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Original scientific paper

EFFECT OF GROWING SEASON AND VARIETY ON QUALITY OF SPRING TWO-ROWED BARLEY

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Quality of barley consists of precisely defined grain quality attributes (grain weight, grading, grain protein concentration, etc.) and malt quality attributes (extract, viscosity, Kolbach index, etc.). Barley quality attributes are quantitatively inherited and greatly affected by environmental factors such as temperature, available water, nitrogen fertilizer and soil type. The main objective of this study was to determine the effects of genotype and growing conditions (year) on grain and malt quality attributes in barley grown under field conditions in the Pannonian zone. The eight spring two-row barley varieties were studied during a seven growing seasons (1998-2004) on the location Novi Sad (45°20'N, 15°51'E, 86 m asl). The growing season predominantly affected variation of the all studied grain and malt quality attributes of spring barley where its percentage of variance was 35.2%, 20.2%, 32.5%, 25.4%, 30.9%, 31.2%, and 38.5% for grain weight (GW), grading (GRA), grain protein content (GPC), viscosity (VIS), Kolbach index (KOL), Hartong number (HAR) and extract content (EXT), respectively. The interaction of GxE comprised of 28.4%, 64.5%, 38.2%, 54.0%, 39.6%, 41.2% and 23.7% of variation for GW, GRA, GPC, VIS, KOL, HAR and EXT, respectively. The genetic component of variance ranged from 11.1% for GRA to 35.0% for EXT. The heritability was the lowest for GRA-0.54 and the highest for EXT-0.91. Across growing seasons GW ranged from 39.6 to 46.1g, GRA from 76.7 to 91.1%, GPC from 12.1 to 13.5g 100^{-1}g dm, VIS from 1.44 till 1.61m.Ps, KOL from 32.5 to 42,9%, HAR from 31.9 to 45.9VZ 45°C and EXT from 76.3 to 80.3% dm. Out of seven growing seasons EXT was acceptable in four ranging from79.2 to 81.4% dm. Although growing conditions in the Pannonian zone are less favorable for malting barley production in relation

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to western Europe it does not exclude malting barley production with acceptable quality in the Pannonian zone environments. The varieties Scarlett and Viktor performed quite acceptable quality in the Pannonian zone and may be recommended for commercial production in this region for malt industry.

Key words: Barley (*Hordeum vulgare* L), growing season, interaction, variety, quality, Pannonian zone

INTRODUCTION

Quality of barley is a complex trait that is determined by numerous genetic and environmental factors. Malting quality attributes are quantitatively inherited and greatly influenced by environmental factors such as temperature, available water, nitrogen fertilizer and soil type (ZHANG *et al*., 2006; PETTERSSON and ECKERSTEN, 2007). In some growing seasons environmental conditions reduce the quality of superior varieties till feeding barley (PRŽULJ and MOMČILOVIĆ, 2008). Genetic variation of complex traits, (yield and quality), has the highest importance since it provides stability of the traits and determines the effectiveness of selection. Malt extract is certainly the most important indicator of barley quality (SAVIN and MOLINA-CANO, 2002). The malt extract content is also a complex trait, which represent the proportion of the potentially fermentable grain components (MOLINA-CANO *et al*., 2000). The quality attributes of malting barley consist of grain quality attributes (e.g. grain weight, grading, grain protein concentration) and malt quality attributes (e.g. extract, viscosity, Kolbach index), which are precisely defined by the barley breeders across the world and the producers that are aware of which barley may be accepted as malting barley.

Grain weight is an important quality attribute of barley due to a positive relationship between grain weight and starch content that is a main source of malt extract (SAVIN and MOLINA-CANO, 2002). The grain size is another important barley grain property since grains >2.5mm are mainly being used for malting and grains <2.5 mm for feeding. Also the grain size is important because it is likely to ensure the germination rate uniformity (PASSARELLA *et al*., 2003). ABELEDO *et al*. (2003) found that the barley grain weight in Argentina in the period from 1944 to 1998 did not increase by breeding and yield increased in that period was result of the increased number of grains per spike. The grain weight threshold of 40 mg is required to achieve the maximum grading percentage. Due to the lower grading approximately 5% of grains are lost per mg of grain weight reduction and crop with thousand grains that weight less than 36-37g would be used for feed barley (SAVIN and MOLINA-CANO, 2002). Hot and dry conditions affect the rate and duration of grain filling thereby reducing grain weight, size and consequently quality (PRŽULJ *et al*., 2000).

Due to the dilution of nitrogen by increased yields high yielding varieties have lower grain protein content (ABELEDO *et al*., 2002; GRAUSGUBER *et al*., 2002; GIANINETTI *et al*., 2005). Although many authors point out the inverse relationship of malt extract and grain protein concentration, SAVIN and MOLINA-CANO (2002) had doubts in the absoluteness of this relationship since the composition of barley grain is very complex and their mutual relationship in interaction with environment defines malt extract. The inverse relationship between malt extract and grain protein content is determined by variety and environment and therefore the value of the relationship is more-less specific for each variety. This negative correlation is mainly due to hordein fraction of the proteins (MOLINA-CANO *et al*., 2004). Hordein fraction has two main negative effects; decreasing starch level due to negative correlation with starch and restricting access by amylolytic enzymes to starch during germination since the starch granules are embedded into endosperm protein matrix with hordein as main component (QI *et al*., 2006). Viscosity is significant indicator of malt modification and it increases the filtration difficulty, it also indicates the amount of wort β-glucan, which affects beer stability (GIANINETTI *et al*., 2005).

