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Evaluation of winter wheat varieties based on grain quality indicators in northern Ukraine

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Abstract. The study was devoted to assessing the impact of hydrothermal conditions on the formation of grain quality indicators of winter wheat varieties in northern Ukraine. The relevance of the work was determined by the intensification of climatic fluctuations, which leads to a decrease in the stability of yield and grain quality, as well as the need to select varieties capable of combining high productivity and proper baking quality. The aim of the study was to identify the impact of temperature and moisture on the quality indicators of winter wheat varieties of different origins and to determine the genotypes most adapted to the conditions of the region. The study was conducted over two growing seasons (2023-2025) on eight varieties of winter wheat of Ukrainian and foreign selection. The evaluation was carried out according to the main quality indicators: weight of 1,000 grains, protein content, gluten content, vitreousness and grain nature. It was found that weather conditions significantly affected grain quality indicators. In the dry conditions of 2023/2024, grain with a higher protein content (up to 11.4%) and gluten content (up to 22.0%) was formed, while in the wetter conditions of 2024/2025, higher yields (up to 7.7 t/ha) were achieved, but the protein content decreased. The highest quality indicators were observed for the varieties 'Vezha Myronivska' and 'MIP Vyshyvanka', and the highest productivity was observed for 'MIP Valenciia' and 'Tobak'. Correlation analysis shows an inverse relationship between yield and grain quality indicators, which is exacerbated by moisture deficiency, while high

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direct correlations between protein, gluten and vitreousness indicate their interdependence and the possibility of balancing quantity and quality under optimal water conditions. The practical significance of the results obtained lies in the identification of varieties capable of producing stable grain quality under different weather conditions, which can be used to improve the varietal composition of winter wheat in Ukraine and optimise agricultural technologies in the context of climate change

Keywords: weather conditions; gluten; protein; vitreousness; development phases

Introduction

Soft winter wheat has long been one of the main grain crops in Ukraine and worldwide. Among grain crops, wheat grain is distinguished by its high protein content. Grain crops provide the world's population with an average of 50-60% of their protein. The protein and gluten content in wheat grain depends largely on the variety. Its content in soft wheat grain, depending on the variety and growing conditions, can average 13-15%. Thus, studying the impact of natural factors that limit the stability of high grain quality in winter wheat varieties is becoming a dominant issue in terms of importance (Zvonar, 2020).

On a global scale, rising temperatures, precipitation deficits and increasing salinity of soils are key factors limiting wheat productivity. Climate change, especially droughts, and the spread of pests and diseases significantly reduce grain yield and quality in semi-arid regions (Holyk *et al.*, 2023). According to M.A.S. Raza *et al.* (2025), the use of zinc oxide nanoparticles (ZnO-NPs) can increase yields by up to 25%, improve grain weight and increase protein content even in the absence of moisture. Such micronutrient fertilisation technologies are considered a promising direction for adapting wheat to stressful environmental conditions. In addition to drought, another serious global problem is secondary soil salinisation. According to the results of research by M.M. Majidi *et al.* (2025), the use of synthetic hexaploid wheat (SHW) lines obtained by hybridising hard and wild forms is a new source of genetic resistance to soil salinisation. These lines are characterised by high variability, good trait inheritance and can increase tolerance to abiotic

factors, which is especially important in the context of climate change and the spread of aridisation around the world.

Grain quality is determined by a combination of morphological, physical, and biochemical properties that determine its technological purpose and baking value. The main indicators used to assess wheat grain quality include the weight of 1,000 grains, grain density, moisture content, vitreousness, protein and gluten content, and the falling number, which reflects the activity of amylase enzymes. It is the combination of these parameters that determines the suitability of grain for processing and the quality of the final product. The work of M. Helguera *et al.* (2020) summarised modern approaches to assessing grain quality in wheat breeding programmes. The authors revealed the genetic, physiological, and technological aspects of the formation of quality indicators, in particular protein content, gluten content, enzymatic activity, and structural properties of the endosperm. The study emphasised the importance of combining genomic selection methods with traditional breeding criteria to improve grain quality. This study has become an important theoretical basis for improving wheat breeding, taking into account the nutritional value and technological parameters of grain.

