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Influence of abiotic and anthropogenic factors on the formation of winter wheat grain quality indicators

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Abstract. The purpose of the study was to establish the influence of growing location, hydrothermal growing season conditions, variety, sowing date, and preceding crop on the formation of winter wheat grain quality indicators. The research was conducted during 2018/19–2020/21 in two locations for two sowing dates after sunflower and soybean as the preceding crops. Four varieties of winter bread wheat were evaluated according to grain, flour, dough, and bread quality indicators. A higher variability of winter wheat grain quality indicators was noted between the years of the study in the conditions of the central part of the Forest-Steppe of Ukraine (Location 1) (CV = 2.7–32.6%) compared to the conditions of the northeastern part of the Forest-Steppe of Ukraine (Location 2) (CV = 1.9–18.0%). The determining influence of the variety on test weight (38.32%), volume of bread (30.22%), wet gluten content (25.65%), protein content (18.55%), porosity of bread crumb (18.17%), and sedimentation value (15.02%) was established. The most influence of the growing location on deformation energy (37.43%) and dough tenacity (35.29%) was revealed The decisive influence of the interaction year × location on 1,000 kernel weight (21.30%) was established. To obtain higher flour-milling properties, winter wheat varieties are recommended to be sown in the third decade of September after sunflower, and to obtain higher baking properties - in the first decade of October after soybeans. By sowing the varieties Podolianka and MIP Yuvileina, it is possible to obtain grain with high flour-milling and bread-making properties, that is, grain balanced in terms of quality.

Key words: ANOVA, coefficient of variation, growing season hydrothermal condition, location, preceding crop, sowing date, *Triticum aestivum* L.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is still one of the oldest, most widespread and most valuable food crops worldwide. It is sown on five continents of the globe and occupies 15% (220 million ha) of all arable land in the world (Bruinsma, 2003). The main producers of wheat grain in the world are China, India, the USA, France, Canada, Germany, Pakistan, Australia and Ukraine (FAOSTAT, 2019–2022).

According to the statistics of the Food and Agriculture Organization (FAO) of the United Nations, the number of the world's population in 2023 was 8.045 billion people, and by the end of 2100 it is expected to grow to 10 billion (Adam, 2021; FAOSTAT, 2022;). Such a rapid increase in the number of people on planet Earth requires a corresponding increase in food production, and primarily wheat grain, because *Triticum aestivum* L. is characterized by high nutritional value being one of the main sources of protein and calories for 35% of the world population (Vrtílek et al., 2019).

Cereal crops due to their unique biological properties are able to accumulate organic compounds, macro- and microelements vital for the human body (Garutti et al., 2022). The ability of wheat grain to preserve its nutritional properties and good taste for a long time makes it a unique raw material for the production of high-quality food products (Farhat, 2020). The food industry needs wheat grain with a high protein and gluten content. In this regard, the efforts of the agro-industrial complex engaged in the production of food grain are aimed at improving its quality indicators. The wheat grain quality is determined by a set of various components (Li, T. et al., 2021). Wheat grain is mainly used in such industries as bakery, cereal, confectionery, and pasta (Hussain et al., 2009).

Wheat grain is evaluated according to milling properties (test weight, 1,000 kernel weight, vitreousness, grain size, etc.) and baking properties (protein content, sedimentation value, wet gluten content and its quality, deformation energy, dough tenacity, water absorption capacity of flour, volume of bread, etc.) (Poblaciones et al., 2009). The 1,000 kernel weight is one of the main components of wheat yield, which characterizes the technological qualities of the variety, grain size and uniformity (Kuzay et al., 2019; Lozinskiy et al., 2021). The test weight indicates well-filled grain (Costa et al., 2013). As the test weight decreases, the baking properties of the flour deteriorate. A direct dependence of flour yield on these two indicators was established (Okon et al., 2016; Valde's et al., 2020). The grain protein content and the ratio between different protein fractions determine the quality of wheat flour (Xue et al., 2016; Luo et al., 2019). Gluten forms the mechanical basis of the dough, and the structure of baked bread crumb depends on its quality (Cappelli et al., 2018). The quality of gluten is determined by combination of its physical properties (tenacity, elasticity, extensibility, viscosity) and the ability to preserve these properties during the bread making process (Zhang et al., 2018). In addition, the quality of gluten depends on the composition of its protein molecules, which form a peculiar spatial structure of strength due to the unequal number of disulfide bonds and their spatial arrangement (Filip et al., 2023; Wieser et al., 2023). The nutritional value of grain is also determined by the amino acids as main structural elements of proteins, which are synthesized by the plant organism. The sedimentation value characterizes flour quality, namely, its protein-proteinase complex and depends mainly on the gluten content and its deformation index (Zhygunov et al., 2019). The direction of use of wheat flour depends on proteins content, wet gluten content, and quality of the protein-gluten complex. Therefore, these indicators play an important role in industry. Deformation energy is an important indicator of bakery quality assessment, which characterizes the ability to form dough with certain physical properties (Cappelli et al., 2018). The level of dough tenacity characterizes the resistance of the dough to deformation. Laabidi (2007) associates the high dough tenacity with a high content of covalent disulfide bonds. Branlard et al. (2013) believe that flour samples with high dough tenacity contain more glutenin. The final stage of research on the quality of breeding material is determination of baking properties of bread wheat grain by the method of test baking. The baked bread volume visually characterizes bread-making properties samples under study (Živančev et al., 2019). The general assessment of bread includes such indicators as bread volume, crumb porosity, crumb elasticity, its color, taste, look of the bread. A high baking score of wheat samples will ensure excellent quality of the finished product.

