and to increase energy efficiency.*

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INTRODUCTION

Wheat is worldwide considered as the main cereal grain in the human diet. Corn is the main cereal crop worldwide to its importance for human, animal, and poultry feed as in dry feed industry by up to 70 %, on bread ingredients by 20 %, as interference in some industries, such as obtaining glucose, fructose, and oil. Common beans is a major grain legume crop in the world [1] and widely consumed in Africa [2]. The engineering properties (such as physical, mechanical and aerodynamic) of grains play an important role in machine design, for processes such as grinding, handling, conveying, extrusion, and compacting equipment [3]. For designing storage containers, the bulk density and particle mass are the most important grain property [4]. Size and shape affect the design of harvesting and separation equipment [3]. Size and shape have significant impact on sowing efficiency and uniformity, because it determines the position and filling rate of the seed drill dispensing units [5]. With a decrease in size, the cohesive strength of grains increases thus reducing the flow ability, which is the one of the parameters determining the optimal angle for hopper and outlet dimensions in storage containers. Moreover, the changes in grain size result in variation in wall friction angle and number of contact points, which will affect the design of conveyors, feeders, and other equipment [6]. The shape of grain will affect the moisture diffusivity of water and thus influencing the drying, aeration, and storage of grains [3]. The physical-mechanical behavior and size and shape characteristics also play a significant role in simulation of bulk grain behavior using discrete element simulation approach [7]. As the prediction accuracy of the computational models depends on the type of grains and contact parameters [5], it is crucial to know variability in properties at different moisture contents. Mechanical and aero-dynamic properties, namely, coefficient of friction, hardness, penetration depth, shear force and stress, repose angle, terminal velocity, Reynold's number and drag coefficients for wheat and corn seeds at different levels of seeds moisture content. Bulk density, true density, and porosity (the ratio of inter-granular space to the total space occupied by the grain) can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling [8]. The design of storage and handling systems for wheat and corn grains requires data on bulk and handling properties, friction coefficients on commonly used bin wall materials (galvanized steel, plywood, and concrete), and emptying and filling angles of repose [9]. Aerodynamic properties of solid materials have been applied to separate and convey grains and seeds during operations of post-harvest. Also, they are needful in the suitable design of separating and cleaning equipment because of dependence of particles behavior in an airstream during pneumatic conveying and separation on their aerodynamic properties. Likewise, knowledge of aerodynamic properties of particles is requisite to set the range of air velocities for grain separation from foreign materials when an air stream is used for separating a product [10]. Previous study showed a variation in terminal velocity for the varieties of the same crop due to the variation in particle mass, air and particle densities [11]. Hence, the difference in terminal velocity offers the possibility of separating such materials from each other in an air stream and it can be utilized in designing air screen, threshing, cleaning and grading equipment. Another report stated that, "the Reynold's number is needful in hydraulic and pneumatic handling of grains, and in accounting thermal diffusivity in drying and heat transfer rates [12]. Previously also showed that, there was a significant difference between the drag coefficients of mung bean seeds at different moisture content [10]. However, the drag coefficients were not affected significantly by mung bean seeds grade. The knowledge about the changes in physical, mechanical and aerodynamic parameters is then essential to properly design the operating machines and improve processing conditions by decreasing the material losses during processing [13].The objective of this study was aimed to determine and measurements of engineering properties including the physical, mechanical and aero-dynamic properties of wheat and corn grains under Libya conditions subjected to design the operating machines using two grain crops wheat and corn.

METHODS

The experimental work was carried out through 2023at the Agricultural Engineering Department, Faculty of Agriculture, Omar Al-Mokhtar University, Al-Beyda, Libya, to verify the engineering properties of different seeds. Samples of wheat and corn grains were selected randomly (average of 100 grain crop) and cleaned by hand. grains dimensions were tested under a moisture level of 8 %. The average of physical, mechanical and aerodynamic properties was determined for each studied grain.

Instrumentation

Digimatic Caliper, Electronic Petit Balance, Grain Moisture Meter, Anemometer, Terminal velocity apparatus, Tilting Table.

