Bread-Making Quality of Standard Winter Wheat Cultivars

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Summary

The purpose of this study was to define an impact of the cultivar, year and cultivation area of the standard Croatian winter wheat on the bread-making quality. The bread-making quality of cultivars 'Divana', 'Žitarka' and 'Sana' from the crop years 1998, 2000, 2002, 2004 and 2006, and from Zagreb and Osijek location was analyzed. Wheat from the cultivar tests cultivated under the same agro technological conditions was used for this testing. The tested winter wheat bread-making quality primarily depended on the genetic properties of cultivar. However, climatic changes occurring during the last 10 years, particularly the increase in temperatures and quantity of rainfalls in the period of the grain development, ripening and harvest, had a negative influence on the wheat bread-making quality. Even though the average values of tested quality factors were within the expected range, a significant dependence of the cultivar Divana bread-making quality upon the cultivation climate conditions was proven. Sana cultivar has proven to be the most stable, whereas its bread-making quality was the lowest. For all three cultivars the bread-making quality has been decreasing in the last 10 years, although the quality of winter wheat from the Zagreb area was higher since the climate conditions were more favourable.

Key words

wheat (*Triticum aestivum* L), cultivar, bread-making quality, climate change

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Introduction

Wheat cultivars can be differentiated by the grain quality and flour quality; such differences are not mediated only by genetic make-up, but also by external factors which have an important influence on the technological grain quality, especially on the bread-making features (Payne, 1987; Bassett et al., 1989; Lukow & McVetty, 1991; Peterson et al., 1992; Mladenov et al., 2001). It is well known that only 10% of grown cultivars are not under biotic and abiotic stress (Solh, 1993), while other cultivars (26%) are under stress caused by drought (26%) and low temperature (15%) (Cristiansen, 1982; Monti, 1987). With the global climate change, especially in the last 10 years, drought has become more frequent in south-eastern Europe and Balkan region (Jovanović et al., 1996). To reduce the negative environmental influence to the minimum, it is necessary that the cereal manufacturers stick to the recommended agro technical standards and to sow stable and adaptable cultivars.

The wheat assortment in Croatia still does not meet the requirements of the processing industry (bread-making, soft wheat products, breakfast cereals, snack foods and pasta production). 'Divana', 'Žitarka' and 'Sana' are the standard Croatian wheat cultivars and on that basis the new wheat cultivars are acknowledged. 'Divana' is the standard wheat of the highest quality; wheat "improver" 'Žitarka' is the standard for the bread making quality, and 'Sana' for the grain yield. There are very few high quality wheat cultivars as 'Divana', and they are not highly spread due to their low grain yield. 'Žitarka' is a bread cultivar of lower grain yield, lower flour yield and a good bread-making quality (Unbehend et al., 2003) compared to cultivar Sana that has lower quality. Moreover, variability in quality stability among Croatian cultivars was established in 1999 and 2000 (Barić et al., 2004). Therefore, selectors have a responsible task of selecting new cultivars with the proper technological quality to ensure high quality finished products on the market.

The purpose of this study was to determine the changes in bread-making quality of standard Croatian wheat cultivars (*Triticum aestivum*) in the period of the last 10 years and to explore the influence of climate change on their quality and define their stability. Grain and flour properties of cultivars 'Divana', 'Žitarka' and 'Sana', from the crop years 1998, 2000, 2002, 2004 and 2006, and two locations, Zagreb and Osijek, were determined.

Materials and methods

Cultivar Žitarka, acknowledged in 1985 (Pedigree OSK-6.30/20xSlavonkaxH-68) of very good baking quality; cultivar Sana, acknowledged in 1983 (Pedigree MuraxCI 14123XBC-2413/72) of good baking quality and cultivar Divana, acknowledged in 1983 (Pedigree MuraxCI 14123XBC-2413/72) of excellent baking quality, were obtained from the **Institute for Seed and Seedlings**, Osijek. Samples for all test years originated from test fields in Osijek and Zagreb, and have been cultivated in the standard and controlled agro technical conditions. The following parameters were determined for the grain samples: hectoliter mass, protein content and sedimentation value according to Zeleny. All analyses were carried out according to the standard methods (National Gazette 53, 1991; ICC Standard 110/1, 1976; ICC Standard 105/1, 1980; ICC Standard 116, 1972). Grain samples were grinded in the laboratory mill (Bühler grinding machine, Buhler GmbH, Germany), without the bran snapper and the milling yield was determined. The ash content in laboratory flour was 0.482% - 0.707% (ICC Standard 104/1, 1990). The quantity of wet gluten according to ICC Standard 106/2 (1984); rheological properties of dough by extensograph (Brabender, Germany) according to the ICC Standard 114/1 (1992); maximum viscosity by amylograph (Brabender, Germany) according to ICC Standard 126/1 (1992), and the activity of α-amylase by the Falling number method according to Hagberg-Perten (ICC Standard 107, 1986) were determined.

