Bulgarian Journal of Agricultural Science, 32 (No 1) 2026, 94–99

Characteristics of technological properties of grain and flour of Bulgarian winter common wheat varieties

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Abstract

Doneva, S. (2026). Characteristics of technological properties of grain and flour of Bulgarian winter common wheat varieties. *Bulg. J. Agric. Sci., 32*(1), 94–99

The present research aims to evaluate the technological qualities of Bulgarian varieties of winter common wheat, developed at the Dobrudzha Agricultural Institute (DAI). The level of variation and adaptability to the change of climatic conditions, as well as the optimal combination of the quality indicators of the different genotypes, were analyzed.Twenty-six varieties were studied in a randomized balanced block experiment in four replications for the 2020–2022 period. The technological properties of grain and flour – sedimentation (ml), wet gluten content (%), bread loaf (cm^3), farinograph quality number, dough resistance, degree of softening (fu), test weight, shape stability (H:D), quality of bread medium, and vitreousness (%) were evaluated. To analyze the variation in the individual quality indicators in order to evaluate their optimal combination, dispersion analysis and the simplex method were applied. The obtained results show that the influence of the climatic conditions was established with the highest degree of statistical reliability in the indicators of wet gluten content and vitreous. The influence of the genotype was established with the highest degree of statistical reliability in the indicators of sedimentation, quality number, and stability of the dough. The interaction of genotype x environmental conditions in the technological indicators of sedimentation, wet gluten, vitreous, bread loaf, and coefficient of shape stability was statistically proven. The results obtained from the applied simplex method show that the winter common wheat varieties Pchelina, Lazarka, Merilin, Bojana, Dragana, Kalina, and Rada come close to the optimal combination of quality indicators and are a high achievement of the Bulgarian breeding selection regarding grain quality. In individual years, these varieties show higher, and in others, lower values for some of their technological indicators, which is explained by their reaction to different environmental conditions. The evaluation of the ecological plasticity and stability of the investigated genotypes will find application in the economic activity of farmers, giving them the opportunity to select the most suitable varieties with great potential for productivity and quality according to the relevant agro-ecological conditions.

Keywords: wheat; genotype-year interaction; bread-making quality; rheology

Introduction

In recent years, agriculture worldwide has faced the increasing trend of extreme deviations from agro-climatic norms. This reflects negatively on the adaptive potential and leads to a decrease in the yield and grain quality of modern wheat varieties (Atanasova et al., 2012; Morgounov et al., 2014). Measurements of the sum of the effective temperatures show an alternation of warm and cold periods with a clearly defined tendency towards an uneven distribution of the amount of precipitation and high temperature amplitudes during the growing season (Penchev and Petrova, 2018; Shivalal et al., 2024). Under these conditions, the cultivation of common wheat requires the development of new selection approaches for sustainable production of quality grain (Tsenov et al., 2023). It has been proven that the quality potential of bread wheat is a complex quantity influenced by various factors (Atanasova et al., 2008; Lachutta and Jankowski, 2024). It can be defined as an interaction between the storage proteins in the endosperm (glutenins and gliadins) with environmental factors (Doneva, 2017), which reflects on the physical qualities of the grain and the rheological and bakery indicators of the varieties (Mangova and Rachovska, 2004; Panayotov and Atanasova, 2004; Stoeva and Ivanova, 2009; Zecevic, 2013, Chamurliyski et al., 2016; Alemu and Gerenfes, 2021). One of the most important directions in the breeding program of Bulgaria is the development of bread wheat varieties, well adapted to local agrometeorological conditions with great potential possibilities of productivity and quality (Stoeva, 2012; Stoeva and Penchev, 2013; Dochev, 2021). Although a negative correlative relationship has been proven between the two quantities, the varieties of winter common wheat created in DAI in the period 2003-2020 combine grain quality with relatively high and stable productive capabilities, with yields ranging from 6500 to 8500 kg/ha (Panayotov et al., 2004; Raykov et al., 2016). The hereditary basis of the quality of a large part of the wheat varieties included in this study was confirmed by applying the electrophoresis of the high- and low-molecular weight glutenins and gliadins, on which the viscoelastic and rheological properties of bread dough mainly depend (Todorov, 2006; Belcar et al., 2020). A significant increase in the proportion of HMW subunits associated with high quality was found – ‘1’ and ‘2*’ in the Glu-A1 locus, ‘7+8’ in the Glu-B1 locus, and ‘5+10’ in the Glu-D1 locus, leading to an increase in the score values in the three HMW loci. At LMW, the share of varieties with the Glu-A3c allele, which determines high quality, increases. The unfavorable influence of the rye translocation – 1BL/1RS (Glu-B3j) on the baking qualities is compensated by a significant increase in the share of the associated high-quality score alleles – Glu-B3b and Glu-D3c. Gliadins of the Gli-1 group are characterized by a high level of genetic polymorphism and predominant expression of the high-quality ‘b’ allele at the three gliadin loci (Gli-A1, Gli-B1, Gli-D1) (Doneva et al., 2019), which was inherited from Bezostaya 1, or lines derived from this cultivar.

