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The influences of genotype, environment, and genotype × environment interaction on quality traits in common winter wheat.

2. Wet gluten yield and its quality

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Abstract: The experiment was carried out on the experimental field of the IPGR “K. Malkov”, Sadovo during the period 2019-2022. Thirty-eight varieties common winter wheat were studied. The assessment of the quality traits was carried out in a technological laboratory. The following quality characteristics were taken into account to characterize the grain: wet gluten yield,% (BDS EN ISO 21 415-2:2008); gluten release, mm (BDS ISO 13375); Bread making strong index by gluten realease; dry gluten content (DGC),%. Gluten release (GR), Bread making strong index (BMSI) and-dry gluten content (DGC) characterize the quality of wet gluten yield. The overall statistical assessment of the presence or absence of differences between the variants was determined using the ANOVA method (Dimova and Marinkov, 1999). To determine the stability index, the software product IPCSSVKYSI by Kang and Magari (1995) was used. The study aimed to analyze the influence of changes in climatic conditions and genotype on the WGY values and quality.

It was found that the influence of genotype, environment and their interaction were significant for both monitored traits. The influence of genotype was leading for gluten release and Bread making strong indexed the environment for wet gluten yield and dry gluten content had the greatest influence. The remaining factors have a significant influence on both traits. Combinations of high values and stability of the indicators for the study period characterize the varieties: Milena - for the traits wet gluten yield and dry gluten content, Kalina – for the trais GR and Bread making strong indexand Albena – for traits Bread making strong indexи DGC.

Key words: common winter wheat; quality; wet gluten yield, gluten release, dry gluten content, bread making strong index, stability

INTRODUCTION

Wheat is one of the most important staple food crops worldwide. The species common wheat (*Triticum aestivum* L.) is frequently used as a general designation encompassing numerous cultivated wheat species and genotypes (Shewry and Hey, 2016; Biesiekierski, 2017; Mattioni et al., 2024). The term “wheat quality” typically refers

to the grain’s processing quality, which largely depends on the composition and physicochemical characteristics of its storage proteins (Shewry and Halford, 2002; Islam et al., 2019).

Among all cereal crops, wheat is unique in its ability to yield flour that can independently form dough exhibiting the rheological properties required for breadmaking and for producing a wide range of bakery and pasta products. The excep-

tional functional properties of wheat grain are primarily attributed to the gluten-forming storage proteins located in the endosperm (Gianibelli et al., 2001; Lullien-Pellerin, 2024).

This major group of proteins is deposited within the cells of the starchy endosperm during grain development (Tosi, 2012; Peng et al., 2022). As development progresses, the protein bodies fuse, and the gluten proteins within an endosperm cell form a continuous matrix (Branlard et al., 2020). Their biological role during germination, through hydrolysis, is to support seedling growth and development. This function imposes certain structural constraints to ensure that these proteins are efficiently deposited, stored, and subsequently mobilized (Vedi et al., 2024; Shewry and Belton, 2024).

The assembly of the gluten protein complex is a complex, multi-step process that continues to be investigated, although the timing of its synthesis has been extensively studied (Shewry et al., 2009a; Koga et al., 2020; Scherf, 2023). These studies indicate that the precise timing varies depending on the plant's growth and developmental conditions. Gluten proteins accumulate during the grain-filling period, and differences in the rate and timing of accumulation among individual subunits are relatively small (Shewry and Belton, 2024).

It is widely accepted that both the growth and rearrangement of the gluten polymer occur during grain maturation. An increase in both the quantity and size of glutenin polymers has been observed throughout this stage (Shewry et al., 2009b; Koga et al., 2020; Shewry and Belton, 2024). Understanding where and how this polymerization occurs is of particular importance, as it is strongly influenced by environmental factors and, consequently, exerts a major impact on overall grain quality (Aussenac et al., 2020; Branlard et al., 2023; Shewry and Belton, 2024).

A large body of wheat gluten research has focused on its crucial role in determining the unique biomechanical properties of wheat dough—specifically, its combination of viscosity, extensibility, and elasticity—and how these properties, in turn, define its suitability for the production of

bread, pasta, and other processed foods (Scherf, 2023; Vedi et al., 2024). Gluten is a highly complex protein composite characterized by a high degree of allelic polymorphism, which encodes its specific protein fractions: glutenins and gliadins. Each wheat genotype produces unique types and quantities of these proteins, which may further vary depending on environmental growing conditions and technological processing factors (Kucek et al., 2015; Biesiekierski, 2017).

Linked through strong covalent and non-covalent interactions, individual gluten proteins and their structural organization collectively contribute to the distinctive rheological and functional properties of gluten. These characteristics are determined by the glutenin-to-gliadin ratio and the interactions between these molecular assemblies, thereby combining the functional advantages of both components (Shewry et al., 2003; Biesiekierski, 2017; Wang et al., 2023). Gluten proteins are among the most structurally complex protein aggregates found in nature. Their qualitative and quantitative composition is governed by genetic and environmental factors, as well as by the interactions between these determinants and the subsequent processing of grain into the final product (Scherf, 2023).

