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DIMENSIONAL AND AERODYNAMIC PROPERTIES OF GLOSA HYBRID WHEAT

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ABSTRACT

In post-harvest operations the physical characteristics and aerodynamic properties of grains and seeds are important. The objective of this paper was to evaluate the dimensional and aerodynamic properties of GLOSA hybrid wheat. Geometrical mean dimensions and aerodynamic properties were calculated, based on the measurement of 1000 grains. The moister content of wheat was 12.5%, with a 40 – 43 g per 1000 grains and hectoliter mass (HLM) of 76 – 79 kg/hl. The mean value for length was 6.10 mm, the width was 3.02 mm and the mean thickness was 2.58 mm. The results show a 99.70% frequency of dimensions between the three-standard deviation of the mean. The theoretical terminal velocity of 11.5 m/s is closely related to the experimental value of 11.9 m/s. The obtained data can be used for machine settings in conveying, sorting,or cleaning processes of grains.

1.Introduction

Since ancient times, ever since the very first food revolution, cereals have had special importance for human food. Among the grains, wheat is the most cultivated cereal in Europe, being a staple raw material in the food industry.

Achieving high quality in wheat crops begins by selecting the best varieties, depending on the area of cultivation and climatic conditions. Since the harvesting stage and the post-harvest processes, the aim is to ensure a high quality of the raw material (Balc 2016). After harvest, grains are subjected to cleaning, sorting, transport, drying, and storage processes (Stefanescu 2003). The functioning principles of the machinery and installations in the post-harvest phase are based on the physical and aerodynamic properties of the grains. Machinery and installations involved in the conditioning processes of the grainsbefore milling have special importance for obtaining high-qualityproducts. Knowing all the physical properties of cereal grains is important also in process analysisstarting from sowing (Csizmasia 2008) and harvesting (Gheres 2020, Pruncu 2020). Furthermore, the design of machines in post-harvest processes for cleaning, sorting, and transport requires knowledge of the geometric and pneumatic characteristics of the grains. For this purpose, the engineers can use image analysis of geometric parameters (Firatligil-Durmus 2010).

The characteristics of wheat grain, such as geometric dimensions, shape, mass, density depend primarily on the variety chosen (Beral 2020, Markowski 2013), the plant development conditions, cultivation area, and climatic conditions (Mandea 2018) as well as the moisture content.

The dimensions of the grains define their shape, in the case of wheat is ellipsoid. The shape of the grains can be expressed mathematically through the factors of sphericity (Kaliniewicz 2015). The analysis of the shape of the grains is also important in terms of pneumatic properties.

Studies of the pneumatic properties of cereals and seeds (Chavoshgoli 2014, Khoshtaghaza 2006, Kumar 2020, Matouk 2005, Nalbandi 2010, Poleak 2016, Shahbazi 2014, Shahbazi 2015a, Shahbazi 2015b) are required in airflow-based sorting, cleaning,and conveying processes (Ghafori 2011).

The terminal speed of grain grains depends on the drag coefficient. Several theoretical methods (Bagheri 2016, Haider 1989, Tran-Cong 2004) and experimental methods (Chavoshgoli 2014, Poleak 2016) for determining the drag coefficient for grains, have been developed in the literature.

For wheat varieties which are grown in Romania, the physical properties are given by Stefanescu 2003: geometric dimensions are within the range (4.0 – 8.6 mm) for length, for width (1.4 – 3.8 mm), thickness between (1.4 – 3.8 mm), absolute mass of 1000 grains between 20 – 42 g, true density of 1.2 – 1.5 kg/dm^3 and bulk density of 0.67 – 0.83 kg/dm^{3}and a terminal speed of 8.9 – 11.5 m/s.

2.Materials and methods

The analyzed materialwas the GLOSA wheat, developed by the National Agricultural Research and Development Institute from Fundulea, Romania. It resulted from the complex hybrid combination of Oflabrad "S", Dor"S", and Bucur varieties. The average height of the plant is 85-95 cm, being similar or slightly superior toFlamura 85 and Fundulea 4varieties. The ear is white, awned,with a cylindrical shape, and has medium density. The grains are medium-sized, elongated in shape, and reddish.The 1000-grain weight was 42 – 43 g and has a hectoliter mass (HLM) of 76-79 kg/hl. The Glosais an early variety, drought-resistant autumn wheat. Recommended for the southern part ofRomania due to climatic conditions, is the second most cultivated in the country. The wheat production of Glosa reached 10,400 kg/hainInsula Mare a Brailei area.