Abiotic, biotic, and anthropogenic factors influence the formation of wheat grain quality, and one of the main factors is genotype (Filip et al., 2023; Robles-Zazueta et al., 2023). In order to achieve one of the important tasks of agricultural science and production, namely increase of the gross harvest of high-quality grain of this crop under certain conditions, the correct selection of the variety for a certain area, applying fertilizers and microelements in due time, complying with crop rotation and sowing date, and harvesting in good time (Skudra & Ruza, 2016).

Significant climate changes, which are accompanied with change in temperature and water regimes, increase in the incidence of extreme hydrothermal phenomena, lead to significant fluctuations in the hydrothermal regime during plant growth stages (Elahi et al., 2022). In turn, this can lead to decrease in grain production and its quality. However, the influence of weather conditions during the growing season on grain quality can be reduced by applying agrotechnical measures (Peng et al., 2022).

One of the important agrotechnical means of improving wheat grain quality is the correct crop rotation, taking into account the biological characteristics of the variety (Yu et al., 2022). The best preceding crops should contribute to creation of satisfactory phytosanitary state of the crops and increase the yield of high-quality grain. Analysis of the structure of cultivated areas of agricultural crops in Ukraine reveals that the largest areas, with the exception of winter wheat (6,411.9 thousand ha), are occupied by sunflower (6,026.1 thousand ha), corn (4,701.5 thousand ha), soybean (1,774.8 thousand ha), rapeseed (1,038.9 thousand ha) (Prokopenko, 2020). Thus, significant areas of winter wheat are sown after the mentioned crops.

Under conditions of climate change in the direction of global warming, it is important to optimize sowing dates, which have a significant impact on plant growth and development, their survival, frost resistance and winter hardiness, formation of productive stems and grain quality (Marenych & Mishchenko, 2010). Sowing too early leads to overgrowth of plants in autumn, and this provokes an increase in damage by pathogens, causes a decrease in winter hardiness (Krivenko, 2019). With late sowing, plants prior to overwintering are less developed, they do not have time to accumulate the necessary amount of reserve substances and to undergo hardening, therefore they have a reduced resistance to adverse wintering conditions (Petrychenko et al., 2021). It has been established that the optimal sowing dates depend on soil and climatic conditions, preceding crops, biological characteristics of varieties, autumn temperature conditions and soil moisture (Saiko et al., 2009). An increase in yield and quality indicators is possible under the condition of using the genetic potential of the variety in interaction with soil and climatic conditions and crop management practice (Litke et al., 2019; Demydov et al., 2022). Because of the global and local climate changes, it is necessary to evaluate genotypes at different sowing dates after different preceding crops in different growing location.

In separate publications, the influence of some preceding crops (bare fallow, peas, corn for silage) and sowing dates (August 16 and 25, September 5, 15, and 25) on yield and grain quality of winter wheat is highlighted (Zhemela & Shakaliy, 2012; Ulich, 2018). But in connection with climate changes, we are observing the shift of sowing dates to later ones, as well as the mass use of crops that occupy the largest sowing areas in Ukraine. This prompts us to identify the variability of winter wheat grain quality indicators depending on the influence of later sowing dates after common precrops. The study of this problem will positively affect the increase in volume of high-quality agricultural grain and increase the competitiveness of agricultural enterprises.

The purpose of the research is to establish the influence of the agro-climatic growing location, hydrothermal conditions of the year, variety, sowing date and preceding crops on the formation of winter wheat grain quality indicators.

MATERIALS AND METHODS

The research was conducted during 2018/19–2020/21 in conditions of the central part of the Forest-Steppe of Ukraine in the fields of the V. M. Remeslo Myronivka Institute of Wheat of the National Academy of Agrarian Sciences of Ukraine (MIW) as Location 1 and in conditions of the northeastern part of the Forest-Steppe of Ukraine in the fields of the State Enterprise 'Research farm 'Pravdynske' of MIW (SE 'RF 'Pravdynske') as Location 2. The Table 1 shows the geographical location and characteristics of the soil cover of the fields of the two test locations. The test locations were selected based on contrasting climatic conditions and soil types to reflect the diversity of the Forest-Steppe of Ukraine.

Table 1. Geographical location of tests, soil type and composition

Location	Geographic location	Soil	pH soil	Humus content (%) in the 0–20 cm soil layer	The content of some chemical elements (mg) per 1 kg of soil		
					N	P	K
MIW (Location 1)	49°38'19.1"N 31°04'32.4"E	Low-humus slightly leached, medium-loam, granulometric	5.3	3.7	60	230	140
σ			0.2	0.3	4	12	8
SE 'RF 'Pravdynske' (Location 2)	50°22'50.7"N 35°10'24.7"E	Low-humus, medium-loamy, large-pollinated	5.8	3.9	87	109	100
σ			0.2	0.2	5	10	8
t-test			-6.9	-3.2	-14.8	40.8	5.5

σ – standard deviation; *t-test* – Student's t-test (statistically significant differences, $p \leq 0.05$).

The object of research was four new varieties of winter bread wheat bred at Myronivka (MIP Fortuna, MIP Lada, MIP Yuvileina, Avrora Myronivska). The winter wheat varieties were sown in two dates (I date is the third decade of September, II date is the first decade of October) after two preceding crops (sunflower and soybean).

