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Impact of Genetic and Climatic Factors on Parameters of Breadmaking Quality of Wheat Kernel and Flour Starch Component

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Summary: This study investigates how genetic and climatic factors affect parameters of breadmaking quality of wheat kernel and flour starch component. Nine wheat cultivars with different combinatons of HMW-GS were grown in three production years. Various rheological devices such as Falling Number (FN), Farinograph, Amylograph, Mixolab and SDmatic were used for characterization of milled wheat samples. The most results showed that climatic factors affected parameters of breadmaking quality of wheat kernel and flour starch component more than HMW-GS composition. However, some results of the bread making quality parameters that are considered to be very reliable indicators of changes in starch component of wheat in wet years, such as FN and maximum peak of viscosity by Amylograph, were dependent of HMW-GS composition.
Key words: climatic factors, cultivars, HMW-GS, starch, wheats

Introduction

Starch is the most important polysaccharide in wheat in the form of semi-crystalline granules. Also, starch is the most abundant in wheat grain in comparison to other chemical compounds (Goesaert et al., 2005). The main starch components are two glucose polymers: amylose and amylopectin. Basically, amylose is linear molecule which is composed of D-glucopyranose units connected by α-1,4 bond. The degree of amylose polymerization is in the range from 500 to 6000 glucose molecules. However, Shibanuma et al. (1994) proved that some fractions of amylose molecule are slightly branched due to the existence of α-1,6 linkages. Contrary to amylose molecule, amylopectin molecule is an immense, highly branched polysaccharide. The degree of amylopectin polymerization is in the range from 3×10^5 to 3×10^6. Chains of D-glucopyranose units connected by α-1,4 bonds are linked among themselves by α–1,6 linkages and thus they form the amylopectin molecule (Zobel, 1988). Amylose and amylopectin ratio in wheat depends on the starch types. Usually amylose content ranges from 25% to 28%, whereas amylopectin content ranges from 72% to 78% (Colonna and Buléon, 1992). During dough mixing, starch absorbs 46% of water, whereas its function in dough is not fully understood (Goesaert et al., 2005). There are various hypotheses for this and Larsson and Eliasson (1997) showed that rheological properties of wheat dough depend on the specific properties surface of starch granules. Also, presence of amylolytic enzymes in wheat could be one of the reasons (Martínez–Anaya & Jiménez, 1997), especially in the case when these are activated during preharvest sprouting, resulting in changes of physical-chemical properties of wheat starch, its partial hydrolysis and increased soluble sugars (Simsek et al., 2014).

Glutenins belong to the largest group of proteins that can be found in nature. They are the polymeric proteins linked by disulfide bonds. The genetic loci which control the synthesis of gluten proteins in wheat can be found in the first chromosome. The high molecular weight (HMW) glutenins are encoded by the Glu 1 locus of the long part of chromosome (Payne and Lawerence, 1983). Three genetically unrelated loci (Glu A1, Glu B1, and Glu D1) are located on homologous chromosomes 1A, 1B, 1D and control the synthesis of HMW glutenin subunits (GS) (Gálová et al., 2002; MacRitchie and Lafiandra 2001). In each cultivar, there can be from 3 to 5 different HMW-GS glutenin subunits encoded by the Glu A1, Glu B1, and Glu D1 loci which are usually identified according to a numerical system developed by Payne and Lawrence (1983) on the basis their electrophoretic mobility. Size of HMW-GS determined by Lab-on-a Chip electrophoretic technique (LoaC) were in the range of 125 to 240 kDa (Živančev et al., 2015) and their specific

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composition is one of the most important genetic factors that affect wheat quality (Payne et al., 1987a).

Also, climatic factors prevailed in some years may also have significant effect on the wheat plant development and wheat kernel development at the starch and gluten synthesis, which result in modified wheat quality. In years when wheat is exposed to daily T> 35 °C without precipitation for more than five days (heat stress), it can cause dough weakling (Randall and Moss 1990), whereas values of Falling Number become higher than 400 s (Gooding, 2003). On the other hand, high amount of rain during spring can induce increase in protein content (Garrido–Lestache et al., 2004).

Therefore, the aim of this study was to examine how genetic and climatic factors cause changes of breadmaking quality parameters of wheat kernel and flour starch component.