Physical properties

To determine and measurements the average physical dimensions of wheat, corn and lentils, a sample of 100 grains of each crop was randomly selected. The three linear dimensions of the grains, namely length (L), width (W) and thickness (T) were carefully measured in mm. Mean dimensions of grains, the arithmetic mean diameter (D_a), mm, geometric mean diameter (D_g), mm, surface area (A_f), mm^2, volume (V), mm^3 and sphericity (φ), % of grains were calculated according to[14-16] were used to calculate the values of the physical properties:

$$D_g = (L.W.T)^{1/3} \quad (1)$$

$$D_a = \frac{(L+W+T)}{3} \quad (2)$$

$$V = \frac{\pi}{6}(L.W.T) \quad (3)$$

$$\phi = \frac{(L.W.T)^{1/3}}{L} \text{x}100 \quad (4)$$

$$A_s = \pi (D_g)^2 \quad (5)$$

$$A_p = \frac{\pi}{4} \text{L.W} \quad (6)$$

The aspect ratio, *Ra*, was calculated by using [17].

$$R_a = \frac{W}{L} x100 \quad (7)$$

According to [18] projected area was measured by using scanner ***(****Type: HP Scanjet 200)* to take a photo of the projected area of each grain type and modifying it by drawing program *(AUTOCAD)* for measuring the projected area. The projected area was determined at two different planes. The first plane included length and width (A1). The second plane included length and thickness (A2). The third plane included width and thickness (A3).

The porosity (ε) of bulk seed was computed from the values of bulk density ρ_B and true density ρ_t using the relationship given by [19]:

$$Bulkd\ density\,(\rho_B) = \frac{mass\ of\ grain\,(kg)}{volume\ of\ grain\,(m^3)} \quad (8)$$

$$True\ density\,(\rho_t) = \frac{mass\ of\ individual\ grain\,(kg)}{volume\ of\ displaced\ toluene\,(m^3)} \quad (9)$$

$$Porosity\,(\varepsilon) = (1 - \frac{Bulk\ density}{True\ density})\,x100 \quad (10)$$

Mechanical Properties

Angle of repose and frictional properties of grains play an important role in selection of design features of hoppers, chutes, dryers, storage bins and other equipment for seed flow.

Determination Angle of Repose

The angle of repose was calculated from the measurements of the height (*h*) of the free surface of the seeds and the length (*L*) of the heap formed outside the box using the relationship described by [20].

$$\theta = \tan^{-1}(\frac{2h}{L}) \quad (11)$$

Where:
θ = The Angle of Repose (degrees),
h =The height of the free surface of the grains
L= The Length of the heap formed outside the box.

Determination of Static Coefficient of Friction

The coefficient of friction between the seed (δ) and the surface on which the material moves is essential for engineers to make the right approach to the design of bins and hoppers. The static coefficient of friction (δ) was determined for four different structural materials, namely, Glass surface, Wood surface and Stainless-steel surface. Thus, the coefficient of friction was calculated as the tangent of the angle of repose.

$$\delta = \tan(\theta) \qquad (12)$$

Where:
δ =The Static Coefficient of Friction.
It should be noted that, four replicates for the measurements of the angle of repose and the same number for friction angle were carried out.

Aero-dynamic properties

Terminal velocity apparatus

The terminal velocity for wheat and corn bean was determined by using the terminal velocityapparatus as shown in Fig (5), the value of the terminal velocity (V_t) "m/s".

Drag coefficient:

The drag coefficient of grain was calculated by the following equation according to [21].

$$C_d = \frac{2 M g}{A_p \rho_a V_t^2} \qquad (13)$$

Where:
C_d : drag coefficient.
M : mass of seed, kg
g : Acceleration of gravity, (9.81 m/s^2)
A_p : projected area of seed, m^2
ρ_a : density of air (1.28 kg/m^3)
V_t : terminal velocity, m/s

Reynold's Number

Reynolds number (R_n) "dimensionless" was calculated by the following equation [22].

$$R_n = \frac{\rho_a V_t D_g}{\mu} \qquad (14)$$

R_n =Reynolds number, (dimensionless
D_g = Geometric mean diameter, (m)
μ = Dynamic viscosity of air, (18× 10^{-6} kg/m.s).

RESULTSAND DISCUSSION

Based on the experiments conducted in the agriculture engineering laboratory for each mentioned property of wheat and corn grains, the moisture content was 12 and 14 % of wheat and corn, respectively. The results are as follows:

Physical properties

The physical properties

The axial dimensions of wheat seeds were measured and found that value of average length was 6.32 ± 1.26 mm, varying in range from 5.06 to 7.58 mm, with coefficient of variation as 19.94%. While, the mean values of width were 4.49 ± 1.48 which ranged from 3.01 to 5.97, with coefficient of variation as 32.96 %. Whilst, the mean values of thicknesswere3.13 ± 1.12 which ranged from 2.01 to 4.25, with coefficient of variation as 35.78 %, as illustrated in Table (1). This shows their shape approaches that of a sphere [23,24]. The dimensions, seed mass, bulk density, true density and projected area of agricultural grains change with variety of grain, agronomical conditions that product was grown and moisture content of grain [25-26].

