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THE TECHNOLOGICAL PROPERTIES OF WINTER WHEAT GRAIN DURING LONG-TERM STORAGE

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ABSTRACT
In the world, the demand for quality and safe grain products is increasing. The need to preserve wheat in the event of a natural disaster requires the study of optimal storage times of grain without degrading technological indexes. The purpose of the work was to study the dynamics of technological properties of winter wheat grown after peas, clover, corn for silage and the industrial, ecological, biological growing systems during 1, 3, and 5 years of storage in the conditions of the ordinary granary. The absence of significant differences in the technological parameters of the grain of wheat grown at industrial and ecological systems, but significantly lower indicators at a biological growing system was found. The highest hectolitre weight obtained when wheat grain was grown after corn for silage, and vitreousness – after the clover. Significantly higher biochemical parameters of grain and alveographic properties of flour were for the cultivation of wheat after peas, which provided additional accumulation of protein substances. There are no significant changes in the indicator of hectolitre weight during the grain storage. Other indicators increased significantly after 1 year of storage (on average by 10 – 30%). For further storage, vitreousness growth was insignificant. After 5 years of storage, the falling number significantly increased (on 21% compared to the initial values and on 7% – after 3 years of storage). The content of protein, gluten in the grain, and alveographic properties of flour significantly decreased after 5 years of storage. The possibility of obtaining grain of wheat with high technological parameters for a more safe ecological growing system was established. It was also confirmed to need for grain storage up to 1 year to improve quality indicators and it was established that it safely stored for 3 years.

Keywords: wheat grain; technological properties; growing systems; predecessors; term of storage

INTRODUCTION
Wheat is the leading crop in temperate countries **(Shewry, 2009)**. It is a source of nutrition for 35% of the world's population. Wheat currently ranks first amongst cultivated plants in terms of cultivation area and production **(Kurt Polat, Cifci and Yagdi, 2016)**. Its success depends partly on its adaptability and high yield potential. The gluten protein fraction of wheat, which confers the viscoelastic properties that allow the dough to be processed into bread, pasta, noodles, and other food products. Wheat also contributes essential amino acids, minerals, and vitamins, and beneficial phytochemicals components to the human diet **(Smetanska et al., 2021)**.

The quality of wheat grain is influenced by genetic factors, growth location, agricultural measures, conditions of harvest, transport, and postharvest storage of grain **(Dziki et al., 2017)**.

One of the most effective measures to improve the quality of the grain is the correct scientifically based fertilizer system. The main factor constraining the improvement of the quality of the grain is the lack of nitrogen in the soil. It is an integral and indispensable part of amino acids, proteins, chlorophyll, enzymes. An important agrotechnical measure to improve the quality of wheat grain is the proper selection of predecessors. Each field crop, depending on the vegetation and farming uses different amounts of water and nutrients and differently affects the physical properties of the soil, which creates different conditions for the cultivation of the next crop. Also important is the timely fight against weeds, protection against diseases and pests **(Kovalyshyna et al., 2020a)**.

Wheat is also an important crop in organic farming. Organic agriculture is of particular interest concerning healthy and ecologically friendly produced food because inputs of chemicals are not allowed. With the increasing consumer pressure to reduce the use of pesticides and fertilizers in food production systems, the demand for organic foods continues to rise **(Kovalyshyna et al., 2020b)**.

Harvest of wheat received once a year and the need to provide food to the population is every day. It is known that grain quality may change during storage. Therefore, it is necessary to create conditions that would ensure the storage of products with the least loss of its quality.

Wheat stored for disaster relief has the potential of being stored for extremely long periods, which may result in undesirable changes in milling and baking quality **(Marzec, Cacak-Pietrzak and Gondek, 2011)**.

Increasing the production and storage of wheat grain is a prerequisite for ensuring food safety of the country and normal consumption of food by the population. Therefore, this study aimed to evaluate different growing systems and precursors for obtaining environmentally safe grain of wheat with high technological parameters necessary for the production of bakery products. Furthermore, we also studied the influence of storage term on wheat grain quality and the possibility of using it for bread production after 1, 3, and 5 years of storage.

Scientific hypothesis

The quality of wheat grain depends on many factors. There are varietal characteristics, soil, climatic conditions, farming systems, post-harvest handling, duration, and regimes of storage. The farming system is one of the most important factors that influence grain quality. An ecological growing system will supply to reduce the cost of production and obtain quality and safe grain products. High technological indicators of wheat grain quality will be kept up for 1 – 3 years of storage.

MATERIAL AND METHODOLOGY

Samples

The grain contains 14.3% protein, 29.2% gluten, deformation energy – 365 x 10^{-4} J, general baking estimation – 4.2 marks. It is the wheat of valuable. The direction of use is grain for the food industry.

Chemicals

No chemical reagents were used for the studies.

Animals and Biological Material:

For the study, a variety of soft winter wheat Poliska 90 was used. The owner of the variety is the Selection-Genetic Institute "Agriculture" of the National Academy of Agrarian Sciences of Ukraine. Variety is erythrosperm.

Instruments

The moisture content of grain was determined by drying in the air oven SESH-3MU (company LLC "OLIS").

"Mass per hectolitre" was determined on a litter chondrometer with a falling load PH-2 (company LLC "OLIS").