Statistical analysis of the impact of the cultivar, area and year on the bread-making quality was performed with Design Expert 7.1.3 (Stat-Ease, USA), using the General Factorial Design test plan with three different factor categories. The actual and coded values of tested factors (cultivar, year and cultivated area) of standard winter wheat cultivars are shown in Table 1. Meteorological data, temperatures, rainfalls quantity and relative humidity per tested year and area, were obtained from Zagreb and Osijek city weather stations. All results ware presented as mean values of at least three determinations.

Results and discussion

The determined quality parameters of grain, flour and dough of tested wheat samples are shown in Table 2. The bread-making quality of wheat grain is described by hectoliter mass (Hm, kg/hL), milling yield (Iz,%), protein quantity (Pr,% dm) and sedimentation value (SE, cm^3). The average Hm of standard winter wheat tested samples was 82.53 kg/hL, ranging from 76.00 – 82.53 kg/hL, with variation coefficient (CV) 2.48%. While the average Hm of cultivars 'Žitarka' and 'Sana' was almost the same, 76.50 kg/hL (CV 2.86%) and 76.46 kg/hL (CV 2.41%) respectively, the Hm of cultivar Divana was 78.80 kg/hL (CV 1.88%). The mean values of temperatures, rainfall quantity and relative humidity per tested year and area are shown in Table 3. Statistical analysis of the data has shown that climate conditions in tested cultivation years ($p<0.0001$) had the most important influence on grain Hm. The cultivar was following ($p<0.0001$) that means that it is a cultivar characteristic. Furthermore, cultivar and area interaction had significant influence on Hm ($p<0.0695$), while the cultivation area i.e. soil quality was not significant ($p<0.3065$). The mathematical model is shown in its coded form (Equation 1):

$$Hm=80.15+1.14^{***}\times A_1-0.074^{***}\times A_2-2.68^{***}\times B_1+2.01^{***}\times B_2-0.32^{***}\times B_3+0.044^{***}\times B_4+0.17^{*}\times C-0.006^{*}\times A_1C+0.49^{*}\times A_2C \quad (1)$$

*** significant at p≤0.01; ** significant at p≤0.05;
* significant at p≤0.1

Table 1. Actual and coded values of tested factors

Sample No	Cultivar	Actual input values				Coded input values			
		mark	Year	mark	Area	mark	Cultivar	Year	Area
1	Divana	A1	1998	B1	Zagreb	C1	1 0	1 0 0 0	-1
2	Žitarka	A2	1998	B2	Zagreb	C1	0 1	1 0 0 0	-1
3	Sana	A3	1998	B3	Zagreb	C1	-1 -1	1 0 0 0	-1
4	Divana	A1	2000	B4	Zagreb	C1	1 0	0 1 0 0	-1
5	Žitarka	A2	2000	B5	Zagreb	C1	0 1	0 1 0 0	-1
6	Sana	A3	2000	B1	Zagreb	C1	-1 -1	0 1 0 0	-1
7	Divana	A1	2002	B2	Zagreb	C1	1 0	0 0 1 0	-1
8	Žitarka	A2	2002	B3	Zagreb	C1	0 1	0 0 1 0	-1
9	Sana	A3	2002	B4	Zagreb	C1	-1 -1	0 0 1 0	-1
10	Divana	A1	2004	B5	Zagreb	C1	1 0	0 0 0 1	-1
11	Žitarka	A2	2004	B1	Zagreb	C1	0 1	0 0 0 1	-1
12	Sana	A3	2004	B2	Zagreb	C1	-1 -1	0 0 0 1	-1
13	Divana	A1	2006	B3	Zagreb	C1	1 0	-1-1-1-1	-1
14	Žitarka	A2	2006	B4	Zagreb	C1	0 1	-1-1-1-1	-1
15	Sana	A3	2006	B5	Zagreb	C1	-1 -1	-1-1-1-1	-1
16	Divana	A1	1998	B1	Osijek	C2	1 0	1 0 0 0	1
17	Žitarka	A2	1998	B2	Osijek	C2	0 1	1 0 0 0	1
18	Sana	A3	1998	B3	Osijek	C2	-1 -1	1 0 0 0	1
19	Divana	A1	2000	B4	Osijek	C2	1 0	0 1 0 0	1
20	Žitarka	A2	2000	B5	Osijek	C2	0 1	0 1 0 0	1
21	Sana	A3	2000	B1	Osijek	C2	-1 -1	0 1 0 0	1
22	Divana	A1	2002	B2	Osijek	C2	1 0	0 0 1 0	1
23	Žitarka	A2	2002	B3	Osijek	C2	0 1	0 0 1 0	1
24	Sana	A3	2002	B4	Osijek	C2	-1 -1	0 0 1 0	1
25	Divana	A1	2004	B5	Osijek	C2	1 0	0 0 0 1	1
26	Žitarka	A2	2004	B1	Osijek	C2	0 1	0 0 0 1	1
27	Sana	A3	2004	B2	Osijek	C2	-1 -1	0 0 0 1	1
28	Divana	A1	2006	B3	Osijek	C2	1 0	-1-1-1-1	1
29	Žitarka	A2	2006	B4	Osijek	C2	0 1	-1-1-1-1	1
30	Sana	A3	2006	B5	Osijek	C2	-1 -1	-1-1-1-1	1

