Effects of Wheat Cultivar and Harvest Year on Technological Quality Studied by Univariate and Multivariate Analyses

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Abstract

Švec I., Hrušková M., Jirsa O. (2007): **Effects of wheat cultivar and harvest year on technological quality studied by univariate and multivariate analyses**. Czech J. Food Sci., 25: 249–256.

The effects of wheat cultivar and harvest year on the wheat technological quality were studied by univariate and multivariate statistical methods. Two wheat varieties sown in the harvest years 2003–2005 were used, the first one of European (cultivar Bezostaja, RUS), the second one of American origin (cultivar Jagger, USA). The evaluated parameter values indicated otherness of technological quality of the varieties studied, mostly in the milling effectivity and in proteins contents and quality. Principal component analysis (PCA) results suggested these differences, but their verifiability based on ANOVA testing was not proved. The harvest year mostly affected also the milling quality and alveograph parameters. The baking test results were not affected by either of both effects studied. The crop of 2003 had higher proximity to the crop of 2004 than to that of 2005. Multivariate analysis (cluster analysis; CA), was used to evaluate the interaction between the wheat cultivar and harvest year effects. In comparison of these effects rate, the technological quality of American cultivar Jagger was strongly influenced by the cultivar (with exception of Falling Number and gases volume). In contrast, the quality of the European wheat cultivar Bezostaja depended significantly on the harvest year.

Keywords: wheat cultivar; processing variables; univariate analysis; multivariate analysis

Both the wheat cultivar and harvest year effects are traditional goals of cereal researchers' interest. It is well known that the wheat end-use quality depends above all on wheat genome. Agricultural treatment as well as the climate during each harvest year causes a distinct fluctuation in the wheat quality (Peterson *et al.* 1992; Muchová 2003; Kučerová 2005; Hrušková *et al.* 2006; Švec *et al.* 2006). Overall technological quality of bread wheat could be examined from different points of view, but basically as milling (Dubois & Juhue 2000) and baking quality (Robert & Denis 1996; Švec *et al.* 2004a, b). The results of experimental baking test are in accordance with its procedure, standard (El-Dash 1981; Kilborn & Tipples 1981) or optimised (Finney 1984). Magnus *et al.* (1997), using univariate and multivariate analyses, studied the effects of wheat cultivar and processing conditions in experimental bread baking. The applied statistical approach based on principal component and variance analyses was adapted to this work for the evaluation of the wheat cultivar and harvest year effects.

The goal of this work was to compare the behaviour of an old Russian cultivar Bezostaja and a new American one Jagger in the central Bohemia climate. The tested samples are deposited in the Gene Bank Department of the Crop Research Institute in Prague-Ruzyně. These varieties were planted within the international breeding test

CIMMYT, thus no one Czech wheat cultivar was included in this study.

MATERIAL AND METHODS

Two winter wheat varieties, Russian cultivar Bezostaja and American cultivar Jagger grown during crops 2002/2003–2004/2005 in the area of central Bohemia were subjected to the harvest year and wheat cultivar investigation. Grain and flour characteristics were evaluated using NIR-spectrophotometer Inframatic (Perten Instruments, Sweden; ČSN 560512) and alveograph (Chopin, France; ČSN ISO 5530-4). The dough parameters were acquired by internal methods with the help of apparatuses fermentograph (SJA, Sweden) (Švec 2003; Švec & Hrušková 2004), maturograph, and OTG (Brabender, Germany) (Kučerová 2002).

Fermentograph describes the fermented dough behaviour during the first stage of fermentation, the dough sample and gases volumes rising are observed. The parameters evaluated are the dough volume, time of fermentation, and gases volume. For the observation of the second stage of fermentation, maturograph is applied. After the standard time of fermentation, the dough sample is periodically weighed and the volume rise is registered. The evaluated parameters are leavening time, dough resistance, dough elasticity, and leavening stability time. Oven rise apparatus records the volume changes of fermented and leavened dough samples during 22 min of their baking in oil bath. The important points of the curve registered are the volumes of dough (at the beginning of the test), of sample (in the middle of the test), and of bread (the volume at the end of the test). Finally, an oven rise as the difference between the final and the initial sample volumes is observed.