The aim of this article is an analysis of the level of variation and adaptability to changing climatic conditions in combination with an optimal combination of the quality indicators of 26 genotypes of winter common wheat, developed during the period 2003–2020 in DAI – G. Toshevo.

Materials and Methods

The study covers three years: the 2020, 2021, and 2022 seasons. Twenty-six Bulgarian varieties of winter common wheat, belonging to different quality groups, which are characterized by ecological plasticity, resistance to the most common diseases, high yield potential, and very good grain quality, were studied. The varieties Pchelina, Merilin, Lazarka, Moresa, Aglika, Iveta, and Gorica belong to the group of high-quality wheats (quality group A). The varieties Shibil, Enola, Fani, Dragana, Bojana, Rada, Kosara, Nikodim, Zhana, Kami, Katarzhina, Kalina, Korona, Stoyana, Sladuna, Kristalina, Karina, Kristi, and Kiara belong to the group of medium-strength wheats with increased qualitative strength (quality group B).

The indicated genotypes were studied in a randomized balanced block experiment with four replications.

The grain samples of the wheat varieties were ground to 70% flour with an MLU-202 mill. Evaluated:

- technological indicators – test weight, TW (kg); virtuosity, G (%); wet gluten in 70% flour, WG (%) (Bulgarian State Standard 13375-88); sedimentation volume, SED (ml) (Pumpyanskiy, 1971)
- the rheological properties of the dough, determined with the „Brabender“ farinograph – dough resistance, R (min.); degree of softening, DS (FU); quality number from the farinograph, QN (conditional unit).
- the bread-making qualities established by a routine bread-making method – loaf volume (cm^3), LV; coefficient of dimensional stability /loaf relation height: diameter (H:D), and quality of the bread medium. (Stoeva, 2000; Stoeva and Penchev, 2005; Stoeva, 2012).

The following analysis of variance model was applied to analyze the change in individual indicators:

$$Yijk = Y.. + Gi + Cj + (GC)ij + Eijk,$$

where Gi is the factor genotype, Cj is the factor climatic conditions, and Eijk is the error of the experiment (Cornelius and Crossa, 1999).

The assessment of the optimal combination of quality indicators was made by linear optimization (simplex method).

The data were processed with the statistical packages SPSS 21.0 and Biostat 6.0.

Results and Discussion

The study period is characterized by diverse meteorological conditions (Table 1). A mild winter and persistent drought in the 2020 crop year have a negative impact on the hardening of winter common wheat varieties. The precipitation in the spring compensates for the low autumn-winter moisture supply and contributes to the normalization of the vegetation of the cereal crop. In the 2021 crop year, two main trends stand out – lower average daily temperatures in November – December and more precipitation in the autumn – winter period. Low average temperatures and large amplitudes suppress the growth and development of wheat. Rainfall in April is the main factor for the accumulation of vegetative mass and the formation of the productivity of the varieties. The 2022 crop year is characterized by an extremely insufficient amount of precipitation in the autumn-winter period and deepening drought until reaching economic maturity, high average daily and absolute maximum temperatures during the winter months (17.5 °C), return frosts at the onset of the spindle phase, and intense amounts of rainfall at waxy maturity.

The results of the variance analysis are presented in Table 2.

The applied F-criterion (Table 2) proves that the genotype of the analyzed varieties has an influence on all the investigated quality indicators, with the highest degree of statistical significance found in: sedimentation volume, quality number from the farinograph, and dough resistance. For the indicators hectoliter and bread volume, the proof is at p=0.01. With regard to wet gluten, glassiness, degree of softening, dimensional stability, and quality of the bread medium, the reliability is at p = 0.05.