In agricultural practices, genotypes that maintain stable quality under varying environmental conditions are of particular importance. It has been established that grain quality traits—especially the content of storage proteins—are quantitatively inherited, as they are influenced by the genotype, the environment, and their interaction (Mutwali et al., 2018; Mahdavi et al., 2022; Tsenov et al., 2023).

The assessment of a variety's stability with respect to grain quality can be performed using any of the indices applied in the study. The stability of a cultivar largely depends on environmental effects, which must be considered when selecting an appropriate evaluation index. Among the most suitable indicators for this purpose are gluten and its quality parameters (Tsenov et al., 2023).

The aim of the present study is to evaluate the stability and adaptability of each wheat variety based on key quality indicators: wet gluten yield,

gluten deformation index, baking strength number, and dry gluten content, under the agro-climatic conditions of couth-central Bulgaria.

MATERIALS AND METHODS

The experiment was carried out on the experimental field of the IPGR “K. Malkov”, Sadovo during the period 2019-2022 (3 vegetations). The cultivation technology adopted at the institute was used. Thirty-eight varieties of common winter wheat were included, breded at the Dubrudzha Agricultural Institute, General Toshevo, obtained during the National Scientific Program “Healthy Foods for a Strong Bioeconomy and Quality of Life”. In the present study, the Enola variety (quality standard group B) was adopted as the standard variety. The assessment of the quality traits of common winter wheat was carried out in a technological laboratory. To characterize the grain from the studied materials, the following quality traits were taken into account during a tree-year study period: Wet gluten yield,% (BDS EN ISO 21 415-2:2008); Gluten release, mm (BDS ISO 13375); Bread making strong indexby gluten realease; Dry gluten content (DGC),%. Gluten release (GR), Bread making strong index (BMSI), and-Dry gluten (DGC) characterize the quality of wet gluten yield. The overall statistical assessment of the presence or absence of differences between the variants was determined using the ANOVA method (Dimova and Marinkov, 1999). The traits stability of the studied materials was assessed using the stability variances σ^2 according to Shukla (1972), the ecovalence W_i according to Wricke (1962) and the phenotypic stability criterion (Y_s) according to Kang (1993). To determine the stability index, the software product IPCSSVKYSI by Kang and Magari (1995) was used.

RESULTS AND DISCUSSION

Based on an analysis and synthesis of multi-year observations, Georgieva et al. (2022) report-

ed a persistent trend of increasing mean monthly temperatures, with the exception of December. Despite an increase in annual precipitation of up to 10–18%, the trend of prolonged dry periods remains. Deviations in precipitation during the pe-riod from April to June - when winter wheat veg-etation resumes and spring crops enter key de-velopmental stages - are negative. In Central and Northeastern Bulgaria, the observed reduction ranges between 10% and 15% (Tables 1 and 2).

The meteorological conditions under which the experiments were conducted varied and are discussed in detail in the first part of the article. Consistent with the previously observed trends, there is a tendency for higher-than-normal tem-peratures and lower precipitation in May, a criti-cal period for wheat development, including heading, flowering, and grain filling. The com-bination of these factors shortens the duration of these developmental phases.

Gluten proteins in wheat grain are primarily formed during the milk and waxy stages of grain development, corresponding to the grain-filling period (Fernie et al., 2022; Lama et al., 2023). Climate change-including higher temperatures, more frequent droughts, and extreme precipita-tion events-leads to unstable gluten quality, of-ten resulting in a higher protein content but lower technological functionality (Han et al, 2025).

Wet gluten can be defined as a “rubbery mass” representing the protein fraction that remains af-

Table 1. Average Monthly Temperature for the Period 2020–2022

Years/Months	III	IV	V	VI
2019/2020	8.9	11.8	18.2	21.6
Multi-year values (1991–2020)	7.6	13	17.9	22
Deviation	1.3	-1.2	+0.7	-0.4
2020/2021	5.8	10.9	18.5	22.3
Multi-year values (1991–2020)	7.6	13	17.9	22
Deviation	-1.8	-1.3	+0.6	+0.3
2021/2022	4.9	13.7	18.5	23.0
Multi-year values (1991–2020)	7.6	13	17.9	22
Deviation	-2.7	0.7	0.6	1.0

Table 2. Amount of precipitation for the period 2020 – 2022

Years/Months	III	IV	V	VI
Rainfall amount for the month of 2019/2020	91.5	93.8	40.1	45.9
Multi-year values (1991–2020)	47.8	46	53.1	58
Deviation	43.7	47.8	-13.0	-12.1
Rainfall amount for the month of 2020/2021	42.5	78.5	32.7	60.4
Multi-year values (1991–2020)	47.8	46	53.1	58
Deviation	-3.5	32.5	-20.4	+2.0
Rainfall amount for the month of 2020/2022	22.3	31	39.8	159.7
Multi-year values (1991–2020)	47.8	46	53.1	58
Deviation	-25.5	-15	-13.3	101.7

ter washing wheat dough to remove starch granules and water-soluble components. It is a combination of gliadin and glutenin, proteins responsible for dough elasticity and extensibility. Depending on the thoroughness of washing, the dry matter typically contains 75–85% protein and 5–10% lipids, with the remainder mainly consisting of starch and non-starch carbohydrates. In practice, the term “gluten” refers to these proteins, as they play a key role in determining the unique quality of wheat (Wieser, 2007).

