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Effects of Genotype, Environment and their Interaction on Quality Characteristics of Winter Bread Wheat

Gergana Desheva*

Department "Plant Genetic Resources", Institute of Plant Genetic Resources "Konstantin Malkov", 2 Druzhba str., 4122 Sadovo, Bulgaria,

*corresponding author: gergana_desheva@abv.bg

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Abstract: Grain quality is a complex character that depends on a number of traits, and the individual contribution of each trait varies depending on specific reaction to environmental conditions. The objective of this study was to assess the effects of genotype, environmental, and genotype x environmental interaction on quality characteristic of 16 wheat genotypes as well as to analyse the relationships between quality traits. The results of two-way analysis of variance showed that the effect of genotype, environment and genotype x environment interaction were significant ($p \leq 0.001$) for the investigated physical characteristics of grain. The strongest individual influence for thousand kernel weight, test weight and vitreousness had genotype. The interaction genotype x environment had stronger influence on the variance for the crude protein (44.98%) and the lysine (34.93%) than genotype and environment effects. Sources of variation genotype and genotype x environment interaction (year) had almost the equal influence on the variance of wet gluten content and bread making strength index. Genotype demonstrated the strongest influence on the sedimentation value and dry gluten content. The genotype x environment interaction influenced in the largest rate on the variance of gluten weakness. Protein content showed significant positive correlation with wet gluten content (0.676), gluten weakness (0.646) and dry gluten content. Vitreousness correlated positively with sedimentation value (0.541) while the test weight significantly correlated with dry gluten content. The results of this study can be used as selection criteria to increase grain quality in bread wheat in the region.

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INTRODUCTION

Breeding programs are mainly directed toward higher yield and grain quality of common winter wheat. Grain quality is a complex character that depends on a number of traits, and the individual contribution of each trait varies depending on specific reaction to environmental conditions (PETERSON et al., 1998). For an effective selection for a particular trait, it is important to determine and quantify the extent to which factors like the genotype (G), environment (E) and genotype x environment interaction (GEI) contribute to variations in each wheat quality parameter (Mladenov, 2001; Abugalieva and Peña, 2010). The understanding of these effects is essential to help breeders to set proper objectives and strategies to develop wheat varieties with high yield potential as well as with specific and consistent quality attributes to meet market needs (Williams et al., 2008).

Many investigations have been made on Genotype x Environmental interaction of bread wheat quality parameters. Šimićet al. (2009) reported that environmental factors strongly influenced the grain protein content and wet gluten content. This strong influence of environment on quality traits of wheat is in agreement with results of many other authors (Vázquez et al., 2012; Denčić et al., 2011; Carson and Edwards, 2009; Wrigley, 2007; Ma et al., 2005; Yong et al., 2004; Johansson et al., 2004, Ruza et al., 2001). Kernel hardness highly influenced by genetic factors (Surma et al., 2012; Carson and Edwards, 2009; Wrigley, 2007). Genotype and environment had stronger influence on the variance for the sedimentation value than the genotype x environments effects (ZECEVIC et al., 2009; BARIC et al., 2004; Yong et al., 2004). Similar results for investigation of genotype x environment interactions for quality traits established by Mikhaylenko et al. (2000), Panozzo and Eagles, (2000), ZECEVIC et al. (2006, 2013), DREZNER et al. (2007), MORIS et al. (2009). However, the magnitude of the effect of genotype and environment differs among most quality components (Yong et al., 2004; Ma et al., 2005; Taghouti et al., 2010; Caffe-Treml et al., 2011, KAYA and AKCURA, 2014).

In Bulgaria the effect of the growing conditions on grain quality in 33 winter wheat varieties at eight locations during two successive years was investigated (Tsenov et al., 2004). In all studied parameters, the genotype x environment interaction was significantly high and it was of the two main types - linear or non-linear. In test weight and relaxation of the gluten, the year conditions and the environmental conditions at the trail location produced almost similar effects. In wet gluten content and bread-making strength index, the environmental conditions at the respective location had a stronger effect on the phenotype in comparison to the year conditions.

The authors concluded that the breeding improvement of some of the investigated parameters caused decrease of their stability under various conditions (Tsenov et al., 2004). Associations between quality parameters are of great interest in defining optimal values of grain quality for a particular region and to help breeders to produce varieties with good quality.

The objectives of this research were to determine the effects of genotype, environmental, and genotype x environmental interaction on quality characteristic of 16 wheat genotypes as well as to analyse the relationships between quality traits.

