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Determination of Physical Properties of Some Agricultural Grains

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Abstract: In this study, for the purpose of determining physical and aerodynamic properties, some varieties of wheat, barley, chickpea and lentil were used. The length, width, thickness, geometric mean diameter, equivalent sphere diameter, sphericity, seed mass, bulk density, true density, projected area, terminal velocity, drag coefficient of each grain variety were determined. The theoretical terminal velocities of those grains were calculated by using equations corrected with the shape factor. For all the grains, theoretical terminal velocities were lower than the experimental values. The average experimental terminal velocity was found to be in the range of 7.52 to 8.14 m/s for wheat varieties, 7.04 to 7.07 m/s for barley varieties, 7.72 to 7.78 m/s for lentil varieties and 11.15 to 12.01 m/s for chickpea varieties. The drag coefficients of seeds according to projected areas in different positions and equivalent spheres were calculated. The drag coefficient in the position of the lowest projected area for all the grain varieties was higher than that in the other position.

Key words: Aerodynamic, drag coefficient, grain, physical properties

INTRODUCTION

Information on physical and aerodynamic properties of agricultural products is needed in design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agricultural materials and convert them into food, feed and fodder. The properties which are useful during design must be known and these properties must be determined at laboratory conditions.

The geometric properties such as size and shape are one of most important physical properties considered during the separation and cleaning of agricultural grains. In theoretical calculations, agricultural seeds are assumed to be spheres or ellipse because of their irregular shapes (Mohsenin, 1980; Nalbandi *et al.*, 2010). Ahmadi and Mollazade (2009) determined the physical and mechanical properties of funnel seed as a function of moisture content. They found that there was a parabolic mathematical equation for sphericity, true density, and deformation on both seed length and width sections with changes of moisture content.

The methods generally used in determining the projected area, which is an important design parameter in cleaning and separating of the agricultural products according to size, shape, aerodynamic and hydrodynamic properties, are photographic enlarger, shadowgraph, camera setup, planimeter and image analysis method (Mohsenin, 1980; Dursun, 2001; Kural and Çarman, 1997; Konak *et al.*, 2002).

The terminal velocity and drag coefficient is the most important aerodynamic properties, which should be known for pneumatic conveying, separation, cleaning, harvesting and drying of agricultural products. The terminal velocity at which the particles are suspended stationary in vertical air stream can be determined by using different methods. These methods are free-fall, vertical air tunnel and elutriator method (Mohsenin, 1980; Grift *et al.*, 1997). The terminal velocity of grains can be calculated by using the equations theoretically developed as well as laboratory studies. A few methods were developed to determine theoretical terminal velocity for some grains (Gorial and O'Callaghan, 1990; Song and Litchfield, 1991). Tiwari (1962) reported that the measured terminal velocities for individual beans were found to be less than the calculated values. He attributed this to the effects of spinning and the rotation of the beans in the air stream. He concluded that 80% of damaged beans could be separated without significant loss of whole beans.

The value of aerodynamic drag coefficient, which is used for determining the aerodynamic drag force (F_d), acting upon a particle moving through air depends upon particle characteristics (mass, projected area, shape and terminal velocity) as well as the conditions of airflow. The projected areas and drag coefficient of agricultural grains changes because of irregular shape and continuous the variation of positions. In studies carried out, the projected area and drag coefficient of grains were usually determined by using the diameter of the sphere equivalent to seed (Mohsenin, 1980; Gorial and O'Callaghan, 1990; Hawk *et al.*, 1966). Zewdu (2007) calculated the drag coefficients for grain and the resistance coefficient (drag coefficient×frontal area) for straw from the experimentally obtained terminal velocities.