The data obtained for wet gluten yield indicate that the mean values for the 16 studied varieties are significantly higher than those of the standard variety Enola (Table 3). In the first year, values ranged from 17.4% for the variety Lazarka to 26.5% for Bozhana and 25.0% for Neda. Twelve of the tested samples showed values lower than Enola.

In the second year, a substantial increase in wet gluten yield was observed, likely due to favorable meteorological conditions. Lower precipitation combined with higher temperatures contributed to higher protein formation. All varieties, except Merelin and Svilena, exceeded the 28% threshold for wet gluten content (WGC). The highest values were recorded for Korona (41.5%), Antonovka (39.6%) and Kristalina (39.6%).

In the third year of the study, the mean wet gluten content was 34.9%, with all varieties meeting the minimum requirement of 28% WGC. The highest yields were recorded for Katarzhina (39.2%) and Chiara (38.4%).

The variability of this trait was moderate during the first two years of the study ($CV \leq 10\%$) and low in the third year and overall for the three-year period ($CV \geq 10\%$) (Dimova and Marinkov, 1999) (Table 3).

The Gluten Release (GR) parameter characterizes the degree of elasticity and plasticity of the gluten network, formed during hydration and mechanical treatment of wheat flour. It is measured as the distance a wet gluten sample stretches under its own weight or under a standard load over a specified period.

For this parameter, 27 of the monitored varieties exhibited values significantly higher than the standard variety Enola. Mean values over the study period ranged from 3.2 to 15 mm, with the optimal range considered to be 7–12 mm. This interval reflects the degree to which the gluten network is sufficiently developed to provide resistance and gas-holding capacity without losing plasticity under mechanical stress and fermentation (Table 3).

Reported high values (12–20 mm) during the study period were associated with high wet gluten content (30–40%), indicating a gluten network that is both strong and plastic. A high gluten percentage provides a structural framework that prevents rupture, while high dough plasticity allows considerable extension under stress. In other words, this reflects a combination of high strength and high plasticity, manifested as significant release in manual or instrumental tests (e.g., Alveograph, Farinograph). Numerous stud-