Baking test was also performed according to the Czech method (Švec 2003; Švec *et al.* 2004a, b), and specific bread volume was calculated; this parameter is usually used for the wheat quality end-use description. Six parameters served for radar graph (also radius, star graph) construction for the view of wheat varieties overall quality. Grain proteins content, Zeleny test value, Falling Number, gases volume, water absorption, and specific bread volume were included in this plot type. Generally, thirteen basic quality characteristics were selected for univariate (analysis of variance (ANOVA) and multivariate analyses (principal component analysis, PCA; cluster analysis; CA) with the help of software Statistica CZ (version 7.1, StatSoft Inc., USA). The pattern of the statistical procedure was adapted from Magnus *et al.* (1997) who studied the effects of wheat cultivar and processing conditions in experimental bread baking on Norwegian wheat varieties.

ANOVA with Tukey's test output calculates homogenous object groups which differ from one another in their average values. Each homogenous group includes those objects which have the symbol "****" in the same column of the numbered ones in Tukey's test result table.

Principal component analysis (PCA) in based on the transformation of the primary data. The result is a new set of variables (principal components) that are linear combinations of the original variables and are uncorrelated. The new variables thus generated are smaller in number, and yet account for the inherent variation of the data to the maximum possible extent. In fact, in this way, a new space (factor space) is generated onto which the cases and the variables can be projected and classified into categories. The significance of the components decreases progressively; however, the contribution of a single principal component to the explanation of each variable variation can not decrease as does the average of the contribution sum over all variables. For PCA results interpretation, plots of variables and objects in the projection of either PCs onto axis x and y are necessary. For the explanation of inherent variation, combinations of PC1, PC2, and PC3 for these plots are usually sufficient (in total 70–90% of explained variation).

Cluster analysis creates groups of samples based on their distances. It seeks objects groups of the same properties which differ at the same time from the next objects group. In a previous work, Euclidean metrics was used together with clustering algorithm "Furthest" (Švec *et al.* 2006). In that work, this algorithm was selected for proper distinguishing of varieties categorised into four different quality classes. Also in this case of two wheats of different origin, the clustering technique "Furthest" was used as appropriate.

RESULTS AND DISCUSSION

Parameters of technological quality

Basic grain traits (Table 1) had comparable values with both wheat varieties. Higher milling quality was observed of the cultivar Bezostaja – the yield

Table 1. Selected qualitative parameters of grain, flour, dough and bread

	Bezostaja (RUS)			Jagger (USA)		
	2003	2004	2005	2003	2004	2005
Grain traits						
Test weight (kg/hl)	87.0	85.7	84.2	82.0	84.7	80.1
Grain hardness (1)	55	54	51	55	57	53
Flour characteristics						
Flour yield (%)	72.9	68.9	64.4	70.3	65.1	60.8
Mohse yield (%)	7.1	–0.1	–5.4	4.5	–3.9	–11.4
Flour proteins (%)	12.8	13.9	13.1	12.4	15.4	14.9
Falling Number (s)	341	371	330	422	432	332
Zeleny test (ml)	63	65	61	63	65	69
Alveograph elasticity (mm)	137	138	110	166	135	110
Alveograph energy (10^{-4} J)	187.0	227.0	208.0	204.0	246.0	269.0
Fermented dough and bread traits						
Gases volume (FeJ)	120	127	113	116	127	112
Dough resistance (MJ)	745	1080	845	720	765	860
Oven spring (OJ)	125	100	85	60	75	60
Specific bread volume (ml/100 g)	384	410	331	378	355	373

of flour was approx. about by 6% higher and also the effectiveness of milling (Mohse yield) was about by 10% better in each of the years observed.

Flour protein quality of the cultivar Jagger did not correspond to its higher content of flour because the values of Zeleny test were comparable in both samples (Table 1). Also dough alveograph elasticity was worse in the harvest years of 2004 and 2005 with the cultivar Jagger. On the other hand, alveograph energy describing viscoelastic behaviour of the flour protein corresponded better to the protein contents with the exception of the crop 2004.