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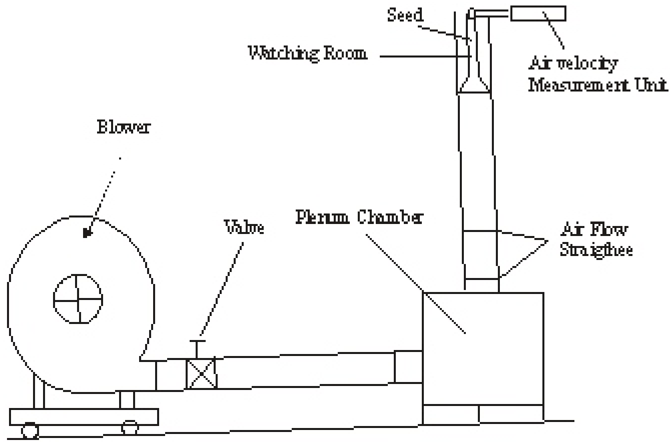

Fig. 1: The Experimental set-up for determination of terminal velocity of grain

The objective of this study was to determine some physical and aerodinamic properties of wheat, barley, lentil and chickpea to develop appropriate technologies in design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agricultural materials and convert them into food, feed and fodder.

MATERIALS AND METHODS

Grains used in this study conducted in South East Anatolia Region of Turkey in 2005 include durum wheats (Firat-93, Diyarbakir-81, Harran-95, Ceylan-95, Aydın-93), bread wheat (Nurkent), barley (Şahin-91, Sur-93), Chickpeas (ILC-482, Diyar-95) and lentil varieties (Fırat-87, Seyran-93), which are registered for South East Anatolia Region of Turkey. Grain varieties were collected from Seed Production Department of South East Anatolia Agricultural Research Institute. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds from a 10 kg sample for each grain variety and randomly selected for the measurement of dimensions, weight, projected area and terminal velocity.

The experimental apparatus used to determine the terminal velocity is shown in Fig. 1. It consists of a fan, electronic revolution regulator, electric motor, plenum chamber, airflow straightener, vertical transparent tube which diameter was 110 mm and an observation window on the tube. The different values of air speed were obtained by changing the revolution of electric motor with an electronic revolution regulator. A 0.35 KW centrifugal blowing fan was used for developing air flow through the tube. A hot wire anemometer having a least count of 0.1 m/s was used for the measurement of air velocity in tube

The dimensions of each seed, namely length, width and thickness, were measured in three directions by using digital vernier caliper with 0.001 mm accuracy. The seeds to be measured were taken randomly as 100 samples. The dimensions of lentil seed were measured as length and thickness because the thickness and width of lentil seeds were nearly same. Equation (1) was used for determining the geometric mean diameter of seeds (Mohsenin, 1980; Song and Litchfield, 1991)

$$d_g = (abc)^{1/3} \quad (1)$$

Where d_g is geometric mean diameter in mm; a is length of seed in mm; b is width of seed in mm; c is thickness of seed in mm. The diameter of equivalent sphere was determined by using Eq. (2) (Gorial and O'callaghan, 1990).

$$d_e = \left[\left(\frac{W_t}{\gamma_t}\right)\left(\frac{6}{\pi}\right)\right]^{1/3} \quad (2)$$

Where d_e is the diameter of equivalent sphere in mm; W_t is weight of seed in kg; γ_t is true density of seed, in kg/m^3. Sphericity used for determining the similarity of seed to sphere was calculated by Eq. (3) as suggested by Mohsenin (1980).

$$\phi = \frac{(abc)^{1/3}}{a} \quad (3)$$

Where ϕ is sphericity index in %. The mass of seeds were measured by using digital electronic balance with an accuracy of 0.0001 g.