Table 3. Variational analysis of the traits WGY and GR

№	Variety	WGY						GR					
		2020	2021	2022	$\bar{x}$	$\pm D$	Sig.	2020	2021	2022	$\bar{x}$	$\pm D$	Sig.
1	Enola – st.	20.2	36.0	34.0	30.1			3.5	3.5	8.0	5.0		
2	Kristalina	22.6	39.6	36.8	33.0	2.9	+++	5.5	8.5	16.0	10.0	5.0	+++
3	Nikodim	17.5	30.3	29.3	25.7	-4.4	---	6.0	5.5	4.0	5.2	0.2	n.s.
4	Todora	19.4	30.5	37.2	29.0	-1.0	--	4.5	8.5	12.0	8.3	3.3	+++
5	Bozhana	26.5	33.0	35.6	31.7	1.6	+++	4.5	6.0	3.5	4.7	-0.3	n.s.
6	Aglika	18.9	32.7	34.4	28.7	-1.4	---	2.0	4.0	4.5	3.5	-1.5	---
7	Stojana	22.0	35.3	35.0	30.8	0.7	+	3.0	8.0	7.0	6.0	1.0	+
8	Milena	22.9	37.2	36.8	32.3	2.2	+++	4.0	8.0	8.0	6.7	1.7	+++
9	Rada	23.1	32.5	32.1	29.2	-0.9	--	5.0	8.8	6.0	6.6	1.6	+++
10	Tina	18.9	34.7	32.2	28.6	-1.5	---	3.5	5.8	7.5	5.6	0.6	n.s.
11	Slaveja	18.6	30.3	31.4	26.8	-3.3	---	2.0	3.5	5.0	3.5	-1.5	---
12	Karat	17.9	34.2	36.8	29.6	-0.5	n.s.	6.5	13.5	9.0	9.7	4.7	+++
13	Kristi	19.2	35.9	30.9	28.7	-1.4	---	4.0	8.0	7.5	6.5	1.5	+++
14	Antonovka	19.6	39.6	33.0	30.7	0.6	n.s.	4.0	12.5	7.5	8.0	3.0	+++
15	Karina	20.4	37.5	33.8	30.6	0.5	n.s.	6.0	11.0	11.0	9.3	4.3	+++
16	Korona	22.2	41.5	36.8	33.5	3.4	+++	8.0	17.0	20.0	15.0	10.0	+++
17	Neda	25.0	36.0	36.4	32.4	2.4	+++	9.0	11.5	13.0	11.2	6.2	+++
18	Boljarka	23.2	34.1	35.2	30.8	0.7	+	2.5	11.0	11.8	8.4	3.4	+++
19	Zlatitsa	20.0	36.2	33.2	29.8	-0.3	n.s.	5.0	13.5	12.5	10.3	5.3	+++
20	Lazarka	17.4	34.8	33.0	28.4	-1.7	---	2.5	9.0	8.8	6.8	1.8	+++
21	Demetra	22.7	39.3	35.5	32.5	2.4	+++	4.0	7.0	9.0	6.7	1.7	+++
22	Lider	18.7	35.2	34.6	29.5	-0.6	n.s.	7.5	11.0	12.0	10.2	5.2	+++
23	Goritsa	24.4	36.8	34.2	31.8	1.7	+++	5.5	11.5	8.5	8.5	3.5	+++
24	Kosara	21.6	28.4	37.8	29.3	-0.8	-	16.8	6.5	11.5	11.6	6.6	+++
25	Laska	24.7	29.6	37.5	30.6	0.5	n.s.	8.0	7.0	8.5	7.8	2.8	+++
26	Merilin	23.2	25.7	36.8	28.6	-1.5	---	7.0	2.5	7.0	5.5	0.5	n.s.
27	Galateja	24.2	31.3	37.9	31.1	1.0	++	4.5	7.0	10.0	7.2	2.2	+++
28	Kami	19.6	34.5	32.0	28.7	-1.4	---	3.0	5.5	8.0	5.5	0.5	n.s.
29	Kalina	20.0	37.8	34.0	30.6	1.9	+++	2.5	6.0	7.0	5.2	1.7	+++
30	Katarzhina	19.2	39.0	39.2	32.5	2.4	+++	2.0	7.5	10.0	6.5	1.5	+++
31	Kiara	22.4	39.2	38.4	33.3	3.3	+++	2.5	7.0	9.0	6.2	1.2	++
32	Kristal	19.2	34.2	36.4	29.9	-0.2	n.s.	2.5	8.0	17.0	9.2	4.2	+++
33	Albena	22.9	36.0	34.8	31.2	1.1	++	4.5	7.0	7.5	6.3	1.3	+++
34	Dragana	21.7	35.9	34.9	30.8	0.7	+	4.0	6.0	11.5	7.2	2.2	+++
35	Iveta	19.9	37.3	36.0	31.1	1.0	++	1.0	3.5	6.5	3.7	-1.3	---
36	Pchelina	19.8	39.0	34.4	31.1	1.0	+++	2.0	3.0	4.5	3.2	-1.8	---
37	Sladuna	22.8	31.5	36.4	30.2	0.2	n.s.	8.0	4.0	9.0	7.0	2.0	+++
38	Svilena	20.0	26.4	31.6	26.0	-4.1	---	17.5	10.5	10.0	12.7	7.7	+++
Minimum		17.4	25.7	29.3	25.7			1.0	2.5	3.5	3.2		
Maximum		26.5	41.5	39.2	33.5			17.5	17.0	20.0	15.0		
Mean		21.1	34.7	34.9	30.2			5.1	7.8	9.2	7.4		
Std. Error		0.4	0.6	0.4	0.3			0.6	0.5	0.6	0.4		
Std. Deviation		2.3	3.8	2.3	1.9			3.5	3.3	3.5	2.7		
CV,%		10.8	10.8	6.6	6.1			68.7	42.3	38.3	35.9		
GD5%=0.68; GD1%=0.89; GD0.1%=1.14								GD5%=0.77; GD1%=1.02; GD0.1%=1.30					

+ -, + + -, + + + -- -, significant at GD 5.0 %, GD 1.0 % u GD 0.1 %; n.s. – non significant

ies confirm this (Xu et al., 2001; Edwards et al., 2003; Vidal et al., 2022). In a review on flour quality assessment using rheological methods, Yazar (2023) emphasized the importance of the parameters gluten release and dough strength as key quality traits.

Climate influences gluten release through long-term effects on grain structure, protein content, and protein composition. Warm and humid conditions favor more plastic dough with higher release, whereas cold and dry conditions lead to firmer dough with lower release.

In the food industry, particularly in bread and pastry production, gluten release is a key indicator of dough plasticity and elasticity.

In our study, the varieties Aglika, Slaveja, Iveta and Pchelina consistently showed very low values throughout the monitoring period, whereas Korona exhibited high values. The coefficient of variation (CV) was very high, ranging from 38.3% to 68.7%.

A high bread-making strong index is an indication of good gluten quality in flour. BMSI values were highest in the second year of the study, when high wet gluten content coincided with gluten release within optimal ranges. The numerical values of the maximum and minimum are close to those recorded in the last year of cultivation.

On average, over the study period, Bozhana and Pchelina achieved consistently higher results. In these varieties, the large amount of wet gluten is accompanied by low release, indicating that the gluten is very “strong” (release below 7 mm). This leads to increased elasticity but reduced plasticity, which makes it harder for the dough to expand during fermentation (Edwards et al., 2003), and accordingly, the BMSI values are high (Table 4).

Conversely, excessive extension above 12 mm is associated with a loss of gluten complex stability and a tendency to tear during shaping. The values obtained in this case are lower. The variation in this trait is similar to that reported by Dimova and Marinkov (1999).