The equation explained 95.35% of total Hm variability in tested wheat grain samples. As shown in Equation 1, the considerable rainfall in the period of grain growth, soaking and harvest itself, had a negative influence on Hm, especially in year 1998. At the same time, the Zagreb area had less rainfall and average temperature was for 1.9 °C higher which had a positive influence on Hm of tested cultivars grain. The Osijek area had a small amount of rainfall (Table 3) in the same period and the same average temperature, and no important variations in Hm were determined.

The average protein content (Pr) in the tested wheat samples ranged from 10.79-16.26% dm, while the mean value was 13.71% dm (CV 10.43%). The average Pr in cultivar Divana was 15.08% dm (CV 3.94%), while lower in cultivar Žitarka, 13.80% dm (CV 7.94%) and in cultivar Sana 12.55% dm (CV 10.43%). The statistical analysis has shown that the most important influence on the protein content in wheat had the cultivar itself ($p<0.0001$). This was expected, since the cultivars differ by the protein quantity and quality that is a genetic characteristic. However, important impact on the protein quantity had the year ($p<0.0007$), area ($p<0.1708$) and the cultivation year-area interaction ($p<0.0210$), which is connected with the soil quality and climate conditions characteristic for the tested year and area. The mathematical model explained 84.93% of total variability ($p<0.0001$) of protein content in tested samples (Equation 2):

$$\begin{aligned}Pr=&+13.71+1.11^{***}\times A_1+0.085^{***}\times A_2+0.15^{***}\times B_1\\&+1.00^{***}\times B_2+0.31^{***}\times B_3-0.21^{***}\times B_4\\&-0.19^{**}\times C+0.20^{**}\times B_1C-0.99^{**}\times B_2xC\\&+0.44^{**}\times B_3\times C+0.25^{**}\times B_4\times C \qquad (2)\end{aligned}$$

The climate conditions were extremely good in the period of protein growth and grain development in the Zagreb area in year 2000. This was not the case in the Osijek area where was drough and high temperature in the same period of grain growing and soaking (Table 3). The protein content in wheat cultivars on both locations was constantly decreasing over the years for all tested cultivars. The protein content in individual cultivars is a cultivar characteristic and was not dependent on cultivation location. Regarding the protein quantity, cultivar Divana was in quality category I (≥13.0%), cultivar Žitarka in between quality category I and II (≥11.5%), and cultivar Sana varied between quality category II and III (≥10%).

