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Effects of genotype and environment on breadmaking quality in wheat

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Abstract

Background: It has long been recognized that bread making quality traits vary considerably as a result of genotype, environment and their interaction. The present study was aimed at determining the effect of cultivar, environment and their interaction on several bread making quality traits as well as to analyze relationship between these traits, **Methods:** Hundred forty wheat genotypes originated from 28 countries were grown in 2000, 2001, 2002 and 2003. Data of 9 bread making quality traits, protein content (PC), wet gluten content (WG), farinograph absorption (FA), farinograph dough development time (FD), farinograph quality number (FQU), resistance to extension (ER), falling number (FN), loaf volume (LV), and baking score (BS), were used to evaluate the effects of cultivar, environment and their interaction. The analysis of variance, ANOVA, and estimates of the components of variance due to genotype and genotype/environment interaction were calculated according to Comstock and Moll (1963). Heritability estimates were similar to those reported by Singh et al. (1993), **Results:** Both cultivar and cultivar by environment interaction had significant effects on all quality traits. Variances of quality traits associated with genetic factors (cultivar) were generally larger than those for cultivar by environmental interaction effects, **Conclusion:** The dominant effect of the cultivar in total variance is probably due to the wide range of bread making quality traits in the examined cultivar set.

Keywords: Wheat; Genotype x environment interaction; Breadmaking quality; Variance.

Introduction

Wheat is a major crop contributing to the nutrient supply of the world's population. Of the total wheat supply, an average of 53% is consumed as food in the developed countries, and close to 85% in the developing countries (Pena, 2007).

It has long been recognized that wheat productivity and quality vary considerably as a result of genotype, environment and their interaction. While wheat growers consider yield as a major issue, millers and bakers emphasize variability in the functional properties of flour as their biggest concern. Consistency in quality and performance of wheat grain and

flour is critical for the output of high quality end products. For the wheat breeder, this means wheat genotypes with good end-use quality must be consistent across environments.

Breadmaking quality is a “super trait” and it can be expressed over numerous single characters related to the protein complex, milling properties and baking performances. Finney (1965) provided a general definition for good quality wheat suitable for milling and bread production. A good milling-quality wheat should have normal bolting and/or sifting properties and a normal flour yield with satisfactory ash content. A flour suitable for bread making was defined as having high water absorption, medium to medium-long mixing requirement, satisfactory mixing tolerance, good loaf volume potential and a loaf with good internal crumb grain appearance and color. It has been known for a long time that the properties of hydrated gluten or flour dough depend on the two main protein types, the gliadins and the glutenins. Hydrated gliadin exhibits plasticity (Wall, 1979), while hydrated glutenin has strong elastic properties (Wall, 1979). In general, a large portion of variation observed in wheat flour quality may be attributed to variation in gluten protein content and composition. The genetics and influence of glutenins on breadmaking quality traits have been described by several researchers (Payne et al., 1987; Lafiandra et al., 1993; Luo et al., 2001).

There is no dilemma that all breadmaking traits are under genetic and environment influence. The traits prevalently controlled by the genetic component are most amenable to improvement by breeding (Falconer, 1960). Environmental variation is often considered as the primary factor influencing end-use quality. Growing-season temperature (Smith and Gooding, 1999), humidity and temperature during grain fill (Graybosch et al., 1995; Peterson et al., 1998), duration of grain fill (Stone and Savin, 1999), distribution of precipitation (Smith and Gooding, 1999), and nitrogen and sulphur fertilization (Kettlewell et al., 1998) are known to have significant influence on breadmaking quality traits.

Which of the two main factors (genotype or environment) is dominant in forming the breadmaking quality traits is still questionable, and it depends on the genetic variability of the tested genotypes and variation of environmental conditions.