The protein content was determined by Kjeldahl device UDK 129 with manual electronic control (company Velp Scientifica).

The number of falling was determining by device FALLING NUMBER 1900 (company Perten's).

The energy of the dough deformation, dough elasticity, and dough extensibility was determining by Alveo-consistograp NG of the company Chopin Technologies.

Grains were milled on Buhler MLU-202 Laboratory Flour Mill of the Buhler's company.

Samples were weighted by laboratory scales ADA320 (AXIS) from the company "Scales of AXIS Ukraine" with the 2nd class of accuracy.

Laboratory Methods

The grain samples were analyzed for the moisture content of the grain to **ISO 712:2009** and test weight (called "mass per hectolitre") to **ISO 7971-1:2009**. The percentage of the vitreous kernel was determined according to the method given in **ICC Standard No. 129**. **(1980)** The percentage of vitreous kernels is determined by examining the cross-section of the grains. Vitreous grains appear dark and translucent, while opaque grains appear yellow and starchy. The percentage of vitreousness represents the mean of the 50 kernels × 2.

The grain samples were analyzed for the total content of crude protein in dry matter of grain according to the **ISO 20483:2013**, the content of wet gluten in dry matter of grain to the **ISO 21415-1:2006**, and the falling number method according to Hagberg-Perten to the **ISO 3093:2009**.

The remaining grains were milled on the Bühler laboratory mill (MLU-202 type). Wheat flour was used to determine deformation energy, dough elasticity, and dough extensibility.

Description of the Experiment

Field experiment

Grain is grown on experimental fields of the stationary experiment of the Separated subdivision of NUBIP of Ukraine "Agronomic Research Station", which is located in the Kyiv region. According to the natural-agricultural zoning of Ukraine, this territory is classified as a forest-steppe zone.

The area of research is a zone of sufficient moisture, with a warm temperate and humid climate. Winter is mild, cloudy, with frequent thaws, and the summer is mostly warm, moderately humid. Autumn and spring, in general, have a protracted and unstable character. But prevailing warm spring, with sufficient margin (160 – 80 mm), productive moisture in the meter soil layer. Average monthly air temperature in January – February ranges from 4 to 8 °C. In the summer, the average monthly air temperature ranges from 15 to 20 °C. The absolute maximum reaches 39 – 40 °C. The period with an average monthly temperature above 5 °C concurs with the vegetation period of the main crops and has a period of 200-215 days. Years of the investigation were characterized by slight deviations from perennial norms of temperature and precipitation.

Soils on experimental plots are typical black earth. The content of humus in the arable layer is 3.67 ±0.13%, the pH of the aqueous extract is 6.7, the pH of the salt extract – 6.3, the absorption capacity – 28.9 mg-equivalent per 100 g of soil. Supply of hydrolysis nitrogen compounds for Tyurin and Kononovoy in a layer 0 – 15 cm – high, 15 – 30 cm – raised; mobile phosphorus according to Chirikov in a layer 0 – 15 cm and 15 – 30 cm – average, exchangeable potassium is also average in both layers. The water of soil is deposited at a depth of 6 m and does not affect the process of soil formation. The research included the study of the impact of growing systems (industrial, ecological, biological), predecessors (clover, peas, corn on silage), and storage of experimental samples of grain during five years.

Under the industrial system, 12 tons of organic and 300 kilograms of the active substance of mineral fertilizers were introduced per hectare of arable soil in crop rotation, and the protection of crops was carried out by industrial pesticides. In the ecological model, priority measures were organic fertilizers of 24 t per ha, mineral fertilizers used for 150 kg per ha, and crops were protected by biological means and industrial pesticides on the criterion of the ecological and economic edge of the number of harmful organisms. The biological model of the agricultural system was provided only by a possible norm of organic fertilizers of 24 tons per hectare of arable soil in crop rotation, and the protection of crops was carried out only by biological means.

The area of the experimental plot in the field experiment was 280 m^2, accounting – 240 m^2, repetition of the experiment four-time. The placement of options is systematic. The experimental cultures were grown in 10 field crop rotations. The changes of crops in the crop rotation are as follows: clover – winter wheat – sugar beet – corn for silage – winter wheat – corn for grain – peas – winter wheat – sugar beet – barley + clover.

Sample preparation: The research was conducted in 2012 – 2017 based on the laboratories of the department technology of storage, processing, and standardization of plant products after named prof. B. V. Lesik NUBIP of Ukraine and State Enterprise «Ukrmetrteststandart».

Number of samples analyzed: Experimental samples of grain designed to study the duration of storage were placed in linen bags of 3 kg. Samples for each variant were taken in sufficient quantities to provide a sample for each period of storage for the quality estimation of the grains.

Number of repeated analyses: Samples of grain in a dry state (humidity up to 14%) were stored in an ordinary granary (storage conditions of commodity grain).

Number of experiment replication: Quality indicators of wheat grain after 1, 3, and 5 years of storage were determined in all variants provided by the research program. Analyzes were performed in three replicates.

