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PHYSICAL AND MECHANICAL PROPERTIES AND QUALITY INDICATORS OF GRAIN OF CEREAL CULTURES

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Досліджено фізико-механічні та якісні властивості зерна пшениці, тритикале, ячменю, кукурудзи та проса залежно від погодних умов і особливостей сорту. Вивчення придатності зерна злакових культур певних сортів для використання у переробній промисловості є новим. Технологічні властивості зерна за сукупними ознаками і показниками їхньої якості характеризують стан зерна в технологічних процесах перероблення та впливають на вихід і якість крупи.

Ключові слова: *зерно, пшениця, тритикале, ячмінь, кукурудза, просо, сорт, властивості, якість, крупа.*

Setting of the problem. Indicators of properties of grain can be divided into two groups: properties peculiar to grain of the crop, as well as properties that vary within the same crop. The technical process of grain processing should be improved towards obtaining maximum endosperm, increasing product yield of highest grades and improving their quality [2, 12]. Studies of eligibility of certain varieties of grain for use in the processing industry is new. In addition, there are no recommendations for triticale grain production for the moment. Eligibility of grain for industry is characterized by its quality as a raw material for recycling.

Analysis of recent studies and publications. Wheat is the most important food crop. It contains all necessary elements of food: proteins, carbohydrates, fats, vitamins, enzymes and minerals. There is good reason that wheat is the staple food in 43 countries with a population of over 1 billion people [6, 24].

Triticale is relatively new winter or spring grass plant artificially created by crossing wheat with rye, and thus many morphological and biological properties of triticale are intermediate between wheat and rye. Triticale is less demanding to growing conditions than wheat which makes it particularly valuable for households with low resource provision [5, 8, 10]. Barley is one of the oldest cultures. In Ukraine barley grown four to five thousand years BC. Barley is widely used by man for food, feed and industrial purposes [13, 18]. Corn is one of the most common crop plants in the world that surely dominated by the gross harvest of grain. In recent years significantly increased rate of harvesting, storage and export of corn, as well as requirements for quality. Corn is used as a universal culture [14, 15]. Millet – ancient culture. Grain of millet – the smallest of the processed crops. Millet – a culture

without waste. In the rough millet is used as a valuable animal feed. Millet less than other cultures, suffering from disease and pests resistant to lodging [1, 3].

For grain, as a raw material for processing, its biometric characteristics, size and uniformity of grain mass have the main technological importance [13, 18]. The shape and linear grain size influence the choice of sieves or separators as well as the characteristics of shelling machines. In addition, the geometric characteristics of the grain determines its density when forming the layer and peculiarities of moving grain while transportation. Different from the average, values of grain shape affect the porosity, the angle of repose and the angle of friction. The larger geometric size of grain is, the greater the angle of slope is, which has a positive effect on gravity feed of grains during transportation by gravity pipes. Because of the complexity of the processes, many cereal and flour mills are characterized by a significant extent of processing grain products, which reaches a few kilometres of machines and different mechanisms for average powered plants [17, 24].

That is why the study of physical and mechanical properties of grain has not only theoretical but also practical meaning. Given that these properties vary considerably depending on weather conditions, growing technologies and features of varieties, it requires thorough study. In addition, physical and mechanical characteristics of triticale grain have not been studied enough and thus it determines the relevance of the study.

The aim of the research is to study the physical and mechanical properties and quality of wheat, triticale, barley, corn and millet grain depending on weather conditions and properties of the variety.

Research methodology. Wheat grain of Podolyanka, Trizo, Lazurna varieties, triticale of Khlibodar Kharkivskyi and Avatar varieties, barley of Zvershennya and Komandor varieties and millet of Veselopodil´ske 16 variety were grown on the experimental field of educational research and production department of Uman NUH, while wheat of Midas variety, barley of Svagor, Talbot varieties and corn of DKS 4685×1390 and PR9B58 varieties was grown in the experimental field of the farm "Prolisok +" in Graniv village, Haysyn district of Vinnitsa region.

The study was conducted during 2011–2023 in the Department of Technology of storage and grain processing of Uman National University of Horticulture and on the production complex farm "Prolisok +" in Vinnytsia region.

Linear dimensions were measured for the grain of wheat, triticale, barley, corn and millet by the method described by N. M. Osokina & K.V. Kosteska [13, 14]. Grains volume (*V*) and an external surface area (F) were calculated by the formulas:

$$V = k \bullet a \bullet b \bullet \ell, \text{ mm}^3 \quad (1)$$

where – *a, b, ℓ* are width, thickness and length of grain;

k – research coefficient (for the grain of wheat and triticale *k* = 0,52; for the grain of barley *k* = 0,58; for the grain of corn *k* = 0,50; for the grain of millet *k* = 0,46).