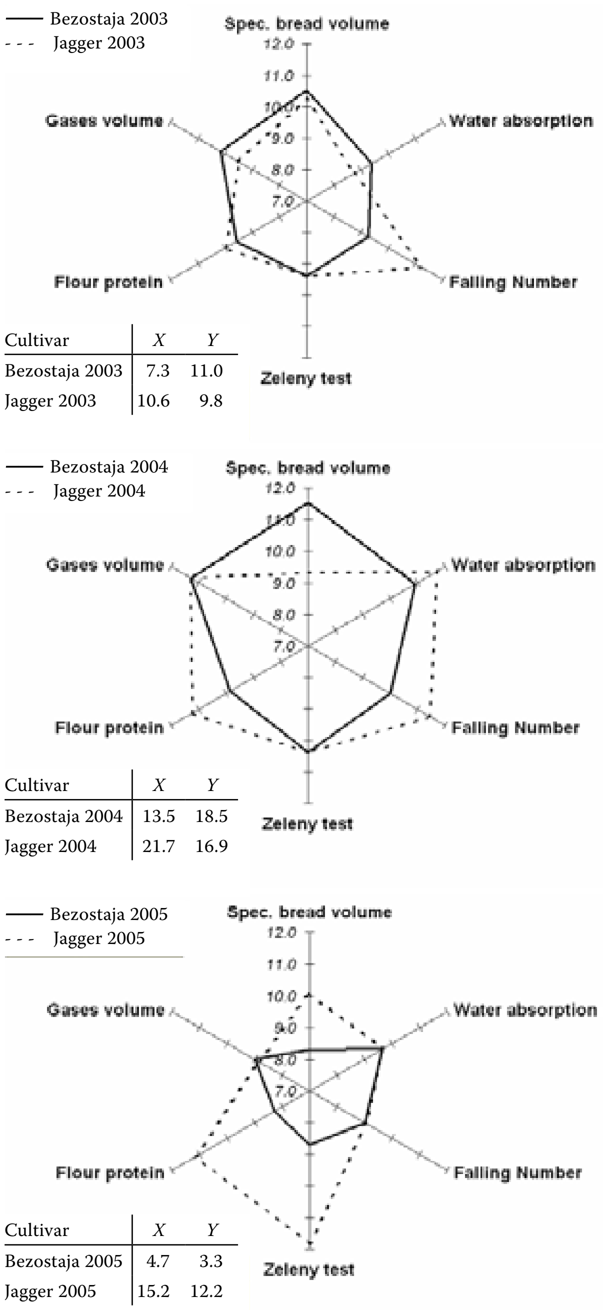
The first stage of fermentation represents fermentograph gases volume (Table 1). The measured values were comparable with respect to the accuracy of measurement. Dough resistance rose with both wheat samples in accordance with the protein quality, especially alveograph energy. The increase in the case of the cultivar Jagger was nearly linear, while in the case of Bezostaja, there was a jump change through the harvest year 2004. Also the run of oven rise values, which did not correspond to any of the other quality traits, is uncommon. There is no simple explanation for this extraordinary behaviour. The cultivar Bezostaja is known as adaptable wheat and it was accepted as standard in pedigrees of a wide range of Central- and Eastern-European cultivars, so these observed trends are surprising.

Baking test was performed according to the internal method; this method is fitted to the Czech, generally to the European, wheat. In this regard, numerically higher specific volumes could be expected with bread from American cultivar Jagger. It was shown, that the reflection of the protein properties (protein content, alveograph energy) into baking test results was more adequate for European wheat cultivar Bezostaja. With the cultivar Jagger, bread volumes kept the same level regardless of the significant changes in the protein content and dough alveograph energy. Due to that, a stronger effect of the harvest year on the technological quality can be presumed with the cultivar Bezostaja than the cultivar Jagger.