Dry gluten content (DGC) represents the amount of gluten remaining after drying wet gluten. It is a concentrated form of wet gluten; high wet gluten usually corresponds to high dry glu-

ten, which is approximately 30% of the wet gluten content. The ratio of wet to dry gluten provides information on gluten’s water-holding capacity and is commonly used to compare flour quality, reflecting protein concentration (Kaushik et al., 2015; Schopf et al., 2021).

On average, eight varieties exhibited significantly higher dry gluten content over the study period. The varieties Kiara and Katarzhina achieved mean values of 11.25% and 11.04%, respectively. Climate influences dry gluten by affecting both the quantity and quality of grain proteins. Conditions favorable for high-quality dry gluten were recorded in the second and third years of the study, with similar values across these years. Variation differed between years: moderate in the first and second years (10.96% and 10.24%) and low in the third year (6.93%).

The influence of environmental factors, genotype, and their interaction on the quality traits studied was analyzed by ANOVA (Table 5). At significance levels $\alpha = 0.05$, 0.01 , and 0.001% , the effect of genotype was highly significant for all studied morphological traits. The effect of environment, genotype, and their interaction was statistically significant at $\alpha = 0.001$. Environmental influence was strongest for wet gluten yield (WGY) and dry gluten content (DGC), exceeding 80%. Genetic determination was strongest for gluten release (GR) and Bread making strong index (BMSI), with contributions of 46.9% and 47.4%, respectively.

Tsenov et al. (2023) reported that environmental conditions (climatic and agronomic) play a major role, particularly in gluten formation. Similarly, Kaya & Akcura (2014) found that the environment strongly affects grain quality traits, including protein and gluten content, as well as morphological and technological properties, highlighting the need for breeders to adapt selection goals to target environments.

A combined ANOVA conducted by Kedir and Letta (2022) showed highly significant differences ($P < 0.001$) between environments, genotypes, and their interactions across all quality traits. For gluten content, environmental effects were dominant. High variability in this trait was

Table 4. Variational analysis of the traits BMSI and DG

№	Variety	BMSI						DG					
		2020	2021	2022	$\bar{x}$	$\pm D$	Sig.	2020	2021	2022	$\bar{x}$	$\pm D$	Sig.
1	Enola – st.	57.0	91.0	66.3	71.4			7.80	12.24	11.48	10.51		
2	Kristalina	57.3	64.7	45.7	55.9	-15.6	---	7.74	12.97	12.14	10.95	0.44	+++
3	Nikodim	52.0	73.7	80.7	68.8	-2.7		5.99	10.16	9.74	8.63	-1.88	---
4	Todora	57.0	62.3	52.7	57.3	-14.1	---	6.60	9.77	12.12	9.50	-1.01	---
5	Bozhana	73.7	74.7	91.0	79.8	8.3	+++	8.75	11.12	11.99	10.62	0.11	n.s.
6	Aglika	57.0	79.7	90.0	75.6	4.1	n.s.	6.56	10.80	11.61	9.66	-0.85	---
7	Stojana	58.3	65.7	73.0	65.7	-5.8	-	7.65	11.20	11.11	9.99	-0.52	---
8	Milena	61.0	65.7	67.3	64.7	-6.8	--	7.98	12.17	12.42	10.86	0.35	+++
9	Rada	61.0	63.3	80.7	68.3	-3.1	n.s.	8.15	10.72	10.91	9.93	-0.58	---
10	Tina	57.0	82.0	68.0	69.0	-2.4	n.s.	6.66	11.79	12.86	10.44	-0.07	n.s.
11	Slaveja	57.0	82.3	86.0	75.1	3.7	n.s.	6.22	10.46	12.58	9.75	-0.75	---
12	Karat	50.0	49.0	62.3	53.8	-17.7	---	5.99	10.59	12.05	9.54	-0.96	---
13	Kristi	57.0	67.3	66.7	63.7	-7.8	---	6.53	11.75	10.28	9.52	-0.99	---
14	Antonovka	57.0	51.3	68.3	58.9	-12.6	---	6.96	12.87	11.21	10.35	-0.16	n.s.
15	Karina	52.0	55.3	55.0	54.1	-17.3	---	7.14	12.48	10.90	10.17	-0.33	--
16	Korona	46.7	44.3	41.7	44.2	-27.2	---	7.55	12.96	11.50	10.67	0.16	n.s.
17	Neda	50.3	54.0	50.0	51.4	-20.0	---	8.61	12.06	12.01	10.89	0.39	---
18	Boljarka	62.0	55.0	52.3	56.4	-15.0	---	8.06	11.33	11.97	10.45	-0.05	n.s.
19	Zlatitsa	56.0	46.7	51.0	51.2	-20.2	---	6.90	12.13	11.37	10.13	-0.37	---
20	Lazarka	57.0	62.3	61.7	60.3	-11.1	---	6.48	11.57	11.73	9.93	-0.58	---
21	Demetra	62.0	73.3	62.3	65.9	-5.6	-	7.89	12.47	11.44	10.60	0.09	n.s.
22	Lider	46.0	55.3	52.7	51.3	-20.1	---	6.57	11.70	11.66	9.98	-0.53	---
23	Goritsa	62.0	54.0	64.0	60.0	-11.4	---	8.53	11.88	11.80	10.74	0.23	+
24	Kosara	33.0	67.7	54.0	51.6	-19.9	---	7.00	9.69	12.85	9.85	-0.66	---
25	Laska	53.3	67.0	64.7	61.7	-9.8	---	8.57	9.83	12.85	10.42	-0.09	n.s.
26	Merilin	52.0	69.0	74.0	65.0	-6.4	--	7.77	8.99	12.60	9.79	-0.72	---
27	Galateja	65.0	69.3	58.3	64.2	-7.2	--	8.49	10.71	12.89	10.70	0.19	n.s.
28	Kami	57.0	86.0	65.3	69.4	-2.0	n.s.	6.52	11.57	10.48	9.52	-0.98	---
29	Kalina	57.0	81.3	72.3	70.2	-5.3	-	6.90	12.57	11.65	10.37	0.72	+++
30	Katarzhina	57.0	70.0	58.3	61.8	-9.7	---	6.82	12.97	13.33	11.04	0.53	+++
31	Kiara	59.0	73.3	62.3	64.9	-6.6	--	7.62	13.13	13.01	11.25	0.75	+++
32	Kristal	57.0	66.7	44.3	56.0	-15.4	---	6.44	11.61	12.37	10.14	-0.37	---
33	Albena	62.0	73.3	69.7	68.3	-3.1	n.s.	8.01	12.24	12.00	10.75	0.24	++
34	Dragana	58.3	81.3	53.7	64.4	-7.0	--	7.66	12.20	11.60	10.49	-0.02	n.s.
35	Iveta	57.0	91.0	77.0	75.0	3.6	n.s.	6.77	12.49	12.44	10.57	0.06	n.s.
36	Pchelina	57.0	91.0	90.0	79.3	7.9	+++	6.99	13.54	11.77	10.77	0.26	++
37	Sladuna	50.0	86.7	62.3	66.3	-5.1	-	8.04	11.11	12.38	10.51	0.00	n.s.
38	Svilena	32.7	49.7	56.7	46.3	-25.1	---	6.45	8.63	10.35	8.48	-2.03	---
Minimum		32.7	44.3	41.7	44.2			5.99	8.63	9.74	8.48		
Maximum		73.7	91.0	91.0	79.8			8.75	13.54	13.33	11.25		
Mean		55.6	68.3	64.5	62.8			7.30	11.54	11.83	10.22		
Std. Error		1.2	2.1	2.1	1.4			0.13	0.19	0.13	0.10		
Std. Deviation		7.4	13.1	12.8	8.8			0.80	1.18	0.82	0.61		
CV,%		13.3	19.1	19.8	14.0			10.96	10.24	6.93	6.00		
GD5%=4.44; GD1%=5.85; GD0.1%=7.51								GD5%=0.20; GD1%=0.26; GD0.1%=0.34					