Statistical Analysis

Mathematical and statistical processing of experimental data was carried out in determining the criteria of Cochran's C test, Fisher, and Student's *t*-test. The accuracy of the data was determined using the Cochrane criterion, and the adequacy of the mathematical model was checked using the Fisher and Student criteria. The obtained data were further subjected to statistical analysis and the consequent evaluations were analyzed for a variance (ANOVA). The statistical differences between the studied variants were estimated through Tukey's test. The Pearson correlation analysis was also carried out on these data. Statistical tests were evaluated at a significance level of $\alpha = 0.05$ using Statistica 6.0 software (StatSoft, Inc., Tulsa, USA).

RESULTS AND DISCUSSION

Physical parameters

The main factor determining the orientation and intensity of physiological and biochemical processes during the storage of grain is its moisture content. Safety long-term storage of wheat grain is possible only at a moisture content not exceeding 14% **(Leary et al., 2018; Ramanathan et al., 2018)**.

In our studies, the moisture content of wheat grain was 13.34 ±0.47% on average. Throughout the shelf life, the grain moisture of the studied variants did not change significantly (<0.9%) and was dependent on the relative humidity of air (Table 1). The research determined the effect on the grain moisture of the storage period and the precursors at the ecological and biological systems (Table 2).

Filling grain or grain with a high hectolitre weight has more endosperm and a higher yield of flour. Under unfavorable conditions for the formation of grain or seeds, the mass of peels in comparison with the weight of the grain increases, and the endosperm decreases **(Dorofee, 1972; Bharti et al., 2016)**.

Before the storage, the wheat grain of all the studied variants had a very high hectolitre weight. The highest initial hectolitre weight values were in wheat grown after corn for silage of 81.73 kg and the lowest after the clover of 76.69 kg. The test criterion F (ANOVA) showed the most significant impact on this indicator was precursors at the ecological and biological growing systems.

No significant difference in hectolitre weight was in the grain of wheat grown at the industrial and ecological systems. We partially confirm of our data the research **Dziki et al. (2017)**, about the absence of a clear impact of the growing system on hectolitre weight **(Bober et al., 2020)**. The lowest hectolitre weight values were in wheat grains grown at the biological system of 79.27 kg, which significantly differed from the grain grown at two other systems. These deny data of **Bilsborrow et al. (2013)** about higher hectolitre weight at organic farming compared to conventional. At the same time, our studies point out a significant impact on the hectolitre weight of agricultural systems at all the predecessors (Table 2), thereby confirming data of other scientists **(Zheplinska et al., 2020)**.

During storage of wheat grain, changes in hectolitre weight fluctuations depend on relative humidity and its changes were not significant. After three years of storage of wheat grains, almost all of the studied variants had a slight increase in hectolitre weight and after five – on the contrary, a slight decrease. Although several previously conducted studies by different scientists indicated that after 6 – 12 months of storage there is a significant reduction in hectolitre weight **(Varella et al., 2017; Jafary, Szabo and Niks, 2006)**.

In our study, the test criterion F confirmed the absence of effect on the hectolitre weight of the shelf life.

The consistency of grain is of great importance for flour processing. The higher the vitreousness is then the greater the number of the fraction can be obtained from the grain, and in the future, it provides a larger yield of varietal flour. In the works **(Casey et al., 2016; Marryat, 1907; Davoyan et al., 2012)** found forms immune to rust, powdery mildew, and soot among *Triticum dicoccum*.

The best ability to give good yield to the cereals and high of flour varieties was at a grain of winter wheat grown after the clover (85% vitreousness), the worst at a grain – after corn for silage (69%). Equally, high vitreousness indexes were in grain grown at the industrial and ecological farming system and significantly lower than the biological system.

In the same way, confirming the data on the effect on the vitreousness index of the amount of fertilizer applied and the content of nitrogen in the soil at different predecessors **(Khaneghah et al., 2018; Kirilenko, 2014)**.

In general, for all agricultural systems, the vitreousness of the grain was quite high, which makes it possible to obtain high yields of cereals and flour.

Table 1 Quantitative evaluation of physical parameter of the winter wheat (LSD, α = 0.05).

Parameter		Moisture (%)			Hectolitre weight (kg)			Vitreousness (%)		
		$\overline{x}$	d_{min}	signi-ficance	$\overline{x}$	d_{min}	signi-ficance	$\overline{x}$	d_{min}	signi-ficance
Term of storage	0 (before storage)	13.80	0.23	a	81.09	1.73	a	56	5.13	a
	1 year of storage	13.74		a	80.42		a	86		b
	3 years of storage	12.91		b	81.06		a	86		b
	5 years of storage	13.81		a	80.61		a	87		b
Predecessor	Clover	13.44	0.50	a	79.69	0.66	a	85	5.59	a
	Peas	13.34		a	80.96		b	81		a
	Corn for silage	13.28		a	81.73		c	69		b
Growing systems	Industrial	13.34	0.50	a	81.27	0.66	a	83	5.59	a
	Ecological	13.35		a	81.85		a	80		a
	Biological	13.37		a	79.27		b	73		b

Note: $\overline{x}$ = average values of the indicators; d_{min} = least significant difference.

Table 2 ANOVA, values of the test criterion F for results of selected physical parameters of winter wheat.