Agricultural techniques for growing winter wheat are conventional for the Forest-steppe zone of Ukraine (shredding plant residues, plowing (18–22 cm), leveling the soil surface, applying the main fertilizer $N_{30}P_{30}K_{30}$ kg ha^{-1} a.s. (active substance), pre-sowing cultivation (5–6 cm), seed dressing, in the spring (IV stage of organogenesis) fertilizing with ammonium nitrate at the rate of N_{30} kg ha^{-1} a.s., at the V stage of organogenesis fungicidal protection with approved drugs in recommended doses). Sowing was carried out with the SN-10 Ts seed drill to the depth of 5 cm with sowing rate of 5 million viable seeds per hectare. Plots were placed according to a completely randomized scheme with four replications, with sample area of 10 m^2. The crop was harvested with combine harvester 'Sampo-130'.

Winter wheat grain quality indicators were determined from each replication. The 1,000 kernel weight (TKW) was calculated by counting and weighing (accurate within 0.1 g) two samples/tests of 500 grains each from one sample (the difference between the mass of the two measurements should not exceed 5%), the weights of these measurements were added and this indicator was obtained. The test weight (TW) in g L^{-1} was determined using the 1 liter cylindrical shaped cup (the difference between parallel determinations did not exceed 5 g). Protein content in flour (PC) was measured using the near-infrared reflection spectrometer (spectral range 1,400–2,400 nm) on the SPEKTRAN 119M device. The sedimentation value (SE) was estimated by the micromethod according to A. Ya. Pumpianskyi using 2% solution of acetic acid and the dye methylene blue. The wet gluten content (WGC) was determined by washing the dough formed by mixing 25 g of flour with 12 mL of 2% salt solution under a stream of water over a thick silk sieve (the temperature of the working solutions was 18 ± 2 °C). The Alveograph Chopin device was used to measure deformation energy (W) and dough tenacity (P). To determine the bread quality indicators, the dough was kneaded in the Swanson dough mixer, model 100-200 A, and kept it in the thermostat 505-SS. The loaves (of 100 g flour) were baked in an electric oven with a horizontally rotating base (t = 230 ºC). Volume of bread (VB) was measured on the OMKh-1 device. The crumb porosity of bread was determined using Zhuravlev device.

Statistical processing of the obtained data was carried out using the methods of descriptive and variational statistics, as well as analysis of variance (ANOVA). The parts of influence of the studied factors were calculated from the sum squares deviations. The coefficient of variation (CV) was calculated according to the formula:

$$CV = \frac{\sigma}{\mathrm{x}} 100\%$$

where σ is the standard deviation of the sample, x is the average value of the sample.
The following scale was used to interpret the coefficient of variation (Kupalova, 2008): $CV \leq 5\%$ – weak variation, $6 \leq CV \leq 10\%$ – moderate, $11 \leq CV \leq 20\%$ – significant, $21 \leq CV \leq 50\%$ – high, $CV \geq 51\%$ – very high.

RESULTS AND DISCUSSION

Hydrothermal regime in the conditions of the central part of the Forest-Steppe of Ukraine (Location 1)

During the growing seasons of the research in the central part of the Forest-Steppe of Ukraine, the average monthly air temperature exceeded the long-term average by 1.9–3.1 °C (Table 2). Most months for the period 2018/19–2020/21 were characterized by a higher average monthly air temperature compared to the long-term average. Abnormally warm, with an excess of the average monthly air temperature by 4.1–5.7 °C, were the months: June 2018/19; December, January, February, and March 2019–2020; September and July 2020–2021.

Table 2. Average monthly values of air temperature (°C) and amount of precipitation (mm) during the period of research in the central part of the Forest-Steppe of Ukraine, 2018/19–2020/21

Growing season	Month												Indicator	
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII		
Air temperature, °C													Average, °C	± to ALT*
2018–2019	22.1	16.9	10.6	0.6	-2.0	-5.0	0.3	4.6	10.4	16.8	22.7	19.6	9.8	+2.1
2019–2020	20.3	15.7	10.9	4.8	2.8	0.7	2.3	6.5	9.6	12.8	21.7	21.6	10.8	+3.1
2020–2021	21.2	18.5	13.1	3.8	-0.3	-2.5	-4.8	2.1	7.5	14.4	20.2	22.1	9.6	+1.9
ALT	19.0	14.1	8.0	1.5	-2.9	-4.6	-3.3	1.3	8.9	14.9	18.0	18.0	7.7	-
σ	1.3	1.9	2.1	2.0	2.5	2.6	3.3	2.4	1.2	1.6	2.0	1.9	-	-
Precipitation, mm													Sum, mm	% of ALT
2018–2019	15	80	29	20	72	40	26	27	23	50	87	50	520	89
2019–2020	10	12	6	16	37	20	52	12	48	93	57	22	382	66
2020–2021	8	21	39	28	38	57	34	29	47	87	110	111	608	105
ALT	59	51	36	42	39	30	29	32	42	51	85	87	582	-
σ	25	31	15	12	17	16	11	9	11	23	21	40	-	-

*ALT – the average long-term value for 1980–2017; σ – standard deviation.

In terms of precipitation, the 2020/21 growing season was close to the long-term average (105% of the ALT), and in 2018/19 and 2019/20 there was an insufficient amount of precipitation (89 and 66% of the ALT, respectively). With critically low amount of precipitation (< 50% to the ALT) there were characterized August and November 2018–2019; March, July, August, September, October, and November 2019–2020; August and September 2020–2021. Their significantly excessive amount (129–194% of the ALT) was noted in September, December, January 2018/19; February and May 2019–2020; January, May, June, and July 2020–2021.

