Stability of four Croatian bread winter wheat (*Triticum aestivum* L.) cultivars for quality traits

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ABSTRACT

Stability of breadmaking quality of four Croatian bread winter wheat cultivars was investigated using rheological traits from the farinogram (dough development time, stability, degree of softening, water absorption, Hankoczy quality number) and the extensogram (extensibility, maximum resistance, ratio of resistance to extensibility, energy) and the indirect traits (protein content, wet gluten content, Zeleny sedimentation volume, Hagberg falling number). Stability was evaluated for four cultivars grown in 12 environments in different parts of Croatia. Four stability parameters, covering a wide range of statistical approaches, were used to estimate cultivar stability. Variability for the stability of quality among cultivars was established. The cultivars Kuna and Banica showed high performance for most quality traits and were also identified as stable for the majority of them. The cultivar Žitarka was stable for four farinogram traits showing high level of performance only for dough development time, while Marija showed stability for only three traits but with unfavourable mean values for all of them. The largest contribution of genotype by environment effects in the total sum of variance components was found for the farinogram traits stability and dough development time, while the lowest, but similar to each other for protein content and wet gluten content.

Keywords: genotype by environment interaction; breadmaking quality; bread winter wheat (*T. aestivum* L.); stability parameters

Stability of wheat quality traits over locations and years is important for the milling and baking industry whose processing technology requires constant quality of raw material.

Breadmaking quality traits follow a dynamic concept of stability, meaning that performance may change from environment to environment but in a predictable way (Becker and Leon 1988). According to this concept, genotypes with a small contribution to the genotype by environment variance (G × E) are more stable than genotypes with larger contribution.

Genotypes, environments and their interaction are known to have influence on the quality traits of wheat grain. Numerous investigations have been conducted on the influence of environmental conditions such as growing-season temperature (Smith and Gooding 1999), temperature fluctuations of daily average and their durability (Borghi et al. 1995), temperature and humidity during grain fill (Peterson et al. 1998), moisture deficit (Guttieri et al. 2001), distribution of precipitation (Salinger et al. 1995), nitrogen fertilisation (Anderson et al. 1998, Monaghan et al. 2001), sowing time and sowing rate (Anderson et al. 1998) on particular quality traits. The results of these investigations showed that environments have an influence on quality traits, and, in some environmental conditions the direction of influence on the trait is known. However, it is the cultivar that responds to the growing conditions and several researches have shown evidence for variation in genetic responses to environments for the various measures of end-use quality (Grausgruber et al. 2000, Barić et al. 2001). From previous investigation (Fišter and Petričević 1999) it is evident that the quality of cultivars has been decreasing if the cultivars were grown for many years. It is therefore necessary to substitute such cultivars with the new, stable ones.

Stability of the cultivar is important and can certainly not have negative influence on the mean values of the traits. Therefore, the important goal for the breeders is to find cultivars with good and stable quality – not only to provide quality raw material for end-users, but also to provide parents in the future crosses. Stable cultivars can also be used as checks for stability in the future investigations.

The objectives of this study were: to determine the contribution of genotype, environment and G × E interaction to the variation observed, in particular to quality traits, and to estimate the qual-

Supported by the Ministry of Agriculture and Forestry of the Republic of Croatia through Agriculture Research Council (ARC) projects, supported by World Bank loans.

Table 1. Cultivars of wheat, year of release and origin

Cultivar	Year of release	Origin
Kuna	1995	Faculty of Agriculture, Zagreb
Banica	1997	Faculty of Agriculture, Zagreb
Žitarka	1985	Agricultural Institute, Osijek
Marija	1988	Bc Institute for Breeding and Production of Field Crops, Zagreb

ity stability of four Croatian bread winter wheat cultivars in twelve different environments.

MATERIAL AND METHODS

Wheat cultivars and environments

Four cultivars of winter wheat used in this study were created through different breeding programs in Croatia (Table 1). Žitarka and Marija were released in the 80's and have been widely spread out in commercial production in Croatia. Žitarka is a quality check in the official state trials, and Marija has quite stable grain yield, but recently its breadmaking quality has been decreasing. Kuna and Banica are newer cultivars with an average yielding ability and higher breadmaking quality compared to the check cultivar Žitarka. Four wheat cultivars were grown in unreplicated field plots on farmer's land at three locations (L) (Hrastelnica-southwestern Croatia, Ramanovci-eastern Croatia and Savska Ves-northwestern Croatia) in the vegetation years (Y) 1999/2000 and 2000/2001 applying two sowing times (T). The details of the husbandry in different environments are shown in Table 2.