Factor		Quality parameter		
		moisture	hectolitre weight	vitreousness
Growing systems				
Industrial	predecessor	1.77^{n}	1.24^{n}	79.40^{*}
	term of storage	46.40^{*}	1.16^{n}	313.22^{*}
Ecological	predecessor	7.00^{*}	31.75^{*}	8.15^{*}
	term of storage	96.33^{*}	2.33^{n}	24.74^{*}
Biological	predecessor	17.52^{*}	44.76^{*}	24.10^{*}
	term of storage	16.00^{*}	3.01^{n}	34.56^{*}
Predecessor				
Clover	growing systems	4.35^{n}	22.14^{*}	1.95^{n}
	term of storage	15.01^{*}	1.17^{n}	27.41^{*}
Peas	growing systems	1.45^{n}	16.79^{*}	2.15^{n}
	term of storage	10.38^{*}	0.32^{n}	9.23^{*}
Corn for silage	growing systems	1.30^{n}	29.20^{*}	3.34^{n}
	term of storage	20.24^{*}	3.77^{n}	10.60^{*}

Note: *statistically significant α = 0.05; n – statistically insignificant.

The glassiness is conditioned by the presence of protein. For insufficient quantity of it create a dense consistency (protein-starch complex), which shows virtuousness "transparent" for light penetration for light consistency **(Vlasenko, Koliuchyi and Chebakov, 2005)**.

We found that after one year of storage of wheat grain, all options were to strengthen the consistency, which was expressed by a quantitative increase in the vitreousness index by 30%. This can be explained by the interaction of protein and starchy substances during the post-harvest maturing of grain **(Kozub et al., 2017; Pirko et al., 2012)**.

Previous studies of the effective term of storage on the vitreousness of the grain indicate that vitreousness, in general, is a stable indicator **(Mushtruk et al., 2020a, Palamarchuk et al., 2019)**. In our studies, also, in the three or five years of storage of wheat grain, the vitreousness remained almost unchanged.

The test criterion F indicated a significant effect on the vitreousness of wheat grain storage term and precursors and the absence of impact on growing systems (Table 2).

Biochemical parameters

The protein content of wheat grain varied significantly depending on the predecessor and growing systems (Figure 1, Table 3). The highest protein content in wheat grain was provided by the predecessor peas – 14.54%, that was explained by the ability of peas in the process of vegetation to accumulate nitrogen, which is necessary for the formation of protein in the grain **(Sukhenko et al., 2019)**. The predecessors of the clover and corn for silage provided significantly less protein in the grain.

A high index of protein content was in the grain of wheat grown for both the industrial system of agriculture – 14.55%, for the ecological – 14.23% and significantly lower than the biological – 12.72%. These results are in agreement with the results obtained by several scientists in previous years **(Zheplinska et al., 2021a)**. However, **Kihlberg et al., (2004)** found that wheat grain grown under normal agricultural systems had lower protein content than organic. Also, there is the notion of the absence of influence of agricultural systems on protein content, or their influence was less significant than the influence of other factors **(Mayer et al., 2015)**.

In our study, test criterion F (ANOVA) showed a significant effect on the protein content of all investigated factors (Table 4). The agricultural systems were the most influential on protein content, especially at the predecessor corn for silage. Great influence on the protein content had predecessors at the biological growing system.

It is important to preserve grain protein for a long time. After one year, the protein content increased significantly compared with the initial values (by 0.35%), which is explained by the transition of simple amino acids to complex proteins in the process of post-harvest maturing **(Park et al., 2015)**. Three years of storage ensured the stability of this indicator. However, **Oleinik and Davidyuk (2009)** scientists noted a tendency to decrease the protein content of grain after 24 months of storage by 0.2 – 0.5%. After five years, the protein content has significantly decreased compared to the first year of storage and has not significantly differed from the initial data.

According to **Menkova et al. (1995)** in the grains of winter wheat, stored for eight years under normal conditions, noticeable changes in the biochemical composition did not observe. Insignificant changes in the content of protein during storage other scientists were noted **(Ceseviciene and Masauskiene, 2009)**.

The main part of the proteins that included the grain presented the solutions in alcohol and alkali – glutenin and gliadin, which form the so-called gluten.

As can be seen from Table 3, wheat grain, grown for all agricultural systems, according to the predecessor peas contained the maximum amount of gluten (32.68%), in corn – the minimum (28.27%). The difference in the content of gluten in wheat grain was significant among all the predecessors. Most scientists explain this by the fact that winter wheat is demanding to the conditions of moisture and fertilizer, so its highest yields obtained when placed after perennial herbs, bean-cereal grass mixtures, and peas for grain **(Palamarchuk et al., 2020)**.

The amount of gluten was significantly higher in grain grown at the ecological system (33.23%) compared to industrial (32.58%). The content of gluten in wheat grain grown at the biological system was significantly lower than at the ecological (6.6%) and industrial (5.95%). This confirms by scientists that the traditional system provides a significantly higher index of gluten than organic. In this case, the limiting factor in the system of organic cultivation is the provision of nitrogen **(L- Baeckström, Hanell, and Svensson, 2004)**.

The dynamics of gluten content during storage are controversial. The variation in the content of gliadin and glutenin is probably due to changes in protein aggregation and their solubility. **Kibar (2015)** founded that the amount of gluten increases during the first two months and subsequently decreases. Other researchers have found a significant reduction in the content of gluten in wheat grains after three and eight months of storage. In our studies, during three years, the changes of gluten content in wheat grain were not significant, although the index increased somewhat after a year of storage and slightly decreased after three years. The amount of gluten in the grain decreased significantly after five years of storage compared to the first year (by 3.15%).