Analysis of variance shows well the differences in the phenotypic expression of the quality indicators depending on variety, year, and the interaction of variety x year. In the 2020 and 2021 harvest years, the analyzed genotypes are characterized by a critically low level of the indicator ‚wet gluten content in 70% flour‘, which reflects negatively on the rheological characteristics of the dough, without significantly affecting the bakery properties. A similar trend has been established for several years in the newly selected varieties. Some authors explain it with the different goals of breeding programs, which in recent decades have been aimed more at improving farinographic parameters, at the expense of increasing the amount of wet gluten (Stoeva and Penchev, 2013; Ivanova et al., 2013; Tsenov et al., 2023). Another probable reason for the observed phenomenon is the occurrence of minor intravarietal heterogeneity in the gluten proteins of individual wheat varieties, causing a decrease in the level of the discussed indicators (Todorov, 2006).

Meteorological conditions of the year influence with the highest degree of statistical reliability on the indicators wet gluten and vitreousness. They also have a significant impact

Table 1. Average monthly temperature (AMT) and total monthly precipitation (TMP) during the period of study

Parameter	Crop year	Sep	Oct	Noe	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
AMT, ºC	2020	17.9	13.4	11.7	5.2	1.8	5.1	8.0	10.0	15.4	19.6	22.3
	2021	19.4	15.3	6.3	5.3	3.0	4.0	4.2	8.8	15.8	18.9	22.8
	2022	16.6	10.2	8.3	4.0	1.6	4.3	2.8	8.8	16.0	20.6	20.3
TMP, mm	2020	36.7	27.6	35.4	21.8	2.8	28.1	28.3	5.8	48.0	192.2	2.7
	2021	34.1	52.9	26.0	74.4	109.7	13.2	22.2	44.6	63.6	162.7	29.7
	2022	2,2	89.2	16.0	86.5	23.7	20.7	31.6	44.6	21.2	77.2	5.8

Source: Author‘s own elaboration

Table 2. Analysis of variance (MS) of the investigated indicators

Indicators	MS G[1]	MS C[2]	MS GxC	MS error	F
Sedimentation volume, SED (ml)	1240.1***	325.1*	472.4*	67.8	18.3***
Wet gluten in 70% flour, WG (%)	28.6*	348.5***	37.5*	10.7	2.7*
test weight, TW (kg)	16.4**	12.8 *	6.9	2.6	6.3**
Quality number, QN (con. unit)	725.8***	224.9**	94.3	25.6	28.4***
Vitreousness, (%)	761.2*	2128.7***	822.6*	106.5	7.1*
Dough resistance, R (min)	21.8***	3.2	5.7	1.7	12.8***
Degree of softening, DS (FU)	3875.6*	7384.2**	1352.9	466.4	8.3*
Loaf volume, LV (cm^3)	20524.1**	27655.4 **	14662.2*	1627.1	12.6**
Coefficient of shape stability, H:D	1.7*	0.9*	1.1*	0.2	8.5*
Quality of bread medium (0-5 points)	0.72*	0.84**	0.32	0.1	7.2*
df	25	2	50	185	

* – significant at P = 0,05 , ** –significant at P=0,01 , *** – significant at P=0,001, [1]G –Genotype, [2]C – Environments

Source: Author‘s own elaboration

on the quality number, degrees of softening, the loaf volume, and the quality of the bread medium (at p = 0.01 of the alternative hypothesis). The sedimentation volume, the hectolitre weight, and the coefficient of shape stability of the bread depend less on the environmental changes during the investigated crop years (at p = 0.05 of the alternative hypothesis), while the influence of the climate conditions of the year on the dough resistance indicator has not been statistically proven.

According to Yan and Hunt (2001) and Dhungana et al. (2007), elucidating the interaction with genotype and environmental conditions is very important for each stage of the cultivation of wheat cultivars and makes it possible to identify the ideal agro-climatic conditions for their optimal adaptation. In the present study, тhe interaction genotype x environmental conditions of the year has effects on the parameters: sedimentation volume, wet gluten, vitreousness , loaf volume, and H: D (at p = 0.05 of the alternative hypothesis). On hectolitre weight, quality number, dough resistance, degree of softening, and quality of bread medium, this mutual influence was not statistically proven.