For the grain of wheat, triticale, barley and corn:

$$F = 1{,}12 \times a^2 + 3{,}76 \times b^2 + 0{,}88 \times \ell^2, \text{ mm}^2 \quad (2)$$

For the grain of millet:

$$F = 0{,}35 \bullet (a + b + \ell)^2, \text{ mm}^2 \quad (3)$$

Peculiarity of grain form is evaluated by its sphericity, which is the ratio of external surface area equivalent grain bullet (F_{sh}) for up to actual grain area (F):

$$\Psi = \frac{F_{sh}}{F}, \quad (4)$$

Thus: $F_{sh} = 4 \times \pi \times r^2$; $r = 0{,}62 \times \sqrt[3]{V}$

Specific surface of grain was set by the ratio of the area of the outer surface (F) to the volume of grains (V):

$$F/V \quad (5)$$

The volume of surface layers ($V_{s.l.}$) of grain was determined by the formula:

$$V_{s.l.} = F \times G, \text{ mm}^3 \quad (6)$$

where G is the thickness of tissue (for the grain of wheat, triticale and corn G = 0,065 mkm; for the grain of barley and millet G = 0.085 mkm).

Mass fraction of starchy endosperm was calculated by the formula:

$$m_e = \frac{V - V_{s.l.}}{V} \times 100 - m_z, \% \quad (7)$$

where m_z is mass of a bud (for the grain of wheat, triticale and barley m_z = 2,5 %; for the grain of corn m_z = 10 %, for the grain of millet m_z = 6 %).

Specific gravity (density) of grain was determined by the formula:

$$\rho = m/V, \quad (8)$$

where m is mass of grain, g/cm^3.

To determine the quality of the grain standard methods were used: sampling (SS 13586.3–83; SS 24104–88); determination of the color and smell (SS 10967–75); contamination (SS 13586.6–93; SS 13586.4–83); debris (SS 30483–97); humidity (SS 13586.5–93); nature (bulk density) (SS 10840–64); 1000 grain weight (SS 10842–89); glasslike structure (SS 10987–76).

Research results. Geometric characteristics of grain affect the movement of grain during transportation and determine its density (porosity) during the formation of the embankment thickness [13–15, 17, 24]. According to the measurements of wheat, triticale, barley, corn and millet grain, parameters of their geometric characteristics varied quite a lot. It is not enough to specify only the linear dimensions to characterize geometric features of grain. Values of grain volume, area, sphericity, specific surface, and its density play an important role during moistening and dehumidification, drying, heating, and cooling of grain (Tables 1–5).

Obtained values of physical and mechanical indicators of wheat and triticale (Tables 1–2) were within the limits given in the literature [6, 7, 24]. However, wheat grain of the studied varieties had a thickness up to 7 % greater, and the length and width – by 4–11 and 2–10 %, respectively, smaller than the average from the literature sources. The greatest linear dimensions were observed in grain of soft winter wheat of Lazurna variety, the smallest – in soft spring wheat of Trizo variety of 2014. These characteristics affected the volume and area of the outer grain surface, the values of which were lower than the average values in the literature by 4–8 mm^3, respectively, and 4–12 mm^2 for wheat varieties of Podolianka, Trizo, Midas, while it was 0.8 and 0.3 % higher, respectively, for grain of Lazurna variety (Table 1).

Table 1. Physical and mechanical properties of wheat grain

Varieties	Year	Size, mm			Grains volume, V, mm^3	Sphericity, φ	External surface area, F, mm^2	Specific surface of grain, F/V	Volume of surface layers, $V_{s.l.}$, mm^3	Mass fraction of tarchy endosperm m_e, %	Specific gravity (density), ρ, g/sm^3	Bulk density, kg/dm^2
		length, ℓ	width, a	thickness, b								
Podolyanka	2011	6.60	3.70	3.10	38.80	0.62	89.40	2.30	5.81	82.50	1.33	0.78
	2012	6.80	3.80	3.10	40.80	0.62	93.00	2.28	6.05	82.70	1.34	0.78
	avarage	6.70	3.75	3.10	39.80	0.62	91.20	2.29	5.93	82.60	1.34	0.78
Trizo	2013	6.50	3.60	3.10	37.70	0.62	87.80	2.33	5.71	82.40	1.38	0.76
	1014	6.10	3.40	2.90	30.90	0.61	76.40	2.47	4.97	81.40	1.38	0.76
	2015	6.40	3.70	3.00	36.90	0.63	85.20	2.31	5.54	82.50	1.40	0.76
	avarage	6.30	3.57	3.00	35.17	0.62	83.13	2.37	5.41	82.10	1.39	0.76
Midas	2014	6.20	3.90	3.10	32.90	0.54	86.00	2.61	5.59	80.50	1.34	0.77
	2015	6.30	3.90	3.20	40.90	0.63	90.50	2.21	5.88	83.10	1.35	0.77
	avarage	6.25	3.90	3.15	36.90	0.59	88.25	2.41	5.73	81.80	1,35	0.77
Lazurna	2013	6.70	3.90	3.20	43.40	0.58	94.60	2.18	6.15	83.30	1.35	0.79
	2014	6.70	4.00	3.20	44.60	0.63	95.90	2.15	6.23	83.50	1.35	0.79
	average	6.70	3.95	3.20	44.00	0.60	95.25	2.17	6.19	83.40	1.35	0.79
According to literature sources*		4.80–8.00	1.60–4.00	1.50–3.30	12.00–54.90	0.36–0.68	58.00–115.00	–	3.77–7.48	77.00–85.00	1.33–1.53	0.73–0.84
		7.00	4.00	3.00	43.70	0.63	94.90	2.18	6.17	83.40	-	-
LSD 5 %		*0.31*	*0.19*	*0.167*	*3.20*	*0.03*	*4.51*	*0.12*	*0.30*	*4.11*	*0.07*	*0.05*