The knowledge of engineering properties of corn is fundamental in order to optimize the design of equipment's for post-harvest handling and processing product. This information on engineering properties is useful for plant and animal breeders, engineers and food scientists. In addition, this information is helpful for data collection in the design of machines, structures, processes, controls and in determining the efficiency of a machine or an operation [14]. The physical properties have been studied for various agricultural products by other researchers such as locust bean seed [27]

The results in Table (2) showed the axial dimensions of corn seeds were measured and found that value of average length was 12.04 ± 3.35 mm, varying in range from 8.69 to 15.39 mm, with coefficient of variation as 27.82%. While, the mean values of width were8.53 ± 3.05 which ranged from 5.48 to 11.57, with coefficient of variation as 35.72%. Whereas, the mean values of thicknesswere5.60 ± 2.59 which ranged from 3.01 to 8.18, with coefficient of variation as 46.20%.

Table (4) showed that, the average value of geometric mean diameter of the wheat and corn was 4.25 and 7.75 mm, respectively. While, value of arithmetic mean diameter of the wheat and corn was 4.43, 8.39 and 12.85 mm, respectively. Whilst, the value of volume of the single seed of wheat and corn was 40.07 and 244.21 mm^3, respectively. The mean sphericity coefficient of the wheat and corn was recorded as 67.28 and 64.50 %, respectively. The average of aspect ratio of the wheat and corn grain was recorded as 59.90 and 72.38 %, respectively.

The average value of surface area of the wheat and corn grain was recorded as 56.60 and 188.77 mm^2, respectively. Whereas, the mean value of projected area of the wheat and corn was recorded as 18.72 and 82.09 mm^2, respectively, as shown in Table (3). The average values of individual seeds masses of the wheat and corn was recorded as 0.045 and 0.363 gm, respectively, as shown in Table (3). The mass of the seed plays an important role in cell design of seed metering mechanisms. The average value of bulk density of the wheat and corn was 805 and 765 kg/m^3, respectively. The mean values of true density of the wheat and corn grains were 1390 and 1131 kg/m^3, respectively. While, the average value of porosity of the wheat and corn grains was 42.09 and 32.36 %, respectively, as shown in Table (3).

Table 1. Axial dimensions of wheat seeds.

Parameter	Range		Mean ± SD	CV (%)
	Min.	Max.		
Length, mm	5.06	7.58	6.32± 1.26	19.94
Width, mm	3.01	5.97	4.49± 1.48	32.96
Thickness, mm	2.01	4.25	3.13± 1.12	35.78

Table 2. Axial dimensions of corn seeds.

Parameter	Range		Mean ± SD	CV (%)
	Min.	Max.		
Length, mm	8.69	15.39	12.04 ± 3.35	27.82
Width, mm	5.48	11.57	8.53 ± 3.05	35.72
Thickness, mm	3.01	8.18	5.60 ± 2.59	46.20

Table 3. The mean value of the physical properties of wheat and corn grains.

Parameter	Wheat	Corn
Geometric mean dimeter, mm	4.25	7.75
Arithmetic mean dimeter, mm	4.43	8.39
Volume of a single seed, mm^3	40.07	244.21
Sphericity coefficient, %	67.28	64.50
Aspect ratio, %	59.90	72.38
Surface area of single seed, mm^2	56.60	188.77
Projected area, mm^2	18.72	82.09
Mass of single seed, g	0.045	0.363
Bulk density, kg/m^3	805.00	765.00
True density, kg/m^3	1390.00	1131.00
Porosity, %	42.09	32.36

Mechanical properties

Table (5) showed that, the mean value of repose angle of the wheat and corn grains was found 27.60, 20.40 and 15.40 ºC, respectively. Whereas, the lowest values of static friction coefficient of wheat grain were on glass surface (15.11) followed by stainless-steel surface (17.48) and wood surface (25.64). Also, the lowest values of static friction coefficient of corn grain were on glass surface (21.30) followed by stainless-steel surface (23.03) and wood surface (30.10). The angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures. Bulk grain angle of repose is a key parameter for inventorying grain, predict ting flow characteristics, and designing bins and grain handling systems.

Table 4. The mean value of the mechanical properties of wheat and corn grains.