Progress in genetic improvement of malting barley quality in many countries is less advanced than yield improvement (PASSARELLA *et al*., 2003). However, grain protein content has been analyzed in some trials where it was found that the nitrogen harvest index was higher in new than in old varieties due to a limited amount of nitrogen being diluted in the higher yield of new varieties (CALDERINI *et al*., 19990).

As far as we are aware, there are very few papers related to the quality attributes of barley in the growing conditions of the Pannonian zone (PRŽULJ *et al.,* 1998). The main objective of this study was to investigate the effects of genotype and growing conditions (year) on grain and malt quality attributes in spring two-row barley grown under field conditions of the Pannonian zone.

MATERIALS AND METHODS

Field trial and grain analysis. The eight spring two-row barley varieties were studied during a seven-year (1998-2004) period in the location of Novi Sad (45°20'N, 15°51'E, 86 m asl). A complete randomized block design with three replications was used. The sowing dates were 16 February 1998, 1 March 1999, 15 February 2000, 13 February 2001, 13 February 2002, 13 March 2003, and 12 March 2004. Plots 5m x 1m in size with 10 cm between rows were sown at the rate of 400 germinable grains m^{-2}. The growing practices applied were those regularly used for large-scale spring malting barley production. The grains were sieved before the analysis on Sortimat machine (Pfeuffer) and the grading percentage (GRA, %), i.e., grains retained on a 2.5mm and 2.8mm sieves (I class) was recorded and used for studying grain physical properties, grain protein concentration (GPC, g 100^{-1}g dm) and micro-malting. Grain weight (GW, g) was determined from graded samples by measuring three sets of 300 grains per plot and expressed as weight of 1000 grains. Grain N concentration obtained by Kjeldahl analysis and protein concentration expressed on a dry weight basis was estimated by multiplying grain N by 6.25. Micro-malting was conducted according to a procedure recommended by the European Brewery Convention (Analytica-EBC, 1998) four months after harvesting using the micromalting plant Seeger, Germany. After malting viscosity (VIS, m.Ps), Kolbach index (KOL, %), Hartong number (HAR, VZ 45°C) and malt extract content (EXT, % dm) were determined.

Statistical analyses. Two-way ANOVA and estimates of variance components due to genotype, year, and genotype x year interaction were made. A mixed model was used, with genotypes considered as fixed and years as random effects (ZAR, 1996). The Genstat v10 procedures and programs were used for the data processing.

Narrow-sense heritability was estimated using the variance components as follows:

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \left(\frac{\sigma_{ge}^2}{e}\right) + \left(\frac{\sigma_{res}^2}{re}\right)}$$

where σ^2_g is the variance component of the genotype, σ^2_{ge} the variance component of the interaction genotype x environment, σ^2_{res} the error, *e* the number of the environments-years, and *r* the number of replications (BORRÀS *et al*., 2009) . The Genstat v10 procedures and programs were used for data processing.