2.1.Dimensional properties

The study on dimensional properties was based on the measurement of 1000 grains (N=1000) with a digital caliper having 0.01 mm accuracy. The length (L), width (W), and thickness (Th) of the first 100 measured grainsare shown in table 1. Based on the measured dimensions the maximum (L_{max}, W_{max}, Th_{max}) and minimum values (L_{min}, W_{min}, Th_{min}) of sizes were determined.The number ofindividual classes was(m_i=20, i=1...20).To obtain the class interval (λ) the formulabelow was used (where*L* subscript relates to length size of the grain):

$$\lambda_L = \frac{L_{max} - L_{min}}{m_i}, \text{[mm]} \quad (1)$$

The lower limits (L_{lowi}, W_{lowi}, Th_{lowi}) and upper limits (L_{upi}, W_{upi}, Th_{upi}) of class intervals were determined based on the expression bellowed:

$$m_{L1} = [L_{low\,1},\ L_{up\,1});\ L_{low\,1} = L_{min};\ L_{up\,1} = L_{min} + \lambda_L$$

$$m_{L2} = [L_{low\,2},\ L_{up\,2});\ L_{low\,2} = L_{up\,1};\ L_{up\,2} = L_{\min 2} + \lambda_L$$

$$\ldots \quad (2)$$

$$m_{Li} = [L_{low\,i},\ L_{up\,i});\ L_{low\,i} = L_{up\,(i-1)};\ L_{up\,i} = L_{\min i} + \lambda_L$$

$$\ldots$$

$$m_{L20} = [L_{low\,20},\ L_{up\,20}];\ L_{low\,20} = L_{up\,19};\ L_{up\,20} = L_{max}$$

Table 1. GLOSA wheat dimensionsfor the first 100 grains

Nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
L [mm]	6.37	5.93	5.4	6.46	6.08	5.99	5.83	5.35	5.84	6.23	6.5	6.71	6.17	6.01	6.45	6.27	6.08	6.09	5.75	6.43	6.03	6.38	5.87	6.14	6.36
W [mm]	3.36	3.23	3.41	3.44	3.1	3.19	2.82	3.02	2.96	3.1	2.81	3.35	3.16	2.98	3.26	3.29	2.96	2.87	2.69	3.48	3.01	3.25	2.9	3.62	3.39
Th [mm]	2.59	2.95	2.73	2.38	2.79	2.89	2.77	2.81	2.74	2.53	1.99	3.19	2.89	2.8	3.15	3.11	2.76	2.66	2.53	2.64	2.8	3.16	2.5	3.16	2.88
L [mm]	6.21	6.36	6.37	6.77	5.86	6.37	6.36	6.6	6.44	6.46	6.22	6.14	6.46	6.25	6.21	6.51	6.2	6.75	6.06	5.9	5.92	5.73	6.2	5.76	6.27
W [mm]	3.04	2.92	3.04	3.05	3.00	3.26	2.92	3.54	2.99	3.39	3.4	3.19	3.29	2.83	3.45	2.92	3.26	3.06	2.98	3.03	2.54	2.86	3.12	2.91	3.13
Th [mm]	2.95	2.18	2.76	3.00	2.59	2.96	2.64	2.47	2.57	2.62	2.66	2.43	3.08	2.6	2.73	2.72	2.88	2.83	2.69	2.33	1.93	2.4	2.24	2.47	2.56
L [mm]	5.99	5.89	6.54	5.95	6.19	6.18	6.22	6.28	5.77	6.2	6.21	6.05	5.89	5.58	6.11	6.26	6.1	6.00	5.82	6.59	6.21	6.09	6.63	5.97	6.11
W [mm]	2.94	3.06	2.97	3.08	2.87	3.02	3.07	3.00	3.02	2.93	2.74	2.96	3.12	3.15	2.75	3.02	2.94	2.67	2.79	3.18	3.53	3.1	3.09	2.91	2.79
Th [mm]	2.17	2.89	2.61	2.93	2.81	2.7	2.49	2.65	2.71	2.46	2.62	2.78	2.73	2.28	2.56	2.59	2.69	2.12	2.52	2.68	2.83	2.32	2.71	2.51	2.68
L [mm]	5.97	6.52	6.54	6.26	6.18	5.47	5.93	5.89	6.18	6.12	5.89	6.13	5.65	5.74	5.69	6.14	5.98	6.13	6.16	6.51	6.34	5.45	6.08	5.8	6.43
W [mm]	2.99	2.74	3.25	2.77	3.33	2.91	3.13	3.26	3.08	3.14	3.05	2.99	2.96	3.55	3.53	3.24	2.82	3.2	3.13	3.12	2.6	3.06	3.04	2.93	3.39
Th [mm]	2.53	2.54	2.81	2.59	2.98	2.37	2.49	2.58	2.98	2.42	2.81	2.57	2.82	2.96	2.92	2.78	2.74	2.58	3.00	2.77	2.48	2.25	2.59	2.45	2.8