Hydrothermal regime in the conditions of the northeastern part of the Forest-Steppe of Ukraine (Location 2)

For the period 2018/19–2020/21, the average annual air temperature in the conditions of the northeastern part of the Forest-Steppe of Ukraine was 9.8–11.0 °C (at ALT 7.2 °C) with monthly variations from -6.4 to 26.3 °C (Table 3). The average monthly air temperature in most months of each growing season significantly exceeded the average long-term value. The August, September, February, March, June 2018/19; October, January, February, March, June 2018/20; September, October and July 2020/21 were extremely warm, with an excess of the average monthly air temperature by 4.0–8.0 °C.

Table 3. Average monthly values of air temperature (°C) and precipitation (mm) during the period of research in the northeastern part of the Forest-Steppe of Ukraine, 2018/19–2020/21

Growing season	Month												Indicator	
	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII		
Air temperature, °C													Average, °C	± to ALT*
2018–2019	24.1	18.3	10.9	-0.9	-3.2	-6.4	-1.3	3.1	10.3	18.7	23.2	20.2	9.8	+2.0
2019–2020	22.2	16.8	11.3	3.6	1.9	-0.1	0.7	7.1	9.1	13.7	23.2	22.8	11.0	+3.3
2020–2021	21.9	19.5	12.9	3.2	-2.7	-2.9	-6.1	1.3	8.0	16.2	21.2	26.3	9.9	+2.2
ALT	19.4	13.7	7.2	0.8	-4.1	-6.5	-6.0	-0.9	8.0	15.1	18.7	20.4	7.2	-
σ	1.9	2.5	2.4	2.1	2.7	3.1	3.4	3.4	1.1	2.1	2.1	2.8	-	-
Precipitation, mm													Sum, mm	% of ALT
2018–2019	1	45	36	21	182	122	23	37	49	58	35	57	664	114
2019–2020	9	22	49	28	54	31	50	16	23	123	50	72	526	90
2020–2021	19	13	44	41	28	76	63	18	59	72	68	14	514	88
ALT	54	44	47	43	37	34	30	30	35	54	68	75	551	-
σ	24	16	6	11	72	43	19	10	16	32	16	28	-	-

*ALT – the average long-term value for 1980–2017; σ – standard deviation.

The growing season of 2018–2019 was characterized by excessive amount of precipitation (114% of the ALT), and 2019–2020 and 2020–2021 were characterized by insufficient precipitation (89 and 66% of the ALT, respectively). An abnormally high amount of precipitation (145–491% of the ALT) was noted in December and January 2018–2019; December, February, May 2019–2020; in January, February and June 2020–2021. A significant lack of moisture (< 50% to ALT) was observed in November 2018–2019; September 2019–2020 and 2020–2021, as well as in August of the three years of the study.

Both in the conditions of the central part and in the conditions of the northeastern part of the Forest-Steppe of Ukraine in 2018/19–2020/21, the highest variation in the average monthly air temperature was observed from November to March, and a critically low amount of precipitation was noted in August.

Variability of grain quality indicators

The hydrothermal conditions of the years of the study in different growing locations had different effect on the formation of grain quality indicators (Fig. 1). Depending on the growing conditions, the highest ($CV = 32.6\%$) variability of the deformation energy and the lowest ($CV = 1.9\%$) variation of the test weight were found. The test weight, 1,000 kernel weight, and porosity of bread crumb were characterized by weak ($CV \leq 5\%$) and moderate ($6 \leq CV \leq 10\%$) variation between years in both growing locations. The significant ($11 \leq CV \leq 20\%$) coefficient of variation was found in the two growing locations for the sedimentation value, volume of bread, and wet gluten content; while under conditions of the SE 'RF 'Pravdynske' (Location 2) it was for protein content, dough tenacity and deformation energy. It should be noted the higher variability of winter wheat grain quality indicators between the years of the study precisely in the conditions of MIW (Location 1).

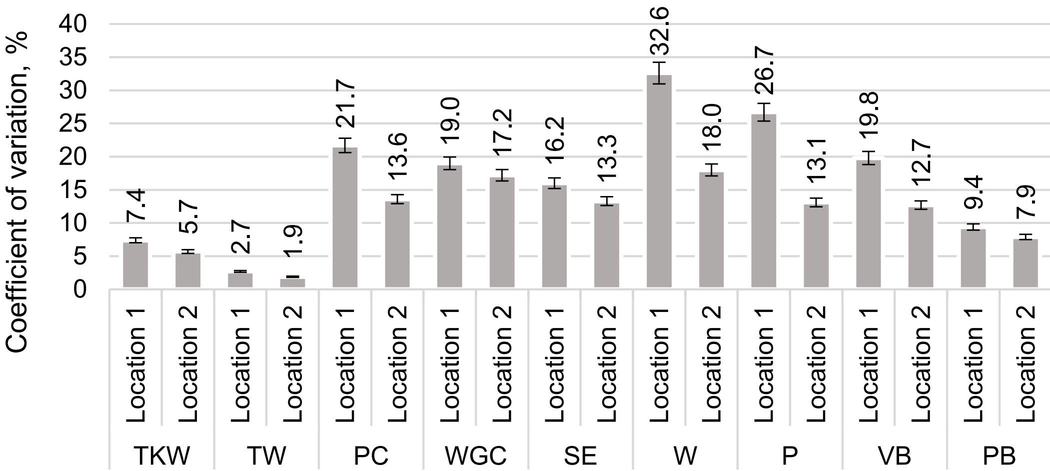

Figure 1. Coefficient of variation (%) of winter wheat grain quality indicators between the three years of the study depending on the growing location (in terms of varieties, sowing dates, preceding crops and replications).