Note: above the line – the border; below the line – average [6, 7, 18, 24].*

Grains of triticale (Table 2) of Khlibodar kharkiv and Avatar varieties have an elongated ellipse shape, their length and width, on average during the years of research are 7–8 % lower than corresponding average values and thickness is 11–15% larger than average data of sources of literature.

Table 2. Physical and mechanical properties of triticale grain

Varieties	Year	Size, mm			Grains volume, V, mm^3	Sphericity, φ	External surface area, F, mm^2	Specific surface of grain, F/V	Volume of surface layers, $V_{s.l.}$, mm^3	Mass fraction of tarchy endosperm m_e, %	Specific gravity (density), ρ, g/sm^3	Bulk density, kg/dm^2
		length, ℓ	width, a	thickness, b								
Khlibodar Kharkivsky	2011	7.60	3.20	2.90	36.10	0.57	93.50	2.59	6.08	80.70	1.27	0.66
	2012	7.80	3.30	2.90	38.10	0.55	97.30	2.55	6.32	80.90	1.30	0.69
	average	7.70	3.20	2.90	37.10	0.56	95.40	2.57	6.20	80.80	1.29	0.68
Avatar	2013	7.90	3.20	3.00	39.40	0.56	100.20	2.54	6.51	81.00	1.27	0.72
	2014	7.70	3.20	3.00	37.00	0.55	98.30	2.66	6.39	80.20	1.27	0.72
	2015	7.80	3.20	3.00	38.90	0.56	98.80	2.54	6.42	81.00	1.28	0.73
	average	7.80	3.20	3.00	38.20	0.55	99.30	2.60	6.44	80.70	1.27	0.72
According to literature sources*		5.00-10.00	1.40-3.60	1.10-3.50	5.00-66.00	–	72.00-148.00	–	4.66-9.66	74.00-81.00	–	0.70-0.75
		8.40	3.50	2.60	39.70	0.56	101.20	2.55	6.58	80.00		-
LSD 5 %		*0.39*	*0.16*	*0.15*	*1.89*	*0.03*	*4.88*	*0.09*	*0.32*	*2.04*	*0.06*	*0.04*

*Note: *: above the line – the border; below the line – average [5, 8, 9].*

Values of volume and area of the outer surface of triticale grain yielded the average data of sources of literature respectively 2–3 mm^3 and 2–6 mm^2. Value of sphericity of grains of crops under investigation are close to data of sources of literature: for wheat – 0.58–0.63; triticale – 0.55–0.57 (Table 1–2).

Obtained values of physical and mechanical indicators of barley (Table 3) were within the limits given in the literature sources [13–15, 18].

Table 3. Physical and mechanical properties of barley grain

Variety	Year	Size, mm			Grains volume, V, mm^3	Sphericity, φ	External surface area, F, mm^2	Specific surface of grain, F/V	Volume of surface layers, $V_{s.l.}$, mm^3	Mass fraction of tarchy endosperm m_e, %	Specific gravity (density), ρ, g/sm^3	Bulk density, kg/dm^2
		length, ℓ	width, a	thickness, b								
Talbot	2022	9.30	3.10	2.80	46.82	0.54	116.65	2.49	9.92	78.30	1.02	0.62
	2023	9.40	3.10	2.90	49.01	0.54	120.14	2.45	10.21	76.70	1.01	0.64
	average	9.35	3.15	2.85	47.92	0.54	118.39	2.47	10.06	77.50	1.02	0.63
Svagor	2014	9.70	3.50	3.00	50.90	0.52	130.30	2.56	11.08	75.70	1.10	0.64
	2015	9.60	3.40	3.00	48.90	0.50	127.90	2.62	10.87	75.30	1.12	0.65
	average	9.60	3.40	3.00	49.90	0.51	129.10	2.59	10.98	75.50	1.11	0.64
Komandor	2013	8.40	2.60	2.30	25.10	0.46	89.60	3.57	7.62	67.20	1.30	0.63
	2214	8.40	2.80	2.50	29.40	0.47	90.90	3.09	7.73	71.20	1.28	0.62
	2015	8.40	2.80	2.40	28.20	0.48	92.50	3.28	7.86	69.60	1.31	0.64
	average	8.40	2.70	2.40	27.60	0.47	91.00	3.30	7.74	69.30	1.30	0.63
Zvershennya	2011	8.90	2.60	2.10	24.30	0.43	93.80	3.86	7.97	64.70	1.29	0.62
	2012	8.80	2.60	2.10	24.10	0.44	101.10	4.20	8.59	61.80	1.28	0.61
	average	8.80	2.60	2.10	24.20	0.43	97.50	4.03	8.28	63.30	1.28	0.61
From literary sources *		7.00-10.00	2.00-3.00	1.70-3.00	12.00-45.00	–	58.50-131.90	–	4.97-11.21	62.00-69.00	1.13-1.28	0.54-0.70
		8.70	2.60	2.30	26.00	0.45	94.10	3.62	8.00	67.00	-	-
LSD 5 %		*0.44*	*0.15*	*0.13*	*1.71*	*0.03*	*5.31*	*0.16*	*0.44*	*3.80*	*0.06*	*0.03*