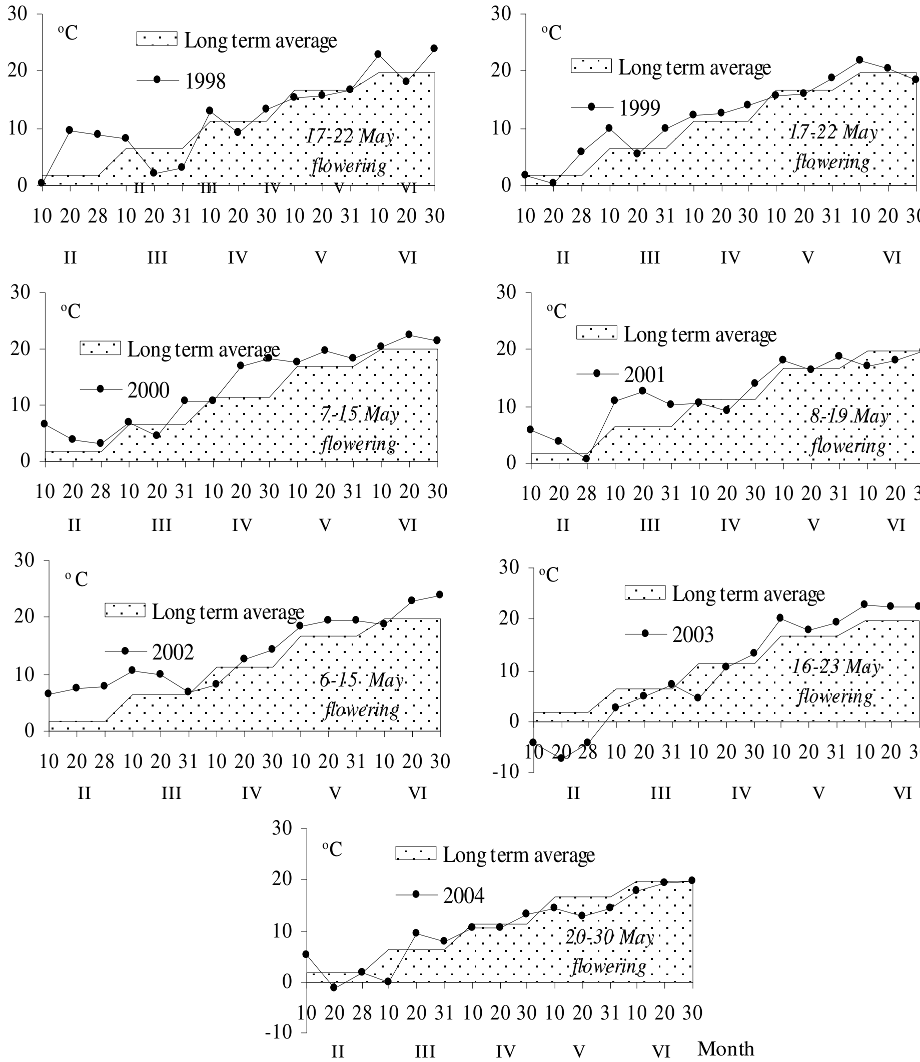

Fig. 1a. Long term average (1964-2004,) and 10 days average (1998-2004 year period,) of temperatures from sowing to harvest of spring barley.

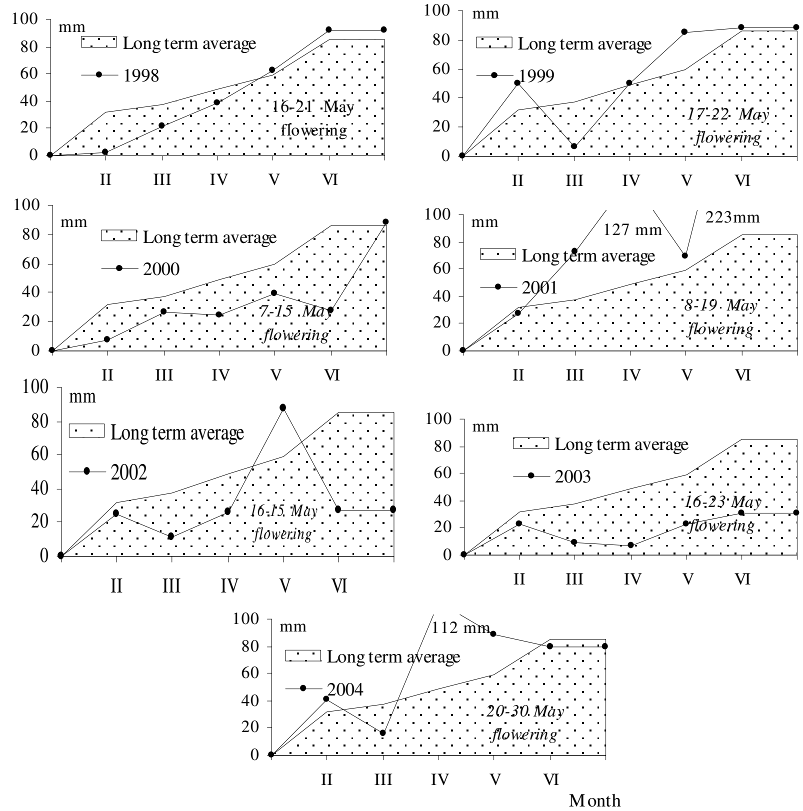

Fig. 1b. Long term average (1964-2004,) and 10 days average (1998-2004 year period,) of precipitation from sowing to harvest of spring barley.

Weather conditions. The 1998 spring barley growing season was characterized by high temperatures and water deficit during tillering and moderate temperatures and precipitation during grain filling. Period from barley emergence to stem elongation in the 1999 was characterized by temperatures above and precipitation under long-term average. Temperatures and precipitation during the grain filling period were similar to the long-term averages. The 2000 growing season was characterized as considerably warm, but not hot, with precipitation lower than the long-term average. In 2001 warm and wet weather persisted during the entire spring barley growing season. In 2002, temperatures during tillering were much higher than the average, while they were on the long-term average level during grain filling. Except for May when spring barley passed through the stage of flowering, the precipitation in all other months were below the long-term average, but it could not be considered as dry. A cold period during tillering and a very warm period during grain filling are main thermal features of 2003. That year was extremely dry. Moderate temperatures and precipitation during tillering and a cold and very wet weather during grain filling are main characteristics of the 2004 growing season of spring barley. Temperature lower than 0°C did not occur after jointing in any of the experimental years.

RESULTS AN DISCUSSION

Growing season was prominently responsible for variation of the all studied grain and malt quality attributes of spring barley (Table 1). Growing season was main factor influencing GW while values of variety and the interaction GxY effects were similar (Table 2). FOX *et al.* (2006) demonstrated the strong genetic and environmental effects on GRA, while in our study the highest variation of GRA was due to the interaction GxY (Table 2). Indeed, genotype determined less variation of GRA (11.14%), but genotype expressed its effects mainly through important interaction with growing season. The genetic variance for GRA is the highest when growing conditions are unstressed (FOX *et al.*, 2006). Heritability for GW was rather high and moderate for GRA.