Grain quality indicators: TKW – 1,000 kernel weight; TW – test weight; PC – protein content; SE – sedimentation value; WGC – wet gluten content; GDI – gluten deformation index; W – deformation energy; P – dough tenacity; VB – volume of bread; PB – porosity of bread crumb; error bars are equivalent to standard deviations.

On average, during 2018/19–2020/21, different coefficients of variation of grain quality indicators were found in the studied varieties depending on the sowing dates after each of two preceding crops (Table 4). Under the conditions of growing MIW (Location 1).

Table 4. Coefficient of variation (%) of grain quality indicators of winter wheat varieties between the sowing dates after various preceding crops, average for 2018/19–2020/21

Variety	TKW		TW		PC		WGC		SE		W		P		VB		PB	
	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB
Location 1																		
Podolianka	4.9	1.0	0.9	0.7	19.6	11.7	18.6	7.1	4.5	3.7	17.6	1.5	3.3	1.7	2.1	5.6	1.0	0.7
MIP Fortuna	0.3	2.5	0.6	0.2	8.8	2.2	9.2	4.2	0.8	1.1	4.5	0.5	0.3	2.9	4.3	4.1	2.2	4.7
MIP Yuvileina	1.6	3.3	0.1	0.4	1.5	7.0	0.4	3.1	3.6	5.0	8.2	1.6	0.8	2.9	0.8	1.3	4.0	0.4
MIP Lada	0.8	5.5	1.5	2.4	7.0	0.4	6.3	7.0	2.2	15.2	10.1	7.4	8.5	1.3	13.9	16.3	7.6	5.7
Avrora Myronivska	2.3	2.8	0.7	0.3	1.2	5.8	1.9	10.6	5.9	0.9	5.3	3.4	3.4	4.8	0.2	3.1	0.9	1.0
Location 2																		
Podolianka	2.4	0.4	0.5	0.1	3.7	1.5	4.0	3.3	4.1	1.3	1.3	16.1	1.0	12.2	3.4	2.3	5.3	2.7
MIP Fortuna	1.3	0.8	0.4	0.3	3.3	3.9	2.8	7.2	2.8	3.1	7.4	12.8	6.4	7.7	8.6	6.3	0.3	3.2
MIP Yuvileina	5.1	0.5	0.2	0.1	1.9	2.1	1.6	0.6	0.6	3.2	18.5	6.6	7.8	5.3	8.0	1.2	6.5	4.2
MIP Lada	4.8	0.9	0.3	0.5	1.4	2.3	1.0	0.1	5.0	1.0	0.9	3.6	0.8	1.6	7.0	0.7	0.8	6.4
Avrora Myronivska	2.3	0.6	0.2	0.4	3.1	3.9	8.0	0.7	2.5	3.8	3.7	8.8	3.5	7.1	2.9	9.6	2.3	10.0

Grain quality indicators: TKW – 1,000 kernel weight; TW – test weight; PC – protein content; SE – sedimentation value; WGC – wet gluten content; GDI – gluten deformation index; W – deformation energy; P – dough tenacity; VB – volume of bread; PB – porosity of bread crumb. Preceding crops: SF – sunflower; SB – soybean.

The significant ($11 \leq CV \leq 20\%$) variability after two preceding crops was noted for protein content in the variety Podolianka, for volume of bread in the variety MIP Lada. Also, a significant variation of some grain quality indicators was found for certain varieties according to the sowing dates after one of the preceding crops. In particular in Location 1 it was established significant variation of the sedimentation value after soybean in the variety MIP Lada ($CV = 15.2\%$), wet gluten content after soybean in the variety Avrora Myronivska ($CV = 10.6\%$), and deformation energy after sunflower in the variety Podolianka ($CV = 17.6\%$); in Location 2 the significant variation was found for deformation energy after sunflower in the variety MIP Yuvileina ($CV = 18.5\%$) and after soybean in the varieties Podolianka ($CV = 16.1\%$) and MIP Fortuna ($CV = 12.8\%$), dough tenacity after soybean in the variety Podolianka ($CV = 12.2\%$). In this way, the grain quality indicators of certain varieties of winter wheat were most responsive to the change in sowing dates after the respective preceding crops. In other variants, variation in grain quality indicators of winter wheat varieties was weak and moderate.

Table 5. Variability of winter wheat grain quality indicators depending on the sowing date and preceding crop, average by varieties and years

Preceding crop	Sowing date	TKW, g	TW, g L^{-1}	PC, %	WGC, %	SE, mL	W, 10^{-4} J	P, mm	VB, cm^3	PB, %
Location 1										
SF	I	40.9	785	12.9	28.2	66	218	97	857	80
	II	40.5	782	14.1	30.9	67	199	94	821	79
SB	I	40.1	779	14.5	30.6	68	211	90	866	79
	II	39.9	785	14.7	31.0	65	205	90	819	79
x	I	40.5	782	13.7	29.4	67	215	94	861	80
	II	40.2	783	14.4	31.0	66	202	92	820	79
x		40.4	783	14.1	30.2	67	208	93	841	79
σ		3.0	21	2.4	4.5	8	59	21	159	8
$LSD_{0.05}$		0.5	5	0.5	0.5	5	5	5	5	5
Location 2										
SF	I	41.4	789	12.2	26.8	63	284	119	814	81
	II	39.6	791	11.9	27.6	63	263	115	747	78
SB	I	38.6	793	12.7	27.8	69	319	118	750	82
	II	38.7	790	13.2	28.5	71	318	130	765	76
x	I	40.0	791	12.4	27.3	66	301	119	782	82
	II	39.1	791	12.6	28.1	67	290	122	756	77
x		39.6	791	12.5	27.7	67	296	121	769	79
σ		2.2	15	1.3	3.7	6	48	14	91	6
$LSD_{0.05}$		0.5	10	0.6	2.7	3	6	5	6	5

Grain quality indicators: TKW – 1,000 kernel weight; TW – test weight; PC – protein content; WGC – wet gluten content; SE – sedimentation value; W – deformation energy; P – dough tenacity; VB – volume of bread; PB – porosity of bread crumb; I and II, I and II sowing dates; x – average value; σ – standard deviation; preceding crops: SF – sunflower; SB – soybean; $LSD_{0.05}$ – least significant difference ($p \leq 0.05$).