*Note: * above the line – the border; below the line – average. (Osokina, 2016; Savchuk, 2005) [13–15, 18].*

The average linear dimensions of barley grain of Zvershennia variety almost coincided with the corresponding average values from literature sources. However, the width and thickness of barley grain of Komandor variety was 0.1 mm greater, and the length was 0.3 mm less than the corresponding average literature data, with a slight advantage of grain of 2014. In turn, the length, width, thickness of grain of Svahor variety were 9.6, 3.4, and 3.0 mm, respectively, which was 10–26 % higher than the corresponding average values from literature sources, as well as 8–30 % higher than in grain of other varieties of barley (Table 3).

For barley grain of Svahor variety, the volume and outer surface area were 49.9 mm^3 and 129.1 mm^2, respectively, which were 1.9 and 1.4 times higher, respectively, than the average values in literary sources (Table 3).

Obtained values of physical and mechanical indicators of corn grain (Table 4) were within the limits given in the literature sources [15, 18].

Table 4. Physical and mechanical properties of corn grain

Variety	Year	Size, mm			Grains volume, V, mm^3	Sphericity, φ	External surface area, F, mm^2	Specific surface of grain, F/V	Volume of surface layers, $V_{s.l.}$, mm^3	Mass fraction of starchy endosperm, m_e, %	Specific gravity (density), ρ, g/sm^3	Bulk density, kg/dm^2
		length, ℓ	width, a	thickness, b								
DKS 4685×1390	2012	10.3	7.6	4.5	176.1	0.65	234.2	1.30	15.22	81.3	1.20	0.74
	2013	10.7	7.8	4.8	200.3	0.66	252.1	1.26	16.39	81.8	1.19	0.75
	average	10.5	7.7	4.6	188.2	0.65	243.2	1.28	15.80	81.5	1.20	0.75
PR 39 B 58	2014	11.9	7.9	4.6	216.2	0.63	274.1	1.27	17.81	81.8	1.18	0.70
	2015	11.8	8.3	5.4	264.4	0.60	309.3	1.17	20.11	82.4	1.14	0.70
	average	11.8	8.1	5.0	240.3	0.61	291.7	1.22	18.96	82.1	1.16	0.70
From literary sources *		5.50-13.50	5.00-11.50	2.50-11.50	167.00-232.00	0.58-0.80	192.40-243.40	1.00-1.40	12.51-15.82	78-90	1.16-1.23	0.68-0.82
		10.2	7.6	4.7	180.4	0.68	228.0	1.1	14.82	81.8	–	0.73
LSD 5 %		*0.57*	*0.41*	*0.23*	*10.71*	*0.03*	*13.36*	*0.06*	*0.88*	*4.10*	*0.06*	*0.04*

*Note: * – limits / average [1, 16, 18].*

However, corn grain (Table 4) of PR39B58 variety had the shape of an elongated ellipse. Thus, its length, width, and thickness were 13.9, 6.2, and 6.0 %, respectively, higher than the average data from literature sources and 11.4, 4.9, and 7.0 % higher than the corresponding average values of DKS 4685×1390 variety. The greatest linear dimensions were found in corn grain of PR39B58 variety of 2015, the smallest – in grain of DKS 4685×1390 variety of 2012.

Values of the volume and outer surface area of corn grain of DKS 4685×1390 and PR39B58 varieties (Table 4) exceeded the average data in literature sources by 22–25 and 4–6 %, respectively. Sphericity of corn was inferior to the average literature values and it was 0.60–0.66. This fact characterized corn of DKS 4685×1390 and PR39B58 varieties as grain of a slightly elongated form.

Grain of millet – the smallest of processed cereals – globular or oval. However, grain millet Veselopodilske 16 variety (Table 5) has an elongated ellipse shape matches its width and length and thickness, respectively, 0.2 and 0.3 mm larger average data. Values of volume, area of the outer surface of millet Veselopodilske 16 variety are respectively 5.9 mm^3 and 18.65 mm^2, exceeding the average data sources References 0.5 mm^3 and 2.45 mm^2 respectively. The value is spherical grains of millet slightly inferior average of sources and literature were 0.89 (Table 5).

Specific grain surface was determined by the F/V ratio. This indicator was extremely important during drying or moistening of grain, as it was responsible for the intensity of heat exchange and diffusion of moisture in grain. Value of this indicator for wheat was 2.15–2.61; triticale – 2.54–2.66 and exceeded the average literature data for the corresponding crops.