+ -, + + -, + + + --, significant at GD 5.0 %, GD 1.0 % u GD 0.1 %; n.s. – non significant

largely attributable to environmental conditions, while genotype effects were smaller. This indicates that both the genotype and its response to the environment are important—a variety may exhibit high gluten content in one environment but not in another.

Based on the demonstrated influence of the sources of variation—genotype, environment, and their interaction—stability parameters were evaluated for the studied traits (Tables 6 and 7). The results indicate that the highest stability for wet gluten yield (Table 6), according to σ_i^2 and W_i^2 , was observed in the varieties Stoyana, Milena, Dragana, and Aglika. Conversely, Merilin, Kosara, and Laska were identified as unstable. According to Kang's KR criterion, which combines high stability and high trait values over the study period, Dragana,

Milena, and Kiara emerged as the most valuable varieties.

For gluten release, high stability was observed in Neda, Tina, Lider, and Kalina. In contrast, the genotypes Kosara, Svilena, and Kristal showed strong fluctuations in trait values over the study period, indicating instability. According to Kang's criterion, the best combination of stability and high trait values was observed in Kalina, Neda, and Demetra.

The calculated stability indices σ_i^2 and W_i^2 for BMSI (Table 7) indicated the highest stability in the varieties Albena, Laska, and Kristi, while Pchelina, Sladuna, and the standard Enola were classified as unstable. According to the KR criterion, Albena, Kalina, and Tina combined both stability and high trait values, making them the most valuable for practical purposes.