Many studies have attempted to relate various breadmaking quality parameters (Branlard and Dardevet, 1985; Bushuk, 1985; Khatkar et al., 2002a, Khatkar et al., 2002b; Cuniberti et al., 2003; Park et al., 2006). Probably one of the first works in this area was reported by Finney and Barmore (1948), who found that loaf volume was related to protein quantity in hard red winter and spring wheat cultivars. Later, Finney and Yamazaki (1967) and Finney (1984) stated that both quantity and quality of proteins influenced many breadmaking characteristics. Mladenov et al. (2001) found high positive correlations between PC and WG on one side and LV and BS on the other. Testing a large group of wheat genotypes under different drought conditions, Mohammadi et al. (2010) concluded that, in addition of cultivar and environment, screening method too contributes to the reliability and validity of conclusions.

The objectives of this research were three-fold: i) to determine relative contributions of genotype, environment and their interaction to the variation in breadmaking traits of 140 wheat genotypes tested across 4 years; ii) to analyze relationships between various breadmaking quality traits and iii) to find the best wheat genotypes based on 5 breadmaking quality traits.

Material and Methods

Plant material

One hundred-forty wheat genotypes (cultivars and experimental lines) originating from 28 countries (Table 1) were grown in a randomized complete block design with five replications at the experiment field of the Institute of Field and Vegetable Crops, Novi Sad, Serbia, in 2000, 2001, 2002 and 2003. Genotypes for the investigation were chosen from a wheat collection which included 3.500 genotypes. The wheat collection had been organized at three levels (World Collection, Genetic Collection and Crossing Block), according to the intensity of evaluation activity. Genotypes from the genetic collection were randomly selected because of a high level of evaluation activity in that collection. The genetic collection had been divided into subunits according to the traits/genes considered important for breeding or scientific purposes. The collection represents a broad spectrum of traits such as winter hardiness (Fr genes), plant stature (Rht genes), earliness, resistance to diseases (Lr, Sr, Pm genes), resistance to lodging, breadmaking quality traits (PC, WG, LV, BS, etc.), leaf position, spike architecture, etc. (Denčić and Kobiljski, 2000). Field plots of 5 m² with 10 rows spaced 10 cm apart were planted at a rate of 550 germinated seed/m². In all experiment years, the genotypes were planted in mid-October and harvested at the beginning of July.

Quality assessment

All analyses of breadmaking quality traits were conducted in three replications. Wheat samples were milled in a pneumatic laboratory mill (Bühler AG, Uzwil, Switzerland) (MLU 202) after tempering to 15% moisture. Grain protein content (PC) (N x 5.7 db) of whole meal was determined according to Kjeldal analysis (Tecator, Höganäs, Sweden) by the ICC method 105/2 (ICC, 1994). Wet gluten (WG) was determined according to the ICC method 116/1 (ICC, 1994).

Flours were tested for dough properties using a Brabender farinograph (Brabender OHG, Duisberg, Germany) according to the ICC method 115/1 (ICC, 1994). Farinograph absorption (FA), farinograph dough development time (FD), and farinograph quality number (FQN) were assessed in the research. FQN is a number from the table prepared by Hankoczy based on the planimetric area of the triangle in the farinogram. The triangle is determined by the middle of the farinographic curve as the hypotenuse and the 500 BU line and the line representing the softening degree of dough as the triangle legs. Extensogram measurements (Brabender OHG, Duisberg, Germany) were produced using 100 g of flour according to the ICC method 114/1 (ICC, 1994). Resistance to extension (ER) at the peak was measured after a rest period of 135 min. Breadmaking properties were evaluated using the standard 350 g pup-loaf procedure, a straight-dough procedure with a fermentation time of 3 hr. The baking formula included: flour, water, salt (2.0%), and yeast (2.0%). Falling number (FN) was determined with a falling number apparatus (Perten Instruments, Huddinge, Sweden) using an AACC method (1995). The loaf volume (LV) was measured by rapeseed displacement. Baking score (BS) (0-7, where 7 is excellent) was determined as a numerical expression based on the organoleptic assessment of bread crumb representing the sum of points for elasticity (0.0-4.5, where 4.5 is excellent) and pore structure fineness (0.0-2.5, where 2.5 is extremely fine).

Table 1. List of wheat genotypes and country of origin.