Quality traits

Stability of breadmaking quality was investigated using indirect and rheological (farinogram, extensogram) traits. Indirect parameters were the protein content (PC) determined by the Kjeldahl method (N concentration × 5.7), wet gluten content (WGC) (ICC standard method 137), Zeleny sedimentation volume (ZSV) (ICC standard method 116), and Hagberg falling number (HFN) (ICC standard method 107). Rheological parameters namely dough development time (DDT), stability (STA), degree of softening (DS), water absorption (Wabs) (ICC standard method 115/1) and Hankoczy quality number (area triangle farinogram) (QN), were taken from a farinogram (ICC standard method 115), and extensibility (E), maximum resistance (R_m), ratio of resistance to extensibility (R/E) and

Table 2. Crop husbandry for each environment studied

Location	Year 1 (1999/2000)			Year 2 (2000/2001)		
	Hrastelnica	Ramanovci	Savska Ves	Hrastelnica	Ramanovci	Savska Ves
T1	1.10.	27.9.	30.9.	29.9.	28.9.	29.9.
T2	23.10.	21.10.	23.10.	23.10.	20.10.	24.10.
N application (kg/ha)	10.9. – 70	7.9. – 60	10.9. – 80	9.9. – 70	8.9. – 80	9.9. – 70
Top dressing (kg N/ha)	28.2. – 50	18.2. – 60	15.2. – 20	19.2. – 45	20.2. – 20	20.2. – 30
	26.3. – 50	19.4. – 60	17.4. – 40	20.3. – 55	19.4. – 50	15.4. – 40
Soil type	Pseudogley on level terrains	Luvisol on loess	Eutric cambisol	Pseudogley on level terrains	Luvisol on loess	Eutric cambisol
Previous crop	oil seed rape	tobacco	potato	oil seed rape	soybean	silage maize
Precipitation (mm, vegetation year)	654	532	445	849	668	642
Average temperature (°C, vegetation year)	11.2	10.9	9.9	12.2	11.6	10.9

T = sowing time

energy (AREA) from an extensogram (ICC standard method 114).

Samples preparation was made according to procedure as each method demand. The samples were milled on a Brabender Quadraplex experimental mill (C.W. Brabender Instruments Inc., South Hackensack, NJ).

Statistical analyses

The tests for quality evaluation were performed on samples taken from unreplicated plots.

Therefore, only one value per genotype in each environment was available and the complete interactive model could not have been tested. The applied additive model resulted with G × E as the residual variance. The calculated stability parameters contain both G × E and experimental error in the same data, which was assumed to be similar among the cultivars. Environments were defined by the year × location × sowing time (Y × L × T) combination. In total, data from 12 environments were available.

Components of variance due to genotypes (σ^2_G), environments (σ^2_E) and interaction ($\sigma^2_{G \times E}$) for all 13 investigated traits were expressed in percentage of total sum of variance components for the specified trait.

Four stability parameters were applied to the data chosen so that they cover a wide range of philosophies in stability analysis (Lin et al. 1986): the mean square deviation from regression of phenotypic values on environmental indices, s^2_{di} (Eberhart and Russell 1966), the variance of a genotype across environments – stability variance σ^2_i (Shukla 1972), the coefficient of variability of a genotype across environments cv_i (Francis and Kannenberg 1978), and the principal component of an additive main effects and multiplicative interaction (AMMI) analysis (Gauch 1992). From AMMI analysis the distance of each genotype to the origin v_i defined by the first two principal components axes was used as a stability parameter (Grausgruber et al. 2000).

A cultivar was regarded as stable if its contribution to the G × E was less than average for three of four stability parameters, the average being defined as the mean of the respective stability parameter.

The simple test of mean differences between genotypes was carried out by analysis of variance where all the effects were treated as fixed. *LSD* test was performed where needed.

All analyses were conducted using SAS version 8.02 (SAS Inst. Inc. 1999–2001).