However, provable differences in baking test were measured in two of the observed harvest years – 2004 and 2005. In the first case, a higher bread volume was measured with the cultivar Bezostaja (the difference was 54 ml/100 g). In the second case, bread volume from the cultivar Jagger surpassed that from the cultivar Bezostaja by about 43 ml/100 g (Table 1).

Effect of wheat cultivar

The influence of the wheat cultivar was evaluated with the help of radar graphs for each harvest year individually (Figure1). For this interpretation, parameters were selected in accordance with the Czech system of wheat cultivar classification. The proposed comparison was constructed from standardised data. The data field in these graphs was split into two sub-areas – area X is demarcated with the flour protein, Zeleny test, Falling Number, and water absorption values, while area Y summarises the points of baking quality (flour protein, gases volume, specific bread volume, and water absorption).



Cultivar	*X*	*Y*
Bezostaja 2003	7.3	11.0
Jagger 2003	10.6	9.8

Cultivar	*X*	*Y*
Bezostaja 2004	13.5	18.5
Jagger 2004	21.7	16.9

Cultivar	*X*	*Y*
Bezostaja 2005	4.7	3.3
Jagger 2005	15.2	12.2

Figure 1. Comparison of the wheat cultivar effect on the six basic quality traits

Total areas (a sum of X and Y) were the highest in the harvest year 2004 – they differed mostly in the flour protein content, falling Number, and specific bread volume values. Bread volumes of the cultivar Bezostaja are in correspondence with the protein contents in each harvest year, but bread volumes from the cultivar Jagger were mutually comparable regardless of the provable differences in grain protein contents. Between the varieties Bezostaja and Jagger, areas of X were incomparable in each of the three harvest years. Areas of Y were close together with the exception of the crop of 2005 in which the cultivar Jagger reached nearly four times larger value.

Main variation in technology characteristics among the wheat varieties

Eighty-five percent of the variation in the wheat technological quality was explained by the three principal components (PCs), 41% by PC1, 29% by PC2, and 15% by PC3, respectively (Table 2). The

Table 2. Proportion (%) of the variance explained by the first three principal components

Technology parameter	PC1	PC1–2	PC1–3
Total	41	70	85
Test weight	41	43	71
Grain hardness	24	83	89
Flour yield	94*	94	96
Mohses' yield	97*	98	98
Flour proteins	41	81	82
Falling Number	17	55	76
Zeleny test	38	87	88
Alveograph elasticity	67*	80	88
Alveograph energy	67*	100	100
Gases volume	19	56	75
Dough resistance	7	9	84*
Oven spring	2	82*	84
Specific bread volume	14	43	71

*Significant correlation (P = 95%)