Modern innovative cultivation technologies demonstrate new opportunities for improving grain quality even under conditions of limited natural resources. The study by G. Albahri *et al.* (2023) focused on a variety of advanced agricultural practices, including the use of microbial biostimulants, nutrient optimisation, lighting management, and adaptation to abiotic stresses

through innovative agricultural systems. It emphasised that such approaches not only increase yields but also improve grain quality (e.g., wheat and rice) in conditions often characterised by limited or stressful resources (such as the impact of abiotic stress). R. Hasana *et al.* (2024) described the impact of alternative agricultural practices, such as regenerative or conservation methods (minimum tillage, zero tillage, mulching), on soil, crop production and the environment. The article notes that these methods are important for ensuring food security, as vital resources such as arable land and water remain limited, but at the same time, such technologies can improve the quality of primary agricultural products.

According to R.I. Topko & H.M. Kovalyshyna (2022), the production of high-quality winter wheat is becoming increasingly important, so breeding institutions must create new varieties that would ensure high grain quality even under unstable weather conditions. Foreign-bred varieties are occupying an increasingly large niche in the Ukrainian seed market, gradually displacing Ukrainian varieties. Thus, it is important to study and evaluate these varieties. Ya. Manziuk & H.M. Kovalyshyna (2022) examined the characteristics of growing foreign-bred winter wheat varieties in the Forest-Steppe zone of Ukraine. The authors noted their high productivity and good adaptation to local climatic conditions, which confirms the feasibility of expanding the use of such varieties in Ukrainian agriculture. With the help of these data, it will be possible to select the most productive and environmentally adapted seed material.

In the context of global climate change, which negatively affects the quantity and quality of crops, the variety is one of the most reliable and cost-effective factors in increasing the yield and improving the quality of winter wheat grain. Scientists note that when the average daily air temperature exceeds 20°C and the relative humidity is below 55%, shriveled, low-quality grain is formed and gluten is destroyed, which negatively affects its quality and baking properties. The optimal conditions for the accumulation

of protein and gluten in grain are daytime temperatures of 20-24°C and daylight hours of 10-12 hours (Adamenko, 2017). Along with the creation of new varieties, the preservation and reuse of the genetic potential of old wheat varieties is becoming increasingly important. N. Maravić *et al.* (2025) proved that ancient varieties and landraces maintain stable levels of protein, gluten and phenolic compounds even under climate change, making them valuable sources of genes for improving the adaptability and nutritional value of wheat.

The aim of the study was to investigate the influence of hydrothermal conditions on grain-quality indicators in winter wheat cultivars of Ukrainian breeding and those bred in Germany, France, and the Czech Republic.

Materials and Methods

The study was conducted using a combination of methods: field, laboratory and statistical, which ensured the reliability and comprehensiveness of the results. Field studies were conducted during the 2023-2024 and 2024-2025 growing seasons. The object of the study was 8 varieties of winter wheat: 'MIP Vyshyvanka', 'Vezha Myronivska' and 'MIP Valenciia' (Myronivka Institute of Wheat named after V.M. Remeslo), 'Nosivochka' (Nosivska Selection and Research Station of the Myronivka Institute of Wheat named after V.M. Remeslo), 'Emerick' (KWS, Germany), 'Mescal' (Limagrains, France), 'Julia' (Selgen, Czech Republic), 'Tobak' (Saaten Union, Germany). The field method was used to establish experimental plots, conduct phenological observations (determining the calendar dates of the onset of the main phenophases – emergence, tillering, heading, ripening) and record yields, which made it possible to assess the dynamics of growth and development of varieties under natural conditions.

Pryluky District, in the territory of the Pidlubivka Starosta District of the Sukhopolovianska United Territorial Community near the village of Tarasivka. In 2023, the preceding crop was sunflower. Sowing was carried out on 01.10.2023, and the first seedlings were obtained on

16.10.2023, which was favoured by the dry period after sowing. The period from late June until harvest was characterised by high air temperatures. During this time, the air temperature exceeded 40°C, which resulted in the formation of small, flattened grains. Meteoblue data was used to characterise the weather conditions (hydrothermal regime) during the growing season and grain formation, which made it possible to quantitatively confirm and describe the temperature conditions. For the 2025 harvest, experimental plots were established in the southern part of the Chernihiv region, within the Pryluky district, on the territory of Malodivysia united territorial community near the village of Novyi Lad. Soybeans were the predecessor crop for the sowing of winter wheat varieties. Sowing was carried out on 29 September 2024. The beginning of germination was noted on 10 October 2023.