On average, according to varieties, preceding crops, and sowing dates, higher values of the 1,000 kernel weight, protein content, wet gluten content, and volume of bread were obtained when growing in the conditions of MIW (Location 1) (Table 5). The highest average test weight, deformation energy and dough tenacity were noted under conditions of the SE 'RF 'Pravdynske' (Location 2). The average values of the sedimentation value and porosity of bread crumb were equal in the central and northeastern parts of the Forest-Steppe.

Differences in the influence of preceding crop on grain quality indicators were observed depending on the conditions of winter wheat growing. For example, higher test weight and dough tenacity were obtained after sunflower when growing wheat in Location 1, but in Location 2 these indicators were higher after soybean. The same variability of the influence of preceding crops was noted for most quality indicators. The winter wheat varieties had a similar response to preceding crop for 1,000 kernel weight, protein and wet gluten content, regardless of growing conditions. Namely, higher 1,000 kernel weight after the preceding crop sunflower, higher content of protein and wet gluten after soybean was established in both growing locations.

Higher values of protein and wet gluten content were found for the II sowing date (average for preceding crops), higher values of deformation energy, volume of bread, and porosity of bread crumb were found for the I sowing date under the conditions of cultivation in both locations. The influence of sowing dates on the formation of other quality indicators varied depending on the growing location. Namely, higher 1,000 kernel weight, sedimentation value, and dough tenacity in the conditions of MIW (Location 1) were obtained for the I sowing date, and in the conditions of the SE 'RF 'Pravdynske' (Location II) these indicators had higher values for the II sowing date.

The Table 6 presents histograms of grain quality indicators of winter wheat varieties, which were built for two sowing dates after the preceding crops sunflower and soybean, in an average of three years. A sparkline model was used for visual interpretation of grain quality indicators. To construct the histograms there were used scales with minimum and maximum values of each indicator: 37.1 and of 42.7 g for 1,000 kernel weight, 753 and 809 g L^{-1} for test weigh, 11.0 and 16.8% for protein content, 23.8 and 35.9% for wet gluten content, 53 and 75 mL for sedimentation value, 153 and 380×10^{-4} J for deformation energy, 72 and 138 mm for dough tenacity, 590 and 1,032 cm^3 for volume of bread, 68 and 89% for porosity of bread crumb.

Differences from the general trend of the influence of sowing dates and the unequal reaction of genotypes to this factor after different preceding crops on the formation of grain quality indicators were revealed. On average, for 2018/19–2020/21, both for growing in the conditions of the MIW (Location 1) and in the conditions of the SE 'RF 'Pravdynske' (Location 2), higher values of the 1,000 kernel weight were established at the I sowing date after the preceding crop sunflower in the varieties Podolianka, MIP Fortuna, MIP Yuvileina; test weight at the II sowing date after sunflower in the variety MIP Fortuna; protein content at the II sowing date after sunflower in the variety MIP Lada, after soybean in the varieties MIP Fortuna and MIP Yuvileina; wet gluten content at the II sowing date after sunflower in the varieties Podolianka and MIP Yuvileina, after soybean in the variety MIP Fortuna; sedimentation value at the II sowing date after sunflower in the variety MIP Lada, after soybean in the variety MIP Yuvileina and at the I sowing date after sunflower in the variety Avrora Myronivska; deformation energy at the I sowing date after sunflower in the variety MIP Yuvileina, after soybean in the varieties MIP Fortuna, MIP Lada, Avrora Myronivska; dough tenacity at the II sowing date after soybean in the varieties Podolianka and MIP Fortuna; volume of bread at the I sowing date after sunflower in the varieties MIP Fortuna, MIP Lada and Avrora Myronivska; porosity of bread crumb at the I sowing date after sunflower in the variety MIP Fortuna, after soybean in the variety MIP Yuvileina.

Table 6. Variability of grain quality indicators of winter wheat varieties depending on the sowing date after two preceding crops, average for 2018/19–2020/21

Variety	TKW, g		TW, g L^{-1}		PC, %		WGC, %		SE, mL		W, 10^{-4}J		P, mm		VB, cm^3		PB, %	
	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB	SF	SB
	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II	I II
Location 1																		
Podolianka																		
MIP Fortuna																		
MIP Yuvileina																		
MIP Lada																		
Avrora Myronivska																		
x																		
max	42.2	42.6	807	801	15.2	16.8	35.0	35.9	73	72	258	274	119	112	910	1,032	84	89
min	39.0	38.1	753	753	11.5	12.5	24.5	27.9	61	53	153	160	72	80	717	630	74	69
Location 2																		
Podolianka																		
MIP Fortuna																		
MIP Yuvileina																		
MIP Lada																		
Avrora Myronivska																		
x																		
max	42.7	40.6	802	809	14.0	15.2	30.7	33.4	69	75	366	380	136	138	925	884	86	86
min	37.8	37.1	771	775	11.0	12.0	23.8	24.3	56	66	192	269	96	111	664	590	75	68

Gain quality indicators: TKW – 1,000 kernel weight; TW – test weight; PC – protein content; WGC – wet gluten content; SE – sedimentation value; W – deformation energy; P – dough tenacity; VB – volume of bread; PB – porosity of bread crumb; Preceding crops: SF – sunflower; SB – soybean; I and II – sowing dates; x, max, min – average, maximum and minimum value, respectively; the maximum values are highlighted in green.