MATERIALS AND METHODS

Plant material

Sixteen genotypes from Bulgarian winter bread wheat were examined. They included eight cultivars (Enola, Sadovo 1, Geya-1, Sadovo 772, Momchil, Tzarevec, Patriot and Bononia) and eight breeding lines (BGR 824, BGR 827, BGR 36334, BGR 36346, BGR 36304, BGR 36339, BGR 36395, BGR 36396).

Experimental conditions

The present study was conducted in the experimental field of the Konstantin Malkov Institute of Plant Genetic Resources at Sadovo, Bulgaria during the 2012-2013 and 2013-2014 growing seasons. Sowings were made in the optimal time for this area: 10-15 October. The experiments were carried out in a randomized block design in four replications on a 10 m^2 plot size. The sowing norms were 550 germinating seeds per m^2. Normal agronomic and cultural practices were applied to the experiment throughout the growing seasons.

Meteorological characteristic in the period of study

1. Air temperature

The Sadovo region is characterized with warmly and continually autumn, softly and very often snowy winter. The spring is short with almost sharply passing to summer temperatures. The mean monthly air temperature is with minimum value in January and maximum values in June and July (Desheva, 2009).

For the condition of the Sadovo region the low air temperatures and failing snow in January and February have negative influence to hibernate of wheat. The high temperatures in June in combination with dry wind also have negative influence for normal filling of grain. (Desheva, 2009).

During the study period the first growing season 2012/2013 is described as the hottest, respectively with 7.43 ºC above mean air temperature sum for 116 annual periods. The second growing season 2013/2014 is not significantly distinguished in comparison with the mean temperature sum for the period 1896/2012 (Table 1).

Table 1.Mean monthly air temperature (°C) for the Sadovo region

Years	Months									Sum
	X	XI	XII	I	II	III	IV	V	VI	
2013/2014	10.7	8.9	1.1	2.9	5.2	9.1	11.9	17.4	21.3	88.5
2012/2013	14.9	8.4	0.59	1.4	4.2	6.7	13.9	20.9	21.1	92.09
1896/2012	13.14	7.34	2.02	1.08	2.59	7.56	12.24	17.51	21.17	84.66

2. Rainfall

The normal distribution of rainfall for 116 years is clearly expressed with maximum value in May and minimum value in November. The mean sum of rainfall was 406.21 l/m^2.The sum of rainfall for the first and the second years was respectively 461.4 l/m^2 and 478.4 l/m^2. The both experimental years significantly exceeded the climatic norm (Table 2).

Grain quality analysis

The grain physical characteristics such as, thousand kernel weight, test weight and general vitreousness were determined according to the methods described in BDS ISO520 (2003), BDS ISO 7971-2 (2000) and BDS 13378 (1976).

Protein content in grain was estimated by the method of Kjeldahl according to BDS ISO 1871 and lysine content in grain was determined by method of Ermakov et al. (1976). Lysine content in percentage of protein was calculated.

Wet and dry gluten content in different flour samples was estimated by the hand washing method according to BDS 13375 (1988). The sedimentation value of whole wheat flour was determined using the method presented by Pumpyanskiy (1971). Bread making strength index and gluten weakness were defined according to BDS 13375 (1988). The whole wheat meal flour of each wheat variety was also tested for fermentation value (Pelchenke et al., 1953).

Table 2. Monthly sum of rainfall (l/m^2) for the Sadovo region

Year	Mounths									Sum rainfall, l/m^2
	X	XI	XII	I	II	III	IV	V	VI	
2013/2014	26.4	51.6	9.2	25.6	6.9	94.9	83.9	58.4	104.5	461.4
2012/2013	36.6	11.4	106.9	49.1	55.4	38.7	87.1	0.9	92.3	478.4
1896/2012	51.30	27.91	53.28	47.90	41.18	39.83	40.16	54.18	50.48	406.21

Statistical analysis
Average data of two growing seasons were used. Statistical analyses were performed using the statistical program SPSS 19.0. The analysis of variance was calculated according to randomize complete block design with two factors: genotype (G) and year (Y). To estimate the degree of genotype and environment influence on different quality traits we applied method described by Plochinskii (1970). The significant differences among the means evaluated according to LSD test. Phenotypic correlations were calculated by using phenotypic variances and covariance. Correlation coefficients were calculated as followed by Lidansky (1988).