No.	Country/genot.	No.	Country/genot.	No.	Country/genot	No.	Country/genot
	Argentina	34	Etio.de choise		Netherlands	105	Anastasija
1	Fontenzuela	35	Talent	70	Flevina	106	NSR 2
2	Klein Forten	36	Bersee	71	Menllea	107	Nizija
3	Pinzon Inta	37	Chanplein	72	Clement	108	Sava
4	Gaboto	38	Top	73	Todorna	109	Simfonija
5	Leones Inta		Germany		Polan	110	NS 1-93
6	Perga. Gaboto	39	Caribo	74	Grana	111	NS 30-00
	Australia	40	Diplomat	75	Luna	112	NS 38-00
7	Condor	41	Bazalt		Romania	113	NS 57-00
8	Cook	42	Granit	76	Lovrin 32	114	NS 24-01
9	Banks		Hrvatska	77	Dacia	115	Dunav
10	Kite	43	U-1	78	Flamura 80		SWEDEN
	Australia	44	Vuka		Russia	116	Diana
11	Amadeus	45	Sanja	79	Bezostaja 1		Switzerland
12	Jozef	46	Baranjka	80	Bezostaja dwarf	117	Arina
13	Perlo	47	Žitarka	81	Pitikul	118	Sardona
	Brazil	48	Slavonka	82	Jubilajnjaja 50		Turkey
14	Frontana		Hungary	83	Stepnaja 30	119	Kirac 66
15	Garazinko	49	Bankut 1205	84	Tarasovska 29	120	Bolal
	Bulgaria	50	MV 17	85	Krasnodarska 39		UK
16	Vraca	51	MV 19		South Korea	121	Maris Huntsman
17	Vitka	52	MV 20	86	Suwon 92	122	Highbury
18	Yantar	53	MV 21		Slovakia	123	Avalon
19	Trakia	54	GK Pinka	87	Amika	124	Norman
20	Dobric	55	Zugoy	88	Roxana		Ukraine
21	Priaspa		Italy		Serbia	125	Obrij
22	Rusalka	56	Libellula	89	Pobeda	126	Tavricanka
	Canada	57	Argelato	90	Sonata	127	Nahodka 4
23	Pembina	58	Irnerio	91	Partizanka	128	Mironovska 808
24	Winalta	59	Acciaio	92	Renesansa	129	Odeska 51
25	Manit. Insence	60	Fortunato	93	Oda	130	Noa
26	Chris	61	Mara	94	Helena		USA
27	Marquis		Japan	95	Sofija	131	Centurk
	Czech REP.	62	Akakomughi	96	Sremica	132	Phoenix
28	Hana	63	Aobakomughi	97	Banačanka 1	133	NE 7060
29	Lada	64	Norin 10	98	Balkan	134	Atlas 66
	Egypt	65	Saitama 27	99	Redeemer	135	Buckskin
30	Giza 155		Mexico	100	Brkulja 4	136	Purdue 39120
31	Saha 8	66	Tanori 71	101	Jugoslavija	137	Auburn
	France	67	Lerma rojo	102	Košuta	138	Stephens
32	Roason	68	Inia 66	103	KG-56	139	Amigo
33	Renan	69	Siete Cerros	104	Pesma	140	Florida

Statistical analysis

The analysis of variance, ANOVA, and estimates of the components of variance due to genotype and genotype/environment interaction were calculated according to Comstock and Moll (1963). Both genotype and environments were treated as random effects. The percentage contribution of each variance component was estimated by summing the appropriate terms to give an estimate of total variance and then dividing the specific variance component by the total variance (Singh et al., 1993). Ratios of variance components were calculated according to Peterson et al. (1992). Heritability estimates were similar to those reported by Singh et al. (1993). Genotype clustering was done by an

agglomerate hierarchy cluster analysis, i.e., the clustering according to the degree of similarity determined on the basis of Euclidean distances. All wheat genotypes were clustered according to their breadmaking quality traits.