Table 5. Physical and mechanical properties of millet grain

Variety	Size, mm			Grains volume, V, mm^3	Sphericity, φ	External surface area, F, mm^2	Specific surface of grain, F/V	Volume of surface layers, $V_{s.l.}$, mm^3	Mass fraction of starchy endosperm, m_e, %	Specific gravity (density), ρ, g/sm^3	Bulk density, kg/dm^2
	length, ℓ	width, a	thickness, b								
Veselopodil´ske 16	3.4	2.1	1.8	5.9	0.89	18.65	3.16	1.59	67.1	1.33	0.72
According to literature sources*	1.80–3.20	1.20–3.00	1.00–2.20	5.00–6.00	0.90–0.94	10.00–20.00	2.00–3.20	0.85–1.62	62–68	–	0.68–0.73
	3.20	2.10	1.50	5.40	0.92	16.20	3.0	1.40	65.0		–

*Note: * limits / average [1, 16, 18].*

Wheat of Lazurna variety of 2014 and triticale of Avatar variety of 2013 and 2015 became exceptions (Tables 1–2). Value of the specific surface indicator for barley grain was determined within 2.56–4.20 (Table 3). Value of this indicator for corn was 1.17–1.30; millet – 3.16, and exceeded the average literature data for these crops (Tables 4–5).

It was obvious that when grain size decreased, the ratio value of volume to outer surface area also decreased, so small grain had a higher content of shells and a lower content of endosperm. In addition, flour and cereals are obtained from endosperm, and the aleurone layer and shells are production waste. Therefore, it is important to have information about the amount of endosperm in grain, the share of the surface layers of grain and to make a prediction regarding the possible yield of the product.

In turn, the mass fraction of endosperm of triticale grain was 80–81 %, a margin of 2013 and 2015 (Table 1–2).

It was established that 63.3 % of starch was presented in barley of Zvershennia variety, and 6–12 % more in Komandor and Svahor varieties (Table 3). Most of the calculations determined the largest mass share of endosperm starch in corn grain of DKS 4685×1390 variety of 2013 and in PR39B58 variety of 2014 – at the level of 81.8 % (Table 4). In turn, the mass fraction of endosperm of millet grain Veselopodilske 16 variety (Table 5) was 67.1 %.

Volume of the surface layers of wheat grain during the years of research fluctuated between 4.97–6.23 mm^3 (Table 1). Among the studied varieties, the highest indicator was determined in grain of Lazurna variety, and the lowest – in Trizo variety (13 % less).

Triticale grains of Avatar variety had 4% less volume compared to the surface layers of the grains of Khlibodar kharkiv variety (Table 2).

However, volume of the surface layers of barley grain during the years of research fluctuated between 7.62–11.08 mm^3 (Table 3). Among the studied varieties, the highest indicator was determined in Svahor variety (10.87–11.08 mm^3), the lowest – in Komandor variety (30 % less).

Grain of DKS 4685 × 1390 variety had a 17 % lower volume of surface layers than PR39B58 variety (Table 4).

The volume of surface layers of grains of millet of Veselopodilske 16 variety (Table 5) was 1.59 mm^3 and slightly above average sources of literature. The largest value of bulk mass was determined in wheat grain of Lazurna variety – 0.79 kg/dm^2, triticale of Avatar variety – 0.72 kg/dm^2 (Tables 1–2); in barley grain of Svahor variety – 0.64 kg/dm^2 (Table 3); corn of DKS 4685×1390 variety – 0.79 kg/dm^2 (Table 4); millet of Veselopodilske 16 variety – 0.72 kg/dm^2.

Specific gravity (density) of grain as a whole characterizes the maturity of grain, chemical composition, structure, completeness, hardness, strength and has a great influence on productive properties. Starch and mineral substances have the greatest density, therefore, with an increase in their share, grain density increases, and, conversely, an increase in protein and fats reduces specific gravity of grain. Value of this indicator (Table 1–2) for wheat was 1.33–1.40 g/cm^3, and for triticale – 1.27–1.30 g/cm^3, with the advantage of Trizo and Avatar varieties, respectively. The highest value of specific gravity was determined in barley grain of Komandor variety – 1.30 g/cm^3, and in Zvershennia and Svahor varieties – 1.5 and 14.6 % less, respectively (Table 3). Value of this indicator (Table 4) for corn of DKS 4685 × 1390 variety was 1.20 g/cm^3, which was 3 % higher than the average indicator of PR39B58 variety. Grain density of millet of Veselopodilske 16 variety was 1.33 g/cm^3 (Table 5).

Technological properties of grain are a set of features and indicators of its quality, which characterize the state of grain during processing and affect the product quality. The study of grain quality showed that the samples had a characteristic smell and taste for cereal crops. No pests of grain stocks were found in the studied samples (Tables 6–10). Tables 6–10 provide a comparative description of technological properties of wheat, triticale, barley, corn, and millet varieties under analysis.