RESULTS AND DISCUSSION

Effect of genotype, environment and their interaction to the quality traits

The relative contribution of genotype (σ^2_G), environment (σ^2_E) and their interaction ($\sigma^2_{G \times E}$) to the total variation of 13 quality traits is shown in Table 3. For all the traits investigated in this study, the component of variation due to genotype was larger than the component of variation due to the environment and varied from 31.64–65.79%. The largest contribution of genotype in the total variance was found for HFN, ZSV and WGC among indirect traits, for QN and DS among farinogram traits and for E among extensogram traits. These results are partially consistent with the results of Grausgruber et al. (2000) who found larger components of variation due to genotype for all extensogram traits and with the results of Graybosch et al. (1996) who found that the variances due to genotype were larger than the variances due to environment for ZSV, while for PC, the components of variance were of the same values. On the contrary, several other authors (Peterson et al. 1998, Rharrabti et al. 2003, but also Grausgruber et al. 2000, for the majority

Table 3. Components of variance due to genotypes (σ^2_G), environments (σ^2_E) and interaction ($\sigma^2_{G \times E}$) in percentage of the total sum of variance for specified traits

Components of variance	Indirect traits				Farinogram traits					Extensogram traits			
	PC	WGC	ZSV	HFN	DDT	STA	DS	Wabs	QN	E	R_m	R/E	AREA
σ^2_G	53.59	58.46	59.96	65.79	44.83	31.64	62.13	53.71	62.61	61.72	42.91	39.97	45.59
σ^2_E	33.95	27.91	20.31	13.75	19.37	25.81	15.16	30.71	18.55	16.77	31.70	29.60	27.54
$\sigma^2_{G \times E}$	12.46	13.63	19.73	20.46	35.80	42.55	22.71	15.59	18.84	21.52	25.39	30.42	26.87

PC = protein content, WGC = wet gluten content, ZSV = Zeleny sedimentation volume, HFN = Hagberg falling number, DDT = dough development time, STA = stability, DS = degree of softening, Wabs = water absorption, QN = quality number, E = extensibility, R_m = maximum resistance, R/E = ratio of resistance to extensibility, AREA = energy (area under the curve)

Table 4. Stability parameters for quality traits in wheat cultivars

Cultivar	σ^2_i	s^2_{di}	v_i	CV^{FK}	Cultivar	σ^2_i	s^2_{di}	v_i	CV^{FK}
		Protein content (PC%)					**Degree of softening (DS)**		
Kuna	**3.78**	**0.368**	1.710	**16.58**	Kuna	5 481.17	537.09	7.543	67.38
Banica	11.52	1.054	**0.865**	**15.82**	Banica	**4 626.42**	**457.42**	7.131	51.62
Žitarka	**4.76**	**0.429**	1.593	18.57	Žitarka	**1 633.51**	**156.92**	8.783	**36.59**
Marija	8.66	0.866	**1.019**	18.31	Marija	8 295.86	816.84	**2.219**	**43.58**
Mean	7.18	0.679	1.296	17.32	Mean	5 009.24	492.07	6.419	49.79
		Wet gluten content (WGC)					**Water absorption (Wabs)**		
Kuna	**48.41**	**4.838**	**2.116**	**23.17**	Kuna	**6.44**	**0.599**	1.602	3.98
Banica	**64.27**	**4.934**	**1.745**	**20.19**	Banica	**15.19**	**0.852**	**0.845**	**2.74**
Žitarka	120.80	9.241	2.957	27.60	Žitarka	27.45	1.436	1.818	5.32
Marija	111.63	10.997	2.970	26.91	Marija	**17.09**	1.419	1.957	**3.35**
Mean	86.28	7.503	2.447	24.47	Mean	20.82	1.077	1.555	3.85
		Zeleny sedimentation volume (ZSV)					**Quality number (QN)**		
Kuna	**279.67**	**27.904**	**3.466**	**26.91**	Kuna	1 116.40	111.49	4.815	**30.77**
Banica	**415.33**	**34.556**	**2.640**	**28.98**	Banica	**744.75**	**72.94**	4.732	**32.24**
Žitarka	579.22	57.718	4.320	32.73	Žitarka	**249.70**	**22.81**	5.601	**32.06**
Marija	512.29	45.273	4.320	31.37	Marija	1 425.32	142.51	**1.804**	37.33
Mean	446.63	41.363	3.687	29.99	Mean	884.04	87.44	4.238	33.10
		Hagberg falling number (HFN)					**Extensibility (E)**		
Kuna	18 204.8	1 766.74	10.818	31.74	Kuna	**2 072.58**	205.23	**2.062**	**16.99**
Banica	18 398.3	**1 028.13**	10.281	**17.59**	Banica	**464.42**	**46.43**	**5.556**	**13.84**
Žitarka	14 598.3	1 290.28	**4.597**	27.24	Žitarka	2 757.82	205.73	7.174	21.27
Marija	**6 000.9**	**533.86**	8.999	**22.89**	Marija	3 688.57	322.03	6.696	**16.69**
Mean	14 300.58	1 154.75	8.670	24.87	Mean	2 245.85	194.86	5.370	17.20
		Dough development time (DDT)					**Ratio R/E**		
Kuna	**9.01**	**0.578**	1.664	**48.05**	Kuna	**0.838**	**0.077**	**0.555**	**35.25**
Banica	12.98	1.286	**1.234**	53.71	Banica	**0.831**	**0.071**	0.850	**32.62**
Žitarka	**7.36**	**0.719**	1.409	**39.64**	Žitarka	**0.641**	0.380	1.190	**36.53**
Marija	**8.44**	**0.738**	**1.284**	55.07	Marija	2.730	**0.151**	**0.609**	47.36
Mean	9.45	0.830	1.398	49.73	Mean	1.260	0.169	0.801	37.94
		Stability (STA)					**Energy (AREA)**		
Kuna	22.25	1.888	1.919	**71.52**	Kuna	**1 604.04**	**159.64**	7.519	**42.20**
Banica	18.52	1.381	1.942	85.39	Banica	4 449.23	416.97	**3.981**	**38.54**
Žitarka	**4.14**	0.136	**1.556**	**60.30**	Žitarka	**1 834.15**	**167.42**	7.539	50.53
Marija	**13.39**	**0.793**	**0.837**	109.75	Marija	4 429.26	442.76	**4.499**	**39.88**
Mean	14.57	1.037	1.564	81.74	Mean	3 079.17	296.69	5.880	42.78