The frequency of occurrence of length, width, and thickness(f_{Li}, f_{Wi}, f_{Thi}),defined by the occurrence of values in individualclasses for each size(n_{Li}, n_{Wi}, n_{Thi}) was calculated with:

$$f_{Li} = \frac{n_{Li}}{N} \cdot 100, [\%] \tag{3}$$

The mean value of individual classes for each size(M_{Li}, M_{Wi}, M_{Thi}) was determined by:

$$M_{Li} = \frac{L_{Low\,i} - L_{up\,i}}{2}, \text{ [mm]} \tag{4}$$

The mean value of each size (M_L, M_W, M_{Th}) can be calculated with expression (5):

$$M_L = \frac{\sum_{i=1}^{m} n_{Li} \cdot M_{Li}}{N}, \text{ [mm]} \tag{5}$$

The deviation from the mean value inindividual classes (D_{Li}, D_{Wi}, D_{Thi})was calculated with equation (6) to obtain the standard deviation (σ_L, σ_W, σ_{Th}) with expression (7):

$$D_{Li} = M_{Li} - M_L, \text{ [mm]} \tag{6}$$

$$\sigma_L = \sqrt{\frac{\sum_{i=1}^{m} (D_{Li})^2 \cdot n_{Li}}{N}}, \tag{7}$$

Statistically, 99.7% of the measured dimensions should fall within the limits of three standard deviations of the mean (M-3σ, M+3σ).

2.2.Aerodynamic properties

The study of aerodynamic properties is important inthe airflow sorting and cleaning processes of seeds.Considering an analogy between a glider and a wheat grain, the aerodynamic forces are represented in figure 1.

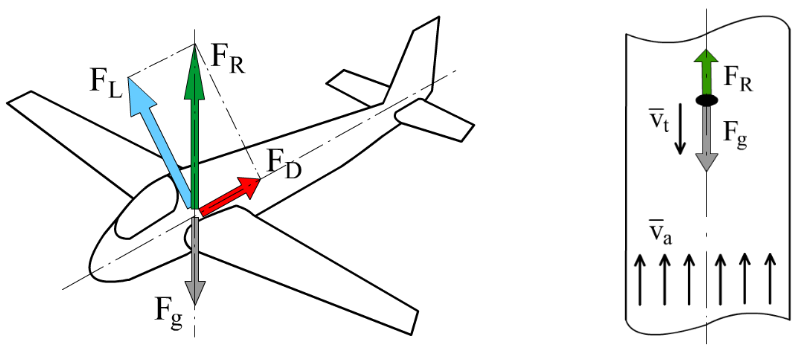

Figure 1. The analogy of aerodynamic forces acting on a glider and wheat grain.