The sedimentation value (SE) is an indicator of gluten quality. Determined SE ranged from 21 to 66 cm^3. The SE mean value for the tested cultivar was 40.57 cm^3 that indicated a very good quality. However the CV was very high 28.89% that implied instability of tested cultivars. The SE for cultivar Divana ranged from 42 – 66 cm^3 (CV 19.44%), cultivar Žitarka 34 – 48 cm^3 (CV 14.21%) and cultivar Sana 21 – 36 cm^3 (CV 13.86%) what is in agreement with previous results by Unbehend et al., 2004. SE was the most influenced by the cultivar ($p<0.0001$) and cultivation year ($p<0.0061$), while cul-

Table 2. Quality properties* of standard winter wheat cultivars (mean values)

Sample No	Pr (% dm)	SE (cm^3)	Hm (kg/hl)	Iz (%)	Vg (%)	BP (s)	KB	Vmax (AU)	E (cm^2)	O/R
1	14.62	42	78.80	73.09	25.00	267	57.1	295	100.2	2.0
2	14.08	35	76.56	68.80	25.40	345	55.4	1330	97.7	3.6
3	12.84	21	76.46	73.96	18.18	307	45.4	1390	62.6	2.7
4	16.26	45	82.37	69.59	31.74	416	92.1	1160	132.2	1.0
5	15.86	35	82.53	67.73	36.33	400	68.0	1380	54.9	1.0
6	15.56	31	81.85	68.69	30.01	391	54.4	1645	48.2	0.9
7	14.21	42	80.98	72.52	33.11	400	92.1	650	111.8	1.0
8	14.10	37	77.76	70.62	36.68	439	61.3	1600	52.7	1.2
9	12.99	29	78.28	73.00	29.33	391	60.2	1430	57.3	1.1
10	15.43	62	82.01	73.76	31.60	353	82.7	780	115.3	1.0
11	13.36	48	79.68	67.94	34.10	306	63.8	1340	73.3	1.2
12	11.52	28	79.24	73.26	24.31	308	45.3	1500	54.5	1.5
13	14.73	66	81.47	72.00	33.90	376	83.7	1320	122.1	1.0
14	12.15	45	80.54	69.25	32.90	345	66.7	950	70.5	1.2
15	10.79	35	81.21	73.25	24.70	357	50.6	1550	58.9	1.2
16	14.48	63	80.28	73.36	33.00	310	100.0	800	128.3	1.4
17	13.90	38	76.75	70.18	32.90	331	65.4	1400	74.1	2.2
18	13.27	36	76.00	73.44	27.00	306	48.6	1650	64.8	1.9
19	15.20	50	82.31	70.68	32.22	399	78.8	1280	89.2	2.0
20	13.06	34	82.34	66.11	36.18	294	58.1	800	51.1	0.9
21	12.36	30	81.58	72.33	27.33	368	52.8	1660	50.5	1.3
22	15.10	42	81.21	72.77	30.80	422	87.5	1030	93.4	1.5
23	15.01	35	81.81	68.75	35.51	393	60.2	1380	77.3	1.4
24	12.74	31	78.93	71.75	28.44	390	52.6	1590	65.9	1.2
25	15.40	52	81.14	70.19	35.20	348	83.7	1100	124.8	1.2
26	13.87	47	80.93	67.67	34.40	359	62.0	1540	80.5	1.4
27	11.44	29	78.18	70.65	27.80	307	48.3	1880	66.2	1.6
28	12.80	66	82.33	68.90	33.00	428	74.6	1510	105.2	1.4
29	12.60	35	81.89	65.60	28.60	403	53.3	1190	75.9	1.7
30	11.68	28	79.17	69.30	23.70	376	36.0	1780	63.0	1.6

*Pr protein content, SE sedimentation value, Hm hectoliter mass, Iz milling yield, Vg wet gluten content, BP falling number, KB quality number, Vmax maximum viscosity, E dough energy, and O/R dough resistance/extensibility

Table 3. Average annual and periodical (March-June) values of temperature, air humidity (RH) and rainfalls in tested wheat cultivation years for Zagreb and Osijek area

	Osijek area					Zagreb area				
	1998	2000	2002	2004	2006	1998	2000	2002	2004	2006
Temperature annual, °C	11.3	12.9	12.1	11.0	11.5	11.2	12.7	12.3	11.2	11.8
3-6 month, mean temperature, °C	13.8	15.7	14.8	12.8	13.6	13.6	15.3	14.8	12.8	13.7
Total rainfalls per year, mm/m^2	684.0	317.0	656.0	865.4	646.9	1026.1	721.2	980.0	918.4	724.5
Total rainfalls 3-6 month, mm/m^2	149.9	104.4	251.0	322.3	308.9	335.3	185.2	321.0	337.4	274.4
Rainfalls, mean 3-6 month, mm/m^2	37.5	26.1	62.8	80.6	77.2	83.8	46.3	80.3	84.4	68.6
RH annual %	74	70	80	81	80	75	71	75	74	74.0
RH 3-6 month %	68.0	62.5	65.0	78.8	75.8	68.3	63.8	67.5	71.3	67.8