The moisture content of each grain variety was determined according to ASAE S352.1 (ASAE, 1984). The bulk density of seeds based on the volume occupied

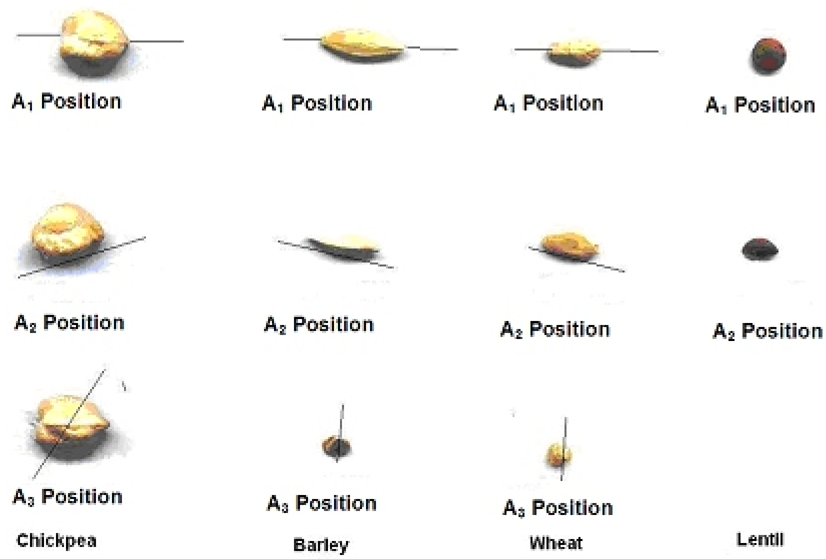

Fig. 2: The positions of different grains for determining projected area; A_1, projected area in position that seed was placed on hilum axis; A_2, projected area in position that seed was placed on its side; A_3; projected area in position that the hilum axis of seed was vertical to horizontal

by the bulk sample was measured by using the standard hectometer method (Çarman, 1996; Konak *et al*., 2002; Tabil *et al*., 1999). The true density, which is defined as the ratio of the mass of a sample to its solid volume was determined by using the liquid displacement method. For this purpose, pycnometer and toluene were used. The projected area of a seed in three different positions was determined by using the image processing method. Intel (R) Celeron (TM) CPU 1100 MH_2, 600x1200 DPI Scanner and the IT version 2.0 of the Uthscsa Image Processing Program were used for processing the images of the files formatted as TIF from scanner to computer. The 100 seeds from each variety were positioned on a white sheet in three different positions. These positions were named as A_1, A_2, and A_3. In A_1 position, the hilum axis of grain was parallel to horizontal plane and seed was placed on hilum axis. In A_2 position, the hilum axis of grain was parallel to horizontal plane and seed was placed on its side. In A_3 position, the hilum axis of grain was vertical to horizontal plane (Fig. 2). The samples, which were scanned with 600x1200 DPI Scanner and translated to computer as TIF file format, were processed by image processing program.

Equation (4) as suggested by Gorial and O'Callaghan (1990) was used for theoretical calculation of terminal velocity. For this purpose, the diameter of equivalent sphere and shape factor calculated by Eq. (5) were used.

$$(V_{krt})^2 = \frac{4 g d_e \gamma_t (6Z/\pi)}{3\gamma_a \, 0.44} \quad (4)$$

$$Z = \frac{\pi}{6}\left(\frac{d_e}{d_g}\right)^3 (\phi) \quad (5)$$

Where;
V_{krt} = The theoretical terminal velocity in m/s
g = Gravitational acceleration in m/s^2
γ_a = True density of air in kg/m^3
Z = Shape factor

A vertical air tunnel with a plexiglass tube was used to determine experimental terminal velocity. Ten seeds from each grain variety were randomly selected for measurement of terminal velocity. The seed sample was placed on a mesh screen in vertical tube. The air velocity was adjusted by increasing the speed of motor until the seed began to float. The air velocity near where the seed became suspended was measured with a hot wire anemometer having a least count of 0.1 m/s.
Equation (6) was used to calculate the drag coefficient of grain varieties.

$$C = \frac{2 m_t g}{\gamma_a (V_{krd})^2 A_t} \quad (6)$$

Where;
C = The drag coefficient
m_t = Mass of seed in kg
V_{krd} = Terminal velocity experimentally measured in m/s
A_t = Projected area of seed in m^2

Table 1: Means and standard errors of values of the length, width, thickness, geometric mean diameter, equivalent sphere diameter, and sphericity of grain varieties.