Results and Discussion

Based on the pooled ANOVA, all sources of variation for each of the 9 breadmaking quality traits were highly significant ($P < 0.01$) (Table 2). As expected from the wide range of breadmaking quality in the varietal set, the genetic component represented the dominant effect in the total variation. This result is in agreement with the breadmaking parameters from alveograph reported by Robert and Denis (1996). Genotype/environment interactions (G x E) were significant (relatively small) for all traits (Table 2), as a result of the different abilities of the cultivars to adjust their breadmaking quality to the environment. Previous studies on breadmaking traits such as flour protein and parameters from farinograph, extensograph and mixograph showed that the G x E interaction component of variation was significant but smaller than the genetic component (Lukow and Mcvetty, 1991; Peterson et al., 1992). Studying the yield of 23 wheat genotypes across 12 environments by various G x E interaction methods, Solomon et al. (2008) obtained a dominant effect of the environment over that of the genotype.

It is quite useful and illustrative to express all components of variance in percentages, which show the relative contribution of each source to the total variance (Table 2). Variance component due to genotype explained most of the total variation, ranging from 41.1% (PC) to 75.9% (BS). This result is in agreement with previous findings for spring wheat from Canada and the U.S. (Lukow and Mcvetty, 1991) and winter wheat from Yugoslavia (Mladenov et al., 2001). The high proportion of genetic variance in BS and LV, the most important traits in the field of breadmaking quality, open the door for breeding work. These high proportion were also confirmed by high heritability values (Table 2). The effect of G x E interaction ranged from 23.9% of the total variance for BS to a relatively high 56.6% of the total variance for PC. The G x E interactions for WG, FD, RE and FN ranged around 40% of the total variance (Table 2), which is lower for the same traits in Mladenov et al., (2001) and higher than in Lukow and Mcvetty (1991).

The proportion of the genotype in the interaction G x E can be shown by the variance component ratio $\sigma^2_g / \sigma^2_{gxe}$. A ratio larger than 1 indicates a predominant influence of genetic factors on the G x E interaction. Highest influences of the genotype were recorded for BS (3.2), FA (2.5) and FQN (2.1), while slightly lower influences but still higher than the interaction were recorded for LV (1.8), FN (1.6), RE (1.4) and WG (1.3). Only the ratio for PC was less than 1, indicating the important influence of the G x E interaction (Table 2). In general, the significant cultivar variance component indicated that the cultivars differed in their genetics for breadmaking quality traits.

Assessment of heritability of various traits is of high importance in crop breeding programs especially for predicting the response to selection and for establishing genetic differences among cultivars. Given a population from which to select, successful selection depends on the heritability levels of its traits. The heritability values for all breadmaking quality traits analyzed are presented in Table 2. The values ranged from a relatively low value for PC (0.41) to very high for BS (0.76). The high heritabilities recorded for FQN, FA, LV and FN also indicated that these traits are suitable for further improvement by breeding. Contrary to these results, Mladenov et al. (2001) found moderate to low heritability in traits such as WG, FA, FD, FQN, LV and BS.

Table 2. Mean squares for Analysis of Variances of the bread making quality traits.

Source of variation ^a	df	Bread making quality traits ^b									
		PC	WG	FA	FD	FQN	ER	FN	LV	BS	
Environment (E)	3	583**	2097**	343**	506**	13978**	200546**	1707978**	248062**	7.70**	
Rep.	8	0.23	0.635	0.60	0.03	1.46	76	146	81	0.01	
Cultivar (C)	139	8.55**	142**	113**	58**	2671**	125723**	66023**	399827**	43.31**	
Interaction Cx E	417	2.22**	23.25**	11**	8.52**	210**	18531**	9056**	49238**	3.17**	
Pooled error	1112	0.03	0.208	0.76	0.01	1.15	22	189	94	0.01	
σ^2_e		41.4	55.6	67.1	59.1	67.7	59.1	60.1	63.9	75.9	
σ^2_{cxE}		56.6	43.2	26.9	40.8	31.9	40.8	37.5	35.8	23.9	
σ^2_e		2.3	1.2	6.0	0.1	0.4	0.1	2.4	0.3	0.2	
$\sigma^2_e / \sigma^2_{cxE}$		0.7	1.3	2.5	1.4	2.1	1.4	1.6	1.8	3.2	
H ²		0.41	0.56	0.67	0.59	0.68	0.59	0.60	0.64	0.76	