Table 1. Ranges of variety and year mean values for the tested attributes of 8 spring barley varieties grown in 7 growing seasons (1998-2004) period

Parameter	Genotype (n=8)			Growing season (n=7)			Mean
	Min	Max	Diff.	Min	Max	Diff.	
Thousand grain weight (TGW)	39.58	46.11	6.53	37.7	49.5	11.8	43.3
Grading (GRA)	76.7	91.1	14.4	75.3	94.6	19.3	85.1
Grain protein concentration (GPC)	12.1	14.1	2.0	11.5	14.6	3.1	13.1
Viscosity (VIS)	1.438	1.607	0.169	1.316	1.695	0.379	1.499
Kolbach index (KOL)	32.52	42.85	10.33	27.44	46.36	18.92	37.73
Hartong number (HAR)	31.91	45.-91	14.0	37.05	47.34	10.3	39.94
Malt extract content (EXT)	76.3	80.3	4.0	76.1	80.9	4.8	78.9

GPC in barley was mainly determined by the interaction GxY and 38% of the variation belonged to this source of variation (Table 2). The range of variation of GPC showed that year was responsible for more than sevenfold variation in relation to the variety (Table 1). Heritability for GPC was high, 0.83. In this study, VIS depended mostly of the interaction GxY and growing seasons (Tables 1 and 2). Heritability for VIS was 0.69. Malt modification, estimated through protein modification (KOL) and cytolytic and proteolytic activities of malt enzymes (HAR), was mainly determined by the interactions, while genotype was responsible for about one quater of the variation. Heritability for the both malt modification attributes was almose equal, 0.81. EXT is the most important trait of malting barley and it is the measure of the amount of fermentable sugars. In our study, EXT depended mostly on growing season and genotype, although 23.7% of variation belonged to the interaction GxY (Table 4). Heritability for EXT content was very high, 0.91.

Across growing seasons varieties significantly differed ($P<0.01$) in GW (Table 3). The varieties Scarlett and Viktor had the highest GW, 46.1g and 45.2g, respectively and the variety NS 450 the lowest (39.4g). The highest GW across varieties was in 2000 and the lowest in 1998 growing season. Six varieties had the highest grain weight in 2000, one in each 2001 and 2002 growing seasons. The low average GW in 1998 was due to value of 5 varieties that had the lowest GW in that growing season. In regard to GW, 1999 growing season was the poorest for the varieties NS 454, Viktor, and NS 462. If GW threshold of 40mg is required to achieve a maximum GRA (SAVIN and MOLINA-CANO, 2002), varieties NS 450 and may be NS 294 are not suitable for malting. In regard to GW almost all varieties had low grain quality for malting in growing seasons 1998 and 1999 (Table 3). For both growing seasons high temperatures and water deficit characterized period from sowing till anthesis (Figure 1a, b).

Table 2. Mean squares from the ANOVA, percentage of variance components and heritability of thousand grain weight (TGW), grading (GRA), grain protein concentration (GPC), viscosity (VIS), Kolbach index (KOL), Hartong number (HAR) and malt extract content (EXT) in 8 spring barley varieties grown in 7 growing seasons (1998-2004) period

Source	df	TGW (g)	GRA (%)	GPC (g 100-1g dm)	VIS m.Ps	KOL (%)	HAR (VZ 45°C)	EXT (% dm)
Genotype (G)	7	139,2**	534,34	8,17**	0,06*	277,84**	386,90**	33,01**
Year (Y)	6	462,7**	1674,35**	29,34**	0,39**	1145,57**	410,89**	76,76**
G x Y	42	20,2**	244,60**	1,40**	0,02**	52,80**	74,36**	3,02**
Pooled error	110	5,7	4,69	0,03	0,00**	1,94	1,44	0,11
% of variance components								
σ_G		30,91	11,14	26,94	17,49	25,02	25,20	35,01
σ_Y		35,22	20,54	32,49	25,36	30,88	31,20	38,53
σ_{GY}		28,36	64,54	38,02	54,03	39,57	41,16	23,71
σ_E		5,51	3,78	2,54	3,12	4,53	2,44	2,76
h_b		0,88	0,54	0,83	0,69	0,81	0,81	0,91

*, ** Significant at the 0.05 and 0.01 probability level, respectively

Table 3. Thousand grain weight (g) in 8 spring barley varieties in 7 growing seasons (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	28,3	36,8	47,1	43,6	46,6	36,2	42,2	40,1
Scarlett	38,7	44,9	51,0	47,0	50,5	39,9	44,7	45,2
NS 450	33,9	36,7	44,3	41,2	44,8	35,5	40,7	39,6
NS 454	40,4	38,7	50,4	42,5	45,6	40,6	43,3	43,1
Viktor	40,9	38,8	53,3	47,9	49,5	45,1	47,3	46,1
NS 460	37,7	38,7	50,0	45,9	47,7	44,2	42,0	43,7
NS 462	43,1	40,7	51,8	48,4	47,0	42,9	41,4	45,0
NS 466	38,2	38,6	48,4	41,1	47,7	44,6	44,5	43,3
Average	37,7	39,2	49,5	44,7	47,4	41,1	43,3	43,3
	A	*B*	*AB*					
LSD 0.05	*0.57*	*0.54*	*1.52*					
0.01	*0.76*	*0.71*	*2.01*					