A laboratory method was used to assess grain quality. The study of the influence of hydrothermal conditions on grain formation and the formation of quality indicators (naturalness, protein content, raw gluten, vitreousness, falling number) was carried out using generally accepted methods (Tkachyk, 2016; Melnyk *et al.*, 2024) and in accordance with the current

standard DSTU 3768:2010 (2010). The choice of these methods was justified, since the field method ensures the representativeness of data, the laboratory method ensures the accuracy of the assessment of quality indicators, and the statistical method (mathematical data processing) is necessary to assess the reliability and validity of the results obtained. The data obtained were processed using Microsoft Excel software. Excel was used to perform basic statistical calculations, in particular to determine the arithmetic mean, standard deviation, coefficients of variation and correlation, and the least significant difference (LSD) between the indicators studied. The difference between the indicators was considered statistically significant at a significance level of $p < 0.05$. Experimental studies of plants, including the collection of plant material, complied with institutional, national or international guidelines. During the study, the standards of the Convention on Biological Diversity (1992) were observed).

Results and Discussion

During the years of research, weather conditions were contrasting, especially during the period of grain formation and grain quality indicators (Table 1, Table 2).

Table 1. Hydrothermal indicators of the growing season for winter wheat, 2023/2024

Month	Indicators					
	Air temperature, °C			Precipitation, mm		
	Decades of the month			Decades of the month		
	I	II	III	I	II	III
2023 September	24.1	24.0	26.0	2.0	5.0	-
October	16.7	14.0	14.2	4.0	24.0	32.0
November	12.6	5.8	-1.8	29.0	21.2	39.4
December	-4.3	1.3	4.1	13.4	34.9	8.3
2024 January	-6.0	-7.2	-3.1	13.3	11.3	9.1
February	3.1	5.0	6.5	25.3	12.2	-
March	5.6	6.7	11.8	-	12.2	14.5
April	18.4	16.0	16.9	1.7	37.5	-
May	17.7	15.6	23.0	4.1	8.1	11.8
June	25.0	23.0	25.5	30.6	31.0	9.0
July	30.0	35.2	29.5	-	-	-

Source: developed by the authors based on own research

Table 2. Hydrothermal indicators of the growing season for winter wheat, 2024/2025 p.

Month	Indicators					
	Air temperature, °C			Air temperature, °C		
	Decades of the month			Decades of the month		
	I	II	III	I	II	III
2024 September	28.4	26.5	25.4	-	1.8	-
October	21.2	12.3	13.0	19.4	30.6	-
November	8.3	6.0	2.3	-	32.0	6.0
December	1.4	0.9	2.9	8.2	14.4	0.3
2025 January	4.2	1.9	5.9	12.2	1.2	0.9
February	-2.0	-8.1	-8.6	-	3.0	-
March	9.7	10.2	13.2	-	7.5	6.7
April	8.6	20.6	14.6	1.3	-	0.7
May	15.1	14.6	23.3	17.3	17.9	33.4
June	24.3	19.6	20.4	17.1	16.9	13.9
July	30.6	28.7	25.8	7.9	4.1	6.6

Source: developed by the authors based on own research

Weather conditions in autumn 2023 were warmer than the long-term average. In September, average daily air temperatures ranged from 24.0 to 26.0°C, which contributed to good germination and initial plant growth. However, precipitation during this month was insufficient (7.0 mm), which limited moisture accumulation in the arable soil layer. In October, the temperature dropped to 14–16°C, and moderate precipitation was observed (60.0 mm per month), which provided optimal conditions for winter crops to tiller. In November, the temperature dropped from +12.6 to -1.8°C, but sufficient precipitation (over 89 mm) ensured the replenishment of soil moisture reserves before wintering. The winter period (December–February) was characterised by unstable temperatures ranging from -7.2°C to +6.5°C. Frequent thaws could have contributed to the compaction of the snow cover and the freezing of the topsoil, but no significant damage to plants was observed. In spring (March–May 2024), average monthly temperatures rose from 5.6°C to 23.0°C. Precipitation during this period was limited (mainly 20–40 mm per month), which caused a moisture deficit during the period of plant emergence and heading. In June–July 2024, high air temperatures (up to 35°C) were observed with

low precipitation, which led to increased temperature stress and accelerated grain ripening. These conditions contributed to the formation of grain with reduced moisture content but higher protein and gluten content, which is consistent with the grain quality results obtained this year. The following growing season was characterised by higher temperatures and more uniform moisture, which created favourable conditions for the growth and productive tillering of winter crops (Table 2). In September 2024, abnormally warm weather (25.4–28.4°C) with little precipitation was observed, which somewhat complicated the initial rooting of plants. However, sufficient moisture in October (up to 50 mm) ensured the restoration of optimal conditions for autumn wheat development. The winter period (December–February) was mild, with average temperatures mostly hovering around zero or slightly above, which helped plants overwinter without significant damage. Precipitation during the winter was moderate (20–30 mm per month).