Where: F_g is the force of gravity, F_L is the force of lift, F_D is the drag force, and F_R is the resultant of aerodynamic forces. The two forces acting on a free-falling grain are the force of gravity and resultant of aerodynamic forces. At the start of the falling phase, $F_R < F_g$ and the grain will accelerate. When $F_R = F_g$ the grain has no acceleration, will reach the maximum and constant falling speed, known as the terminal velocity, v_t. In the case of an airflow, with a velocity of v_a, acting on the grain from below, three situations can be considered: $v_t>v_a$ the grain will fall, $v_t = v_a$ the grain will float, and $v_t<v_a$the grain will be lifted.

The mathematical expression used for terminal velocity, also adopted in the literature (Mujumdar 2015) is given below:

$$v_t = \sqrt[2]{\frac{2\cdot m_g\cdot g\cdot(\rho_g-\rho_a)}{C_d\cdot A_g\cdot \rho_g\cdot \rho_a}}\ , [\text{m/s}] \qquad (8)$$

Parameter $m_g=42\cdot10^{-6}$ kg,is the weight of wheat grain, $g=9{,}81$ $m/s^2$is the gravitational acceleration. Thedensity of grainρ_g inkg/m^{3}was calculated with equation (9), $\rho_a=1.2047$ kg/m^3 is the density of air at 20 °C.

$$\rho_g = \frac{m_g}{V_g}\ , [\text{kg/m}^3] \qquad (9)$$

Parameter $A_g$is the surface area of the grain section normal to the airflow, and $V_g$is the theoretical volume of the grainobtained by expressions(10)and (11). Where d_g is the equivalent diameter of the grain and was determined with equation (12) based on mean values of length ($M_L=6.1\cdot10^{-3}$ m), width ($M_W=3.01\cdot10^{-3}$ m), and thickness ($M_{Th}=2.58\cdot10^{-3}$ m).

$$A_g = \frac{\pi\cdot d_g^2}{4}\ , [\text{m}^2] \qquad (10)$$

$$V_g = \frac{4}{3}\cdot\pi\cdot\left(\frac{d_g}{2}\right)^3\ , [\text{m}^3] \qquad (11)$$

$$d_g = \sqrt[3]{M_L\cdot\frac{(M_W-M_{Th})^2}{4}}\ , [\text{m}] \qquad (12)$$

The value for the drag coefficient C_d can be adopted from literature or can be determined theoretically (Bagheri 2016).For this study,a drag coefficient of $C_d=0.5$ was adopted, a commonlyused value in the literature (Mujumdar 2015).

For the experimental study of floating speedthe behavior of the grains in an observation column with monitored airflow was used.

It was observed that the grains begin to float at an airspeed of 9.5 m/s (Figure 2.a). At the airspeed of 11.9 m/s, a balance occurred between the descending and climbing grains in the observation column (Figure 2.b). For an airspeed higher than 13 m/s in the observation column, all the grains were lifted and transported pneumatically.

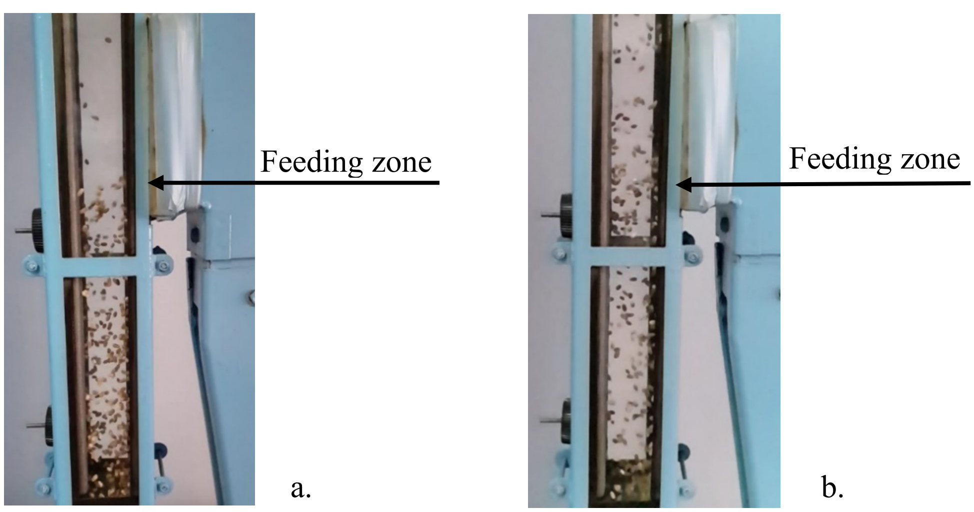

Figure 2. Observation column during experimental measurements:
a – floating velocity at 9.5 m/s, b – floating velocity at 11.9 m/s.