tivation area (p<0.5100), cultivar - year interaction (p<0.0318) and year - area interaction (p<0.0195) had lower influence. The mathematical model (Equation 3) explained 96.10% of the total SE variability (p<0.0001) in tested wheat samples:

$$SE=+40.57+12.43^{***}\times A_1-1.67^{***}\times A_2-1.40^{*}\times B_1 -3.07^{*}\times B_2-4.57^{*}\times B_3+3.77^{*}\times B_4+0.50^{*}\times C+0.90^{*}\times A_1B_1 -1.00^{*}\times A_2B_1-2.43^{*}\times A_1B_2-1.33^{*}\times A_2B_2-0.43^{*}\times A_1B_3 + 1.67^{*}\times A_2B_3 +0.23^{*}\times A_1B_4+4.83^{*}\times A_2B_4+6.00^{*}\times B_1C -0.50^{*}\times B_3C-2.17^{*}\times B_4C \quad (3)$$

Unlike the total protein content, the sedimentation value for all tested cultivars has been increasing over the investigated years in the Zagreb and Osijek area.

For all tested samples, the average milling yield (Iz) was in the range from 65.60 – 73.96%. In average, the Iz of cultivar Divana was 71.69% (CV 2.39%), cultivar Žitarka 68.27% (CV 2.36%), and cultivar Sana 71.96% (CV 2.55%). By statistical analysis it was shown that the cultivar (p<0.0001) and cultivation year - climate conditions (p<0.0057) had the highest influence on the wheat milling yield. The obtained mathematical model (Equation 4) explained 73.59% of the total variability (p<0.0001) of milling yield in tested wheat samples:

$$Iz=70.64+1.05^{***}\times A_1-2.37^{***}\times A_2+1.50^{***}\times B_1 -1.45^{***}\times B_2+0.93^{***}\times B_3-0.060^{***}\times B_4 \quad (4)$$

As shown in Equation 4, the milling yield was highly depended on the cultivar and represents a cultivar characteristic, but was also changed under the influence of external conditions. In year 2000, intensive drought occurred in the Osijek area (Table 3), especially in the period of grain growth, development and soaking that had negative influence on milling yield, particularly in the case of cultivar Žitarka. Milling yield of all cultivars decreased during the tested year caused by increased average annual temperature and decreased rainfalls.

The gluten quantity and quality is considered as the most important flour quality parameter that determines technological usage (Ćurić et al., 2001). The average value of wet gluten content (Vg) in tested flour samples was 30.45%. Cultivar Divana flour contained 25.00 – 35.20% Vg (CV 8.59%), cultivar Žitarka flour contained 25.40 – 36.68% Vg (CV 10.99%), and cultivar Sana flour 18.18 – 30.01% Vg (CV 13.41%). The wet gluten content of flour samples correlated to the protein content in the grain (r=0.5451), SE value (r=0.5326), flour KB (r=0.5541) and Hm (r=0.5027). By statistical analysis it was shown that the follwing parameters: cultivar (p<0.0001), cultivation year (p<0.0001) and cultivation year - area interaction (p<0.0001) had the most important influence on the wet gluten content. The important influence of cultivation area (p<0.0086) and cultivation year - cultivar interaction (p<0.0114) on Vg was also proven. The mathematical model (Equation 5), explained 98.13% of the total variability (p<0.0001) of wet gluten content in the tested flour samples:

$$Vg = 30.45+1.51^{***}\times A_1+2.85^{***}\times A_2-3.53^{**}\times B_1 +1.86^{**}\times B_2+1.87^{**}\times B_3+0.79^{**}\times B_4+0.63^{**}\times C +0.58^{*}\times A_1B_1-0.62^{*}\times A_2B_1-1.83^{*}\times A_1B_2+1.10^{*}\times A_2B_2 - 1.87^{*}\times A_1B_3+ 0.93^{*}\times A_2B_3+0.65^{*}\times A_1B_4+0.16^{*}\times A_2B_4 +3.43^{**}\times B_1C-1.02^{**}\times B_2C1.35^{**}\times B_3C+ 0.61^{**}\times B_4C \quad (5)$$

The flour samples of all three tested wheat cultivars had lower wet gluten content in the years with increased rainfall and higher average temperature in the harvest period that caused germination and enzyme degradation of the grain protein (Table 3). Wet gluten content was slowly decreasing for all tested cultivars during the investigated period. In 'Sana' flour samples there was not enough wet gluten to produce high quality bread, since required quantity is more than 24% of wet gluten. Therefore the addition of flour with higher gluten content in optimal quantity is needed.