In March–April 2025, the temperature rose to 13–20°C, with little precipitation, which led to a moderate moisture deficit at the beginning of spring vegetation. However, in May, there was a significant amount of precipitation (over 68 mm),

which improved the water regime during the critical period of formation of the generative organs of winter wheat plants. In June–July 2025, high temperatures (up to 30.6°C) were observed with sufficient precipitation (an average of 15–20 mm per decade), which contributed to uniform grain filling and high yield formation, albeit with slightly reduced protein content and vitreousness. The hydrothermal conditions of both growing seasons had a significant impact on the productivity and quality of winter wheat grain. 2023/2024 was characterised by warmer but drier conditions, which contributed to the formation of grain with a high protein and gluten content, but with lower yields. In contrast, 2024/2025 was marked by a more optimal combination of temperature and moisture, which ensured a higher yield, but with a slight decrease in grain quality indicators. For both years, there is a clear trend

towards an increase in average monthly temperatures by 2–4°C compared to long-term averages, especially in the autumn and spring months. Precipitation is unevenly distributed: there is a deficit during the sowing period (September–October) and during grain filling (June–July), while in the winter months, precipitation often exceeded the norm. Such fluctuations confirm the general trend towards a shift in climatic seasons, an increase in the duration of rainless periods and more frequent occurrence of drought conditions during the critical phases of winter wheat development – emergence, tillering and heading. The study of the influence of hydrothermal conditions on grain formation and the formation of grain quality indicators of the studied varieties of winter wheat of Ukrainian and foreign selection was carried out in accordance with the generalised calendar dates of phenophases (Table 3).

Table 3. Phases and calendar dates of grain formation in winter wheat varieties (2024, 2025)

Grain formation phases	Grain formation dates	
	2024	2025
Grain formation	12-15.06	10-12.06
Milk ripeness	22-27.06	18-22.06
Wax ripeness	05-06.07	02-04.07
Full ripeness	10-11.07	12-14.07

Source: developed by the authors based on own research

An analysis of the calendar dates for winter wheat grain formation indicates a shift in the phenological phases of development to earlier dates in 2025 compared to 2024. Thus, grain formation and the phases of milk and wax ripeness began 2–4 days earlier, which is due to an increase in average air temperatures in the spring–summer period. This trend is characteristic of most regions of Ukraine. According to field observations by researchers M. Shtakal *et al.* (2022), in the Forest-Steppe zone during 2010–2021, the average daily air temperature for April–October increased by 2.2°C, and precipitation decreased by 27 mm relative to the norm, which led to an acceleration in the development of winter crops, a reduction in the grain filling period, and a decrease in soil moisture reserves during

ripening. Under these conditions, even high-yielding varieties cannot always effectively withstand the effects of weather fluctuations, in particular elevated temperatures during the grain formation phase.

Yields varied among varieties in 2024 and depended on the conditions during the grain formation period. The following varieties had significantly high, statistically reliable yield indicators: 'MIP Valenciiia' (5.6 t/ha) and 'Tobak' (5.3 t/ha). At the same time, the grain moisture content of the studied varieties was within the range of 9.2–9.5%. The average weight of 1,000 grains per variety was 46.8 g, with significantly high values for the varieties 'MIP Vyshyvanka' and 'Nosivochka' (50.5 and 48.9 g). The value of wheat grain largely depends on its protein and gluten content. High gluten

content was observed for the Ukrainian varieties 'MIPVyshyvanka' and 'Vezha Myronivska' – 22.0%, respectively. For foreign varieties – 'Emerick', 'Mescal', 'Julia', and 'Tobak' – this indicator was 20.8%, 18.4%, 21.0%, and 17.6%, respectively. The protein content

in the grain of Ukrainian varieties was also higher, ranging from 11.2% to 11.4%, while that of foreign varieties was slightly lower, ranging from 9.6% to 11.2%. The vitreousness index of the grain in all studied varieties ranged from 48% to 50% (Table 4).