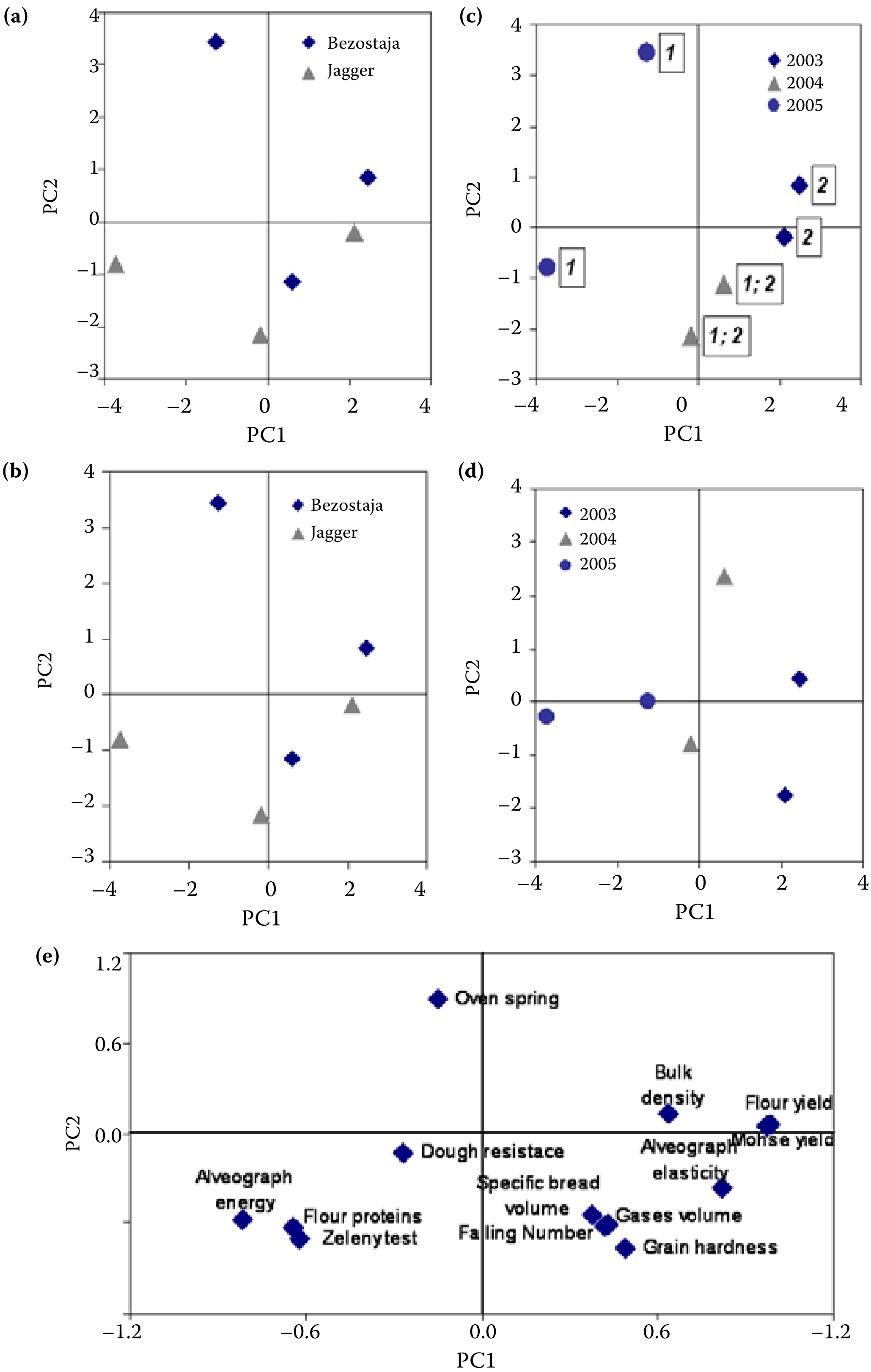


Figure 2. (a) PC1 and PC2 score for the different varieties; (b) PC1 and PC3 score for the different varieties; (c) PC1 and PC2 score for the different crop years. Different number indicate significantly different principal component 1 and 2 scores, respectively; (d) PC1 and PC3 score for the different crop years; (e) Plot of loadings for principal components 1 and 2

values of PCs pointed by a star denoted provable correlation (P = 95%) between the relevant quality trait and the principal component. It could be noticed that the milling quality and behaviour of non-fermented dough (alveograph traits) was included primarily into PC1, and the baking quality was covered by the other two PCs (maturograph dough resistance and oven rise traits).

The results of the first three PCs are presented in Figure 2a, b. In these PC1 vs. PC2 or PC1 vs. PC3 score plots, the American variety is located in the lower part of these pictures, whereas the European cultivar mostly in the upper part. However, the results of ANOVA on the PC1-3 scores (Figure 3) showed that the wheat cultivar did not significantly (α = 0.05) affect the scores.