Grain	Length(a), mm	Width(b), mm	Thickness(c), mm	(d_g), mm	(d_e), mm	(ϕ), %
Wheat						
Fırat-93	7.39±0.46	3.08±0.26	3.13± 0.24	4.14±0.26	4.17±0.26	56.1±2.8
DYB-81	7.12±054	2.71±0.28	2.81±0.33	3.78±0.33	3.81±0.34	53.3±4.4
Harran-95	7.14±0.54	2.82±0.32	2.95±0.31	3.89±0.33	3.86±0.32	54.9±3.0
Ceylan-95	6.91±0.50	2.69±0.26	2.26±0.29	3.71±0.28	3.72±0.29	53.8±2.9
Aydın-93	6.40±0.26	2.84±0.28	2.93±0.26	3.75±0.27	3.72±0.26	58.7±2.9
Nurkent	6.59±0.48	2.56±0.28	3.08±0.36	3.72±0.33	3.76±0.35	56.5±2.8
Barley						
Şahin-91	9.98±1.60	2.60±0.29	3.58±0.31	4.51±0.42	4.11±0.32	45.8±4.5
Sur-93	9.82±1.04	2.42±0.24	3.46±0.28	4.34±0.32	4.07±0.30	44.4±3.2
Lentil						
Fırat-87	4.16±0.36		2.53±0.23	3.24±0.23	3.47±0.20	78.0±4.1
Seyran-96	4.63±0.27		2.50±0.15	3.40±0.17	3.66±0.17	73.5±2.3
Chickpea						
ILC-482	8.38±0.50	6.69±0.41	6.75±0.40	7.23±0.38	7.12±0.39	86.3±2.4
Diyar-95	9.52±0.56	8.12±0.52	8.17±0.47	8.54±0.43	8.50±0.43	89.8±3.4

d_g, Geometric mean diameter
d_e, equivalent sphere diameter
ϕ, sphericity

Table 2: Means and standard errors of seed mass and bulk density, true density, moisture content values of grain varieties

Grain	Mass of seed (m_u), mg	Bulk Density (γ_b), kg/m^3	True Density (γ_t), kg/m^3	Moisture Content (N_t), %
Wheat				
Fırat-93	53.47±9.3	789	1395	9.77
DYB-81	40.81±10.1	775	1373	9.10
Harran-95	43.07±10.2	777	1397	8.78
Ceylan-95	39.21±8.7	788	1420	8.91
Aydın-93	39.51±7.8	803	1441	8.60
Nurkent	39.67±9.8	775	1388	9.25
Barley				
Şahin-91	49.63±11.0	687	1339	9.52
Sur-93	47.87±9.8	669	1320	9.35
Lentil				
Fırat-87	30.91±5.3	805	1395	8.11
Seyran-96	36.45±5.0	809	1409	8.53
Chickpea				
ILC-482	268.29±4.03	795	1406	8.08
Diyar-95	454.19±67.9	792	1402	7.98

The drag coefficient of each grain variety was calculated according to the projected area in different positions of seed; as the projected areas of agricultural grains may vary because of their irregular geometric shape and the changing of their position in airflow. Besides, it was calculated by using the diameter of sphere equivalent to seeds (Mohsenin, 1980; Gorial and O'Callaghan, 1990).