GRA is very important from the economical point of view. The mean GRA (>2.5mm) across eight varieties and seven years of 85%, obtained in this study (Table 4), is difficult to be acceptable economically. PASSARELLA *et al.* (2002) found a strong positive and significant relationship between screening percentage and grain weight.

PASSARELLA *et al.* (2002) found that mild heat stress late in the grain filling period is reducing grading. Heat stress in this period of grain filling is quite common in the Pannonian zone (PRŽULJ and MOMČILOVIĆ, 2009; OLESEN *et al.*, 2010). In more than 50% of the growing seasons in our study, GRA across varieties was lower than 80%. Except for two varieties that are not important in commercial production, GRA of the rest studied varieties ranged from 84% to 91%. Participation of genetic factors in the total variation was relatively low, with heritability of 0.54, which indicated a necessity to find appropriate genetic resources for improving GRA. In most countries the malting industry requires that more than 80% of the grains have bigger size than 2.5mm (SAVIN and MOLINA-CANO, 2002). Therefore, the decrease in grain weight generate higher proportion of grains <2.5mm and a smaller quantity of maltable grains, which decrease malt yield.

Grain size is an important trait for breeding both, malting and feed barley. In practical breeding large grain size is one of the primary grain quality attribute as smaller grains generally have lower levels of starch and higher protein levels, thus reducing the extract content (SAVIN and MOLINA-CANO, 2002; FOX *et al.*, 2006). Even FOX *et al.* (2006) suggested using, grain size, i.e., plumpness as important breeding criterion. FOX *et al.* (2006) found that GRA was most affected by environment but with a strong genetic effect too. The permanent stressed environment decreased levels of genetic variance suggesting that GRA is reduced to a point where it may not be useful for selecting genotypes with large grain. The selection for GRA was obviously very difficult to perform in 1998 growing season. High temperatures during grain filling diminished final grain weight and simultaneously increased GPC. Heat stress is likely to have a rather direct effect within the grain, reducing starch synthesis than related to the reduction in duration of green leaf area (PASSARELLA *et al.*, 2002; and references quoted therein).

Table 4. Grading (%) in 8 spring barley varieties in 7 growing seasons (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	42,0	71,7	95,0	96,3	94,0	59,7	92,3	78,7
Scarlett	70,0	77,0	95,0	94,7	93,3	88,0	86,7	86,4
NS 450	59,7	76,0	91,0	91,7	93,0	48,0	77,7	76,7
NS 454	80,3	76,7	95,0	91,0	95,0	84,0	84,0	86,6
Viktor	80,7	79,6	97,0	93,0	96,0	84,3	90,0	88,7
NS 460	90,0	82,0	70,7	95,0	94,0	83,3	74,0	84,1
NS 462	92,0	84,0	97,0	95,0	94,0	78,0	81,0	88,7
NS 466	87,7	87,7	96,7	94,7	97,7	89,0	84,7	91,1
Average	75,3	79,3	92,2	93,9	94,6	76,8	83,8	85,1
	A	*B*	*AB*					
LSD 0.05	*1.32*	*1.23*	*3.48*					
0.01	*1.74*	*1.62*	*4.61*					

Across growing seasons, the lowest GPC was found in the variety Scarlett (Table 5). Generally, the varieties Scarlett and Viktor had acceptable GPC for malt production. The highest GPC had the varieties NS 294 and NS 450. Due to the negative correlation between GW and GPC (SAVIN and MOLINA-CANO, 2002; PRŽULJ *et al*., 2012) this result was expected since these varieties had the lowest GW values (Table 3). The 2002 and 2001 growing seasons were quite favorable for malting barley production, when the lowest GPC was recorded across varieties, 11.5 and 11.9g 100^{-1} g dm, respectively (Table 5). Except for the variety NS 450, all other varieties had the lowest GPC in 2002. On the other side, according to GPC, the poorest malting barley was produced in the 2000 growing season. Indeed, 5 of the 8 varieties had the highest GPC in 2000 growing season, more than 13g 100^{-1}g dm. Two varieties had the highest GPC in 1999 and one in 1998 growing season (Table 5). GPC frequently increases as result of moderately high temperature during grain filling (STONE, 2001). The Pannonian zone generally characterized by increased temperatures and water shortage, especially in barley grain filling period (Figure 1a, b) and obtained values of increased GPC were expected. However, temperature and water are not only factors determining the quality attributes of barley. This is confirmed by low GPC in 2001 and 2002 growing season that were characterized as warm, but not with high temperatures.