Material and Methods

Nine wheat cultivars of which every third possesses different combinations of HMW-GS (2 * 7 + 9 5 + 10, null 7 + 9 2 + 12 and null 7 + 9, 5 + 10) were chosen as materials. Wheat cultivars were grown at the experimental fields of the Institute of Field and Vegetable Crops in Novi Sad (locality Rimski Šančevi, elevation - 86 m, latitude 45° 20' and longitude 19º 51') in three production years (2008, 2009 and 2010). The highest amount of rainfall was recorded in 2010 from anthesis to harvest (Table 1). Duration of insolation were 2008 ≈ 2009 > 2010 whereas the mean temperature from anthesis to harvest in these three years was the lowest in May 2010 and the highest in July 2010.

The content of the sprouted kernels was determined in 100 g wheat samples according to EN 15587. Also, falling number (FN) was determined on wheat kernels according to Hagberg-Perten (method number 107/1, ICC 2006). The rest of the wheat samples were milled on a laboratory mill MLU 202 (Bühler, Uzwil, Switzerland) and 60% extraction flours were examined by Brabender devices (C. W. Brabender, Duisburg, Germany) Farinograph and Amylograph (method numbers 115/ and 126/1, respectively; ICC 2006). Furthermore, parameters were evaluated with Chopin devices (Chopin, Paris, France) using Mixolab (method number 173, ICC 2011) and SDmatic.

The data were statistically analyzed by two-factorial analysis of variance (ANOVA). The first factor was the production year, whereas the second factor was the group of wheat cultivars with different combinations of HMW-GS followed by the comparison of mean values based on Tukey's multiple means comparison tests, correlation matrix (Pearson), linear regression analysis and principal component analysis (PCA). All analysis were performed by XLSTAT-Pro (demo version, Version 3.02, 2009) software.

Results and Discussion

Significant effect of the production year (Y) was found for the sprouted kernels content (SPC), falling number (FN), maximum peak of viscosity by Amylograph (AMS), water absorption by Farinograph (WA), degree of softening by Farinograph (DS), rate of starch enzymatic degradation (γ) by Mixolab, C3-C4 by Mixolab, C5-C4 by Mixolab, and level of damage starch by Sdmatic (UCD KSDAM) ($p<0,01$), whereas level of significance for C3 by Mixolab was at lower level ($p<0,05$) (Table 2). The effect of the production year on these parameters was due to a high amount of rainfall in June and July of 2010 (Table 1) which caused preharvest sprouting in wheat and elevated α-amylase activity in wheat kernels. As a result, viscosity parameters of wheat kernels and flour starch component changed. On the other hand, significant effect of group of cultivars with different combinations of HMW-GS (G) was proven only for SPC, FN, AMS, DS and γ (Table 2). The results for FN were in accordance with Denčić et al. (2013) and Barbeau et al. (2006) who found genotypic differences between groups of cultivars in FN values.

The results of Tukey test (Table 3) showed that FN, AMS, C3, and γ in 2008 were statistically higher than in 2010. Contrary to these, WA, DS, C3-C4 and C5-C4 showed the opposite trend. Moreover, two of these parameters (AMS and C5-C4) showed statistical difference in all three years. The reason probably lies in the fact that in 2008 germinated kernels (Table 3)

Table 1. Weather conditions characterizing the production seasons from wheat flowering to harvest (May to July)

Year	Month	Insolation [h]	Rainfall [mm]	Mean temperature [°C]
2008	May	302.6	40.6	18.3
	June	293.5	115.9	21.7
	July	306.5	41.6	21.7
2009	May	303.4	50.4	18.4
	June	249.3	127.2	19.5
	July	369.8	58.1	22.8
2010	May	189.5	113.7	17.0
	June	226.6	171.8	20.1
	July	326.1	99.0	23.1

Table 2. Breadmaking quality parameters of wheat kernel and flour starch component affected by year of production and group of cultivars with different combinations of HMW-GS

	DF	SPC (%)	FN (s)	AMS (BU)	WA (%)	DS (BU)
Year (Y)	2	0.600**	33758**	584112**	95.92**	3623**
Group (G)	2	0.102**	23560**	544545**	6.19ns	2268**
YxG	4	0.054**	1926ns	87779**	1.77ns	384*
Error	18	0.008	851	2842	5.84	120
	DF	C3 (Nm)	γ (Nm/min)	C3-C4 (Nm)	C5-C4 (Nm)	UCD KSDAM
Year (Y)	2	0.17*	0.0040**	3.15**	3.48**	12.18**
Group (G)	2	0.04ns	0.0015**	0.11ns	0.06ns	0.43ns
YxG	4	0.02ns	0.0005ns	0.08ns	0.03ns	0.84ns
Error	18	0.04	0.0002	0.13	0.06	3.77