Winter wheat varieties which formed higher indicators at the first sowing date after both preceding crops in two growing locations were singled out, namely, MIP Yuvileina for test weight, Podolianka and MIP Lada for porosity of bread crumb. At the I sowing date after sunflower and at the II sowing date after soybean in both growing locations, higher protein content was obtained in the variety Avrora Myronivska, higher deformation energy was in the variety Podolianka and significant dough tenacity was in the variety MIP Lada.

Higher test weight was noted in the variety Avrora Myronivska at the II sowing date after sunflower and at the I sowing date after soybean, when growing both in the conditions of the MIW (Location 1) and in the conditions of the SE 'RF 'Pravdynske' (Location 2). For other winter wheat varieties, the formation of quality indicators depended not only on the sowing date and the preceding crop, but also on the growing location. Thus, experimental data indicate that in order to obtain higher grain quality indicators, it is necessary to more carefully choose the sowing dates and preceding crops in both growing locations for each variety separately.

On average, according to the varieties and years of the research for both growing zones higher flour-milling properties of winter wheat grain were obtained at the I sowing date after sunflower, while higher baking properties were at the II sowing date after the preceding crop soybean. Also, two universal varieties of winter wheat, namely, Podolianka and MIP Yuvileina were singled out which combine in one genotype high values of grain, dough and bread quality indicators.

Analysis of variance. According to the results of ANOVA (Table 7), taking into account the agro-climatic growing location, determining (at $p \leq 0.01$) influence of the variety on test weight (38.32%), volume of bread (30.22%), wet gluten content (25.65%), protein content (18.55%), porosity of bread crumb (18.17%) and sedimentation value (15.02%) was established. The constitutive influence of the growing Location was found on deformation energy (37.43%) and dough tenacity (35.29%). The decisive influence of the interaction of factors year × location on the formation of 1,000 kernel weight (21.30%) was noted.

The hydrothermal growing season conditions had the greatest influence on 1,000 kernel weight (11.14%), the preceding crop - on the protein content (6.86%), the sowing date – on the porosity of bread crumb (2.66%). There was revealed the lowest (< 1%) reliable influence of growing season conditions on dough tenacity (0.48%) and volume of bread (0.90%); of preceding crop on dough tenacity (0.05%) and test weight (0.11%); of sowing date on test weight (0.23%), dough tenacity (0.29%), and deformation energy (0.31%). The lowest part of influence of variety on deformation energy (8.99%), and growing location on 1,000 kernel weight (1.84%) were determined. Significant influence of unaccounted factors on porosity of bread crumb (20.69%) and sedimentation value (13.37%) was noted.

There was established significant (≥ 5%) influence of the interaction of variety × year factors on most of grain quality indicators; variety × location on porosity of bread crumb and volume of bread; year × preceding crop on protein content; year × location on test weight and deformation energy; preceding crop × location on sedimentation value; year × preceding crop × location on protein content and wet gluten content. The parts of influence for interaction of other factors among themselves did not exceed 5%. The reliably significant influence of the interaction of factors variety × year × location with different parts of influence (3.60–11.38%) on the studied indicators of grain quality was noted. This indicates that genetic potential of varieties in terms of grain quality indicators is manifested differently in individual locations under certain growing conditions.