Maximum viscosity (Vmax) of tested flours determined by Brabender amylograph ranged from 295 -1880 AU with a high variation coefficient, 27.57%. Divana cultivar flour had the maximum viscosity from 295 - 1510 AU, mean value was 992.5 AU with high CV 36.56%. Žitarka cultivar flour had the maximum viscosity from 800 - 1600 AU, mean value was 1291 AU, with high CV 19.26%. Sana cultivar flour had the maximum viscosity 1390 - 1880 AU, mean value was 1607 AU (CV 9.36%). Statistically, the cultivar had the strongest influence on Vmax (p<0.0001) and therefore the cultivar stability is genetic characteristic. Vmax was influenced by the cultivation year (p<0.255), cultivation area (p<0.0445), and cultivar - cultivation year interaction (p<0.0144). The mathematical model (Equation 6) explained 87.14% of the total variability (p<0.0001) in maximum viscosity of tested flour samples:

$$Vmax=1297.0-304.50^{***}\times A_1-6.00^{***}\times A_2 -152.83^{**}\times B_1+23.83^{**}B_2-17.00^{**}\times B_3+59.67^{**}\times B_4 +75.67^{**}\times C-292.17^{**}\times A_1B_1+226.83^{**}\times A_2B_1 +203.67^{**}\times A_1B_2-24.83^{**}\times A_2B_2-135.50^{**}\times A_1B_3 +216.00^{**}\times A_2B_3-112.17^{**}\times A_1B_4+89.33^{**}\times A_2B_4 \quad (6)$$

The cultivar Divana showed the highest variability in the maximum viscosity, and Sana cultivar was the most resistant to climate changes although they were very different regarding quality factors (Divana>Žitarka>Sana). The optimum values of maximum viscosity of flour for the production of good bakery products are within the range of 500 -700 AU. Amylolitic enzymes as improver have to be added to all flour samples with Vmax>700 AU, while flours with Vmax<500 AU are to be mixed with flours of low amylolitic activity in appropriate ratio.

Similar results of analysis of the tested factors influence on the falling number (BP) were obtained. Falling number of the tested samples ranged from 267 - 439 s, with CV 12.39%. BP of cultivar Divana flour was from 267 - 428 s and mean value was 371.9 s (CV 14.07). BP of cultivar Žitarka flour ranged from 294 - 439 s, mean value was 361.5 s (CV 12.82%), and cultivar Sana BP was from 306 - 391 s, with mean value 350.1 (CV 11.03%). Statistical analysis has shown that the cultivation year i.e. climate conditions (p<0.0001), had the most significant influence on BP. The obtained mathematical model (Equation 7) explained 61.41% of the total variability (p<0.0001) in falling number of the tested samples:

$$BP=361.1-50.17^{***}\times B_1+16.83^{***}\times B_2+44.67^{***}\times B_3 -31.00^{***}\times B_4 \quad (7)$$

All tested samples had low amylolitic activity (>300 s). Sana cultivar has shown the highest stability and adaptibility to the climate changes.

Quality number (KB) of the tested flours ranged from 36.0 - 100.0, with high CV 24.76%. KB of cultivar Divana flours was in the range from 57.1 - 100.0 and the mean value was 83.23 (CV 14.07%). All flours were categorized as quality group A apart for 1998 flour that was categorized as quality group B. KB of cultivar Žitarka flour ranged from 53.3 - 68.0, mean value was 61.42 (CV 7.82%) and therefore 'Žitarka' flours were categorized as quality group B1. KB of cultivar Sana flour was in the range of 36.0 - 60.2, mean value was 50.32 (CV 12.91%). These flours were categorized under B2 and C1 quality group. By statistical analysis it was shown that the cultivar had the strongest influence on KB (p<0.0001), while significant influence of cultivation year (p<0.1363), cultivation area (p<0.6128) and cultivation year-area interaction (p<0.0027) were also proven. The significant correlation between KB and SE (r=0.7496); Pr (r=0.6907); and Vg (r=0.5541) was determined. The obtained mathematical model (Equation 8) explained 91.61% of the total variability (p<0.0001):

$$KB=64.69+18.54^{***}\times A_1-3.27^{***}\times A_2-2.71^{***}\times B_1 +2.68^{***}\times B_2+4.29^{***}\times B_3-0.39^{***}\times B_4 -0.56^{***}\times C+9.91^{***}\times B_1C-3.57^{***}\times B_2C -1.65^{***}\times B_3C+0.93^{***}B_4C \quad (8)$$