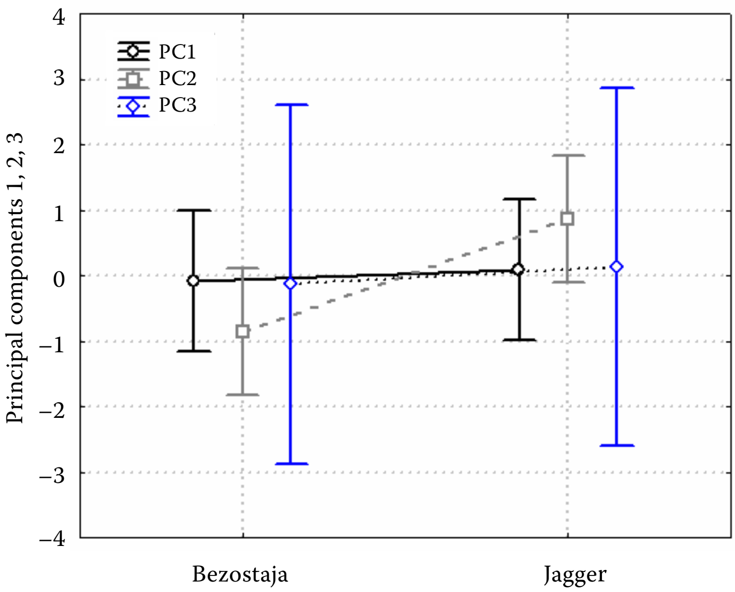
Effect of harvest year

The plots of the first three PCs for the case of the harvest year are graphically presented in Figure 2c and 2d. The harvest years are evidently separated in these plots, although standard errors are relatively high. In the PC1 vs. PC2 plot (Figure 2c), the distance between the points of the harvest year 2005 is approx. four times greater in comparison with the pairs of the harvest years of 2003 and 2004. The sample distribution is in Figure 2d similar to that in Figure 2c – crop 2003 samples are located on the left-hand side, those of the crop 2004 close to axis x, and finally crop 2005 samples on the right-hand side in these plots. By ANOVA and Tukey's multiple comparison test on the principal components scores, the harvest years observed were grouped into pairs 2003–2004 and 2004–2005 based on their PC1 scores (Figure 4). These crop pairs are marked in Figure 2c by numbers "1" and "2". Crop 2004 belonging to both groups was marked "1; 2". Affinity of crops 2003 and 2004 was identified also for eleven Czech winter wheat bred in the same area (central Bohemia) in the years of 2002–2004 (Švec 2006).

According to Table 2, the traits mainly affected by the harvest year were flour and Mohse yields, and alveograph elasticity and energy. ANOVA of further PCs did not prove any differences among the harvest years (Figure 4) regardless of the significant correlation of oven spring parameter to PC2 and dough resistance to PC3 (Table 2).

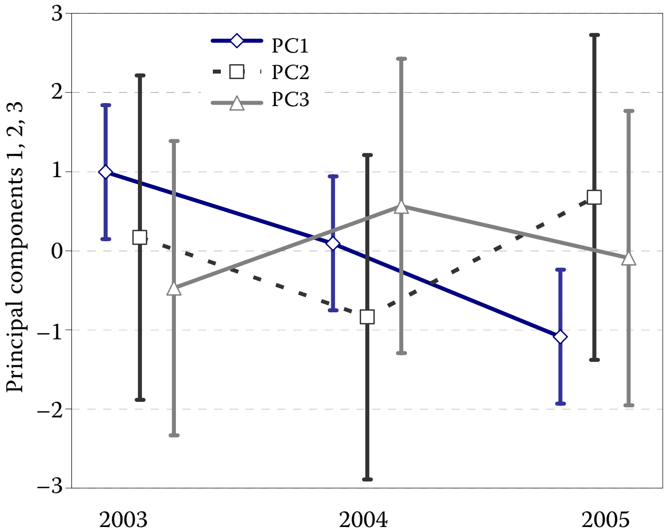
Interaction of wheat cultivar and harvest year effects

Cluster analysis (CA) was chosen to express reciprocal relations between the effects studied. A dendrogram was constructed on the basis of all thirteen quality traits given in Table 1. The algorithm "Furthest" was used, and the result gained (Figure 5) was comparable to UPGMA algorithm (not shown), which is usually used in the field of bioinformatics. The first three steps of clustering confirmed a weaker effect of the harvest year on the technological quality of the wheat cultivar Jagger – 80% of its properties from the harvest



Cultivar	PC1	1
Jagger	–0.2629	****
Bezostnaja	0.2629	****
	PC2	1
Jagger	–0.5344	****
Bezostnaja	0.5344	****
	PC3	1
Jagger	–0.6804	****
Bezostnaja	0.6804	****