Table 4. Grain quality indicators for Ukrainian and foreign soft winter wheat varieties (2024, 2025)

Variety	Yield, t/ha	Weight of 1,000 grains, g	Moisture, %	Grain density, g/dm ³	Gluten, %	Vitreousness, %	Protein, %	Fall number, s
2024								
'Nosivochka'	3.9	48.9	9.3	763.0	21.0	48.0	11.4	304.0
'MIP Vyshyvanka'	3.9	50.5	9.2	792.0	22.0	50.0	11.3	292.0
'Vezha Myronivska'	3.9	46.5	9.2	792.0	22.0	48.0	11.3	290.0
'MIP Valenciia'	5.6	47.7	9.2	812.0	21.6	50.0	11.2	266.0
'Emerick'	4.7	43.8	9.5	789.0	20.8	50.0	11.2	253.0
'Mescal'	5.1	46.1	9.5	770.0	18.4	50.0	10.1	260.0
'Julia'	4.6	46.6	9.4	787.0	21.0	48.0	10.7	215.0
'Tobak'	5.3	44.1	9.4	743.0	17.6	40.0	9.6	226.0
Arithmetic mean	4.6	46.8	9.3	781.0	20.6	48.0	10.9	263.3
Standard deviation	0.7	2.3	0.1	21.4	1.7	3.4	0.7	31.7
Coefficient of variation	15.0	5.0	1.0	3.0	8.0	7.0	6.0	12.0
Coefficient of correlation	-	-0.53	0.36	-0.03	-0.56	-0.25	-0.60	-0.63
2025								
'Nosivochka'	5.6	50.6	12.4	766.0	16.0	32.0	9.8	271.0
'MIP Vyshyvanka'	5.4	51.7	12.4	766.0	16.0	32.0	9.8	280.0
'Vezha Myronivska'	6.2	47.1	12.3	793.0	18.2	40.0	10.9	276.0
'MIP Valenciia'	7.1	48.8	12.2	781.0	17.8	38.0	10.8	274.0
'Emerick'	6.9	44.6	12.6	785.0	17.0	38.0	10.7	302.0
'Mescal'	7.2	47.7	12.6	771.0	18.4	38.0	10.1	297.0
'Julia'	7.3	48.5	12.5	768.0	15.0	34.0	9.8	265.0
'Tobak'	7.7	45.3	12.4	769.0	15.4	36.0	10.1	270.0
Arithmetic mean	6.7	48.0	12.4	774.9	16.7	36.0	10.3	279.4
Standard deviation	0.8	2.4	0.1	10.2	1.3	3.0	0.5	13.2
Coefficient of variation	13.0	5.0	1.0	1.0	8.0	8.0	5.0	5.0
Coefficient of correlation*	-	-0.72	0.22	0.10	0.02	0.50	0.22	0.05

Note: * – coefficient of variation relative to yield; values in columns that are significantly higher than the average at the 5% significance level are highlighted in bold

Source: developed by the authors based on own research

In 2025, the average yield of winter wheat varieties was 6.7 t/ha. High, statistically significant yield indicators were observed for the 'Tobak' variety (7.7 t/ha). The grain moisture content ranged from 12.2 to 12.6%. The average weight of 1,000 grains across varieties was 48.0 g, ranging from 44.6 g ('Emerick' variety) to 51.7 g (MIP Vyshyvanka variety). Weather conditions during the grain formation and filling period significantly affected quality indicators. The average gluten content in the varieties was 16.7%. High values for this trait were observed in the varieties 'Vezha Myronivska' (18.2%), 'Mescal' (18.4%) and 'MIP Valenciiia' (17.8%), while the lowest were found in the varieties 'Julia' (15.0%) and 'Tobak' (15.4%). The average protein content across varieties was 10.3%. High statistically significant indicators were observed in the varieties 'Vezha Myronivska' (10.9%), 'MIP Valenciiia' (10.8%) and 'Emerick' (10.7%). The average vitreousness index for all varieties was 36.0%, which is significantly lower than last year's index (48.0%). This indicator was high in the varieties

'Vezha Myronivska' (40%), 'MIP Valenciiia', 'Emerick' and 'Mescal' (38%). According to the results of research, in the favourable moisture conditions of 2025, higher plant productivity was achieved, but with a slight decrease in grain quality indicators, primarily protein, gluten and vitreousness content. In 2024, under drier conditions, on the contrary, lower yields but higher protein and raw gluten content were observed.