Table 5. Anova- influence of sources of variation

Traits	Source of Variation	SS	df	MS	F exp.	F tabl.	$\eta, \%$	sig.
WGY	Envirpmental A	14235.4	2	7117.7	40352.8	7.1	83.6	***
	Genotype B	1150.2	37	31.1	176.2	2.0	6.8	***
	Interaction/ A x B	1594.4	74	21.5	122.2	1.7	9.4	***
	Within	40.2	228	0.2			0.2	
	Total	17020.3	341				100	
GR	Envirpmental A	988.5	2	494.2	2153.2	7.1	19.8	***
	Genotype B	2345.6	37	63.4	276.2	2.0	46.9	***
	Interaction/ A x B	1611.1	74	21.8	94.9	1.7	32.2	***
	Within	52.3	228	0.2			1.0	
	Total	4997.6	341				100	
BMSI	Envirpmental A	9694.7	2	4847.3	636.1	7.1	17.8	***
	Genotype B	25851.5	37	698.7	91.7	2.0	47.4	***
	Interaction/ A x B	17233.3	74	232.9	30.6	1.7	31.6	***
	Within	1737.3	228	7.6			3.2	
	Total	54516.8	341				100	
DGC	Envirpmental A	1465.6	2	732.8	47329.5	7.1	82.8	***
	Genotype B	125.4	37	3.4	218.8	2.0	7.1	***
	Interaction/ A x B	175.2	74	2.4	152.9	1.7	9.9	***
	Within	3.5	228	0.0			0.2	
	Total	1769.7	341				100	

SS - sum of squares; gf - degrees of freedom; MS - variance; F exp. - F experimental; F tab. - F tabular; η - force of influence of the factor (%); *** - significant at $\alpha = 0.001$

Table 6. Stability parameters for WGY and GR

№	Variety	WGY				GR			
		$\bar{x}$	σ^2_i	W_i^2	KR	$\bar{x}$	σ^2_i	W_i^2	KR
1	Enola – st.	30.1	1.5	3.2	30	5.0	2.9	5.8	51
2	Kristalina	33.0	3.4	6.9	20	10.0	13.7	26.3	41
3	Nikodim	25.7	0.9	2.0	45	5.2	9.6	18.5	60
4	Todora	29.0	11.2	21.6	59	8.3	2.9	6.0	32
5	Bozhana	31.7	13.5	26.0	41	4.7	7.2	14.1	60
6	Aglika	28.7	0.7	1.8	35	3.5	0.5	1.3	46
7	Stojana	30.8	0.0	0.3	18	6.0	1.7	3.6	44
8	Milena	32.3	0.0	0.3	8	6.7	0.4	1.2	29
9	Rada	29.2	7.0	13.6	53	6.6	4.7	9.3	45
10	Tina	28.6	2.0	4.1	44	5.6	-0.1	0.1	30
11	Slaveja	26.8	0.7	1.8	41	3.5	0.3	0.9	8
12	Karat	29.6	6.7	13.1	49	9.7	9.5	18.3	36
13	Kristi	28.7	7.0	13.7	26	6.5	0.7	1.8	36
14	Antonovka	30.7	15.2	29.1	52	8.0	12.8	24.7	46
15	Karina	30.6	4.7	9.2	42	9.3	1.2	2.6	24
16	Korona	33.5	9.9	19.1	30	15.0	18.2	34.9	36
17	Neda	32.5	2.0	4.1	17	11.2	-0.2	0.0	5
18	Boljarka	30.8	1.8	3.8	24	8.4	10.5	20.3	42
19	Zlatitsa	29.8	2.9	5.8	39	10.3	8.7	16.8	32
20	Lazarka	28.4	3.6	7.3	53	6.8	3.6	7.2	39
21	Demetra	32.5	4.4	8.7	25	6.7	0.0	0.4	5
22	Lider	29.5	2.2	4.5	39	10.2	0.0	0.3	9
23	Goritsa	31.8	4.2	8.4	28	8.5	5.2	10.3	36
24	Kosara	29.3	23.9	45.6	64	11.6	47.5	90.4	41
25	Laska	30.6	23.7	45.3	54	7.8	4.5	8.9	37
26	Merilin	28.6	42.4	80.7	72	5.5	13.7	26.3	62
27	Galateja	31.1	14.4	27.7	45	7.2	0.6	1.6	27
28	Kami	28.7	1.7	3.6	39	5.5	0.2	0.7	7
29	Kalina	30.6	5.7	11.2	23	5.2	0.0	0.3	4
30	Katarzhina	32.5	13.4	25.7	31	6.5	4.1	8.1	21
31	Kiara	33.3	2.6	5.4	16	6.2	1.4	3.1	42
32	Kristal	29.9	2.9	5.9	39	9.2	30.5	58.2	46
33	Albena	31.2	0.8	1.9	16	6.3	0.1	0.7	31
34	Dragana	30.8	0.2	0.7	3	7.2	5.0	9.8	24
35	Iveta	31.1	3.7	7.4	31	3.7	0.6	1.6	47
36	Pchelina	31.1	9.5	18.4	28	3.2	0.8	1.8	52
37	Sladuna	30.2	7.9	15.4	48	7.0	11.8	22.7	49
38	Svilena	26.0	14.2	27.2	70	12.7	40.7	77.5	39

σ^2_i – Shukla's stability variance; W_i^2 – Wricke's ecovalence; KR – Kang's rank-sum;

For dry gluten content, the varieties Milena, Aglika, and Albena were identified as the most stable. Moreover, Milena and Albena exhibited both high trait values and stability ac-

cording to Kang's phenotypic criterion, with Lazarka also showing high trait values. Instability for dry gluten was observed in Svilena and Merlin.