RESULTS AND DISCUSSIONS
Mean values for wheat quality characteristics of crop years are shown in table 3, table 5 and table 7. Significant differences ($p \leq 0.5$) are observed among accessions with regards to studied characteristics. The analysis of variance showed that the effect of genotype, environment and genotype x environment interaction were significant for all quality traits studied. However, the extent of effect of genotype, environment and genotype x environment varied (Taghouti et al., 2010).

Physical characteristics of grain
Milling yield is defined by the amount of flour that can be extracted from grain and is dependent on the proportion of endosperm (75–83%) in the mature kernel relative to its other components of the embryo (germ), aleurone and seed coat (bran) (Hammermeister, 2008) and is strongly dependent on grain hardness (Hruskova and Svec, 2009). Typically also for small and shrivelled grains, the higher proportion of bran relative to endosperm produces a lower milling yield (Marshall et al., 1984).

Thousand grain weight and test weight characteristics, which can be used to predict potential flour yield in wheat grain, are recognized as principal quality parameters by the milling industry (Schuler et al., 1995). In our study thousand kernel weight varied between 33.20-47.40 g during the first growing season and between 34.84-50.02 g during the second growing season of the experiment. The mean thousand kernel weight of the first year (41.85 g) was found to be lower than the one in the second year (43.13 g). Momchil variety had the highest thousand kernel weight during the first year, while breeding line- BGR 36339 had the highest value during the second year. Patriot variety is characterized with the smallest seeds during two years of study. In the present study test weight in the average for all years had the highest value for BGR 36339 (77.59 kg/hl) and the lowest for Geya-1 (71.08 kg/hl). Looking at the years the average test weight values varied in narrow rate (74.59 and 74.05 kg/hl) (Table 3).

The grain vitreousness is important as a character for kernel grading and bread-making properties (Popov, 1965; Wang et al., 2002). Average values of vitreousness varied in the range of 33.50% (BGR 824) to 69.50% (Enola). The highest values for vitreousness were found for Enola and BGR 36396 in 2012-2013 growing season (62.00 and 51.50%, respectively), while the lowest values were confirmed statistically for five accessions. Five varieties and lines (Enola, BGR 36334, BGR 36304, BGR 36395 and Momchil) possessed high vitreousness in the range 59-77% during 2013-2014 growing season. The coefficients of variation were the highest for vitreousness, intermediate for thousand kernel weight, while low values were found for test weight (Table 3).

Table 3. Mean values for physical characteristics of grain in sixteen winter bread wheat varieties and breeding lines during two growing seasons

Variety/Line	Vitreousness, %			Thousand kernel weight, g			Test weight, kg/hl		
	2013	2014	Average	2013	2014	Average	2013	2014	Average
Mean St	**40.28**	**47.63**	**43.95**	**41.85**	**43.13**	**42.49**	**74.59**	**74.05**	**74.32**
Enola	62.00+	77.00+	69.50+	35.00-	39.64-	37.32-	73.74-	76.40+	75.07+
BGR 824	34.00-	33.00-	33.50-	44.00+	47.12+	45.56+	75.72+	75.66+	75.69+
BGR 827	38.00	36.00-	37.00-	38.40-	42.04	40.22-	75.18+	75.20+	75.19+
BGR 36334	46.00+	67.00+	56.50+	45.60+	42.88	44.24+	74.54	72.94-	73.74-
BGR 36346	40.00	29.00-	34.50-	39.20-	42.76	40.98-	72.28-	73.24-	72.76-
BGR 36304	42.00	61.00+	51.50+	38.20-	35.60-	36.90-	75.98+	72.80-	74.39
BGR 36339	30.00-	45.00-	37.50-	43.80+	50.02+	46.91+	77.42+	77.76+	77.59+
BGR 36395	32.00-	64.00+	48.00+	46.20+	45.70+	45.95+	74.44	74.40+	74.42
BGR 36396	51.50+	36.00-	43.75	43.80+	48.84+	46.32+	74.00-	74.06	74.03-
Sadovo 1	39.50	49.00	44.25	46.40+	46.80+	46.60+	76.00+	74.90+	75.45+
Geya-1	37.50	47.00	42.25	44.80+	44.83+	44.81+	71.38-	70.98-	71.18-
Sadovo 772	40.00	37.00-	38.50-	43.00	38.22-	40.61-	74.66	70.36-	72.51-
Momchil	44.00+	59.00+	51.50+	47.40+	47.42+	47.41+	75.38+	75.14+	75.26+
Tzarevec	36.00-	35.00-	35.50-	38.80-	38.98-	38.89-	73.00-	70.96-	71.98-
Patriot	32.00-	41.00-	36.50-	33.20-	34.84-	34.02-	75.40+	76.38+	75.89+
Bononia	40.00	46.00	43.00	41.80	44.44	43.12	74.24-	73.54-	73.89-
LSD 0.5	**3.375**	**2.522**	**2.167**	**1.359**	**1.608**	**1.056**	**0.255**	**0.339**	**0.174**
CV,%	**19.16**	**28.25**	**20.95**	**9.73**	**10.28**	**9.37**	**1.93**	**2.73**	**2.10**