3.Results and discussions

The maximum, minimum, and mean values of dimensions, standard deviations, calculated, and measured terminal velocity for the GLOSA wheat are shown in Table 2.

Table 2. Mean values and standard deviations of grain dimensions and terminal velocity

Dimension	Max. Value, mm	Min. Value, mm	Mean, mm	Standard Deviation	Calculated terminal velocity, m/s	Measured terminal velocity, m/s
Length	6.99	5.03	6.10	0.27067	11.5	11.9
Width	3.63	2.46	3.02	0.19075		
Thickness	3.21	1.88	2.58	0.22828		

The maximum and minimum geometric dimensions established for the analyzed GLOSA wheat fall within the intervals given in the literature according to Stefanescu 2003. The average dimension found for length was 6.1 mm, the width was 3.02 mm and for thickness, a value of 2.58 mm was determined.The standard deviations show a higher dispersion of values for length size, while in the case of width the dimensions are closer to the mean value.

The calculated terminal velocity (for C_d=0.5) was 11.5 m/s and the measured floating velocity was 11.9 m/s with a difference of3.4%.

The one-standard deviation of the mean (M-σ, M+σ),two-standard deviation of the mean (M-2σ, M+2σ), three-standard deviation of the mean (M-3σ, M+3σ)and the frequency occurrence of dimensions are presented in table 3.

Table 3. Standard deviations of the mean and frequency occurrence of dimensions

Dimension	One-standard deviation of the mean	Frequency, %	Two-standard deviation of the mean	Frequency, %	Three-standard deviation of the mean	Frequency, %
Length	(5.83, 6.37)	83.8	(5.56, 6.64)	97.8	(5.29, 6.92)	99.7
Width	(2.83, 3.21)	67.3	(2.64, 3.41)	95.3	(2.45, 3.60)	99.8
Thickness	(2.40, 2.80)	67.6	(2.12, 3.03)	95.8	(1.89, 3.26)	99.9

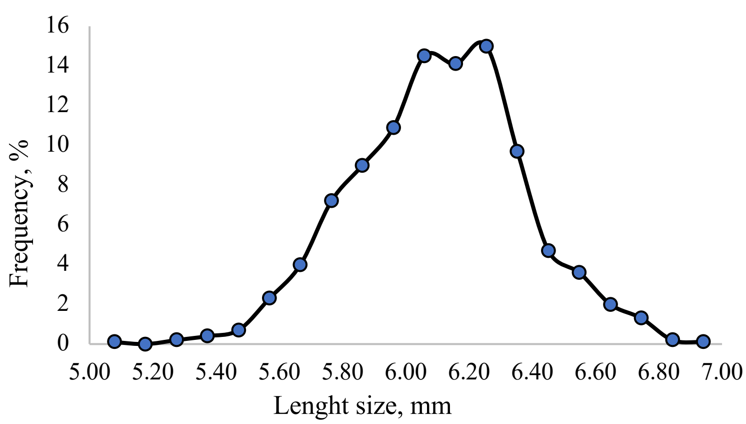

Figure 3. Frequency occurrence of length valuesin classes against the size range.

In the case of width and thickness, the standard deviations of the mean show a good correlation with the 68-95-99.7 rules.For length, the one and two-standard deviation of the mean shows higher values for frequency occurrence than expected and in the case of the three-standard deviation of the mean, the 99.7%rule is respected.

The frequency occurrence of lengthvaluesin classes plotted against the size rangeis shown in figure 3.

The highest occurrence of 145 and frequency of 14.5% of length values are in class 11 with interval limits of (6.01, 6.11), as shown in table 4.