** significant at 0.01 probability level; * significant at 0.05 probability level; ns not significant

Table 3. Mean values of breadmaking quality parameters of wheat kernel and flour starch component by the production year and different combinations of HMW-GS with differentiation by Tukey test

	SPC (%)	FN (s)	AMS (BU)	WA (%)	DS (BU)	C3 (Nm)	γ (Nm/ min)	C3-C4 (Nm)	C5-C4 (Nm)	UCD KSDAM
Group										
2* 7+9 5+10	0.40a	331a	611b	63.1a	61.1b	1.93a	-0.06a	0.98a	1.42a	22.67a
null 7+9 2+12	0.31a	304b	732a	62.2a	90.6a	1.86a	-0.05a	0.94a	1.33a	22.94a
null 7+9 5+10	0.18b	232b	258c	61.4a	86.1a	1.79a	-0.08b	0.77a	1.25a	22.51a
Year										
2008	0.00b	358a	767a	58.5b	56.7b	2.00a	-0.04a	0.24b	0.64c	21.71a
2009	0.44a	265a	573b	63.6a	86.1a	1.85ab	-0.07b	1.38a	1.50b	23.98a
2010	0.45a	243b	262c	64.6a	95.0a	1.73b	-0.08b	1.08a	1.85a	22.43a

Tukey test, different letters indicate significant difference at 0.05 probability level

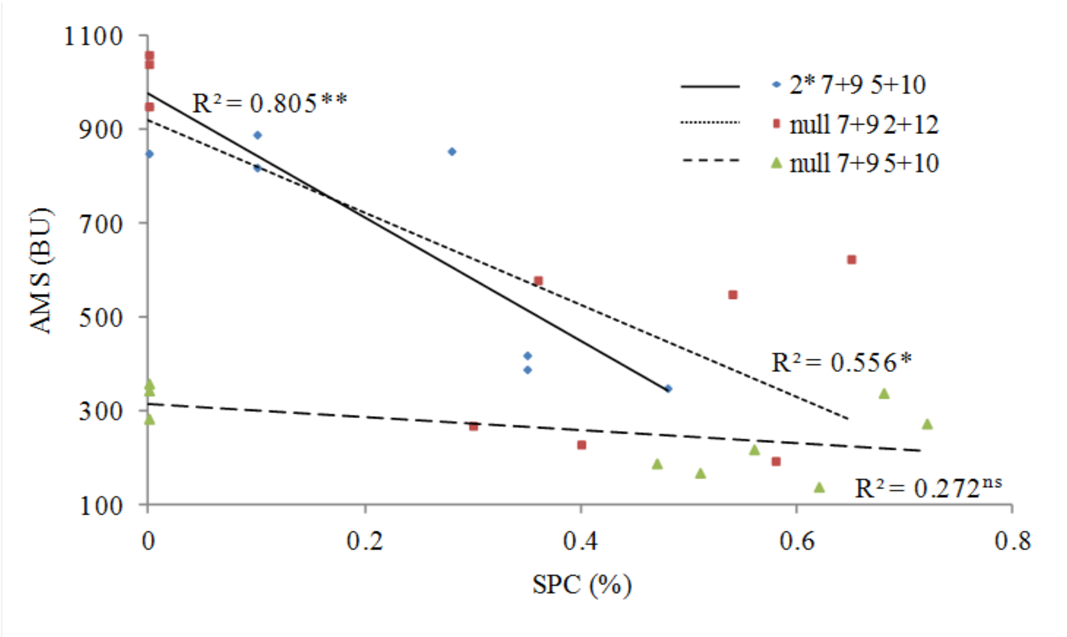

Figure 1. Linear regression analysis between AMS and SPC at wheat cultivars with different composition of HMW-GS