The test criterion F (ANOVA) showed the greatest influence on wet gluten content in grain the predecessors at the industrial growing system (Table 4). Also, was influenced strongly by the investigated parameter of growing systems, especially at the grain grown after the clover and corn for silage. The effect on the wet gluten content in grain of the predecessors and the term of storage at the biological system and also the term of storage at the predecessor peas were not essential.

The changes that occur with starch in grain significantly affect the quality of products. Formation and cleavage of starch is carried out by amylolytic enzymes, the degree of activity in grain determined by the index of the falling number. The winter wheat grain of all the variants had a low activity of amylolytic enzymes. The high falling number with insignificant difference between the variants of research, was in the grain grown for all agricultural systems and predecessors.

Significant changes in the falling number were after one year of storage of grain wheat – the index increased on 28 seconds. Further storage was characterized by a gradual increase in the falling number. Again, a significant increase was noted after five years of storage – by 28 seconds compared to the third year of storage and by 72 seconds compared to the initial data.

By our studies, we confirmed and supplemented the results of other scientists regarding the decrease in alpha-amylase activity and the increase in the falling number with an increase in the storage period of wheat grain.

Also, **Linina and Ruza (2016)** noted the dependence of the falling number from weather conditions, storage duration, and the amount of nitrogen fertilizer. **Sulek and Cacak-Pietrzak (2018)** argued that the activity of amylolytic enzymes is more dependent on the variety than cultivation technology. In our research, the test criterion F (ANOVA) shown a statistically significant effect on the falling number predecessors, growing systems, and term of storage (Table 4).

Quantitative evaluation of flour alveograph properties of the winter wheat

The evaluation of wheat flour at the mechanized or automated baking production has rheological properties of the dough, in particular deformation energy (W) or the energy used to tear the dough semi-finished. It determines the area of the alveogram and characterizes the baking power of the flour **(Zheplinska et al., 2021b)**.

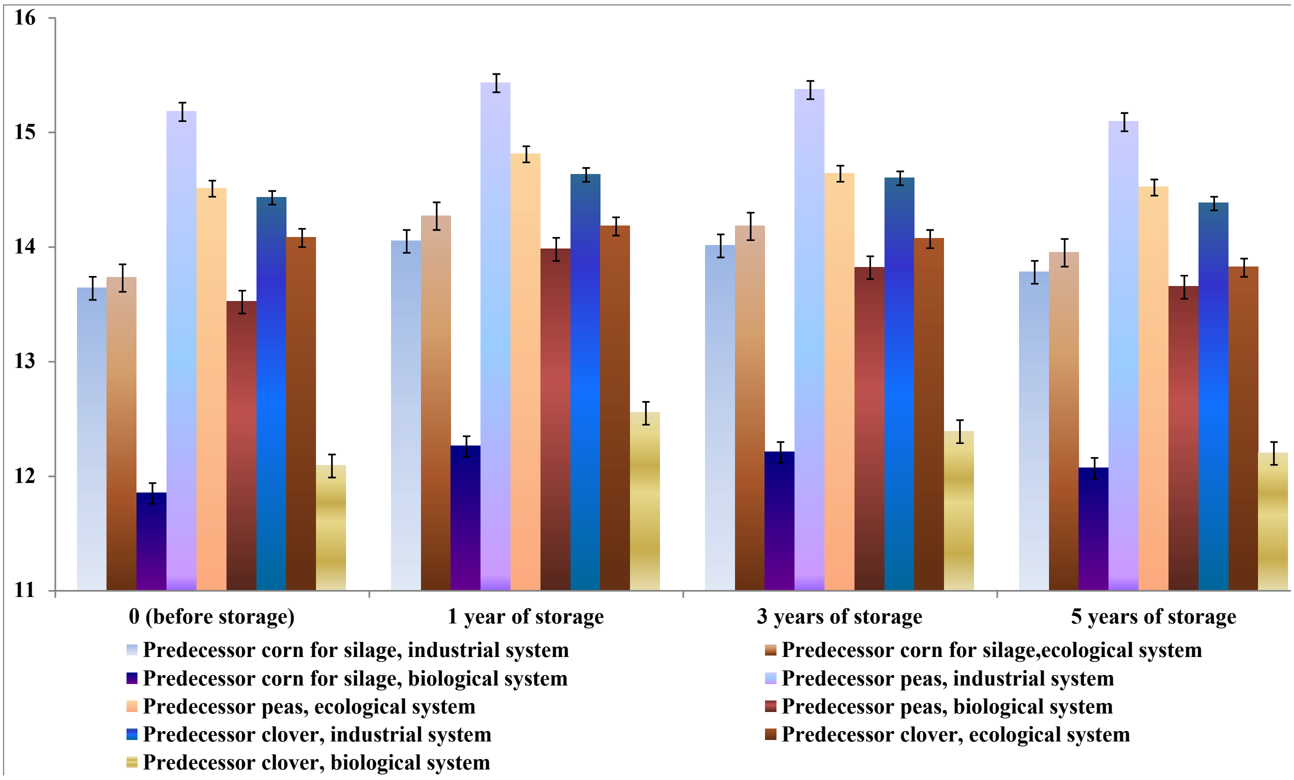

Figure 1 Protein content in winter wheat grain during stored (%).