The results obtained (Table 5) confirm the existence of an inverse correlation between yield and grain quality indicators, in particular protein, gluten and vitreousness content. In years with higher moisture levels, an increase in yield was observed, but a decrease in protein content in the grain, while in drier conditions, on the contrary, the protein and gluten content increased, but the yield decreased. A similar trend was noted by Y. Wang *et al.* (2023), who point out that long-term selection aimed at increasing yield is often accompanied by a decrease in grain quality due to a reduction in the protein fraction as grain weight increases.

Table 5. Interdependence between the indicators studied in 2024 and 2025

	Yield, t/ha	Weight of 1,000 grains, g	Moisture, %	Grain density, g/dm ³	Gluten, %	Vitreousness, %	Protein, %	Fall number, s
Yield, t/ha	1	-	-	-	-	-	-	-
Weight of 1,000 grains, g	-0.51/-0.71	1	-	-	-	-	-	-
Moisture, %	0.36/0.21	-0.70/-0.33	1	-	-	-	-	-
Grain density, g/dm ³	-0.03/0.08	0.33/-0.51	-0.47/-0.25	1	-	-	-	-
Gluten, %	-0.56/-0.00	0.59/-0.17	-0.68/-0.11	0.80/0.67	1	-	-	-
Vitreousness, %	-0.24/0.48	0.44/-0.69	-0.13/-0.07	0.76/0.85	0.63/0.77	1	-	-
Protein, %	-0.60/0.20	0.56/-0.53	-0.57/-0.35	0.69/0.95	0.94/0.70	0.69/0.88	1	-
Fall number, s	-0.62/0.04	0.66/-0.38	-0.59/0.62	0.22/0.31	0.53/0.56	0.45/0.41	0.68/0.31	1

Note: the table shows data for 2024 and 2025 (2024/2025) separated by a slash

Source: developed by the authors based on own research

Analysis of the interdependencies between the main indicators of grain yield and quality (Table 5) confirms the existence of close correlations between the studied characteristics, which

indicates their interdependence. In 2024, there was a clear inverse correlation between yield and protein content ($r = -0.60$), gluten content ($r = -0.56$) and 1,000-grain weight ($r = -0.51$). This

indicates that an increase in yield is accompanied by a decrease in the concentration of protein and gluten in the grain, which is a manifestation of the so-called dilution effect. A study by Y. Wang *et al.* (2023), based on a global meta-analysis, confirms the existence of a fundamental trade-off between yield and protein content in grain, despite significant improvements in both indicators due to optimisation of nitrogen nutrition. At the same time, Y. Wang *et al.* noted that grain protein content shows higher growth in years when temperatures during the ripening period are higher. In the current study, despite extremely high temperatures during grain formation, which could theoretically stimulate protein accumulation, drought was the limiting factor. Stress caused premature formation of small grains (confirmed by low 1,000-grain weight), which prevented full protein accumulation in the cells. In addition, the results obtained correlate with the conclusions of R. Koppel *et al.* (2020), who, assessing the variability of wheat quality in Northern Europe, emphasised that the variability of protein and gluten content depends most on the year (i.e. on dominant environmental factors such as the hydrothermal regime). The observations in the current study, which record a sharp manifestation of the negative “yield-quality” relationship precisely in the unfavourable, dry conditions of 2024, fully confirm this thesis, indicating that annual agroclimatic conditions were the main factor determining the relationship between productivity and quality.

At the same time, in 2025, when weather conditions were more favourable and humid, the nature of the relationship partially changed: the correlation between yield and quality indicators weakened or even became slightly positive. Thus, for protein and gluten, the coefficients were $r=0.20$ and $r=\text{absent}$, respectively. This indicates that under conditions of optimal moisture and moderate temperatures, the grain formed in a more balanced manner, without a significant decrease in quality as yield increased. Among the internal relationships between quality indicators, it is worth noting the high direct correlation

between protein and gluten content ($r = 0.94$ in 2024 and $r = 0.70$ in 2025), which confirms their close functional interaction. There is also a strong positive correlation between vitreousness and protein content in grain ($r = 0.69-0.88$), which determines the structural and mechanical quality of the endosperm. The correlation between the falling number and protein and gluten ($r = 0.53-0.68$) indicates a certain stability of amylase activity within the studied varieties.