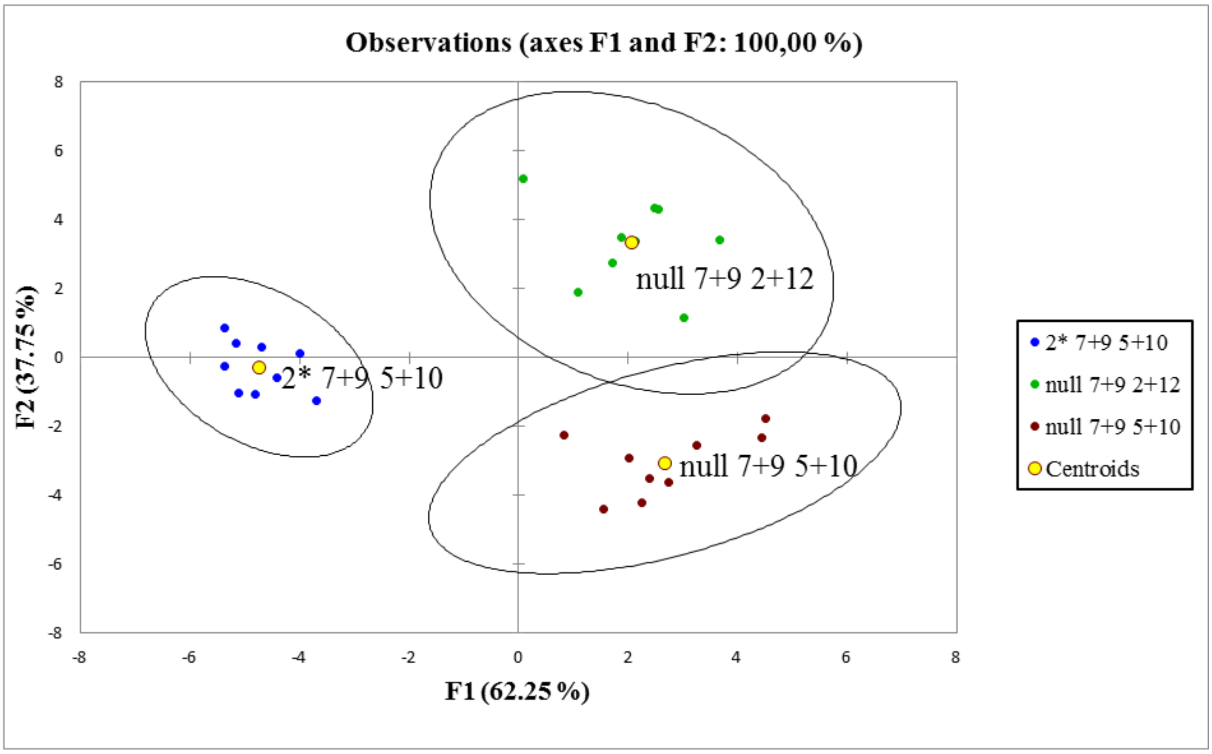

Figure 2. PCA analysis of wheat cultivars according to parameters of breadmaking quality of starch component of wheat kernel and flour

Table 4. Correlation matrix (Pearson) of breadmaking quality parameters of wheat kernel and flour starch component

Variables	SPC (%)	FN (s)	AMS (BU)	WA (%)	DS (BU)	C3 (Nm)	γ (Nm/min)	C3-C4 (Nm)	C5-C4 (Nm)
FN (s)	-0.81**								
AMS (BU)	-0.66**	0.81**							
WA (%)	0.61**	-0.45*	-0.38*						
DS (BU)	0.71**	-0.78**	-0.73**	0.56**					
C3 (Nm)	-0.48*	0.55**	0.50**	-0.61**	-0.56**				
γ (Nm/min)	-0.69**	0.78**	0.72**	-0.57**	-0.66**	0.49*			
C3-C4 (Nm)	0.57**	-0.32	-0.25	0.44*	0.34	-0.02	-0.42*		
C5-C4 (Nm)	0.68**	-0.46*	-0.29	0.64**	0.49**	-0.15	-0.55**	0.89**	
UCD KSDAM	0.27	-0.13	-0.08	0.53**	0.33	-0.35	-0.27	0.25	0.39*

** significant at 0.01 probability level; ** significant at 0.05 probability level

induced by preharvest sprouting (PHS) were not detected. This was additionally confirmed by decreased trend of DS from 2008 to 2010 as an indirect measure of protease expression, which is companion of two isoforms of α-amylase during PHS (Rall et al., 2016). Group of cultivars with combinations of HMW-GS 2 * 7 + 9 5 + 10 and null 7 + 9 2 + 12 had significantly higher values of the FN, DS, AMS and γ in comparison to group of cultivars with subunits null 7 + 9 i 5 + 10 (Table 3). The result for FN is accordance with Denčić et al. (2013) who found that groups of wheat cultivars can differentiate according to FN values even in the productions years with wet periods.