Table 7. Stability parameters by BMSI and DG

№	Variety	BMSI				DG			
		$\bar{x}$	σ^2_i	W_i^2	KR	$\bar{x}$	σ^2_i	W_i^2	KR
1	Enola – st.	71.4	154.6	297.1	42	10.51	0.31	0.62	25
2	Kristalina	55.9	117.5	226.8	57	10.95	0.37	0.75	16
3	Nikodim	68.8	101.4	196.3	32	8.63	0.17	0.37	41
4	Todora	57.3	44.1	87.7	42	9.50	1.10	2.12	65
5	Bozhana	79.8	105.3	203.6	24	10.62	0.94	1.83	38
6	Aglika	75.6	152.4	292.9	38	9.66	0.07	0.18	34
7	Stojana	65.7	30.3	61.5	27	9.99	0.29	0.59	34
8	Milena	64.7	15.4	33.3	25	10.86	-0.02	0.00	6
9	Rada	68.3	116.3	224.5	37	9.93	1.02	1.98	55
10	Tina	69.0	43.6	86.7	23	10.44	0.72	1.40	41
11	Slaveja	75.1	106.6	206.1	28	9.75	1.16	2.24	63
12	Karat	53.8	84.2	163.7	52	9.54	0.65	1.28	55
13	Kristi	63.7	0.8	5.5	24	9.52	0.80	1.55	59
14	Antonovka	58.9	134.4	258.8	58	10.35	1.15	2.22	51
15	Karina	54.1	21.7	45.2	41	10.17	0.91	1.76	48
16	Korona	44.2	72.3	141.0	57	10.67	0.82	1.59	35
17	Neda	51.4	27.0	55.3	45	10.89	0.33	0.67	15
18	Boljarka	56.4	127.3	245.2	58	10.45	0.23	0.48	25
19	Zlatitsa	51.2	128.6	247.7	67	10.13	0.34	0.69	36
20	Lazarka	60.3	12.4	27.6	29	9.93	0.20	0.42	7
21	Demetra	65.9	20.4	42.7	23	10.60	0.47	0.94	29
22	Lider	51.3	1.0	6.0	39	9.98	0.19	0.41	31
23	Goritsa	60.0	115.1	222.1	50	10.74	0.42	0.84	23
24	Kosara	51.6	126.0	242.8	62	9.85	2.16	4.13	65
25	Laska	61.7	-0.5	3.1	25	10.42	2.86	5.47	56
26	Merilin	65.0	44.8	89.0	32	9.79	3.54	6.75	68
27	Galateja	64.2	62.3	122.1	38	10.70	1.33	2.56	43
28	Kami	69.4	95.0	184.0	29	9.52	0.48	0.96	52
29	Kalina	70.2	33.5	67.5	20	10.37	0.60	1.19	40
30	Katarzhina	61.8	19.1	40.2	30	11.04	1.31	2.53	35
31	Kiara	64.9	13.0	28.7	23	11.25	0.42	0.84	17
32	Kristal	56.0	142.6	274.2	62	10.14	0.51	1.02	42
33	Albena	68.3	-1.5	1.2	1	10.75	0.08	0.19	10
34	Dragana	64.4	148.4	285.3	53	10.49	0.19	0.41	22
35	Iveta	75.0	117.6	227.0	33	10.57	0.61	1.20	34
36	Pchelina	79.3	181.1	347.2	40	10.77	1.67	3.21	41
37	Sladuna	66.3	175.9	337.5	50	10.51	0.39	0.79	28
38	Svilena	46.4	61.6	120.8	54	8.48	1.15	2.23	69

σ^2_i – Shukla's stability variance; W_i^2 – Wricke's ecovalence; KR – Kang's rank-sum;

CONCLUSIONS

Under the conditions of Sadovo, south-central Bulgaria:

During the study period 92% of the genotypes had average DMG values above 28%, with the highest content recorded in the varieties Kristalina and Korona.

Average gluten release ranged from 3.2 to 15.0 mm, with BMSI values between 44.2 and 79.8 by GR (arbitrary units-a.u.).

Dry gluten content varied from 8.48 to 11.25%.

Determining these parameter values, as well as their ratios, can serve as a criterion for assessing flour quality and, indirectly the content and functionality of the proteins in it.

The influence of environment, genotype, and their interaction is statistically proven.

Traits GR and BMSI are most strongly influenced by genotype, while WGY and DGC are influenced by annual environmental conditions.

Climate changes (higher temperatures, more frequent droughts, and sudden rainfall) lead to unstable gluten quality - often resulting in a higher protein percentage but with lower technological quality.

Combinations of high values and stability of traits during the study period were observed in the following varieties:

Milena – for WGY and DGC

Kalina – for GR and BMSI

Albena – for BMSI and DGC

In breeding and introducing varieties attention should be paid to the stability of quality traits (not only yield) and adaptation to the local environment.

To achieve high and stable wet gluten content in wheat. It is necessary to combine a suitable genotype (variety with good quality) with a suitable growing environment and agronomic practices. This means: Testing varieties in different locations. Optimizing agronomic practices to achieve high grain quality and considering the effects of the environment (soil, climate, stress conditions).

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