Table 5. Grain protein concentration (g 100^{-1}g dm) in 8 spring barley varieties in 7 growing seasons (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	13,6	14,5	15,1	12,9	12,0	13,1	13,6	13,5
Scarlett	13,3	13,0	12,8	10,6	10,3	12,3	12,4	12,1
NS 450	15,3	12,8	15,3	13,1	14,6	13,2	14,3	14,1
NS 454	13,5	14,8	15,3	12,8	11,4	13,3	13,3	13,5
Viktor	13,4	13,8	14,3	11,2	10,1	12,4	12,5	12,5
NS 460	13,8	14,8	14,6	11,6	11,2	12,7	13,0	13,1
NS 462	12,8	14,8	14,6	11,4	10,7	13,2	12,7	12,9
NS 466	13,7	12,7	15,0	11,7	11,7	13,3	13,0	13,0
Average	13,7	13,9	14,6	11,9	11,5	12,9	13,1	13,1
	A	*B*	*AB*					
LSD 0.05	*0.11*	*0.10*	*0.28*					
0.01	*0.14*	*0.13*	*0.37*					

VIS is the measure of cytolytic degree of modification during malting of barley grain. There were significant differences (P<0.01) in VIS across years, across varieties and among varieties in different years. Across growing seasons, VIS ranged from 1.44 for Scarlett to 1.61 for NS 454. The best cytolytic modification of malt across varieties was in 2001 growing season (1.32) and the worst in 2000 and 2003 growing season (1.63 and 1.70, respectively). All studied varieties had the lowest VIS value in 2001 growing season. Five out of eight varieties had the highest VIS in 2003, two in 2000 and one in 2002 (Table 6). PASSARELLA *et al.* (2002) found higher β-glucans content in varieties with lower average size of grain while in our previous study there was no significant relationship between VIS and GW (PRŽULJ *et al*., 2012).

Table 6. Viscosity (m.Pas) in 8 spring barley varieties in 7 growing seasons (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	1,3573	1,4800	1,5580	1,3117	1,3640	1,6400	1,5297	1,4630
Scarlett	1,3367	1,4433	1,5667	1,1857	1,4380	1,6043	1,4917	1,4380
NS 450	1,3667	1,6100	1,6660	1,3470	1,4647	1,7283	1,5467	1,5328
NS 454	1,6000	1,4500	1,7607	1,4290	1,4623	1,9703	1,5740	1,6066
Viktor	1,4267	1,3667	1,5390	1,3303	1,6223	1,5920	1,4777	1,4792
NS 460	1,6133	1,4500	1,6570	1,3067	1,3413	1,6347	1,5070	1,5014
NS 462	1,5267	1,4800	1,6360	1,2957	1,3793	1,7907	1,4807	1,5127
NS 466	1,5200	1,3400	1,6330	1,3213	1,3470	1,6020	1,4907	1,4649
Average	1,4684	1,4525	1,6270	1,3159	1,4274	1,6953	1,5123	1,4998
	A	*B*	*AB*					
LSD 0.05	*0.0113*	*0.0106*	*0.0299*					
0.01	*0.0149*	*0.0140*	*0.0396*					

Variation of KOL depended mainly on the varieties behavior in different growing seasons (Table 2). Across the growing seasons, the two varieties had KOL lower than 36, while KOL of Scarlett and Viktor was 43 and 41, respectively (Table 7). KOL across varieties was lower than 35 in two growing seasons, 2000 and 2002. Despite the high GxY interaction, growing seasons with good and poor protein modifications may be distinguished. Of the 8 varieties under study, 5 had the poorest protein breakdown in 2000, two in 2002 and one in 1999. Four varieties had the highest protein breakdown in 2001 and four in 2004.

Table 7. Kolbach index (%) in 8 spring barley varieties in 7 growing seasons (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	46,63	42,00	30,27	49,49	31,95	37,27	46,97	40,65
Scarlett	49,27	44,00	33,10	51,50	29,60	40,73	51,76	42,85
NS 450	38,73	43,97	26,33	44,10	23,91	36,86	41,45	36,48
NS 454	32,77	28,50	30,37	34,62	28,70	28,52	44,16	32,52
Viktor	37,80	41,90	23,87	55,84	41,87	40,75	46,37	41,20
NS 460	31,30	32,43	24,53	35,54	33,27	33,02	47,14	33,89
NS 462	34,13	38,77	25,93	47,76	33,23	31,54	48,50	37,12
NS 466	43,40	36,17	25,13	45,23	30,36	34,79	44,53	37,09
Average	39,25	38,47	27,44	45,51	31,61	35,44	46,36	37,73
	A	*B*	*AB*					
LSD 0.05	*0.86*	*0.80*	*2.27*					
0.01	*1.14*	*1.06*	*3.00*					

Similar to KOL, HAR was mainly determined by the GxY interaction (Table 2). Across growing seasons, the variety NS 454 had poor enzymatic activity, the variety NS 460 close to satisfactory, while other varieties had HAR ranging from 39.6 to 45.9VZ 45°C. Four varieties had the lowest HAR value in 2002, two varieties in 2000 and one variety in each 1998 and 1999 growing season. Four varieties had highest cytolytic and proteolytic activities of malt enzymes in 2004, three varieties in 2001 and one variety in 2002 growing season.