Multiple linear regression analysis was applied to determine the optimal combination of the quality indicators of the studied varieties. The goal is to find the objective function for optimization, as well as the system of linear equations, making it possible to apply the simplex method (linear optimization). The main indicator determining the bread-making qualities of the wheat variety is „bread volume," and it is the basis of the formation of the objective function, having the following form:

$$Z = 1246.9 - 0.4X1 - 0.2X2 + 0.4X3 + 0.2X4 - 0.01X5 + 0.05X6 + 0.55X7 + 0.18X8$$

The system of constraint conditions of the simplex method has the form:

$$
\begin{aligned}
& -0.6X2 - 1.5X3 + 0.23X4 + 1.32X5 + 0.05X6 + 0.55X7 + 0.5X8 < 83 \\
& -0.03X1 - 0.92X3 + 0.58X4 + 0.84X5 - 0.45X6 + 0.4X7 + 0.41X8 < 80 \\
& -0.3X1 - 0.27X2 + 0.21X4 + 0.81X5 - 0.15X6 + 0.37X7 + 0.35X8 < 70 \\
& X1 - 0.22X2 + 1.14X3 - 0.93X5 + 0.37X6 - 0.47X7 - 0.29X8 < 40 \\
& 0.14X1 + 0.29X2 + X3 - 0.22X4 + 0.13X6 - 0.27X7 - 0.22X8 < 8 \\
& -0.9X1 + 0.06X2 - 0.96X3 + 0.4X4 + 0.67X5 + 0.7X7 + 0.61X8 < 80 \\
& 0.45X1 + 0.33X2 + 1.3X3 - 0.3X4 - 0.74X5 - 0.41X6 - 0.31X8 < 0.5 \\
& 0.43X1 - 0.22X2 + 0.85X3 + 0.6X4 + 0.58X5 - 1.12X6 + 0.31X7 < 5.0
\end{aligned}
$$

where X1 is the indicator of hectolitre weight, X2 – vitreousness, X3 – sedimentation volume, X4 – wet gluten content, X5 – dough resistance, X6 – quality number, X7 – H: D, and X8 – quality of bread medium.

The solution of the linear optimization problem is Zmax = 695, which is obtained at the following values of the individual indicators: X1 = 79.2, X2 = 43.7, X3 = 67.8, X4 = 31.5, X5 = 6.5, X6 = 82.6, X7 = 0.47, and X8 = 4.8.

Using the obtained optimal model of the high-quality wheat variety, wheat varieties with average values of technological, rheological, and bakery parameters corresponding to the condition for optimal combination of quality indicators were selected from the studied genotypes (Table 3).

The technological, rheological and baking qualities of the selected varieties Pchelina, Lazarka, Marilyn, Bojana, Dragana, Kalina and Rada are of high mean values (Table 2). The sedimentation volume is in the range of 62 to 80 ml. The amount of wet gluten varies from 27.0 to 30.5%, and its quality is related to excellent extensibility and gas-forming ability. An indicator of this is the dough resistance data (from 5 to 10 min) and the quality number from the farinograph (from 55 to 96 FU). The specified rheological parameters of the dough determine the large loaf volume, from 660 to 740 cm^3, and the excellent quality of the bread medium, including its color, fineness, and evenness of the pores.

The electrophoretic analysis by SDS-PAGE of HMW- and LMW- glutenin subunits (Doneva et al., 2019) showed an allelic composition of 2* (GluA1), 7+8 (GluB1), 5+10

Table 3. Selected quality genotypes by their mean values according to the optimal model of the high quality variety