Table 4. Analysis of variance for vitreousness (V), thousand kernel weight (TKW) and test weight (TW)

Source of variation	SS	df	MS	F	P-value	F crit.	Degree of influence,%
Vitreousness, %							
Genotype	5558.61	15	370.57***	175.68	2.34E-26	1.99	**63.16**
Environment (Year)	862.89	1	862.89***	409.07	8.54E-20	4.15	9.80
GEI	2311.86	15	154.12***	73.07	2.02E-20	1.99	26.27
Error	67.50	32	2.11				0.77
Total	8800.86	63					100.00
Thousand kernel weight, g							
Genotype	1036.84	15	69.12***	130.94	2.36E-24	1.99	**84.84**
Environment (Year)	26.34	1	26.34***	49.90	5.19E-08	4.15	2.16
GEI	142.04	15	9.47***	17.94	1.83E-11	1.99	11.62
Error	16.89	32	0.53				1.38
Total	1222.12	63					100.00
Test weight, kg/hl							
Genotype	160.72	15	10.71***	500.68	1.47E-33	1.99	**77.37**
Environmental (Year)	4.67	1	4.67***	218.02	7.74E-16	4.15	2.25
GEI	41.66	15	2.78***	129.78	2.71E-24	1.99	20.05
Error	0.68	32	0.02				0.33
Total	207.73	63					100.00

*** Significant at the 0.001 probability level according to F-test.

The combination of genotype morphological characters and the interaction with environment determines the phenotypic expression of the productive and quality characters. The effects of genotype, environment and interaction between them have an important role in new variety creation and breeding programs success. The results of two-way analysis of variance showed that the effect of genotype, environment and genotype x environment interaction were significant (p≤0.001) for the investigated physical characteristics of grain. The strongest individual influence for thousand kernel weight, test weight and vitreousness had genotype, respectively 84.84%, 77.37% and 63.16%, while the lowest influence had experimental year respectively 2.16%, 2.25% and 9.80% (Table 4).This strong influence of genotype on physical characters of grain is in agreement with Finlay et al. (2007). In contrast Yong et al. (2004), KAYA and AKCURA (2014) indicate that thousand kernel weight and test weight mainly influence by the environmental variance components.

Biochemical characteristics

The results from biochemical analysis are presented in Table 6. Grain protein content is an important quality parameter. It is generally accepted that the higher the protein, the better the quality (Vázquez et al., 2012). Protein content in the grain varied from 10.36% to 12.47% during the first growing season and between 9.63 and 12.53% during the second experimental year (Table 6). The highest average protein content confirmed statistically was observed in BGR 36334 (12.37%) next followed by Sadovo 1 (12.17%), Bononia and Enola (11.70%). However the crude protein content is not the crucial factor of grain quality. It is also important for describing the structure of protein fractions, baking quality and the composition of amino acids. Lysine is the most limiting essential amino acid in cereal grains (Shewry, 2006). The average lysine in the studied accessions varied from 0.30% to 0.36%. The highest lysine content was observed in BGR 36346 (0.36%). This accession is characterized also with high lysine content towards protein content in the kernel, respectively 3.14%. The coefficients of variation were higher for first growing season in comparison with second year for both lysine and lysine content towards protein content (Table 5).

Analysis of variance showed highly significant differences among genotypes and investigated years for the studied biochemical characters. The interaction genotype x environment had stronger influence on the variance for the crude protein (44.98%) and the lysine (34.93%) than genotype and environment effects (Table 6). According to Wılıams et al. (2008), protein content was one of the most responsive traits since it was predominantly affected by environment and genotype x environment interaction. Many other studies demonstrated that environmental conditions have a larger effect on protein content than the genotype (Uhlen et al., 1998; Rharrabti et al., 2001; Mut et al., 2010; Surma et al.2012).