Table 8. Hartong number (VZ 45 °C) in 8 spring barley varieties in 7 years (1998-2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	38,90	38,20	42,29	46,85	38,37	41,31	44,33	41,46
Scarlett	46,07	43,23	38,04	52,86	32,04	41,93	45,27	42,78
NS 450	35,67	33,27	36,83	44,71	35,61	38,95	52,26	39,61
NS 454	27,87	27,60	28,17	30,30	25,58	30,62	53,24	31,91
Viktor	45,33	45,07	41,97	52,07	48,68	42,41	45,83	45,91
NS 460	39,53	35,20	29,11	34,51	32,04	36,75	45,94	36,16
NS 462	34,67	35,20	38,30	47,82	54,03	37,38	46,27	41,95
NS 466	36,67	38,63	41,71	44,88	31,59	38,84	45,61	39,70
Average	38,09	37,05	37,05	44,25	37,24	38,52	47,34	39,94
	A	*B*	*AB*					
LSD 0.05	*0.74*	*0.69*	*1.96*					
0.01	*0.98*	*0.91*	*2.59*					

EXT is the most important economic trait of malting barley. After 7 growing seasons of testing, the varieties Scarlett and Viktor had the highest EXT, 79.6 and 80.3% dm, respectively (Table 9). Obviously, in regard to EXT 2002 growing season was the most suitable for malting barley production in the Pannonian zone since the average EXT across varieties was 80.9% dm. In 2001 and 2004 growing seasons, EXT was also acceptable, with averages of 79.8 and 79.2% dm, respectively. In 1998, 2000, and 2003 growing seasons EXT was very low, 76.1, 76.5, and 77.5, respectively. The interaction GxY was significant for all varieties. The varieties NS 294, Scarlett, NS 450 and NS 454 had lowest EXT values in 1998, the highest one in 2002, 2001, 2002, and 2004 growing seasons, respectively. The varieties, Viktor NS 460, NS 462 and NS 466 had best quality in 2002.

Although growing season and interaction GxE were responsible for the highest percentage of the variation of all studied traits, the differences among varieties were also considerably important for the quality parameters, being significant for TGW, GPC, VIS, KOL, HAR and EXT (Table 2). This indicates a possibility to select varieties with an appropriate and stabile quality in different growing conditions. The varieties Scarlett and Viktor performed quite acceptable quality in the Pannonian zone and may be recommended for commercial production in this region for malt industry. Even in less favorable growing conditions when GPC was rather high, as it was in 1999 and 2004 growing seasons, these two varieties had acceptable malt modification and EXT. Good malt modification of Scarlett and Viktor was probably due to higher quantities of starch degrading enzymes during germination. Although permitted range of GPC of malting barley in Europe is 9.5-11.5% (PETTERSSON and ECKERSTEN, 2007) some varieties with higher GPC are able to supply malt with high EXT too (MOLINA-CANO *et al*., 2000).

Table 9. Fine extract content (%, dm) in 8 spring barley varieties in 7 growing seasons (1998- 2004) period

Variety (A)	Year (B)							Average
	1998	1999	2000	2001	2002	2003	2004	
NS 294	76,2	76,9	76,4	79,5	81,4	77,3	77,8	77,9
Scarlett	75,7	79,3	78,9	81,6	81,3	80,3	80,4	79,6
NS 450	74,6	78,6	75,5	79,3	80,7	76,4	78,6	77,7
NS 454	73,7	75,5	73,8	77,1	78,7	74,6	80,6	76,3
Viktor	78,0	80,1	78,4	82,3	83,1	79,7	80,5	80,3
NS 460	75,6	77,5	76,2	79,0	80,7	77,9	76,5	77,6
NS 462	76,7	77,4	76,6	79,8	80,7	75,5	79,8	78,1
NS 466	78,2	78,2	76,0	79,9	81,0	78,2	79,5	78,7
Average	76,2	76,9	76,4	79,5	81,4	77,3	77,8	77,9
	A	*B*	*AB*					
LSD 0.05	*0.20*	*0.19*	*0.54*					
0.01	*0.27*	*0.25*	*0.71*					

MOLINA-CANO *et al.* (1999) discussed generalization that barleys from southern Europe due to their higher GPC are always of inferior malting quality to those from humid regions. Since negative effect of GPC on EXT was obtained on barley grown in narrow environment, in England, this rule is hardly acceptable for barleys grown under very contrasting environmental conditions where environmental and interaction GxE induced variation may have different values. MOLINA-CANO *et al.* (2004) found that under Mediterranean type climate the negative effect of barley protein on final malt extract yield is less marked. They explained this statement by growing conditions of the Mediterranean and the non-Mediterranean, which differ greatly during spring barley development. Indeed, planting in the Mediterranean region was in autumn and plants subjected to short day length while planting in non-Mediterranean region was in spring and plants subjected to long day length. Contrasting day length and temperature regimes across the crop life cycle were supposed to be responsible for the recorded differences.