Table 6. Characteristics and quality standards of wheat grain

Indicator	Permissible limits (SSU 3768:2019)	The actual quality grade													*LSD 5 %*
		Podolyanka			Trizo				Midas			Lazurna			
		year													
		2011	2012	average	2013	2014	2015	average	2014	2015	average	2013	2014	average	
Moisture, %	not more that 14.0	12.9	12.5	12.7	12.9	12.6	13.0	12.8	12.8	13.2	13.0	13.7	13.5	13.6	*0.64*
Waste impurities, %	not more that 1,0/2,0/2,0/3,0	1.20	1.20	1.20	1.60	1.50	0.60	1.20	0.60	0.60	0.60	1.80	0.90	1.30	*0.05*
Grain impurities, %	not more that 5,0/8,0/8,0/15,0	3.70	2.20	3.00	3.10	2.80	3.00	3.00	3.00	3.00	3.00	3.10	3.10	3.10	*0.15*
Nature, g/l	no less 775/750/730/ not limited	780	780	780	765	760	764	763	770	775	772.5	790	790	790	*38.82*
Weight of 1000 grains, g	35–75**	51.6	54.3	53.0	52.0	42.6	51,2	48.6	44.1	55.2	49.65	58.6	60.2	59.4	*2.63*
Vitrescence, %	no less 50/40/ not limited	32.0	37.0	34.5	42.0	42.0	44.0	42.7	44.0	50.0	47.0	45.0	45.0	45.0	*2.10*

*Note: * norms for the class: 1/2/3/4; ** [6–7, 24].*

Results of studies of technological indicators of grain quality showed that studied varieties of wheat and triticale (Tables 6–7) met the quality standards. Thus, moisture content of wheat and triticale grain was 0.4–1.2 % and 1.7–2.9 %, respectively, less than the tolerance limit. According to the content of waste impurities, grain was classified as the second class, with the exception of grain of Midas variety, as well as Trizo variety of 2015 and Lazurna variety of 2014, which were determined to be the first class. Content of grain impurities in wheat grain was 3 % on average, which was 2 % less than the limit for the first-class wheat (Table 6).

Weight of 1000 wheat grain of Lazurna variety was 59.4 g, which was 18, 16, and 11 % higher than grain of Trizo, Midas, and Podolianka varieties, respectively. The highest value of volume weight was determined in wheat grain of Lazurna variety – 790 g/l, while it was 3–4 % less in grain of other varieties.

In turn, the waste impurities content is less than allowable for triticale grain of Khlibodar Kharkivskyi and Avatar by 0.7 and 0.6 % respectively. Grain impurities in the triticale grain of indicated varieties is 5.5 and 5.3 % on average which is less than the allowable values by 1.5 and 1.7 % respectively (Table 7).

Table 7. Characteristics and quality standards of triticale grain

Indicator	Permissible limits (SSU 4762:2007)	The actual quality grade							*LSD 5 %*
		Khlibodar Kharkivskyi			Avatar				
		2011	2012	average	2013	2014	2015	average	
Moisture, %	not more that 14.5	11.7	11.5	11.6	12.7	13.0	13.0	12.8	*0.64*
Waste impurities, %:	not more that 2.0	1.6	1.2	1.4	1.3	1.3	1.4	1.3	*0.07*
mineral admixture	not more that 0.3	–							
Grain impurities, %	not more that 7.0	5.9	4.6	5.3	6.1	6.2	4.3	5.5	*0.27*
Nature, g/l	630–750	663	690	676	720	722	726	722.7	*34.96*
Weight of 1000 grains, g	10–50*	45.8	49.5	47.7	50.0	47.0	49.8	48.9	*2.42*
Vitrescence, %	–	24.0	28.0	26.0	24.0	24.0	24.6	24.2	*1.21*

Source: [5, 8, 10].

Weight of 1000 triticale grain of Avatar variety, on average over the years of research, was 48.9 g, which was 1.2 g more than grain of Khlibodar Kharkivskyi variety. Nature of triticale grain was 663–726 g/l. With an increase in the glassiness of grain, protein content also increased, and technological properties were better. The yield of groats and flour with high glassiness was greater. The samples of the studied grain had floury endosperm with glassiness (32–50 %) of wheat grain was twice higher than in triticale grain (24–28 %).

Table 8 shows comparative characteristics of technological properties of barley grain of the studied varieties. It was found (Table 8) that moisture content of barley grain was 6–13 % less than the upper tolerance limit of the standard. The total content of waste impurities in barley grain of Zvershennia variety corresponded to acceptable norm, and barley of Komandor and Svahor varieties was less than acceptable norm by 35 and 25 %, respectively.

Table 8. Characteristics and quality standards of barley grain

Indicator	Permissible limits (1 class) (SSU 3769:1998)	The actual quality grade													*LSD 5 %*
		Zvershennya			Komandor				Svagor			Talbot			
		year													
		2011	2012	average	2013	2014	2015	average	2014	2015	average	2022	2023	average	
Moisture, %	not more that 14.5	13.4	13.8	13.6	13.0	13.0	13.5	13.2	12.6	13.6	13.1	13.5	12.6	13.0	*0.66*
Waste impurities, %	not more that 2.0	2.0	2.1	2.1	1.1	1.3	1.6	1.4	1.9	1.1	1.5	0.8	0.3	0.5	*0.07*
mineral admixture	not more that 0.3	–										0.15	0.08	0.11	*0.006*
Grain impurities, %	not more that 7,0	2.8	2.2	2.5	3.4	3.5	3.0	3.2	2.8	2.8	2.8	1.8	3.0	2.4	*0.14*
Nature, g/l	no less 600.0	615	606	611	631	624	640	632	636	645	640	619	645	632	*31.44*
Weight of 1000 grains, g	25–56*	31.3	30.7	31.0	32.6	37.6	36.8	35.7	54.8	54.7	54.8	47.6	49.6	47.0	*2.11*

Source: [13–15, 18].