Food processing properties of bread wheat varieties and lines

The interaction between the genotype and the environment during vegetation formed the basis of the wheat quality. Good levels of wet gluten are essential for better bread-making quality. However this character s very much affected by climatic and husbandry factors (Mangova and Kolev, 2011). The *wet gluten content* varied in accordance with genotype and years (Table 7). The mean wet gluten content of the first year (26.56%) was found to be higher than the one in the second year (22.66%). During the first growing season Enola, Sadovo1, Momchl and Bononia varieties and BGR 824, BGR 827, BGR 36334, BGR 36346 and BGR 36396 breeding lines had high gluten contents, while BGR

Table 5. Mean values for biochemical characteristics of grain in sixteen winter bread wheat varieties and breeding lines during two growing seasons

	Crude protein, %			Lysine, %			Lysine content (% of protein)		
Variety/lines	**2013**	**2014**	**Average**	**2013**	**2014**	**Average**	**2013**	**2014**	**Average**
Mean St	**11.77**	**10.91**	**11.34**	**0.33**	**0.31**	**0.32**	**2.83**	**2.82**	**2.83**
Enola	12.30+	11.10+	11.70+	0.32	0.29	0.30	2.60	2.57	2.58-
BGR 824	12.30+	10.52-	11.41	0.34	0.31	0.33	2.80	2.95	2.87
BGR 827	12.40+	9.94-	11.17	0.36+	0.31	0.33	2.90	3.07	2.98
BGR 36334	12.26+	12.49+	12.37+	0.32	0.32	0.32	2.65	2.56	2.60-
BGR 36346	12.58+	10.08-	11.33	0.41+	0.31	0.36+	3.25+	3.03	3.14+
BGR 36304	11.16-	11.24+	11.20	0.32	0.32	0.32	2.87	2.85	2.86
BGR 36339	10.84-	11.64+	11.24	0.30-	0.29	0.30	2.82	2.49	2.65
BGR 36395	10.46-	11.5+	10.98-	0.33	0.31	0.32	3.20+	2.69	2.95
BGR 36396	12.50+	9.63 -	11.06-	0.32	0.30	0.31	2.60	3.06	2.83
Sadovo 1	12.71+	11.64+	12.17+	0.31	0.29	0.30	2.44-	2.49	2.46-
Geya-1	11.96	10.92	11.44	0.32	0.33	0.32	2.63	3.02	2.83
Sadovo 772	10.50-	10.78	10.64-	0.29-	0.31	0.30	2.81	2.88	2.84
Momchil	11.64	11.20+	11.42	0.34	0.31	0.32	2.66	2.72	2.69
Tzarevec	11.08-	10.84	10.96-	0.30-	0.33	0.32	2.76	3.00	2.88
Patriot	11.14-	10.16-	10.65-	0.38+	0.29	0.34	3.45+	2.80	3.12+
Bononia	12.54+	10.86	11.70+	0.35+	0.33	0.34	2.83	2.99	2.91
LSD 0.5	**0.311**	**0.155**	**0.198**	**0.025**	**0.041**	**0.024**	**0.230**	**0.366**	**0.204**
CV,%	6.47	6.46	**4.07**	9.16	6.46	**5.35**	9.46	8.36	**6.80**

Table 6. Analysis of variance for protein content (PC) and lysine (L)

Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit.**	**Degree of influence,%**
Protein content in grain, %							
Genotype	13.69	15	0.91***	65.37	1.12E-19	1.99	28.84
Environment (Year)	11.98	1	11.98***	857.74	1.12E-24	4.15	25.23
GEI	21.36	15	1.42***	101.94	1.17E-22	1.99	**44.98**
Error	0.45	32	0.01				0.94
Total	47.48	63					
Lysine, %							
Genotype	0.02	15	0.001***	3.83	0.000693	1.99	27.91
Environment (Year)	0.01	1	0.012***	44.51	1.58E-07	4.15	21.62
GEI	0.02	15	0.001***	4.79	9.8E-05	1.99	**34.93**
Error	0.01	32	0.000				15.54
Total	0.06	63					