RESULTS AND DISCUSSION

Dimensions, geometric mean diameter, equivalent sphere diameter and sphericity: The average and standard error values of the length, width, thickness, geometric mean diameter, equivalent sphere diameter, and sphericity of grain varieties are shown in Table 1. The frequency distributions for the length, width, and thickness were approximately normally distributed. Amongst wheat varieties, Fırat-93 had the highest values for length, width and thickness. Barley varieties as well as lentil varieties according to dimensions weren't very different. The dimension values of Diyar-95 from chickpea varieties were bigger than ILC-482. The barley seeds were longer and wider than wheat seeds. This shows that wheat and barley seeds may be separated according to their length. The geometric mean diameter ranged from 3.71 to 4.14 mm for wheat varieties, 4.34 to 4.51 mm for barley varieties, 3.24 to 3.40 mm for lentil varieties and 7.23 to 8.54 mm for chickpea varieties as the equivalent sphere diameter ranged from 3.72 to 4.17 mm for wheat varieties, 4.07 to 4.11 mm for barley varieties, 3.47 to 3.66 mm for lentil varieties and 7.12 to 8.50 mm for chickpea varieties. The sphericity values were found to be in range of 53.3 to 58.7% for wheat varieties, 44.4 to 45.8% for barley varieties, 73.5 to 78.0% for lentil varieties and 86.3 to 89.8% for chickpea varieties. Lentil and chickpea had higher sphericity values. This shows their shape approaches that of a sphere (Tabil *at al.*, 1999; Gorial and O'Callaghan, 1990).

Seed mass, bulk density and true density: The seed mass, bulk density, true density and moisture content, which are very important in separating and grading of grains according to density and aerodinamic properties, are as shown in Table 2. The average seed mass varied

Table 3: Means and standard errors of projected area values of grain varieties in different positions

Grain	(A_1), mm^2	(A_2), mm^2	(A_3), mm^2	(A_{ort}) mm^2
Wheat				
Fırat-93	22.62±2.41	21.95±2.42	9.91±1.70	18.10±1.16
DYB-81	19.96±2.12	19.38±1.98	9.02±1.44	16.12±1.01
Harran-95	19.44±2.71	17.94±1.96	9.14±1.90	15.51±1.25
Ceylan-95	18.27±1.60	17.82±1.76	8.39±1.58	14.82±0.87
Aydın-93	16.77±1.86	15.44±1.85	9.35±1.24	13.85±0.98
Nurkent	18.82±3.10	17.43±2.42	9.85±1.68	15.37±1.56
Barley				
Şahin-91	29.87±4.14	24.50±2.94	10.93±2.05	21.72±1.88
Sur-93	29.66±3.03	24.89±2.89	9.24±1.88	21.27±1.73
Lentil				
Fırat-87	14.8±1.79		9.92±1.10	12.36±1.16
Seyran-96	16.81±1.71		9.97±1.35	13.39±1.12
Chickpea				
ILC-482	51.72±7.11	50.42±7.46	50.73±7.42	50.94±3.50
Diyar-95	63.43±8.24	62.61±7.95	61.26±7.99	62.53±4.67

A_1, Projected area in position that seed was placed on hilum axis
A_2, Projected area in position that seed was placed on its side
A_3, Projected area in position that the hilum axis of seed was vertical to horizontal
A_{ort}, Average projected area

from 39.21 to 53.47 mg for wheat varieties, 47.87 to 49.63 mg for barley varieties, 30.91 to 36.45 mg for lentil varieties, and 268.29 to 454.19 mg for chickpea varieties. Aydın-93 from wheat varieties had the highest average bulk density (803 kg/m^3). The true density of wheat varieties ranged from 1373 to 1441 kg/m^3 compared to 1320 to 1339 kg/m^3 for barley varieties, 1395 to 1409 kg/m^3 for lentil varieties, and 1402 to 1406 kg/m^3 for chickpea varieties.

Projected area: In all grain varieties, the projected area (A_3) of seed in position, which is vertical to horizontal plane, was lower than that in other positions (Table 3). When the projected areas of grain varieties in A_1 and A_2 positions were compared, the projected areas of grains in A_1 position were generally higher than that in A_2 position. The projected areas of chickpea varieties in every three position weren't very different. The difference among the projected areas of grain varieties in different positions reduced with increase in sphericity. Similar trends have been reported for other biological materials (Tabil *et al*., 1999; Dursun, 2001).

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 (Konak *et al*., 2002; Aydin, 2002).