Achieving a combination of consistently high yield, resistance to adverse environmental factors and high product quality in a single variety remains an extremely challenging task in modern breeding, due to the inverse correlations between these traits. The results of the current study, which recorded negative correlations between yield and quality indicators ($r = -0.51$ to -0.60) in the stressful year of 2024, fully confirm this general pattern. Ukrainian scientists O.A. Demydov *et al.* (2023) in their field studies on Myronivka wheat cultivars, found that the maximum variation range of key quality indicators (sedimentation, crumb porosity, dough strength) is determined by the complex interaction of the factors “year \times predecessor” and “year \times sowing date”. This confirms that grain quality is highly variable and sensitive to environmental changes, and it is this instability that complicates the selection of varieties that combine high productivity and consistently high quality. Similarly, V.M. Pochynok & O.V. Radchenko (2011), analysing the genetic nature of protein content in grain, emphasised that this trait is controlled polygenically, but its level significantly depends on environmental conditions, in particular on temperature and precipitation during the grain filling period, which directly correlates with observations of the impact of the abnormal heat of 2024. A study by O.V. Barabolia (2008) focused on spring durum wheat also directly points to the existence of inverse relationships: an increase in sowing rates and nitrogen fertiliser doses, which increase yield and protein/gluten content, simultaneously leads to a decrease in 1,000-grain weight and specific weight. This is key

confirmation of the “dilution effect” and the negative correlation between yield and grain weight that was observed ($r = -0.51$). In addition, O.V. Barabolia (2008) also noted that arid conditions during the grain formation period, regardless of the growing background, contribute to a decrease in the weight of 1,000 grains. V.V. Bazalii (2009), analysing progress in breeding for adaptability, noted that new varieties, although highly ecologically plastic, still require study under combined use of optimal and stressful conditions (such as water supply), which justifies the need for research under hydrothermal stress conditions and confirms the complexity of the breeding process. Thus, the results of the work on the negative correlation between yield and quality under stress conditions are fully consistent with the long-term conclusions of scientists and confirm the urgency of the problem of balanced selection.

Many scientists point out that the highest quality grain is formed in years with moderate or even insufficient rainfall during the filling period. This pattern is particularly relevant for Ukrainian breeding. For example, M.A. Lytvynenko (2005), analysing the potential of Ukrainian wheat, emphasised that with proper agricultural techniques and favourable but moderate moisture, the quality of domestic grain can be no worse than that of leading world producers (such as Canada). This indirectly confirms that in order to achieve high baking properties and protein concentration, preference is given not to excessive moisture, but to balanced conditions that prevent the “dilution effect”. The results of the present study were consistent with this approach in that excessive moisture is undesirable, but they revealed a critical limitation: under the conditions of heat stress that were observed in 2024, even a moderate precipitation deficit did not lead to high quality, as the dominant negative factor was heat shock, which stopped protein synthesis. At the same time, V.T. Kolyuchyi & M.I. Blokhin (2007) summarise that high grain quality in the Forest-Steppe zone of Ukraine is associated precisely with periods when a moderate moisture deficit ensures

intensive protein accumulation during the filling period. This is explained by the fact that a moderate water deficit at the ripening stage can accelerate metabolic processes and the redistribution of nitrogen in the grain. The results of 2024 show that if such a deficit is accompanied by high temperatures, then instead of intensified protein accumulation, accelerated ripening occurs (formation of small, flattened grains), which leads to a low final concentration of protein and gluten.

Similar results are reported by R. Koppel *et al.* (2020), emphasising that in temperate climates, consistently high yields are achieved at the expense of reduced baking properties. Thus, the negative correlation between yield ($r = -0.56$) and protein content established in the present study is consistent with international observations and confirms the need to search for varieties capable of balancing quantity and quality of production under changing climatic conditions.

Summarising the results of the studies, it can be noted that the data obtained indicate a significant influence of hydrothermal conditions on the quality and productivity of winter wheat. A pronounced dependence between the level of moisture, temperature regime and the formation of the protein-gluten complex of grain has been established. Analysis of correlation relationships confirms the interdependence of the main quality indicators that determine baking properties.