As shown in Equation 8 flour quality was dependent on the genetic predispositions, but also on the cultivation area and year. The Zagreb area was evidently more favourable for all cultivars than Osijek area. Sana cultivar flour should be mixed with "improver" cultivar flour to accomplish optimal dough consistency for bread making.

The results of the performed rheology analysis by exstensograph have shown that cultivar Divana flour had energy (E) in the range from 89.2 - 132.2 cm^2 (CV 14.07%), cultivar Žitarka from 51.1 - 97.7 cm^2 (CV 21.08%), and cultivar Sana flours from 48.2 - 66.2 cm^2 (CV 10.89%). The dough resistance/extensibility (O/R ratio) for cultivar Divana was in the range of 1.1 - 2.0 (CV 21.52%); cultivar Žitarka in the range of 0.9 - 3.6 (CV 50.7%) and the range for cultivar Sana flour was 0.9 - 2.7 (CV 31.14%). Statistical analysis has shown that only the cultivar significantly influenced E (p<0.0001). The significant correlation between E and SE (r=0.7792) and Pr (r=0.5628) as well as negative correlation with Vmax (r=-0.5322) was found. The O/R ratio was affected by the cultivation year - climate conditions (p<0.0000), cultivation area (p<0.4020), cultivar (p<0.1242), cultivation year - area interaction (p<0.0020), and cultivar - year interaction (p<0.0189). The Equation 9 explained 78.56% of the total variability (p<0.0001) of dough energy of the tested flour samples:

$$E = 80.75 + 31.50^{***} \times A_1 - 9.95^{***} \times A_2 \quad (9)$$

The mathematical model as shown in Equation 10 explained 94.62% of total variability (p<0.0001) of O/R ratio in dough of tested flour samples:

$$O/R = 1.48 - 0.13^{**} \times A_1 + 0.10^{**} \times A_2 + 0.82^{***} \times B_1 - 0.29^{***} \times B_2 - 0.24^{***} \times B_3 - 0.16^{***} \times B_4 + 0.037^{**} \times C - 0.47^{**} \times A_1B_1 + 0.50^{**} \times A_2B_1 + 0.44^{**} \times A_1B_2 - 0.34^{**} \times A_2B_2 + 0.14^{**} \times A_1B_3 - 0.037^{**} \times A_2B_3 - 0.090^{**} \times A_1B_4 - 0.12^{**} \times A_2B_4 - 0.50^{**} \times B_1C + 0.18^{**} \times B_2C + 0.097^{**} \times B_3C + 0.047^{**} \times B_4C \quad (10)$$

As shown in Equations 9 and 10, only 'Divana' flour formed dough with an optimal energy and O/R ratio. 'Žitarka' and 'Sana' flours formed dough of lower energy and increased O/R, which was affected by the gluten content and quality in wheat protein as a cultivar characteristic. Only with improver addition or by mixing those flours with higher quality flours, it is possible to obtain dough of satisfying energy and optimal O/R ratio. The negative correlation between O/R ratio and Hm (r=-0.6142) as well as Vg (r=-0.5322) was found. The O/R ratio is primarily a cultivar characteristic but the influence of the cultivation year and area was significant.

Conclusion

The bread-making quality of the tested winter wheat cultivars was primarily dependent on the cultivar's genetic properties. However, the climate changes which have been occurring for the last 10 years, especially increased temperatures and rainfalls in the period of growth, ripening of the grain and at harvest time, had a significant negative influence on the grain bread-making quality. The rheological properties of wheat dough were significantly influenced by the increased rainfalls in the period of growth and soaking of the grain, as well as in the harvest time. Even though the average values of tested quality factors were within the range of expected values for the cultivar, it has to be emphasized that cultivar Divana bread-making quality was significantly dependent on the climate conditions. Sana cultivar was proven as the most stable, although it's bread-making quality was the lowest. For all three cultivars the bread-making quality has been decreasing over the last 10 years, though it was better for winter wheat cultivars originating from the Zagreb area.

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