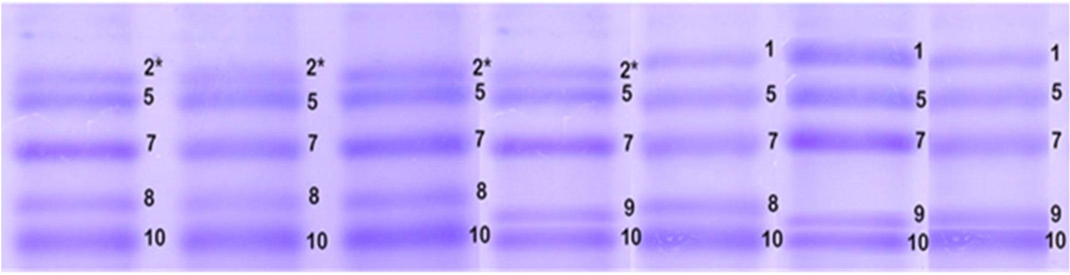
Quality indicators	Pchelina	Lazarka	Merilin	Bojana	Dragana	Kalina	Rada	Optimal values
Hectolitre weight, (kg)	79	81.2	79.4	81.9	84.5	79.3	80.1	79.2
Vitreousness, (%)	25	51	45	47	43	50	40	43.7
Sedimentation volume, (ml)	80	69	74.5	71.5	65	62	67	67.8
Wet gluten in 70% flour, (%)	27.4	27.8	28.6	28	30.5	30	27	31.5
Dough resistance, (min)	7.1	7.5	10.0	5.0	5.4	6.9	6.2	6.5
Quality number, (con. unit)	96	67.2	87.4	75	58	60	55	82.6
Coefficient of shape stability, H: D	0.52	0.52	0.50	0.54	0.52	0.56	0.53	0.47
Quality of bread medium (0–5 points)	4.9	5	5	4.9	5	4.9	4.8	4.8
Loaf volume, (cm^3)	695	740	725	680	695	660	690	695

Source: Author's own elaboration

Table 4. Allelic composition of HMW- and LMW-glutenins and quality score of winter common wheat varieties

Wheat varieties	HMW			Glu-1 score*	LMW			Glu-3 score
	GluA1	GluB1	GluD1		GluA3	GluB3	GluD3	
Lazarka	2*	7+8	5+10	10	c	b	c	10
Merilin	2*	7+8	5+10	10	c	b	c	10
Kalina	2*	7+8	5+10	10	c	b	c	10
Pchelina	2*	7+9	5+10	9	c	b	c	10
Rada	1	7+8	5+10	9	c	b	c	10
Dragana	1	7+9	5+10	8	c	b	c	10
Bojana	1	7+9	5+10	8	c	j	c	7

*Payne, 1987



1 2 3 4 5 6 7

Fig. 1. Electrophoretic analysis (SDS-PAGE) of storage proteins and allelic composition of high molecular weight glutenins (HMW) of the wheat varieties: 1. Lazarka, 2. Marilyn, 3. Kalina, 4. Pchelina, 5. Rada, 6. Dragana, 7. Bojana

Source: Author's own elaboration

(GluD1) (Glu-1 score 10) for the varieties Lazarka, Merilyn and Kalina, 2* (GluA1), 7+9 (GluB1), 5+10 (GluD1) (Glu-1 score 9) for the variety Pchelina and 1 (GluA1), 7+8 (GluB1), 5+10 (GluD1) (Glu -1 score 9) for Rada variety (Table 3, Fig. 1). Bojana and Dragana varieties have a lower Glu-1 score 8, corresponding to allelic composition 1 (GluA1), 7+9 (GluB1), 5+10 (GluD1), but it does not have a significant impact on their bread-making qualities (Table 3, Fig. 1). In the case of low molecular weight glutenins, the varieties Pchelina, Lazarka, Merilin, Dragana, Kalina and Rada have been identified with the allelic configuration GluA3c, GluB3c, GluD3c, which is associated with a high Glu-3 score of 10 (Table 3). The identified rye translocation – 1BL/1RS (Glu-B3j) in the spectrum of the Bojana variety does not have the expected negative effect on the baking parameters due to the presence of the low molecular weight glutenin alleles associated with a high quality score – Glu-B3b and Glu-D3c (Table 4).

Conclusions

The obtained results of the applied linear optimization show that, regardless of belonging to different quality groups, the bread wheat varieties analyzed approach the optimal combination of quality indicators and are a high achievement of the Bulgarian breeding regarding grain quality, which is also confirmed by the allelic composition of storage proteins – glutenins and gliadins.

In some of the harvest years, the studied genotypes show higher values, and in others – relatively lower values of their technological, rheological, and bakery indicators. This is explained by their specific reaction to the different agro-ecological conditions during the relevant crop year.

The assessment of ecological plasticity and adaptability of winter common wheat varieties is a good approach to select the most suitable genotypes with high potential for productivity and quality to be offered to farmers' economic activities.

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Received: **November, 07, 2024**; *Approved*: **December, 12, 2024**; *Published*: **February, 2026**