The least amount of this impurity was found in grain of Talbot variety – only 0.5 %, which was 4 times less than acceptable norm. Mineral admixture in grain of this variety was found within allowed limits. In turn, grain admixture in barley grain was determined within 1.8–3.0, which was 2.3–3.9 times less than the tolerance limit. Compliance of the impurity level with quality standards indicated thorough grain cleaning.

Weight of 1000 grain of barley of Komandor variety was 32.6–37.6 g (with higher values in 2014), of Zvershennia variety – 30.8–31.3 g, of Talbot variety – 46–48 g, while this indicator was 54.8 g (30–40 %, 43–44 and 12–16 % more, respectively) for Svahor variety. Volume weight of the specified barley varieties was 606–645 g/l with slightly lower values of Zvershennia variety.

Barley does not belong to membranous crops, therefore the determination of the value of membranousness is not standardized and is not mandatory. However, we found that the content of the shell in barley of the studied varieties was 10.9–12.4 %, which corresponded to literature data (10–13 %) [13, 14, 18].

Table 9 presents comparative characteristics of technological properties of corn grain. Corn grain was determined to be typical, confirming its suitability for processing into groats. Studies results of technological indicators of grain quality (Table 9) showed that the studied varieties of corn met the quality standards. Thus, moisture content was 13.8–14.9 %, which was 0.1–1.2 % less than tolerance limit of moisture. Compliance of the impurities content in grain with quality standards indicated its thorough cleaning. The total content of waste impurities in corn grain of DKS 4685 × 1390 and PR39B58 varieties was 35 and 10 %, respectively, lower than acceptable limit and spoiled grain was 30 and 40 % less, respectively. In turn, the content of grain impurities in corn grain of the specified varieties, on average over the years of research, was 3.3 and 5.3 %, and damaged grain – 0.6 and 0.9 %, respectively, which was within acceptable limit.

Table 9. Characteristics and quality standards of corn grain

Indicator	The actual quality of corn grain						*LSD 5 %*	Permissible limits (SSU 4525:2006)
	DKS4685×1390			PR39B58				
	year							
	2012	2013	average	2014	2015	average		
Typical composition	VII			III			-	I-VIII
Moisture, %	14.8	14.9	14.8	14.8	13.8	14.3	*0.72*	not more that 15.0
Grain impurities, %	3.5	3.1	3.3	5.3	5.3	5.3	*0.21*	not more that 7.0
damaged grains	0.8	0.4	0.6	0.9	0.9	0.9	*0.04*	1.0
sprouted grains	-						-	2.0
Waste impurities, %	1.4	1.1	1.3	1.8	1.6	1.8	*0.07*	not more that 2.0
spoiled grains	0.8	0.8	0.7	0.7	0.6	0.6	*0.03*	not more that 1.0
mineral	-	0.1	0.05	-	-	-	-	0.3
harmful	-	0.1	0.05	-	-	-	-	0.2
Weight of 1000 grains, g	214.8	240.4	227.5	255.0	301.3	278.3	*12.64*	210–360*
Nature, g/l	737	746	739	700	700	700	*36.03*	680–820*

Source: [13, 15, 16, 18].

No sprouted grain, mineral and harmful impurities were detected in corn grain of PR39B58 variety. In turn, 0.1 % of such impurities were determined in corn grain of DKS 4685 × 1390 variety grown in 2013, but they were within tolerance limit (Table 9). The samples of the studied corn grain had a floury endosperm with grain glassiness of 30 %. Weight of 1000 corn grain of PR39B58 variety, on average over the years of research, was 278.3 g (predominance of grain of 2015 harvest), which was 50.7 g more than in grain of DKS 4685×1390 variety (predominance of grain of 2013 harvest). Volume weight (nature) of corn grain was 700–750 g/l (Table 9).

Table 10 present comparative characteristic of technological properties of grain millet of Veselopodil´ske 16 variety.

Table 10. Characteristics and quality standards of grain millet of Veselopodil´ske 16 variety

Indicator	The actual quality	Permissible limits (SSU 5026:2008)	Conclusion on compliance
Moisture, %	12.78	not more 13.5	meets
Shell, %	17.20	15.0 – 22.0	meets
Grain impurities, %:	4.20	not more 5.0	contents grain and waste impurities meets the requirements, indicating that careful cleaning of grain
- damaged grains	0.21	1.0	
- sprouted grains	0.40	1.0	
Waste impurities, %:	1.80	not more 2.0	
- mineral	0.20	0.2	
- organic	0.60	1.3	
- spoiled grains	0.06	0.5	
Weight of 1000 grains, g	7.85	3–9	is within the recommended data
Size of grain, %	80	no less 71	is within the recommended data
Nature, g/l	720	680–730*	is within the recommended data

Source: [1, 3, 18].