*** Significant at the 0.001 probability level according to F-test.

824, BGR 36334, BGR 36304, BGR 36339, BGR 36334 breeding line and Sadovo 1 and Momchil varieties had high gluten content during the second year. Significant positive compared to mean value for all growing seasons (24.63%) at the 0.05 level were shown by six of evaluated accessions- Enola, BGR 824, BGR 36334, Sadovo 1, Momchil and Bononia. Low wet gluten content was determined for seven accessions. Gluten quality is characterized by the degree of extensibility and the elasticity (Curic et al., 2001). It is well known that wheat grown under high temperature and low moisture characterize strong gluten with less extensibility and the opposite conditions produce weak gluten and extensible dough. Genotypes with higher gluten strength have been characterized as bread improvers and these have shown higher contents of total glutenins as well as content of high-molecular- weight glutenin subunits (Horvat et al., 2009). The results in the study showed that in the first growing season 2012/2013 the all analyzed accessions exception BGR 36395, Sadovo 772 and Patriot showed high values of *gluten weakness* relating to low gluten quality. The value of *gluten weakness* in the 2013/2014 varied between 4 and 14 mm. The gluten weakness between 4-7 mm was recorded for ten accessions, while the high values between 10-14 mm was registered for six samples. The best combination of grain gluten properties in average for all investigated years was observed in Patriot, BGR 36395 and Tzarevec. The bread-making strength index of above samples was also very high as an indication for good gluten quality (respectively 55.50, 56.00 and 53.75). *Sedimentation value* determines viscosoelastic character of gluten albumines and their quality which provide fermentative processes in dough (Konvalina, 2008). Sedimentation value was found to be higher in the 2013 harvest year. It varied from 22.50 to 50.50 cm^3. The highest rate of sedimentation value was described of bread wheat cultivars Enola, respectively 50.50 cm^3, while contrariwise the lowest value was detected for BGR 36339 (22.50 cm^3). In 2014 year the values were recorded between 15.50 and 45.50 cm^3. The highest rate of sedimentation value in average of the all investigated years was described of bread wheat cultivars Enola and Momchil, respectively 41.50 cm^3 and 42.75 cm^3.

The success of plant breeding and production depends not only on genetic but on environmental factors as well. There are significant phenotypic differences among wheat genotypes with regard to grain and flour quality (MLADENOV *et al*., 2001). In addition to the genotypic mean for any trait, the breeder is also interested in its stability, which depends on genotype x environment interaction (ZECEVIC et al., 2009). Influence of genetic and agro-ecological conditions on quality properties of wheat flour (wet gluten content, gluten weakness, bread making strength index, sedimentation value and dry gluten content) are presented in table 8. Analysis of variance showed highly significant differences among investigated genotypes, years and among their interactions. Sources of variation genotype and genotype x environment interaction (year) had almost the equal influence on the variance of bread making strength index (respectively 41.04 % and 41.90%). Genotype demonstrated the strongest influence on the sedimentation value (44.06) and dry gluten content (39.52%). Sedimentation value significantly influenced by protein content and the magnitude of the effect varies according to the genotype (Cubadda et al., 2007). The interaction genotype x environment influenced in the largest rate on the variance of gluten weakness (42%). Sources of variation genotype, environment and genotype x environment interaction had almost equal effect on the variance of wet gluten content (Table 8).

Correlation between investigated quality characters

Many studies have attempted to relate various bread making quality parameters (Warechowska et al., 2013; Denčić et al., 2011, Park et al., 2006; Rharrabti et al., 2003; Cuniberti et al., 2003; Khatkar et al., 2002a, 2002b).

Kaya and Akcura (2014), Ghadami et al. (2014), Dimitrov et al. (2013), Ozturk and Aydin (2004), Mladenov et al. (2001), Chinnaswamy et al. (2005), found high positive correlations between protein content and wet gluten content. A significant positive correlation of grain protein content with vitreousness was reported by Figiel et al. (2011), Różyło and Laskowski (2007), El-Khayat et al. (2006), Martinez et al. (2005), El-Khayat et al. (2003). Sedimentation value is also significantly influenced by protein content, and the magnitude of the effect varies according to the genotype (Cubadda et al., 2007; Kolev et al., 2011; Hrušková *et al.*, 2004). The highest correlation was observed between wet gluten content and dry gluten content (Ghadami et al., 2014). A significant negative correlation between grain protein content and test weight was reported by Warechowska et al. (2013) and Rharrabti et al. (2003), while a positive correlation was reported by Schuler et al. (1995).