Terminal velocity: The theoretical and experimental terminal velocity of grain varieties used in the study are shown in Table 4. The Diyarbakir-81 from wheat varieties had the lowest theoretical average terminal velocity with 8.41 m/s and the highest with 9.06 m/s for Fırat-93. The lowest average experimental terminal velocity was 7.52 m/s for Ceylan-95 and the highest with 8.14 m/s for Fırat-93. The theoretical and experimental terminal velocity

Table 4: Theoretical and experimental terminal velocity values of grain varieties

Grain	Theoretical terminal velocity (V_{krt}), m/s	Experimental terminal velocity (V_{krd}), m/s
Wheat		
Fırat-93	9.06	8.14±0.27
DYB-81	8.41	7.56±0.28
Harran-95	8.53	7.86±0.38
Ceylan-95	8.45	7.52±0.33
Aydın-93	8.80	7.54±0.24
Nurkent	8.67	7.65±0.38
Barley		
Şahin-91	7.23	7.04±0.26
Sur-93	7.24	7.07±0.10
Lentil		
Fırat-87	10.40	7.72±0.29
Seyran-96	10.47	7.78±0.23
Chickpea		
ILC-482	14.47	11.15±0.33
Diyar-95	16.27	12.01±0.25

was different because of irregular shape and their rotation in the air stream. Besides, the terminal velocities of wheat varieties were different because their seed mass, projected area and sphere values were different. The result obtained for the terminal velocities of wheat varieties in the study were similar to the results obtained by Bilanski and Lal (1965), Uhl and Lamp (1966), Song and Litchfield (1991), Özerdem and Toksoy (1993) and Hauhouot-O'Hara *et al.* (2000). The theoretical terminal velocity values were found to be in the range of 7.23 to 7.24 m/s for barley varieties and 10.40 to 10.47 m/s for lentil varieties. These values were lower than values for Sultan variety of Lentil obtained by Çarman (1996). This difference in results obtained are resulted because the terminal velocity of grains are affected by the seed mass, shape, projected area and moisture content of grain. The Diyar-95 from chickpea varieties, which has the highest seed mass among grain varieties, had the highest experimental and theoretical terminal velocity. The

Table 5: Drag coefficient values according to the projected areas in different positions and equivalent sphere of grain

Grain	C_{A1}	C_{A2}	C_{A3}	C_{Aort}	C_{de}
Wheat					
Fırat-93	0.588	0.606	1.342	0.735	0.979
DYB-81	0.589	0.607	1.305	0.730	1.033
Harran-95	0.591	0.640	1.257	0.741	0.982
Ceylan-95	0.625	0.641	1.362	0.771	1.052
Aydın-93	0.683	0.742	1.225	0.827	1.054
Nurkent	0.593	0.641	1.134	0.727	1.007
Barley					
Şahin-91	0.552	0.673	1.510	0.760	1.245
Sur-93	0.532	0.634	1.708	0.744	1.214
Lentil					
Fırat-87	0.577		0.861	0.691	0.904
Seyran-96	0.590		0.995	0.741	0.944
Chickpea					
ILC-482	0.687	0.705	0.701	0.698	0.894
Diyar-95	0.818	0.829	0.847	0.830	0.915

C_{A1}, Drag coefficient in A_1 position of seed
C_{A2}, Drag coefficient in A_2 position of seed
C_{A3}, Drag coefficient in A_3 position of seed
C_{Aort}, Drag coefficient according to mean projected area of seed
C_{de}, Drag coefficient according to diameter of equivalent sphere

terminal velocity for ILC-482 Chickpea was theoretically calculated as 14.47 m/s and experimentally measured as 11.15 m/s. These results had satisfactory agreement with results obtained by Tabatabaeefar *et al.* (2003). The experimental terminal velocity values for all of grain varieties were found to be less than the theoretical terminal velocity.