Conclusions

As a result of two years of research (2023-2025) on eight varieties of winter wheat of Ukrainian and foreign selection, it was established that the hydrothermal conditions of the growing seasons are the dominant factor that significantly affects the formation of the quality indicators of winter wheat grain. The contrast in weather conditions between 2023/2024 and 2024/2025 made it possible to clearly differentiate varieties according to their response to stressful and optimal conditions. Under the conditions of 2023/2024, the average yield was lower (4.6 t/ha), but the grain formed with a higher protein content (10.9% on average)

and gluten content (20.6% on average). The highest quality indicators were recorded for the Ukrainian varieties 'MIP Vyshyvanka' and 'Vezha Myronivska', with a gluten content of 22.0% and a protein content of up to 11.4%. At the same time, the varieties 'MIP Valenciia' (5.6 t/ha) and 'Tobak' (5.3 t/ha) demonstrated the maximum yield under these conditions.

On the other hand, the more humid and favourable conditions of 2024/2025 ensured a significant increase in average yield to 6.7 t/ha, with the maximum indicator in the 'Tobak' variety (7.7 t/ha). However, this was accompanied by a decrease in average quality indicators: gluten content decreased to 16.7%, and protein content to 10.3%. The best quality varieties this year were 'Vezha Myronivska' (18.2% gluten, 10.9% protein) and 'Mescal' (18.4% gluten). Correlation analysis confirmed the existence of an inverse relationship between yield and quality indicators, which was particularly pronounced in the stressful year of 2024 (correlation coefficient $r = -0.60$ for protein and $r = -0.56$ for gluten). In the more favourable conditions of

2025, this relationship weakened significantly, indicating the possibility of balancing quantity and quality under optimal water conditions.

Based on the data obtained, the most adapted genotypes capable of producing stable grain quality for the conditions of Northern Ukraine are the varieties 'Vezha Myronivska' and 'MIP Vyshyvanka', which combine high quality indicators with sufficient productivity. The prospect for further research to expand the evaluation of winter wheat varieties in terms of grain quality in different agroclimatic zones of Ukraine and to identify genotypes that are most adapted to changing hydrothermal conditions.

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Conflict of Interest

None.

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Оцінка сортів пшениці озимої за показниками якості зерна в умовах північної України

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Анотація. Дослідження присвячено оцінці впливу гідротермічних умов на формування показників якості зерна сортів пшениці озимої в умовах Північної України. Актуальність роботи зумовлена посиленням кліматичних коливань, що призводить до зниження стабільності врожайності та якості зерна, а також необхідністю добору сортів, здатних поєднувати високу продуктивність і належну хлібопекарську якість. Мета дослідження – виявити вплив температурного режиму та зволоження на показники якості зерна сортів пшениці озимої різного походження та визначити найбільш адаптовані генотипи до умов регіону. Дослідження проводили протягом двох вегетаційних періодів (2023-2025 рр.) на восьми сортах пшениці озимої української та іноземної селекції. Оцінювання здійснювали за основними показниками якості: масою 1000 зерен, вмістом білка, клейковини, скловидності та натурою зерна. Встановлено, що погодні умови значно впливали на показники якості зерна. У посушливих умовах 2023/2024 рр. формувалося зерно з підвищеним вмістом білка (до 11,4 %) і клейковини (до 22,0 %), тоді як у вологіших умовах 2024/2025 рр. забезпечувалася вища врожайність (до 7,7 т/га), але знижувався вміст білку. Найвищі показники якості відмічено для сортів 'Вежа Миронівська' та 'МІП Вишиванка', а найвищу продуктивність – 'МІП Валенсія' та 'Тобак'. Кореляційний аналіз засвідчує зворотний зв'язок між урожайністю та якісними показниками зерна, який посилюється за дефіциту вологи, водночас високі прямі кореляції між білком, клейковиною та скловидністю свідчать про їхню взаємну залежність і можливість балансування кількості та якості за оптимального водного режиму. Практичне значення отриманих результатів полягає у визначенні сортів, здатних формувати стабільну якість зерна за різних погодних умов, що може бути використано для удосконалення сортового складу пшениці озимої в Україні та оптимізації агротехнологій у контексті кліматичних змін

Ключові слова: погодні умови; клейковина; білок; скловидність; фази розвитку