Table 7. Mean values for technological characteristics of flour in sixteen winter bread wheat varieties and breeding lines during two growing seasons

Variety/lines	Wet gluten content, %			Gluten weakness, mm			Bread making strength index			Sedimentation value, cm3			Dry gluten content, %		
	2013	2014	Means	2013	2014	Means	2013	2014	Means	2013	2014	Means	2013	2014	Means
Mean St	**26.59**	**22.66**	**24.63**	**12.33**	**7.84**	**10.09**	**47.06**	**52.22**	**49.64**	**36.81**	**29.22**	**33.02**	**8.61**	**7.54**	**8.08**
Enola	33.04+	22.40	27.72+	17.00+	4.50-	10.75+	44.00-	60.50+	52.25+	50.50+	32.50+	41.50+	10.24+	7.60	8.92+
BGR 824	30.88+	23.38+	27.13+	17.50+	6.25-	11.87+	42.50-	56.50+	49.50	30.00-	20.50-	25.25-	9.80+	7.65	8.72+
BGR 827	29.04+	20.80-	24.92	19.00+	7.00-	13.00+	42.0-	48.00-	45.00-	35.00	25.0-	30.00-	9.15+	7.06-	8.11
BGR 36334	27.52+	26.76+	27.14+	13.00	11.00+	12.00+	47.00	49.50-	48.25	38.00	31.50+	34.75+	8.84+	8.80+	8.82+
BGR 36346	28.64+	19.70-	24.17-	13.00	5.00-	9.00-	48.00	57.00+	52.50+	40.00+	18.50-	29.25-	9.20+	6.55-	7.87-
BGR 36304	25.02-	24.16+	24.59	10.00-	11.50+	10.75+	48.00	45.00-	46.50-	31.5-	34.00+	32.75	8.13-	7.55	7.84-
BGR 36339	23.00-	24.74+	23.87-	12.50	14.00+	13.25+	41.00-	43.00-	42.00-	22.50-	24.00-	23.25-	7.65-	7.93+	7.79-
BGR 36395	21.38-	24.26+	22.82-	5.00-	7.00-	6.00-	57.00+	55.00+	56.00+	28.00-	29.50	28.75-	7.29-	7.95+	7.62-
BGR 36396	29.52+	19.70-	24.61	17.50+	4.00-	10.75+	42.50-	57.00+	49.75	40.00+	15.50-	27.75-	9.04+	6.80-	7.92-
Sadovo 1	28.92+	25.08+	27.00+	12.50	11.25+	11.87+	49.00	47.50-	48.25	42.00+	30.50	36.25+	9.45+	8.25+	8.85+
Geya-1	23.40-	16.82-	20.11-	9.00-	12.00+	10.50	48.00	37.00-	42.50-	34.00-	29.50	31.75	7.54-	5.40-	6.47-
Sadovo 772	23.00-	20.62-	21.81-	6.50-	6.00-	6.25-	54.50+	52.00+	53.25+	34.00-	38.00+	36.00-	8.00-	7.20-	7.60-
Momchil	26.92+	25.56+	26.24+	15.50+	6.50-	11.00+	44.00-	61.50+	52.75+	40.00+	45.50+	42.75+	8.82+	8.80+	8.81+
Tzarevec	23.52-	23.08	23.30-	10.25-	5.00-	7.62-	45.50	62.00+	53.75+	38.00	35.50+	36.75+	7.61-	7.90+	7.75-
Patriot	23.34-	22.24	22.79-	7.00-	4.50-	5.75-	52.00+	59.00+	55.50+	42.50+	29.50	36.00+	7.96-	7.65	7.80-
Bononia	28.32+	23.32	25.82+	12.00	10.00+	11.00+	48.00	45.00-	46.50-	43.00+	28.00	35.50+	9.06+	7.55	8.31+
LSD 0.5	**0.313**	**0.666**	**0.366**	**0.831**	**0.256**	**0.435**	**2.401**	**2.538**	**1.766**	**2.404**	**1.403**	**1.346**	**0.148**	**0.256**	**0.141**
CV,%	**12.21**	**10.95**	**8.34**	**32.76**	**39.37**	**23.10**	**9.39**	**13.74**	**8.44**	**17.76**	**24.59**	**15.79**	**9.81**	**10.69**	**7.65**

Table 8. Analysis of variance for wet gluten content (WGC), gluten weakness (GW), bread making strength index (BMSI), sedimentation value (SV) and dry gluten content (DGC)

Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit.**	**Degree of influence,%**
Wet gluten content, %							
Genotype	277.65	15	18.51***	287.20	9.99E-30	1.99	34.79
Environment (Year)	246.80	1	246.80***	3829.39	6.95E-35	4.15	30.93
GEI	271.51	15	18.10***	280.85	1.42E-29	1.99	34.02
Error	2.06	32	0.06				0.26
Total	798.02	63					
Gluten weakness, mm							
Genotype	356.71	15	23.78***	264.69	3.63E-29	1.99	30.36
Environment (Year)	321.75	1	321.75***	3581.26	2.01E-34	4.15	27.39
GEI	493.43	15	32.90***	366.14	2.12E-31	1.99	**42.00**
Error	2.88	32	0.09				0.25
Total	1174.78	63					
Bread making strength index							
Genotype	1135.48	15	75.70***	52.09	3.53E-18	1.99	**41.04**
Environment (Year)	425.39	1	425.39***	292.74	1.16E-17	4.15	15.38
GEI	1159.36	15	77.29***	53.19	2.57E-18	1.99	**41.90**
Error	46.50	32	1.45				1.68
Total	2766.73	63					
Sedimentation value, cm3							
Genotype	1778.73	15	118.58***	128.63	3.12E-24	1.99	**44.06**
Environment (Year)	922.64	1	922.64***	1000.83	1.02E-25	4.15	22.85
GEI	1306.11	15	87.07***	94.45	3.83E-22	1.99	32.35
Error	29.50	32	0.92				0.73
Total	4036.98	63					
Dry gluten content, %							
Genotype	25.06	15	1.67***	160.57	9.64E-26	1.99	**39.52**
Environment (Year)	18.43	1	18.43***	1770.62	1.37E-29	4.15	29.05
GEI	19.60	15	1.31***	125.59	4.53E-24	1.99	30.91
Error	0.33	32	0.01				0.53
Total	63.43	63					

*** Significant at the 0.001 probability level according to F-test.

Table 9. Correlation between investigated quality parameters

	PC	L	V	TKW	TW	WGC	GW	BMSI	SV	DGC
PC	1									
L	-0.058	1								
V	0.484	-0.327	1							
TKW	0.384	-0.222	-0.053	1						
TW	0.082	-0.232	0.073	0.130	1					
WGC	0.676**	-0.062	0.463	0.151	0.488	1				
GW	0.646**	-0.145	0.171	0.429	0.383	0.567*	1			
BMSI	-0.377	0.138	0.075	-0.310	-0.116	-0.001	-0.784**	1		
SV	0.193	-0.106	0.541*	-0.334	-0.199	0.230	-0.221	0.401	1	
DGC	0.573*	-0.099	0.425	0.113	0.515*	0.962**	0.403	0.183	0.351	1

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level
Abbreviation: PC- protein content, L- lysine, V- vitreousness, TKW- thousand kernel weight, TW- test weight, WGC- wet gluten content, GW- gluten weakness, BMSI- bread making strength index, SV- sedimentation value and DGC- dry gluten content

Pearson's correlation coefficients between 10 quality characters are presented in Table 10. Protein content showed significant positive correlation with wet gluten content (0.676), gluten weakness (0.646) and dry gluten content (0.573). Vitreousness correlated positively with sedimentation value (0.541). Test weight significantly correlated with dry gluten content (0.515) at the 0.05 level. Wet gluten content was positively associated to dry gluten content (0.962) and gluten weakness (0.567), while gluten weakness correlated negatively at the 0.01 level with bread-making strength index (-0.784). Bread-making strength index was in positive relationship with sedimentation value but not significant correlation was noted between them (Table 9).

CONCLUSIONS

The results of two-way analysis of variance showed that the effect of genotype, environment and genotype x environment interaction were significant (p≤0.001) for all of the investigated quality characteristics of winter bread wheat. The strongest individual influence for thousand kernel weight, test weight and vitreousness had genotype, while the lowest influence had experimental year.

The interaction genotype x environment had stronger influence on the variance for the crude protein, the lysine content and the gluten weakness than genotype and environment effects. Sources of variation genotype and genotype x environment interaction (year) had almost the equal influence on the variance of bread making strength index and wet gluten content. Genotype demonstrated the strongest influence on the sedimentation value and dry gluten content. Protein content showed significant positive correlation with wet gluten content, gluten weakness and dry gluten content. Vitreousness correlated positively with sedimentation value. Test weight significantly correlated with dry gluten content. Wet gluten content was positively associated to dry gluten content and gluten weakness, while gluten weakness correlated negatively with bread-making strength index.

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