Table 3 Quantitative evaluation of biochemical parameters of the winter wheat (LSD, α = 0.05).

Parameter		Protein content in grain (%)			Wet gluten content in grain (%)			Falling number in grain (seconds)		
		$\overline{x}$	d_{min}	signi-ficance	$\overline{x}$	d_{min}	signi-ficance	$\overline{x}$	d_{min}	signi-ficance
Term of storage	0 (before storage)	13.67		a	30.62		ab	312		a
	1 year of storage	14.02		b	32.51		a	340		b
			0.29			3.03			22.3	
	3 years of storage	13.92		ab	30.77		ab	356		b
	5 years of storage	13.72		a	29.36		b	384		c
Predecessor	Clover	13.62		a	31.49		a	350		ab
	Peas	14.54	0.18	b	32.68	1.49	b	363	30.05	a
	Corn for silage	13.33		c	28.27		c	332		b
Growing systems	Industrial	14.55		a	32.58		a	352		a
	Ecological	14.23	0.18	b	33.23	1.49	a	350	30.05	a
	Biological	12.72		c	26.63		b	342		a

Note: $\overline{x}$ = average values of indicators; d_{min} = least significant difference.

The specific deformation energy of the dough varies widely from 30 to 800 x 10^{-4} J. In our studies, the highest rates of deformation energy were at the growing of grain after the peas' predecessor, insignificantly smaller than the clover (33 x 10^{-4} J) and significantly lower than corn for silage (45 x 10^{-4} J). Deformation energy indices did not differ significantly during the cultivation of grain at industrial and ecological growing systems (Figure 2, Table 5). Significantly lower were the indicators at the biological system: 41 x 10^{-4} J compared with the industrial system and 38 x 10^{-4} J compared with the ecological system. This agrees with the data of scientists about significantly higher baking properties in the traditional system, compared with organic, but denies the data of other scientists about the insignificant impact of growing systems on these indicators. At the same time, confirming the findings of **L-Baeckström, Hanel and Svensson (2004)**, that nitrogen is the most limiting factor for the organic growing system.

Rose et al. (2011) found that grain of wheat retains its nutritional qualities up to 32 years, although they noticed a negative correlation of indicators with the time of storage. **Mushtruk et al. (2020b)** indicated a possible improvement of rheological properties during storage, especially at elevated temperatures. But **González-Torralba et al. (2013)** set only fewer changes of alveographic parameters during storage after 180 – 240 days.

In our studies, after one year of grain storage, there was a significant increase in the deformation energy (on 74 x 10^{-4} J), after three years there was a slight decrease (on 14 x 10^{-4} J) and after five years a significant decrease (on 42 x 10^{-4} J) compared to each previous term.

The test criterion F (ANOVA) showed a significant influence of all investigated factors on the selected flour alveograph properties of winter wheat (Table 6). The greatest impact on deformation energy had storage period at the industrial system and peas predecessor. Also, predecessors at the industrial and biological systems of agriculture had a great influence on this index.

Dough extensibility (L) is the diameter of the test bubble during bursting. This indicator is due to the resistance of the gluten-free frame to spatial reorientation during dough formation and it is a converse characteristic to dough elasticity.

Indicators of dough extensibility differed considerably at the cultivation of wheat grain after clover and peas (on 2 mm), but at industrial and ecological growing systems (on 1 mm). Significantly lower dough extensibility observed in growing wheat grain after corn for silage (9 – 13 mm) and a biological system (6 – 7 mm). The grain storage process characterized a significant increase in the dough extensibility after one year of storage (on 11 mm) and a significant decrease – after five years (9 mm). This confirmed the data of **Kolyanovska et al. (2019)**, which indicated the possible improvement of rheological properties during storage and data by **Rose et al. (2011)** – on the gradual decline of these indicators during long-term storage.

The most important for dough extensibility had the precursors at cultivating grain at the industrial agricultural system. Also, the great impact growing systems and storage periods on the dough extensibility indicator had on growing grain after peas.

Dough elasticity (P) is the maximum pressure created inside the dough at the time of its mechanical destruction during inflation in the form of bubbles. The value of this index quantitatively characterized the resistance of the gluten of the yeast dough to deform during fermentation and dough arise **(Sheiko et al., 2019)**.

Indicators of dough elasticity differed significantly in the cultivation of wheat at industrial and ecological growing systems (on 3 mm) and substantially for the biological system (13 – 16 mm). It confirmed data by **Krejčířová et al. (2007)** about twice the amount of glutenins, which is responsible for the elasticity of the dough, in the grain grown under the traditional system, as compared to the organic. The indicator varies considerably depending on the predecessor. At the same time, the highest values were in the cultivation of wheat grain after peas, which provided a higher content of nitrogen for the formation of proteins in wheat grains.

The tendency of changes in dough elasticity was similar to deformation energy. The most significant changes in dough, elasticity were noted after one year of storage – it increased by 46 mm in comparison with the initial data. After three years of storage, we observed an insignificant decrease in the indicator. Significant reduction in dough elasticity was only after five years of wheat grain storage – on 23 mm compared with the third year of storage.