Table 7. The part of sum squares (%) for winter wheat grain quality indicators

Source of variation	TKW	TW	PC	SE	WGC	W	P	VB	PB
Variety (A)	9.63	38.32	18.55	15.02	25.65	8.99	20.55	30.22	18.17
Year (B)	11.14	8.71	9.86	9.99	8.05	6.31	0.48	0.90	4.87
Preceding crop (C)	4.79	0.11	6.86	5.68	2.32	1.79	0.05	0.47	0.34
Sowing date (D)	1.47	0.23	0.57	0.11^{ns}	1.19	0.31	0.29	0.87	2.66
Location (E)	1.84	3.84	13.07	0.00^{ns}	7.15	37.43	35.29	8.78	0.09^{ns}
A × B	6.66	2.52	7.98	5.47	6.68	4.13	7.87	12.79	3.20
A × C	1.46	0.63	0.51	0.48	0.43	4.81	4.47	3.87	4.49
A × D	0.45	0.23	0.44	1.38	1.20	0.71	0.35	0.99	1.57
A × E	1.92	4.12	2.15	1.31	1.95	4.97	4.72	7.43	9.14
B × C	0.27	0.98	5.85	1.96	3.21	0.03	0.12	0.41	0.02^{ns}
B × D	0.99	0.40	0.03^{ns}	0.49	0.65	0.20	0.61	0.61	0.01^{ns}
B × E	21.30	5.51	3.75	3.03	2.29	5.00	1.69	2.50	1.28
C × D	1.16	0.02^{ns}	0.01^{ns}	0.16	0.20	0.11	0.56	0.11	0.24
C × E	1.49	0.63	0.29	6.78	0.21	3.94	2.88	0.03	0.13^{ns}
D × E	0.18	0.30	0.20	0.31	0.04^{ns}	0.05	0.10	0.001	2.96
A × B × C	1.90	1.17	1.36	1.98	1.13	0.44	0.69	1.42	4.40
A × B × D	1.08	0.79	1.22	1.91	1.56	1.27	1.90	1.44	1.88
A × B × E	7.17	10.43	6.37	5.44	11.18	3.60	6.45	11.38	7.77
A × C × D	1.38	1.44	1.73	2.81	1.25	1.70	0.17	0.61	0.70
A × C × E	4.65	1.55	0.65	3.67	3.25	3.78	1.70	2.58	2.06
A × D × E	1.36	0.09^{ns}	0.26	1.54	0.36	1.43	0.78	1.18	0.90
B × C × D	1.55	0.75	0.05	0.17^{ns}	0.07	0.14	0.00^{ns}	0.29	0.23^{ns}
B × C × E	4.25	0.88	6.56	3.37	5.06	0.51	0.31	1.44	0.49
B × D × E	0.25	1.28	1.27	0.37	0.06^{ns}	0.21	0.49	0.26	0.83
C × D × E	0.49	0.43	0.72	1.71	0.14	0.19	1.05	1.37	0.12^{ns}
A × B × C × D	1.69	1.49	1.06	3.36	1.57	2.13	1.08	0.79	0.45
A × B × C × E	2.84	0.80	0.71	4.63	1.12	0.87	0.88	2.51	2.14
A × B × D × E	2.18	0.58	1.74	1.59	0.93	1.78	1.03	2.23	3.73
A × C × D × E	1.40	2.15	2.07	0.52	3.10	1.28	0.63	0.74	0.96
B × C × D × E	0.05	0.60	0.06	0.40	0.01^{ns}	0.03	0.07	0.67	1.84
A × B × C × D × E	1.50	1.74	1.11	1.00	0.95	1.64	0.73	1.04	1.65
Error	1.49	7.29	2.96	13.37	7.05	0.23	1.99	0.06	20.69

Gain quality indicators: TKW – 1,000 kernel weight; TW – test weight; PC – protein content; SE – sedimentation value; WGC – wet gluten content; W – deformation energy; P – dough tenacity; VB – volume of bread; PB – porosity of bread crumb; ns – insignificant effect.

Therefore, the results obtained indicate that the level of grain quality indicators more or less depends on variety, year conditions, growing location, preceding crop, sowing date and their interactions.

Zhou et al. (2021) have conducted a number of studies to establish the relationship between climatic factors and protein content in wheat grain. Many scientists consider weather factors to be the main factors in formation of grain quality. The flour-milling and baking properties of grain are more depend on air temperature and amount of precipitation that occurred during the period of grain formation and filling (Balla et al., 2011). Fluctuations in air temperature and variability in amount of precipitation are very dynamic and are in a complex relationship, so the influence of these factors on grain quality is considered in a complex manner (Tańska et al., 2018).

It should be noted that there is a small amount of papers on the identification of the influence of a wide range of factors on flour milling and baking properties of winter wheat grain. When analyzing the experimental data of other scientists, different parts of influence of various factors on grain quality indicators were revealed. Namely, some scientists established the largest part of the influence of year conditions on 1,000 kernel weight, test weight, protein content and sedimentation value (Parvej et al., 2020; Sasani et al., 2020; Twizerimana et al., 2020), but another scientists have found a determining part of influence for variety on these indicators (Zavadska & Baiba, 2019; Li, S. et al., 2021; Demydov et al., 2022). The maximum influence of the interaction of factors year × genotype on protein content, wet gluten content, rheological properties of dough, volume of bread and porosity of crumb was determined (Finlay et al., 2007; Denčić et al., 2011; Van der Laan et al., 2020). A number of studies indicate that the quality indicators of flour, dough and bread depend both on the hydrothermal conditions of the year and on varietal characteristics (Bagulho et al., 2015; Valde´s et al., 2020; Sobolewska et al., 2020). In this way, both similarities and differences in the influence of various factors on grain quality indicators were revealed. The difference in the obtained experimental data can be explained by the fact that the researches were conducted in different soil and climatic zones using other varieties of wheat. Also, different agrotechnical measures can affect the difference in the obtained results.

It should be noted that other factors such as pests, plant and soil diseases, daylight duration, carbon dioxide content in air, and others can affect the obtained results. However, we did not monitor these factors, which limits this study and may affect the final result.

CONCLUSIONS

A different influence of the hydrothermal growing season conditions in the growing locations on grain quality indicators was established. The most variability of deformation energy and the least variation of test weight were revealed. Varieties of winter wheat with weak and strong variation in grain quality indicators depending on the sowing dates after the preceding crops sunflower and soybean were identified.

The significant influence of variety on test weight, volume of bread, wet gluten content, protein content, porosity of bread crumb and sedimentation value was established. The constitutive influence of the growing location was revealed on deformation energy and dough tenacity. The decisive influence of the interaction of factors year × location on the formation of the 1,000 kernel weight was noted.

It has been experimentally proven that in order to obtain higher grain quality indicators, it is necessary to carefully choose sowing dates and preceding crops depending on growing location for each variety of winter wheat. However, both in the conditions of the central part of the Forest-Steppe of Ukraine and in the conditions of the northeastern part of the Forest-Steppe of Ukraine, in order to obtain higher flour-milling properties of grain, we recommend sowing these winter wheat varieties in the third decade of September (the I sowing date) after sunflower, while to obtain higher baking properties the varieties must be sown in the first decade of October (the II sowing date) after soybeans. The varieties Podolianka and MIP Yuvileina combine high flour-milling and bread-making properties, i.e. their grain is balanced in terms of quality.

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