^a% Total variance for each source of variation (σ^2_e ; σ^2_{cxE} ; σ^2_e); $\sigma^2_e / \sigma^2_{cxE}$ ratio of variances estimated for cultivar main and interaction.
^bPC, protein content; WG, wet gluten content; FA, farinograph absorption; FD, farinograph dough development time; FQN, farinograph quality number; ER, resistance to extension (in Extensigram); FN, falling number; LV, loaf volume; BS, baking score; H², heritability.

Wide variability ranges were observed in each breadmaking quality trait (Table 3). Ranges in all analyzed traits, except PC, were notably larger across cultivars than across environments (Table 3). Peterson et al. (1992) and Mladenov et al. (2001) reported that higher ranges occurred across environments for the same or similar breadmaking quality traits. Especially high ranges have been recorded for FD and BS, reaching variation coefficients higher than 60%. In our study, the variation in baking score (BS) was more than 10 times higher across cultivars than across environments (Table 3) emphasizing the genetic variability existing among the cultivars used.

Table 3. Ranges of cultivar and year mean values for quality traits of 140 wheat cultivars.

Trait	Ranges				Mean n=560	CV%
	Cultivar n=140	CV% ^a	Year n=4	CV%		
Protein content (%)	11.8-15.9	6.21	12.6-15.2	8.67	13.6	11.18
Gluten content (%)	21.3-40.6	11.54	28.0-32.7	7.56	29.8	15.48
Farinograph absorption (%)	53.1-67.3	5.16	58.5-60.6	1.52	59.5	6.00
Farinograph develop. time (min)	1.7-12.6	50.69	3.5-5.9	25.25	4.3	64.47
Farinograph quality number (BU)	24.4-100.0	24.00	57.2-69.8	9.27	62.2	27.80
Resistance to extension (BU)	138-591	29.84	322-370	6.37	343.0	36.16
Falling number (sec)	205-594	19.50	302-457	16.76	380.5	27.28
Loaf volume (mL)	890-1770	15.14	1182-1239	2.01	1208.5	17.71
Baking score (0-7)	0.20-6.80	56.45	3.22-3.50	4.01	3.4	62.27

^a coefficient of variation.

One of the most important prerequisites for successful breeding for breadmaking quality is the knowledge of the dependence of breadmaking quality characteristics on its components and on the interdependence of breadmaking quality traits. When several traits are involved in the expression of a phenomenon, in this case the breadmaking quality, it is desirable to determine correlations among them. Although high correlations do not always signify the cause-and-effect relationship, this procedure, in general, can tell us how closely two variables are related, and whether their relation is consistent or attributable to chance. In the present study, 36 possible pairs of traits were examined for intercorrelation. The correlation matrix in Table 4 summarized the relationships between the breadmaking quality traits studied. A number of positive correlations occurred among the analyzed traits. Very high correlations were found between LV and BS, which is logical since both traits are the result of baking efficiency. All of the farinographic measurements (FA, FD and FQN) had high positive correlations with BS and LV (Table 4). These results are not in agreement with previous results obtained in the same laboratory for the same traits (Mladenov et al., 2001). Different cultivars were probably the reason for that. PC showed a high positive correlation only with WG, which was expected since gluten is part of total protein, but the lack of any relationship with BS came as a surprise. It means that a high protein content in wheat grain or in flour cannot by itself secure good bread quality. This fact is also confirmed by the results presented in Table 5, where five of the 15 best cultivars had the protein content lower than the average for the 140 tested genotypes.