As expected, SPC showed a statistically significant negative correlation with FN, AMS (P≤0.01), C3 (P≤0.05) and a positive correlation with DS (P≤0.01) (Table 4). Also, according to Table 4 SPC and Mixolab parameter γ was negativelly corellated (P≤0.01) which indicate that increase of SPC lead to increasing of rate of starch enzymatic degradation. Moreover, SPC showed a statistically significant (P≤0.01) positive correlation between WA and parameters determined by Mixolab C3-C4 and C5-C4. The result of correlation coefficient of C5-C4 was in accordance with Mangan et al. (2016) who examined existence of correlation among amylase activity, FN, mixolab parameters and baking quality. On the other hand, the result of correlation coefficient of C3-C4 was not in accordance with Mangan et al. (2016). The similar situation was with correlation coefficients of these parameters with FN. The only difference was that level of significance for C5-C4 was P≤0.05, whearas in case of C3 -C4 there was no statistically significant correlation. Correlation coefficients among FN and AMS and C3 were expectedly positive with significance level of P≤0.01, whereas in case of DS it was expectedly negative. WA had a statistically significant (P≤0.01) negative correlation with the FN and AMS, while γ had a positive one. Similar to results of correlation coefficient between FN and DS, the correlation coefficient between AMS and DS and between C3 and DS was found, which inicated that proteolitic activity is a companion of amylase activity gained by the PHS, as was mentioned above. Expectedly, correlation coefficient between WA and UCD KSDAM was statistically positive (P≤0.01), since level of WA of damaged starch is very high and can vary from 200% to 430% (Barrera et al. 2007). Also, WA had a statistically significant positive correlation with the C5-C4 (P≤0.01), C3-C4 (P≤0.05) and negative with C3 and γ (P≤0.01).

Additional statistical analysis by using linear regresion showed the significant relationship between SPC and AMS in group of cultivars with combinations of HMW-GS 2 * 7 + 9 5 + 10 and null 7 + 9 2 + 12 (Figure 1). According to Figure 1, it can be concluded that AMS values decrease as SPC values increase. Furthemore, an increase of SPC in samples of group of cultivars with null subunits 7 + 9 and 5 + 10 HMW-GS was also followed by a reduction of AMS values, but this effect was not significant. This indicates that AMS is dependent on this combination of HMW-GS.

PCA analysis was used to assess wheat cultivars group according to parameters of breadmaking quality of wheat kernel and flour starch component (Fig. 2). The first principal component explained 62.25% variability of data set, whereas the second principal component explained 37.75%. The score plot (Fig. 2) shows that cultivars were completely separated according to their HMW-GS composition in three previously defined groups.

Conclusions

Based on the results of two-factorial ANOVA, it could be concluded that climatic factors that prevailed in 2008, 2009, and 2010 affected parameters of breadmaking quality of wheat kernel and flour starch component more than HMW-GS composition of the examined wheat cultivars. Also, this confirmed the results of Tukey test. However, ANOVA showed that some parameters of bread making quality that are considered to be very reliable indicators of changes in starch component of wheat in wet years, such as FN and AMS, were dependent on HMW-GS composition. Additionally, this was confirmed throughout the linear regresion where there was no significant relationship between SPC and AMS at samples of group of cultivars with null subunits 7 + 9 and 5 + 10 HMW-GS. Furthermore, PCA analysis of breadmaking quality parameters of wheat kernel and flour starch component completely separated wheat cultivars according to their HMW-GS composition.

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Uticaj genetskih i klimatskih faktora na pokazatelje tehnološkog kvaliteta skrobne komponente pšeničnog zrna i brašna

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Sažetak: Cilj ovog rada je bio da se ispita kakve promene na pokazateljima tehnološkog kvaliteta skrobne komponente pšeničnog zrna i brašna imaju genetski i klimatski faktori. Devet sorti pšenice različitih kombinacija HMW-GS proizvedenih u tri različite godine uzeti su kao materijal za istraživanje. Na različitim reološkim uređajima poput Perten-ovog broja padanja, Farinografa, Amilografa, Mixolab-a i SDmatic urađena je karakterizacija samlevenih pšeničnih uzoraka. Većina rezultata pokazala je da klimatski faktori izazivaju veće promene na tehnološkom kvalitetu skrobne komponente pšeničnog zrna i brašna nego HMW-GS sastav. Sa druge strane, neki pokazatelji tehnološkog kvaliteta koji se smatraju veoma pouzdanim indikatorima promena na skrobnoj komponenti pšenice u godinama sa velikom količinom padavina, poput broja padanja i maksimalnog viskoziteta na amilografu, ipak su zavisili od HMW-GS sastava.

Ključne reči: HMW-GS, klimatski faktori, pšenica, skrob, sorta

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