Variation in malt extract levels from season to season could not be completely explained by differences in GPC, from which conclusion can be drawn that other factors, e.g., types of proteins, starch properties, β-glucan composition etc. could affect malt extract independently of GPC (MOLINA-CANO *et al*., 1999).

Early sowing of spring cereals, which are generally sown as soon as the soil dries beyond field capacity, may mitigate negative effects of high temperature through earlier anthesis and earlier finishing grain filling (MALEŠEVIĆ *et al.* 2011). PETTERSSON and ECKERSTEN (2007) found that date of sowing was related to GPC, thus GPC increased by 0.07% for each day of sowing delay. This statement should be accepted with suspicion since our results show that despite the early sowing in 2000 growing season, (February 15), GPC was the highest – 14.6g 100^{-1}g dm, while in the case of late sowing in 2003 growing season (March 13) GPC was moderate, 12.9g 100^{-1}g dm (Table 5).

It is evident that environments in the Pannonian zone are less favorable for malting barley production than those described by SCHELLING *et al.* (2003) in Germany. Although the growing conditions in the Pannonian zone are less favorable for malting barley production in relation to western Europe it does not exclude malting barley production in this region with acceptable quality. It is obvious from our results that temperature and precipitation are not merely factors influencing malting barley production. Indeed, malting barley with low quality can be produced even if temperature and precipitation are near the optimum.

Additional problems in malting barley production are mainly related to growing practices. Contribution of nitrogen application could be quite questionable (MALEŠEVIĆ, professor of crop science, personal communication). To achieve higher yields, barley growers apply excessive doses of nitrogen. Preceding crops and mineralization of their harvest remains increases the available N during plant growth, which in turn increases the nitrogen level in grain. Surplus of available N was probably the cause of elevated GPC and low EXT in 1998, 1999 and 2000 growing season, when severe stress was not registered.

CONCLUSION

Although environmental factors in the Pannonian zone are less favorable for spring barley production, the Pannonian zone cannot be classified as unfavorable region for growing spring malting barley. It is evident from our study that precipitation and temperature during growth and development are not merely factor determining spring barley quality, since good barley produced in the growing seasons with restricted available water and elevated temperature. More detailed study of spring barley growing practice and testing larger genetic variability will offer the solution for more successful production of spring malting barley. Due to acceptable quality in all growing seasons the varieties Scarlett and Viktor may be recommended for commercial production in the Pannonian zone.

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UTICAJ SEZONE GAJENJA I SORTE NA KVALITET JAROG DVOREDOG JEČMA

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Izvod

Kvalitet ječma kao sirovine za proizvodnju slada određen je precizno definisanim osobinama kvaliteta zrna (masa zrna, veličina zrna, sortiranje, sadržaj proteina u zrnu) i kvaliteta slada (sadržaj ekstrakta, viskozitet, Kolbach indeks i sl.). Osobine kvaliteta ječma nasleđuju se kvantitativno i nalaze se pod jakim uticajem faktora sredine, kao što su temperatura, dostupna voda, azot i tip zemljišta. Cilj ovoga rada je određivanje uticaja genotipa i uslova gajenja (godine) na osobine kvaliteta zrna i slada u poljskim uslovima Panonske zoni. Osam sorti jarog dvoredog ječma proučavane su tokom sedam sezona (1998-2004) na lokalitetu Novi Sad (45°20'N, 15°51'E, 86 m n.v.). Uslovi gajenja imali su jedan od najvećih uticaja na variranje svih proučavanih osobina zrna i slada jarog ječma. Udeo varijanse koji je bio pod kontrolom uslova gajenja iznosio je 35,2% za masu hiljadu zrna (GW), 20,2% za sortiranje (GRA), 32,5% za sadržaj proteina u zrnu (GPC), 25,4% za viskozitet (VIS), 30,9% za Kolbach indeks (KOL), 31,2% za Hartongov broj (HAR) i 38,5% za sadržaj finog ekstrakta (EXT). Udeo varijanse koji je bio pod kontrolom interakcije GxE iznosio je 28,4% za GW, 64,5% za GRA, 38,2% za GPC, 54,0% za VIS, 39,6% za KOL, 41,2% za HAR i 23,7% za EXT. Genetička komponentna virijanse imala je vrednosti od 11,1% za GRA do 35,0% za EXT. Heritabilnost je bila najniža za GRA, 0,54, a najviša za EXT, 0,91. Prosečne vrednosti sorti za osam ispitivanih godina iznosile su 39,6-46,1g za GW, 76,7-91,1% za GRA, 12,1-13,5g 100^{-1}g sm za GPC, 1,44-1,61m.Ps za VIS, 32,5-42,9% za KOL, 31,9-45,9VZ 45°C za HAR i 76,3-80,3% sm za EXT. Iako su uslovi za gajenje pivskog ječma u Panonskoj zoni manje pogodni nego u zapadnoj Evropi, to ne isključuje mogućnost njegove uspešne proizvodnje u ovim ekološkim uslovima. Sorte jarog pivskog ječma Scarlett i Viktor gajene u uslovima Panonske zone imale su u potpunosti prihvatljiv kvalitet za industriju slada i mogu se preporučiti za komercijalnu proizvodnju.

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