Crop	Angle of repose, ºC	Coefficient of fraction		
		Glass surface	Wood surface	Stainless steel
Wheat	27.60	15.11	25.64	17.48
Corn	20.40	21.3	30.1	23.03

Aero-dynamic properties

The mean values of terminal velocity of the wheat and corn grains was 7.80 and 15.02 m/s, respectively. Whereas, the average value of drag coefficient of the wheat and corn grains 0.61 and 0.30, respectively, as illustrated in Table (5).

The results in Table (5) showed that, the mean value of Reynold's number was 2378.94 and 9592.03, respectively. The results showed that the pattern of air flow is in the range of turbulent flow.

The aero-dynamic properties can be utilized in designing air screen, threshing, cleaning and grading equipment.

Table 6. The mean value of the aero-dynamic properties of wheat and corn grains.

Parameter	Wheat	Corn
Terminal velocity (m/s)	7.80	15.02
Drag coefficient	0.61	0.30
Renold's Number	2378.94	9592.03

CONCLUSION

The results showed that the different physical and other engineering properties of selected verities of wheat and corn grains. The differences in the physical properties among the wheat and corn grains observed in this study are due to variations in the compositions and structures of these materials.

Conflict of Interest

There are no financial, personal, or professional conflicts of interest to declare.

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الخواص الهندسية للقمح والذرة في ظل ظروف ليبيا

زبيدة الزبير

قسم الهندسة الزراعية، كلية الزراعة، جامعة عمر المختار، البيضاء، ليبيا

المستخلص

الخلفية والأهداف. الحبوب هي مواد بيولوجية، وبالتالي لها خصائص فريدة معينة. تعد المعرفة بالخصائص الفيزيائية والميكانيكية للحبوب أمرًا بالغ الأهمية لتصميم الماكينة والكفاءة التشغيلية والتعامل معها. تُستخدم الخواص الديناميكية الهوائية للمواد الصلبة منذ فترة طويلة لنقل وفصل البذور والحبوب خلال عمليات ما بعد الحصاد. تم تنفيذ العمل التجريبي خلال العام 2023 بقسم الهندسة الزراعية بكلية الزراعة جامعة عمر المختار، البيضاء، ليبيا. الهدف الرئيسي من هذا البحث هو تحديد وقياس الخواص الهندسية بما في ذلك الخواص الفيزيائية والميكانيكية والهوائية لحبوب القمح والذرة تحت ظروف ليبيا الخاضعة لتصميم آلات التشغيل. طُرق. تم تنفيذ العمل التجريبي حتى عام 2023 بقسم الهندسة الزراعية كلية الزراعة جامعة عمر المختار البيضاء ليبيا للتحقق من الخواص الهندسية للبذور المختلفة. تم اختيار عينات من حبوب القمح والذرة عشوائياً (متوسط 100 محصول حبة) وتم تنظيفها يدوياً وتم اختبار أبعاد الحبوب تحت مستوى رطوبة 8%. تم تحديد متوسط الخواص الفيزيائية والميكانيكية والهوائية لكل حبة مدروسة. **النتائج**. ومن الواضح أن قيمة المتوسط الهندسي للقطر سجلت أكبر قيمة للذرة يليها القمح 7.75 و4.25 ملم على التوالي. وكانت المساحة المتوقعة لحبوب القمح والذرة 18.72، 82.09 ملم2 على التوالي. بينما بلغت مسامية القمح والذرة 42.09 و32.36% على التوالي. وكان متوسط زاوية الراحة أكبر بالنسبة للقمح يليه حبات الذرة حيث بلغ 27.60 و20.4 درجة مئوية على التوالي. في حين بلغ معامل الكسر الأكبر للذرة تليها حبوب القمح 24.81 و19.41 على التوالي. وكانت السرعة النهائية أكبر لحبوب القمح تليها حبات الذرة وكانت 7.80 و 15.02 م/ث على التوالي. وعلى خلاف ذلك، بلغ معامل السحب الأكبر لحبوب الذرة والقمح 0.30 و0.61 على التوالي. كما أن عدد رينولد الأكبر من الذرة يليه القمح بـ 9592.03 و2378.94 على التوالي. **الخاتمة**. أظهرت نتائج هذه التجارب على حبوب القمح والذرة عند رطوبة 12 و14% محتوى الأساس الجاف. أظهرت النتائج أن نمط تدفق الهواء يقع في نطاق التدفق المضطرب. تطوير التصاميم لتحسين جودة المنتج وزيادة كفاءة الطاقة.

الكلمات الدالة. الخصائص الهندسية، الفيزيائية، الميكانيكية، الهوائية، القمح، الذرة.