# RELATIONS BETWEEN THE GRAIN HARDNESS AND OTHER QUALITY PARAMETERS OF WHEAT*

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The tested set for statistical evaluation consists of 191 commercial wheat samples harvested during 2006–2009 in six Bohemia localities. Food wheat was described by quality traits, in emphasis of PSI and NIR hardness, one-stream and fraction milling (grinder FQC 109 and laboratory mill CD1 Auto, respectively). Statistical methods confirmed our hypothesis of wheat hardness importance in quality depending on the external condition. Milling parameters as TW or PSI hardness and baking ones (e.g. protein content or the Zeleny's value) showed comparable quality oscillation in regards to crop year and locality. Measured PSI hardness of 13–29% corresponded with classification 'hard' and 'medium hard' (37% of samples sorted into the former and 52% into the latter category). Significant correlations of grain hardness to the gluten content and the flour yield were confirmed (0.35, 0.67 for one-stream and 0.68 for total flour yield, respectively; P = 99%). ANOVA and PCA statistics detected primary impact of harvest year factor on commercial wheat, and as crucial features were found out the gluten and protein contents, the Zeleny's value, PSI hardness and the one-stream flour yield. According to statistical analysis, grain hardness and flour yield of commercial wheat belong to significant quality features with year crop changes.

statistical analysis; commercial wheat quality; grain hardness; harvest year; planting locality

## INTRODUCTION

Wheat is considered to be the greatest importance among cereals because of its processing characteristics; it is basically classified into hard, soft, and durum categories. Agricultural treatment and weather during each harvest year cause a distinct fluctuation in wheat quality (Muchová, 2003; Kučerová, 2005; Hrušková et al., 2006), which finally corresponds to end-use (from flour to bread, pasta, or cookies). In spite of wheat use, the endosperm structure belongs to one of the important criteria for the wheat technological parameters. Physical properties of the endosperm, such as hardness, are closely related to the milling process affecting the starch damage, particle size distribution of semolina and flour size, and total milling score. The grain hardness is therefore one of the important distinguishing factors in the wheat cultivars (Faměra et al., 2004; Kleijer et al., 2007) and evaluation for commercial purposes, and plays an important role with regard to the suitability of grinding on a commercial mill. According to various researches, the wheat hardness is transmitted by breeding (Pomeranz, Williams, 1990; Posner, Hibbs, 2005). The puroindolines A and B and a single locus (Ha) located on chromosome 5D are referred with the different wheat hardness (Morris, Massa, 2003; Wanjugi et al., 2007).

Wheat texture is commonly assessed empirically using either the granularity (particle size distribution) of the meal produced by grinding or the force/fracture characteristics of individual kernels observed during crushing. Between methods as the wheat hardness index (Faměra et al., 2004), the single-kernel characterisation system (SKCS 4100), the hardness index (AACC Method 55-31) and the pearling index (PI, Rodney et al., 2007), the Particle Size Index (PSI) is used as the reference procedure (AACC Method 55-30, 2000). The PSI values obtained by grinding wheat samples through grinder LM 3303 Perten and by sifter (0.075 mm sieve) correlate significantly with the flour yield. At present, the grain hardness may be determined by near infrared (NIR) spectroscopy, either with whole grain or milled samples, but the respective equipment must be calibrated on the basis of the PSI or the PI results (Brown et al., 1993; Faměra et al., 2004; Hrušková et al., 2008).

The wheat hardness correlated well with the semolina and flour yields (Hrušková et al., 2008) and other wheat characteristics (Slaughter et al., 1992; Kouřimská et al., 2004; Souza et al., 2004). Koeksel et al. (1993) reported a significant rela-

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tion to the wheat vitreousness. A close relationship between the grain hardness and energy consumption during milling was described on a collection of hard and soft samples (Glenn et al., 1991).

The present work has been aimed at evaluating of the representative set of commercial wheat samples (with the emphasis to grain hardness and results of milling tests) for statistical description in relation to the external and internal quality factors including the harvest year and planting locality. Statistical analysis of the results obtained forms the main part of this study. Relation of PSI hardness to flour yields from different milling regimes was not statistically verified in the Czech commercial wheat delivered to industrial mills. We supposed that used statistical methods confirm our hypothesis of the hardness role as an important wheat milling feature.