Values printed in bold are lower than the mean

Cultivars with lower values than the mean for three of four parameters are regarded as stable

σ^2_i = stability variance, v_i = distance to the origin, s^2_{di} = deviation mean square, CV^{FK} = coefficient of variation of traits) found that the variances due to genetic effects were lower or equal to the variance due to environmental effects. Although the component of variance due to the genotype in our study is probably overestimated, because of the small influence of sowing time on the variability among environments. Its large contribution to the total variances indicates that genetic diversity among the four cultivars is high enough to be used for breeding improvements.

A low contribution of the genotype to the total sum of variance components was found for STA and the majority of extensogram traits (R/E, AREA and R_m). Grausgruber et al. (2000) also found for STA and other farinogram traits lower variances for genetic effects than for environmental effects.

The components of variation due to environment varied from 13.75–33.95%. The largest contribution of the environment to the total variance was found for PC and WGC among indirect traits, for Wabs and STA among farinogram traits and for majority of extensogram traits. Indirect traits PC, WGC and Wabs (farinogram trait) were strongly influenced by the main effects of cultivar and environment.

The contribution of G × E effects in total sum of variance components varied between 12.46–42.55%. The highest G × E effects were found for some farinogram traits (STA and DDT) and for extensogram traits R/E, AREA and R_m. According to the dynamic concept of stability (Becker and Leon 1988), it is difficult to predict stability for the traits with high G × E effects.

The indirect traits PC and WGC as well as Wasb (farinogram trait) had the lowest G × E components with similar values. The values of the G × E component for PC and WGC were also similar to each other in the study of Grausgruber et al. (2000).

In general, considering the contributions of genotypic, environmental and G × E effects to the total variance, genotype and environment had stronger influence on the variance for the majority of investigated traits than the G × E effects. Several other authors (Baenziger et al. 1985, Robert and Denis 1996, Peterson et al. 1998) also obtained low G × E component for quality traits.

Estimation of cultivar stability for quality traits

Calculated stability parameters for 12 quality traits are presented in Table 4 (data for R_m are not shown because there was no cultivar regarded as stable for this trait). Kuna, Banica, Žitarka and Marija were stable for seven, six, four and three quality traits respectively (Table 5). Kuna showed stability for indirect (PC, WGC, ZSV), farinogram (DDT), and extensogram (E, AREA, R/E) traits. For all of these traits, except AREA, Kuna showed not

Table 5. Means of quality traits and summary of the stability analyses of the wheat cultivars