Humidity millet is 12.78 %, which is 0.72 % less than the permissible limits moisture plivchastist (17,2 %) – within the allowable confirming the suitability of millet varieties Veselopodilske 16 for processing in the rump (Table 10).

Determining the color of millet grains, found that it is inherent in this sort – without marked yellow shades. Natura grain millet varieties Veselopodilske 16 was 720 g/l, which is within the literature [1, 3, 18]. Indicators of size (80 %) and weight of 1000 grains (7.85 g) make it to increase efficiency of flaking millet and affect the overall output of grains. Thus, the yield of grain millet Veselopodilske 16 variety is 62 %, the basic norms of output – 65 %.

Compliance with the content of impurities standards (Table 9) as evidence of a thorough cleaning. Thus the total content of grain impurities below the limits of 16 %, including damaged grains below the norm in almost 5 times. In turn, waste impurities below the norm of 10 %, which is ranked primarily organic impurities, which is 2.2 times less than the allowable limit.

Conclusions. Thus, comparing geometric parameters of wheat grain, it was found that the grain of Midas variety had the most rounded shape, and the grain of Lazurna variety had the predominant linear dimensions. Comparing geometric parameters of barley, it was established that the grain of Svahor variety had the predominant linear dimensions, and the grain of Zvershennia variety had the most elongated shape. This should be used in the preparation of grain for processing, as well as in choosing of machines, the speed of rotation of their working bodies, and selecting of sieves.

We observed a tendency of changes in geometric characteristics of grain of the studied varieties under the influence of weather conditions of the studied year. It was recorded a significant difference in physical parameters of grain of different years of cultivation in terms of length, width, volume, outer surface area, specific surface area and volume of surface layers of grain in wheat grain of Trizo variety; in terms of volume, outer surface area, specific surface area in Midas variety; in terms of sphericity in Lazurna variety; in terms of volume in triticale grain of Khlibodar Kharkivskyi variety; in terms of volume and specific surface area in Avatar variety; in terms of outer surface area, specific surface and volume of the surface layers in barley grain of Zvershennia variety; in terms of thickness, volume and specific surface area in Komandor variety; in terms of volume in Svahor variety; in terms of thickness, volume, outer surface area in corn grain of DKS variety 4685 × 1390; in terms of thickness, volume, outer surface area, volume of surface layers in PR39B58 variety.

Wheat grain of Lazurna variety, barley grain of Svahor variety and corn grain of PR39B58 variety had predominant linear dimensions. Wheat grain of Trizo, Midas, Podolianka and Lazurna varieties; triticale grain of Khlibodar Kharkivskyi and Avatar varieties; barley grain of Komandor, Zvershennia, Talbot and Svahor varieties; corn grain of DKS4685×1390 and PR39B58 varieties showed pronounced features of the species and variety, met the standards by external geometric parameters, volume, outer surface area, sphericity, specific and volume weight,

volume of surface grain layers and mass fraction of endosperm starch, which indicated its suitability for processing.

Technological properties of wheat, triticale, barley, corn and millet grain of the studied varieties were quite high. Moisture content of grain, content of waste and grain impurities were determined within the acceptable limits of the standards.

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Annotation

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Physical and mechanical properties and quality indicators of cereal grain

The study has been conducted in the Department of Food Technologies of UNUH. Given that physical and mechanical properties of grain vary considerably depending on weather conditions, growing technologies and features of varieties, it requires thorough study. The aim of the research is to study the physical and mechanical properties and quality of wheat, triticale, barley, corn and millet grain depending on weather conditions and properties of the variety. Studies of eligibility of certain varieties of cereal grain for the use in the processing industry is new. The quality of the finished product depends on the quality of raw materials.

Conducting research on grain quality showed that the samples are characteristic odor and taste cultures. Technological properties of grain – a set of signs and indicators of quality, characterizing the grain processing and manufacturing processes affect the yield and quality of cereals. The largest linear dimensions were determined for the grain of soft winter wheat of the Lazurnaya variety. Barley grains differ from wheat and triticale grains in grain length, which is about 1.4 and 2.2 times longer, but wheat grains are superior to their sphericity. Wheat grain of Podolyanka, Trizo, Lazurna and Midas varieties; triticale of Khlibodar kharkiv and Avatar varieties; barley of Zvershennya, Komandor and Svagor varieties; corn of DKS 4685×1390 and PR39B58 varieties; millet of Veselopodil´ske 16 variety has marked peculiarities of type and variety, meets the requirements in terms of external geometric parameters, volume, area of the outer surface, sphericity, specific and volume weight, volume of surface layers of grains and mass fraction of endosperm starch, indicating its suitability for processing.

Key words: *grain, wheat, triticale, barley, corn, millet, variety, properties, quality, groat.*