A dendrogram was constructed from cluster analysis data for 140 wheat genotypes (Figure 1). The genotypes formed four main clusters, with one cultivar being out of these clusters. Each cluster gathered cultivars originating from different countries. The first cluster included 45 genotypes originating from 19 countries, the second had 18 cultivars

from 11 countries. All genotypes in the second cluster had excellent breadmaking quality. The third cluster included 30 genotypes from 17 countries, the fourth included 46 genotypes from 18 countries. It was characteristic for the third and fourth clusters that they comprised of cultivars with inferior breadmaking quality. These results indicate that breadmaking quality is not determined by the location of origin, but it depends mostly on breeding objective, i.e., genes introgressed into the genotype.

The priority list of the traits ranging cultivars according to quality was: baking score > loaf volume > wet gluten > protein content > farinograph absorption. The best cultivar with regard to all of the breadmaking quality traits based on the 4-year average was the Argentine cultivar Pinzon Inta (Table 5). The group of the top 15 cultivars included cultivars from Serbia and seven other countries, which confirmed that environments such as the one in central Europe, do not modify the genetically determined breadmaking quality.

Table 4. Correlation among 9 bread making quality traits in 140 wheat genotypes.

Trait ^a	WG	FA	FD	FQN	ER	FN	LV	BS
PC	0.803 ^{**b}	0.268 ^{**}	0.306 ^{**}	0.098	-0.180 [*]	0.328 ^{**}	0.233 ^{**}	0.088
WG		0.476 ^{**}	0.307 ^{**}	0.090	-0.311 ^{**}	0.412 ^{**}	0.374 ^{**}	0.237 ^{**}
FA			0.500 ^{**}	0.463 ^{**}	0.048	0.420 ^{**}	0.669 ^{**}	0.709 ^{**}
FD				0.843 ^{**}	0.452 ^{**}	0.382 ^{**}	0.675 ^{**}	0.651 ^{**}
FQN					0.691 ^{**}	0.395 ^{**}	0.680 ^{**}	0.698 ^{**}
ER						0.165	0.320 ^{**}	0.398 ^{**}
FN							0.293 ^{**}	0.273 ^{**}
LV								0.944 ^{**}

^a PC, protein content; WG, wet gluten content; FA, farinograph absorption; FD, farinograph dough development time; FQN, farinograph quality number; ER, resistance to extension (in Extensigram); FN, falling number; LV, loaf volume; BS, baking score.

^b,*,** Significant at P<0.05 and 0.01, respectively.

Table 5. Rank of the first 15 best cultivars based on 4-years average.

Rank	Genotype	Bread making quality traits ^a				
		BS	LV	WG	PC	FA
1	Pinzon Inta (AR)	6.9	1770.0	38.4	15.9	65.5
2	FT HP Redeemer (SRB)	6.3	1587.0	35.7	15.5	61.5
3	Klein Forten (AR)	6.3	1562.0	35.3	15.3	67.2
4	Bankut 1205 (HU)	6.2	1557.0	38.3	15.1	62.2
5	Bezostaja 1 (RU)	6.0	1557.0	34.7	14.6	63.2
6	Manitou Insence (CAN)	6.1	1540.0	34.2	14.4	63.1
7	NS 38-00 (SRB.)	6.2	1545.0	30.7	13.1	61.3
8	Garazinko (BRA)	6.1	1485.0	30.9	13.0	63.5
9	Inia 66 (MEX)	6.1	1575.0	29.4	13.2	59.3
10	Dacia (ROM)	5.3	1517.0	32.3	14.9	59.8
11	Chris (CAN)	5.2	1435.0	36.5	15.0	63.9
12	Sofija (SRB)	5.9	1425.0	31.4	13.8	63.7
13	Flamura 80 (ROM)	5.9	1440.0	27.9	13.5	60.3
14	Pesma (SRB)	5.9	1410.0	30.6	14.4	59.4
15	NSR 2 (SRB)	5.5	1380.0	30.8	13.0	63.3
	Average of all 140 cultivars	3.4	1208.5	29.8	13.6	59.5

^a BS, baking score; LV, loaf volume; PC, protein content; WG, wet gluten content; FA, farinograph absorption.