Cultivar	Indirect traits				Farinogram traits					Extensogram traits			
	PC (%)	WGC (%)	ZSV (ml)	HFN (s)	DDT (min)	STA (min)	DS (FU)[a]	Wabs (%)	QN	E (mm)	R_m (EU)[b]	R/E ratio	AREA (cm^2)
Kuna	13.63	30.16	46.13 AB	258.67 A	3.17	2.83 A	65.83 A	65.02 AB	66.92	158.11 AB	236.67 BC	1.301 A	57.29 BC
	(+)	(+)	(+)	(–)	(+)	(–)	(–)	(–)	(–)	(+)	(–)	(+)	(+)
Banica	12.92	29.44	50.83 A	275.00 AB	2.79	2.33 A	75.33 AB	63.46 BC	63.50	180.33 A	314.00 AB	1.601 A	86.02 A
	(–)	(+)	(+)	(–)	(–)	(–)	(–)	(+)	(+)	(+)	(–)	(+)	(–)
Žitarka	12.83	31.94	39.42 BC	309.67 AB	3.29	1.00 B	108.13 B	66.85 A	52.48	164.42 AB	163.42 C	0.818 B	43.15 C
	(–)	(–)	(–)	(–)	(+)	(+)	(+)	(–)	(+)	(–)	(–)	(–)	(–)
Marija	12.42	26.29	34.67 C	330.75 B	2.13	0.82 B	96.25 AB	62.51 C	55.83	147.42 B	331.33 A	1.712 A	73.55 AB
	(–)	(–)	(–)	(+)	(+)	(+)	(–)	(–)	(–)	(–)	(–)	(–)	(–)
LSD	ns	ns	10.54	60.92	ns	1.25	33.94	2.12	ns	23.12	84.31	0.424	22.61

[a]FU farinograph units, [b]EU extensograph units, + stable for three or all four stability parameters

only stability but also a high level of performance. For the farinogram trait STA Kuna was not stable, but had the highest mean value among all cultivars. Banica was stable for indirect (WGC, ZSV), farinogram (Wabs, QN), and extensogram (E, R/E) traits and for the two of them (ZSV, R/E) it also showed a good level of performance. Although Banica did not show stability for indirect trait HFN, its mean value was favourable. Žitarka was stable only for farinogram traits (DDT, STA, DS, QN) but only for DDT it also showed a high level of performance. Žitarka had the highest mean value for farinogram trait Wabs, but was not stable in this trait. The substitution of the cultivar Žitarka as a quality check with another cultivar has been the subject of numerous discussions in Croatia. The results of this study will probably fasten this decision.

Marija was stable for indirect trait HFN, and farinogram traits (DDT and STA), but unfavourable mean values for these traits decrease the significance of the stability detected. Although Marija was not stable for extensogram trait R/E, it had the best performance for this trait. Some cultivars were stable for some traits and unstable for some other, which is in accordance with results of Grausgruber et al. (2000) who suggested that the genetic factors involved in the control of the G × E interaction are different for different quality traits.

The newer cultivars Kuna and Banica showed in this investigation better performance and stability for a larger number of milling and baking quality traits compared to the two widely grown older cultivars Žitarka and Marija. The results indicate that the cultivars Kuna and Banica are suitable to be the checks in future investigations as well as parents in breeding programs for quality improvement. Furthermore, they can be grown with a lower risk of quality decrease in common agroecological conditions, which is of importance for the milling and baking industry as well as for the farmers alone.

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Received on September 19, 2003

ABSTRAKT

Stabilita čtyř chorvatských pekařských odrůd ozimé pšenice (*Triticum aestivum* L.) v kvalitativních znacích

Stabilita pekařské jakosti čtyř chorvatských pekařských odrůd pšenice byla zjišťována prostřednictvím reologických ukazatelů s využitím farinografu (doba vývinu a stability těsta, stupeň změknutí, vaznost, Hankoczyho číslo jakosti), extenzografu (tažnost, maximální odpor, poměr odporu k tažnosti) a nepřímých ukazatelů (obsah bílkovin, obsah mokrého lepku, Zelenyho sedimentační test, číslo poklesu). Stabilita byla hodnocena u čtyř odrůd vypěstovaných v podmínkách dvanácti různých prostředí v různých částech Chorvatska. Pro vlastní hodnocení stability pekařské jakosti odrůd byly použity čtyři parametry stability, zahrnující širokou oblast statistických přístupů. Byla zjišťována variabilita mezi odrůdami ve stabilitě kvality. Odrůdy Kuna a Banica vykazovaly vysokou výkonnost v největším počtu hodnocených jakostních znaků a také byly charakterizovány jako stabilní ve většině z nich. Odrůda Žitarka byla stabilní ve čtyřech farinografických znacích, ale vykazovala vysokou výkonnost pouze pro dobu vývinu těsta, zatímco Marija byla stabilní pouze ve třech znacích a dosahovala u nich nepříznivých průměrných hodnot. Největší podíl interakce genotyp × prostředí z celkové sumy komponentů variance byl zjištěn u farinografických znaků doba stability a vývinu těsta, zatímco nejnižší, vzájemně obdobný podíl byl zaznamenán u obsahu bílkovin a mokrého lepku.

Klíčová slova: interakce genotyp × prostředí; pekařská jakost; pekařská ozimá pšenice (*T. aestivum* L.); parametry stability

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