Drag coefficient: The drag coefficients according to the projected areas in different positions and the equivalent sphere of grain varieties used in the study are shown in Table 5. The drag coefficient in A_3 position for all of grain varieties was higher than that in A_1 and A_2 positions. The drag coefficient calculated according to the diameter of equivalent sphere was higher than that in A_1 and A_2 positions, but lower than that in A_3 Position. The results obtained were in conformity to the results reported by Hawk *et al.* (1966). But, the values of drag coefficient obtained in this study were higher than the values of reported coefficient, which was 0.85 for wheat, 0.98 for barley, 0.81 for chickpea, calculated according to diameter of equivalent sphere by Gorial and O'Callaghan (1990).

CONCLUSION

According to the study results, the barley seeds were longer and wider than wheat seeds. Amongst wheat varieties, Fırat-93 had the highest values for length, width, and thickness. Barley varieties as well as lentil varieties according to dimensions weren't very different. The dimension values of Diyar-95 from chickpea varieties were bigger than ILC-482.

The geometric mean diameter of Diyar-95 chickpea variety amongst grain varieties was the highest as well as the equivalent sphere diameter. The sphericity values were found to be in range of 53.3 to 58.7% for wheat varieties, 44.4 to 45.8% for barley varieties, 73.5 to 78.0% for lentil varieties and 86.3 to 89.8% for chickpea. Lentil and chickpea had higher sphericity values.

The average seed mass varied from 39.21 to 53.47 mg for wheat varieties, 47.87 to 49.63 mg for barley varieties, 30.91 to 36.45 mg for lentil varieties, 268.29 to 454.19 mg for chickpea. The true density of wheat varieties ranged from 1373 to 1441 kg/m^3 compared to 1320 to 1339 kg/m^3 for barley varieties, 1395 to 1409 kg/m^3 for lentil varieties, and 1402 to 1406 kg/m^3 for chickpea.

In all grain varieties, the projected area (A_3) of seed in position, which is vertical to horizontal plane was lower than that in other positions. The difference among the projected areas of grain varieties in different positions reduced with increase in sphericity.

The Diyar-95 from chickpea varieties, which has the highest seed mass among grain varieties, had the highest experimental and theoretical terminal velocity. The Fırat-93 amongst wheat varieties had the highest theoretical and experimental average terminal velocity with 9.06 and 8.14 m/s, respectively. The experimental terminal velocity values were found to be in the range of 7.04 to 7.07 m/s for barley varieties and 7.72 to 7.78 m/s for lentil varieties.

The drag coefficient in A_3 position for all of grain varieties was higher than that in A_1 and A_2 positions. The drag coefficient calculated according to the diameter of equivalent sphere was higher than that in A_1 and A_2 positions, but lower than that in A_3 Position.

Notation:

a Length of seed, mm

A_1 Projected area in position that seed was placed on hilum axis, mm^2
A_2 Projected area in position that seed was placed on its side, mm^2
A_3 Projected area in position that the hilum axis of seed was vertical to horizontal, mm^2
A_{ort} Average projected area, mm^2
A_t Projected area of seed, mm^2
b Thickness of seed, mm
C Drag coefficient
C_{A1} Drag coefficient in A_1 position of seed
C_{A2} Drag coefficient in A_2 position of seed
C_{A3} Drag coefficient in A_3 position of seed
C_{Aort} Drag coefficient according to mean projected area of seed
C_{de} Drag coefficient according to diameter of equivalent sphere
c Width of seed, mm
d_e The diameter of equivalent sphere, mm
d_g Geometric mean diameter, mm
g Gravitational acceleration, m/s^2
m_t Mass of seed, kg
N_t Moisture of seed, %
V_{krd} Terminal velocity experimentally measured, m/s
V_{krt} Terminal velocity theoretically calculated, m/s
γ_b Bulk density, kg/m^3
W_t Weight of seed, kg
Z Shape factor
ϕ Sphericity, %
γ_a True density of air, kg/m^3
γ_t True density of seed, kg/m^3

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