The greatest impact on the dough elasticity had the terms of storage at predecessors' peas and clover and also at the biological system of agriculture **(Sukhenko et al., 2017)**.

Table 7 presents the correlation coefficients between the physical, biochemical parameter of grain and alveograph properties of flour the winter wheat after 5 years of storage.

Pearson's correlation coefficients confirmed the strong negative effect of moisture on the hectolitre weight of wheat grain (r = -0.74), which researchers noted in past years. Simultaneously hectolitre weight had the highest positive correlation with protein content in grain (r = 0.68) and a noticeable positive correlation with deformation energy (r = 0.53).

It was found that the vitreousness index was very positively correlated with wet gluten content in grain (r = 0.96) and strongly with the following indices: deformation energy, dough extensibility, and protein content (r ≥0.80). This is confirmed by the data of the direct dependence of the content of the protein, gluten, and hence the baking properties of the flour from the vitreousness grain **(Mushtruk et al., 2021b)**.

The results showed, that falling number in grain has a strong positive relationship with dough elasticity, dough extensibility, and wet gluten content in grain (r >0.70). This is a confirmation that the quality of starch and the activity of amylolytic enzymes of wheat grain and have a direct effect on the quality of the dough.

The main indicator of flour power is the quantitative-physical properties of gluten and protein content, which confirm the correlation coefficients. Protein content in grain is very positively correlated with the deformation energy (r = 0.96) and strongly with dough extensibility, dough elasticity, and wet gluten content in grain (r >0.70). Wet gluten content in grain had the highest positive correlation with dough extensibility (r = 0.82).

Table 4 ANOVA, values of the test criterion F for results of selected biochemical parameters of winter wheat.

Factor		Quality parameter		
		Protein content in grain (%)	**Wet gluten content in grain (%)**	**Falling number in grain (seconds)**
Growing systems				
Industrial	predecessor	549.29*	449.51*	22.07*
	term of storage	19.96*	14.90*	25.56*
Ecological	predecessor	32.23*	28.96*	5.48*
	term of storage	5.19*	5.50*	10.62*
Biological	predecessor	2169.63*	1.33^n	13.84*
	term of storage	76.05*	2.69^n	18.23*
Predecessor				
Clover	growing systems	632.10*	116.55*	7.92*
	term of storage	7.43*	5.77*	29.67*
Peas	growing systems	658.53*	20.31*	8.93*
	term of storage	21.90*	2.60^n	19.06*
Corn for silage	growing systems	3089.34*	110.47*	18.98*
	term of storage	85.27*	13.46*	27.71*

Note: *statistically significant α = 0.05; n – statistically insignificant.