The frequency occurrence of width values in classes plotted against the size rangeis shown in figure 3.

Table 4. Frequency and occurrence of length values

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Interval, [mm]	5.03	5.13	5.23	5.32	5.42	5.52	5.62	5.72	5.81	5.91	6.01	6.11	6.21	6.30	6.40	6.50	6.60	6.70	6.79	6.89
Occurrence	1	0	2	4	7	23	40	72	90	109	145	141	150	97	47	36	20	13	2	1
Frequency, [%]	0.1	0	0.2	0.4	0.7	2.3	4.0	7.2	9.0	10.9	14.5	14.1	15.0	9.7	4.7	3.6	2.0	1.3	2.0	1.0

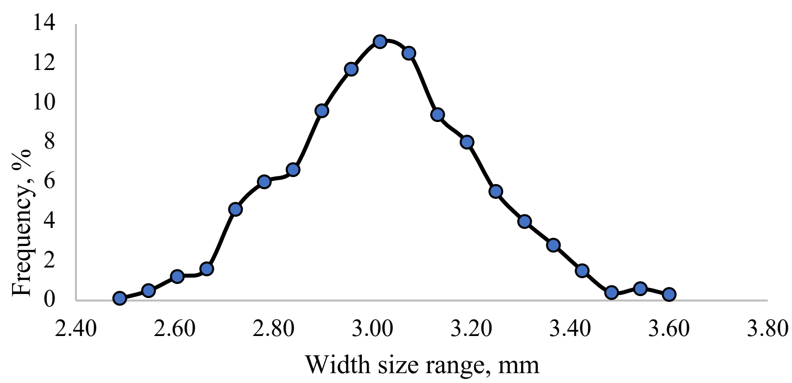

Figure 4. Frequency occurrence of width values in classes against the size range.

The highest occurrence of 131 and frequency of 13.1% of width values are in class 10 with limits of (2.99, 3.05).

The frequency occurrence of thickness values in classes plotted against the size rangeis shown in figure 4.

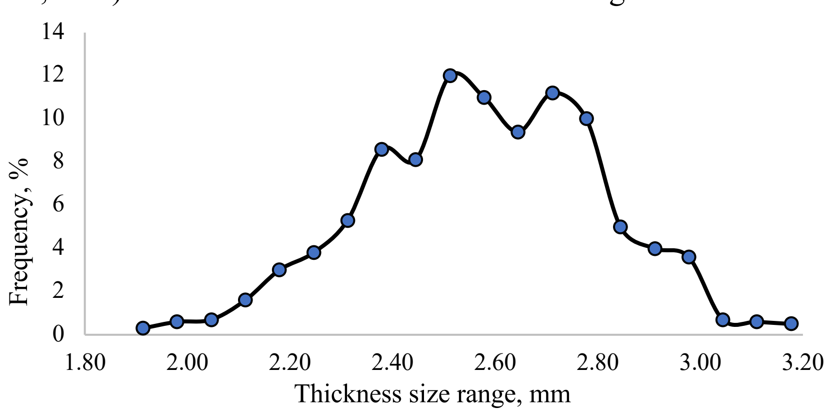

Figure 5. Frequency occurrence of thickness values in classes against the size range.

The highest occurrence of 120 and frequency of 12.0% of thickness values are in class 10 with interval limits of (2.48, 2.55).

4.Conclusions

In this paper, the geometrical dimensions, and aerodynamic properties of GLOSA wheat were analyzed. The value found for the mean length was 6.10 mm with a standard deviation of 0.27.The mean width was 3.02 mm with a standard deviation of 0.19.The mean thickness was 2.58 mm with a standard deviation of 0.228. Mean dimension and standard deviation values of grains are important in choosing the size of sieve openings in mechanical cleaning and sorting operations.

The calculated terminal velocity of 11.5 m/s was very closely related to the measured value the floating velocity of 11.9 m/s. The GLOSA wheat's terminal velocity is in the upper limit of the given interval of (8.9, 11.5 m/s) found in the literature. Terminal velocity of grains is critical in pneumatic cleaning, sorting, and conveying processes.

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