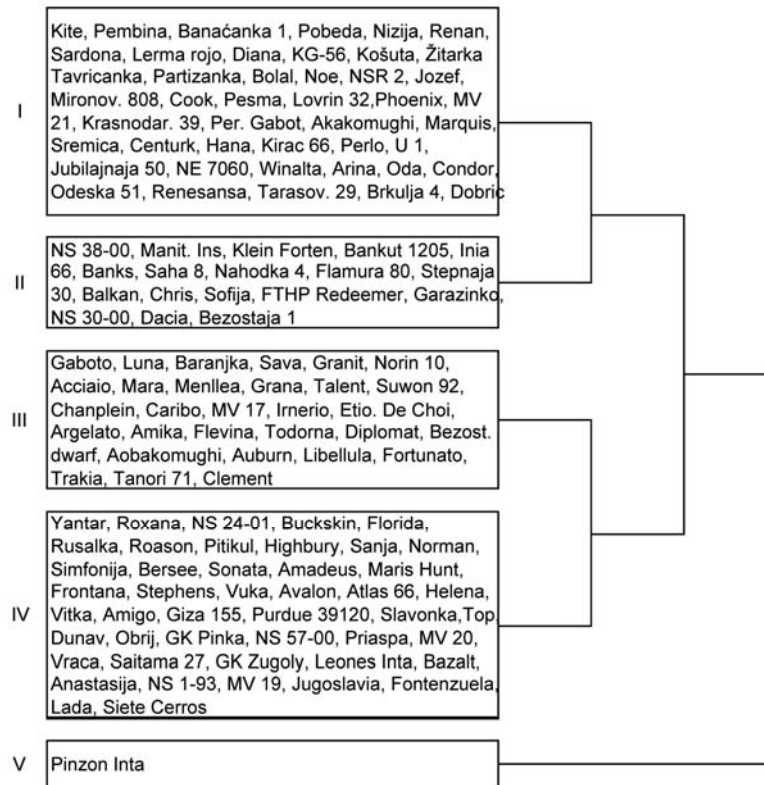


Figure 1. Dendrogram of 140 wheat genotypes based on bread making quality traits.

Conclusions

The 4-year tests of 140 wheat genotypes originating from 28 countries showed that all sources of variation for each of the 9 breadmaking quality traits were highly significant. The genetic component represented the dominant effect in the total variation, which is probably resulted from high heterogeneity of the varietal set used in the experiment. Especially high cultivar variances were recorded in BS, FQN and FA. The variation attributed to the genotype and environment interaction was smaller than that resulting from the genetic component but still significant especially in the variations of protein content and wet gluten.

The heritability for the analyzed traits varied from high for the baking score (0.76) to relatively low for the protein content (0.41).

A wide range in all breadmaking quality traits was observed. With the exception of protein content, ranges in all other traits were significantly higher across cultivars than across environments. An extremely high range was found in farinograph developing time and baking score, with coefficient of variation more than 60%. Variation in baking score was 10 times higher across cultivars than across environments (years).

A number of positive correlations were found among the analyzed traits. A very high correlation was observed between loaf volume and baking score, which is logical since both traits result from loaf baking efficiency. All farinographic traits, (FA, FD and FQN) were positively correlated with LV and BS. Protein content showed high positive correlations with wet gluten content, which was expected since gluten is part of total protein and it has significant but low correlations with FA, FD, FN and LV. Baking score as the final grade of breadmaking quality was positively correlated with all of the analyzed traits except protein content.

Cluster analysis showed that the clustering of wheat genotypes according to quality is not governed by their geographic origin.

All genotypes were ranked according to the values of BS, LV, WG, PC and FA. Among the best 15 cultivars, 2 were from Argentina, 5 from Serbia, 2 from Canada, 1 from Russia, 2 from Romania, 1 from Mexico, 1 from Brazil and 1 from Hungary. The most superior cultivar considering the traits mentioned was the Argentine cultivar, Pinzon Inta.

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