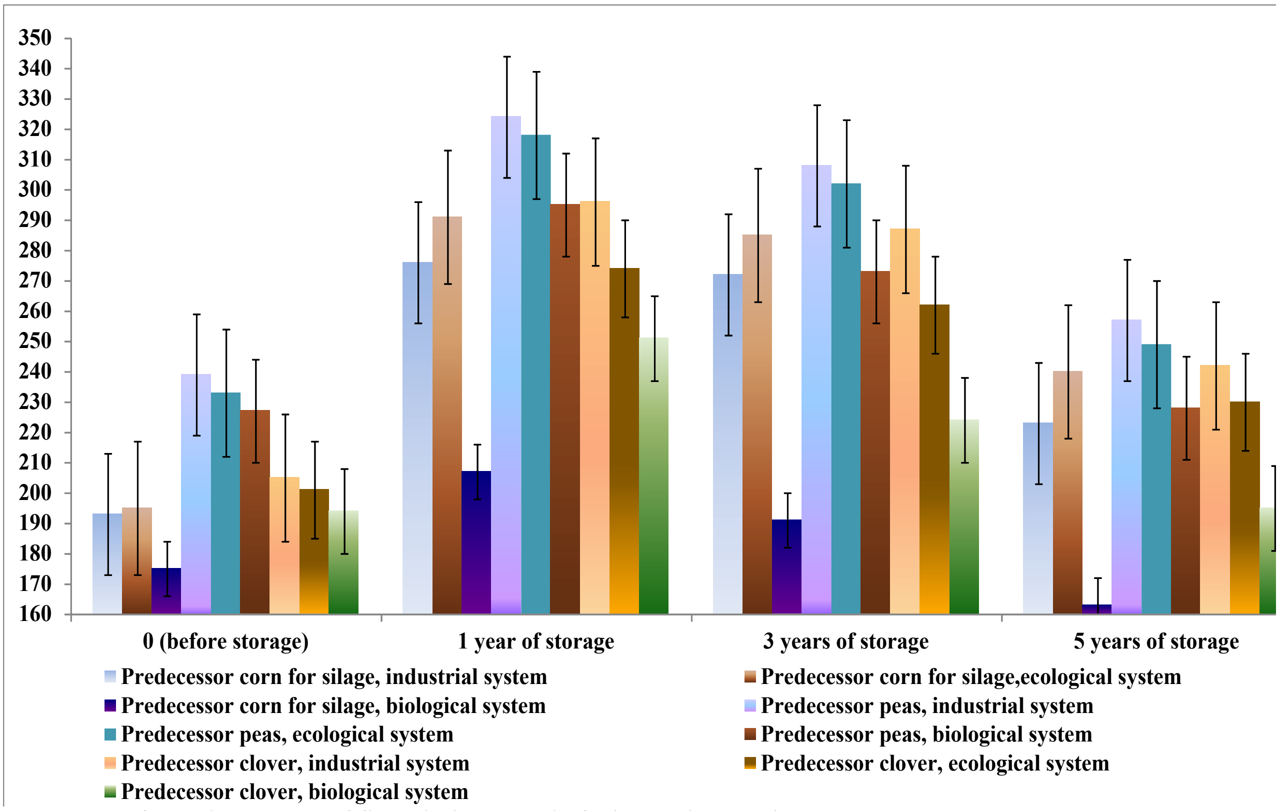

Figure 2 Deformation energy of flour during stored of winter wheat grain (10 – 4 J).

Table 5 Quantitative evaluation of flour alveograph propertiesof the winter wheat (LSD, α = 0.05).

Parameter		Deformation energy (10^{-4} J)			Dough extensibility (mm)			Dough elasticity (mm)		
		$\bar{x}$	d_{min}	signi-ficance	$\bar{x}$	d_{min}	signi-ficance	$\bar{x}$	d_{min}	signi-ficance
Term of storage	0 (before storage)	207	31.03	a	73	5.42	a	118	13.78	a
	1 year of storage	281		b	84		b	164		b
	3 years of storage	267		b	80		bc	159		bc
	5 years of storage	225		a	75		ac	136		d
Predecessor	Clover	238	35.71	ab	80	4.99	a	144	11.39	a
	Peas	271		a	82		a	157		b
	Corn for silage	226		b	73		b	132		c
Growing systems	Industrial	260	35.71	a	81	4.99	a	150	11.39	a
	Ecological	257		a	80		a	147		a
	Biological	219		b	74		b	134		b

Note: $\bar{x}$ = average values of indicators; d_{min} = least significant difference.

Table 6 ANOVA, values of the test criterion *F* for results of selected flour alveograph properties of winter wheat.

Factor		Quality parameter: Deformation energy (10^{-4} J)	Dough extensibility (mm)	Dough elasticity (mm)
Growing systems				
Industrial	predecessor	77.77*	124.64*	87.38*
	term of storage	227.60*	58.27*	123.00*
Ecological	predecessor	16.31*	33.81*	31.13*
	term of storage	63.47*	42.25*	111.64*
Biological	predecessor	70.82*	39.36*	87.32*
	term of storage	28.83*	44.05*	186.75*
Predecessor				
Clover	growing systems	13.70*	19.56*	81.00*
	term of storage	26.13*	16.23*	297.09*
Peas	growing systems	23.02*	107.48*	86.64*
	term of storage	135.20*	84.69*	311.59*
Corn for silage	growing systems	17.08*	29.27*	57.06*
	term of storage	10.54*	81.87*	236.58*

Note: *statistically significant α = 0.05; n – statistically insignificant.

Table 7 Pearson's correlation coefficients between the physical, biochemical parameter of grain and alveograph properties of flour the winter wheat after 5 years of storage.

Quality parameter	M	H	V	FN	PC	WG	W	L	P
M	1.00								
H	-0.74*	1.00							
V	-0.38	0.45*	1.00						
FN	-0.27	0.06	0.66*	1.00					
PC	-0.60*	0.68*	0.80*	0.61*	1.00				
WG	-0.40*	0.44*	0.96*	0.75*	0.74*	1.00			
W	-0.46*	0.53*	0.84*	0.57*	0.96*	0.73*	1.00		
L	-0.35	0.32	0.88*	0.77*	0.90*	0.82*	0.94*	1.00	
P	-0.28	0.27	0.68*	0.82*	0.84*	0.66*	0.83*	0.91*	1.00

Note: *Statistically significant coefficients (a = 0.05). M – moisture of grain, H – hectolitre weight, V – vitreousness, FN – falling number in grain, PC –protein content in grain, WG – wet gluten content in grain, W – deformation energy, L – dough extensibility, P – dough elasticity.

CONCLUSION

These studies have shown the possibility of obtaining grain of wheat with high technological parameters necessary for the production of bakery products with less cost and in better safety ecological growing system.

The best predecessor for the formation of high biochemical and alveographic indexes in wheat grain was peas, which provided additional protein accumulation and increased gluten content.

The indicator quality of hectolitre weigh does not significantly change during the grain storage, but other indicators had increased significantly after 1 year of storage (on average by 10 – 30%). The vitreousness of grain during the further storage increased insignificantly.

The number of falling, after 5 years of storage, significantly increased (on 21% compared to the initial values and on 7% – after 3 years of storage). The protein content, grain's gluten, and alveographic properties of flour significantly decreased after 5 years of storage.

It has been established that under ordinary granary conditions the best technological parameters of wheat form after 1 year of storage and hold them during 3 years of storage.

Greater impact on the vitreousness and the falling number was of the term of storage and on the indicators of protein and gluten content – growing systems and predecessors. It was established a very strong positive bond of vitreousness with the amount of gluten and the content of protein with energy deformation.

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Conflict of Interest:

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Ethical Statement:

This article does not contain any studies that would require an ethical statement.

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