Figure 3. Wheat variety dissimilarity test



Harvest year	PC1	1	2
2005	–1.0861	****	
2006	0.0919	****	****
2007	0.9942		****
	PC2	1	
2003	0.1652	****	
2004	–0.8310	****	
2005	0.6750	****	
	PC3	1	
2003	–0. 7284	****	
2004	0.5447	****	
2005	–0.0919	****	

Figure 4. Harvest year dissimilarity test

year 2003 were detected in the next one. Moreover, the distance between the harvest years 2003 and 2005 was close to 50% with that cultivar. For comparison, the average distance with the wheat cultivar Bezostaja was 87, i.e. only 13% of the cultivar properties had been in average preserved during the harvest years observed.

The first step of clustering is supported by the results of Tukey's test – the affinity between the harvest years 2003 and 2004 was proved (samples Jagger'03–Jagger'04). In the second step, both varieties from crop 2003 were connected with 70% of statistical propinquity. The results of CA (in the last two steps) reconfirmed dissimilarity of crops 2003 and 2005, as was shown by ANOVA on PCs scores. In Figure 5, there exists a connection of crops 2003 (cultivar Jagger) and 2005 (cultivar Bezostaja) on the level of 93% of dissimilarity. Besides that, CA determined evident difference of the year 2004 from the other crops – an absolute unlikeness (100%) of 2003 and 2004 harvest years (Jagger vs. Bezostaja) was proved.

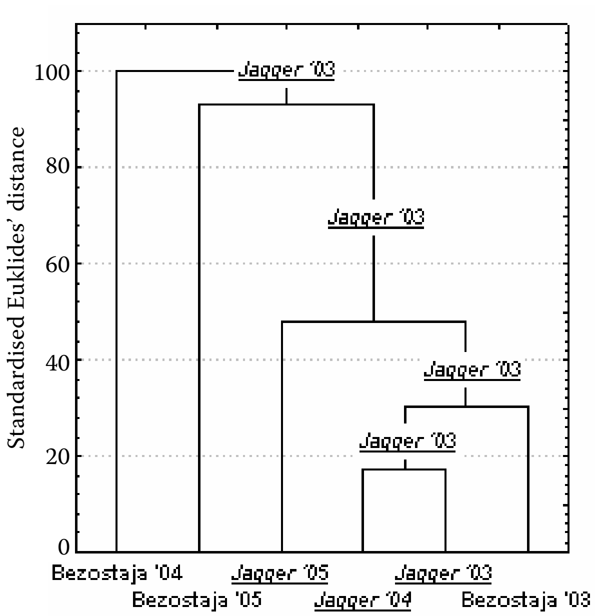


Figure 5. Analysis of wheat cultivar and harvest year interactions

CONCLUSIONS

Two wheat cultivars, the cultivar Bezostaja and the cultivar Jagger, of different origins (Russia and America, respectively) were used for statistical testing of the wheat cultivar and harvest year effects on the technological quality. Generally, the presumption of a different technological quality based on the unequal continental origin was confirmed by radar graphs. The most affected were the traits of milling effectivity, and proteins content and quality. For each of both wheat varieties studied, a different sensitivity was identified to the harvest year influence. The technological quality of the American cultivar Jagger was more stable during the observed years than that of the cultivar Bezostaja. This conclusion of ANOVA on PCs scores was reconfirmed by cluster analysis, which evaluated 80% similarity of Jagger samples from 2003 and 2004 harvests.

The results of statistical methods ANOVA (Tukey's test) and PCA show, that the differences between the wheat varieties are insignificant because of higher standard errors of quality traits with the cultivar Bezostaja. However, the same methods provided a proof of disparity between the observed three harvest years, 2003–2005. In that case, the two pairs of harvest were distinguished (2003–2004 and 2004–2005) based on milling quality and dough viscoelastic properties. In addition, also the harvest year 2004 was evaluated as dissimilar to either of the two others by cluster analysis.

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Received for publication January 16, 2007
Accepted after corrections April 27, 2007

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