## MATERIAL AND METHODS

Wheat quality evaluation with the emphasis on PSI hardness was assessed in the set of 191 commercial samples (harvest years 2006–2009) withdrawn at industrial mill in Prague in approximately two-month intervals. Samples origin was specified according to the six mill contractors' locations covering the Central Bohemia region and its surroundings. Localities can be closer specified by cities as follows: L1 – Mladá Boleslav, L2 – Pelhřimov, L3 – Jesenice u Prahy, L4 – Břežany u Prahy, L5 – Milín, L7 – Písek. Selected localities (about 100 km local distance) represent important region for wheat planting in the Czech Republic. Farming conditions are an important external factor for wheat quality. In our cases the temperature and humidity, soil types etc. in tested places belong to characteristics of individual locality. The process of the wheat milling quality evaluation involved the test weight (according to the Czech standard No. 46 1011-5), protein quality as the Zeleny's value (ISO 5529) and starch-amylases complex stage as the Falling Number (ISO 3093). Grain hardness was measured by the PSI method (AACC Method 55-30, reference to NIR evaluation), using the Perten's grinder LM 3303. The near infrared (NIR) spectrophotometer Inframatic 8600 was employed for the grain NIR hardness as well as wet gluten and protein contents evaluation. One-stream flour yield was determined by using the laboratory mill FQC 109 (Labor Mim, Hungary) for all 191 samples. Fraction milling under standard conditions was performed on the laboratory mill CD1 Auto (Chopin, France) for 60 selected samples of the harvest years 2007 and 2008. In that case, break, reduction and total flour yield (break plus reduction) values were obtained.

Statistical data processing in terms of analysis of variance (ANOVA), correlation analysis and principal component method (PCA) were processed in the software programme Statistica 7.1 (StatSoft Inc., USA). At the first stage, influence of the crop year and the planting locality factors were described. Secondary, grain hardness relation to the other quality factors was verified by correlation analysis. Finally, the aim of PCA was to discover significance of both technological parameters and factors on wheat quality profile.

## RESULTS AND DISCUSSION

### Wheat analytical quality

Oscillations in a wheat quality between the observed period were statistically provable (P = 95%) both for harvest years and planting localities, however, they did not exceed common range. During the years 2006 and 2007, the test weight was about 3% lower (means of 791 and 796 $kg \cdot ha^{-1}$, respectively) and the wet gluten and the protein contents by up to 5% higher (means of the latter 14.2% and 14.0%, respectively) compared to the further harvests. Independently to the protein content, its bakery quality according to Zeleny's sedimentation fluctuated between 18–52 ml – technologically satisfying averages were measured in the years 2006 and 2009 (43 and 42 ml). Harvest year significantly affected also the amylases activity, but the Falling Number calculated averages of 298, 358, 324, and 338 are comparable with respect to measurement accuracy.

Table 1. Commercial wheat quality profile – the harvest year means

| Locality | Test weight ($kg \cdot hl^{-1}$) | | Wet gluten content (%) | | Protein content (%) | | Zeleny's test value (ml) | | Falling Number (s) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | mean | SD | mean | SD | mean | SD | mean | SD | mean | SD |
| L1 | $807^{c}$ | 13 | $29.9^{a}$ | 2.2 | $13,5^{a}$ | 0.6 | $39^{b}$ | 5 | $351^{b}$ | 41 |
| L2 | $789^{a}$ | 26 | $30.6^{a}$ | 3.7 | $13,6^{a}$ | 1.2 | $34^{a}$ | 7 | $372^{b}$ | 48 |
| L3 | $803^{ab}$ | 16 | $30.5^{a}$ | 1.9 | $13,6^{a}$ | 0.6 | $39^{ab}$ | 6 | $320^{a}$ | 34 |
| L4 | $799^{ab}$ | 18 | $33.1^{b}$ | 1.9 | $14,4^{b}$ | 0.6 | $39^{b}$ | 5 | $381^{b}$ | 43 |
| L5 | $807^{c}$ | 16 | $29.8^{a}$ | 0.7 | $13,6^{a}$ | 0.3 | $41^{b}$ | 4 | $320^{a}$ | 42 |
| L7 | $792^{a}$ | 8 | $29.7^{a}$ | 1.1 | $13,6^{a}$ | 0.4 | $42^{b}$ | 3 | $315^{a}$ | 15 |

SD - standard deviation; $^{a, b}$ mean in single column tagged with the same letter are not significantly different (P = 0.05)

Table 2. Wheat hardness and flour yield – the locality means

| Feature | NIR (1) | | YFQC (%) | |
|---|---|---|---|---|
| | mean | SD | mean | SD |
| L1 | 57[a] | 2 | 54.7[b] | 5.8 |
| L2 | *n* | – | 60.5[d] | 1.5 |
| L3 | 58[bc] | 1 | 55.2[bc] | 4.8 |
| L4 | *n* | – | 59.7[cd] | 1.2 |
| L7 | 59[c] | 1 | 48.3[a] | 2.4 |

SD – standard deviation, n – non-evaluated; [a, b] mean in single column tagged with the same letter are not significantly different (P = 0.05); NIR – wheat grain hardness determined by NIR spectroscopy; YFQC – flour yield on the FQC mill

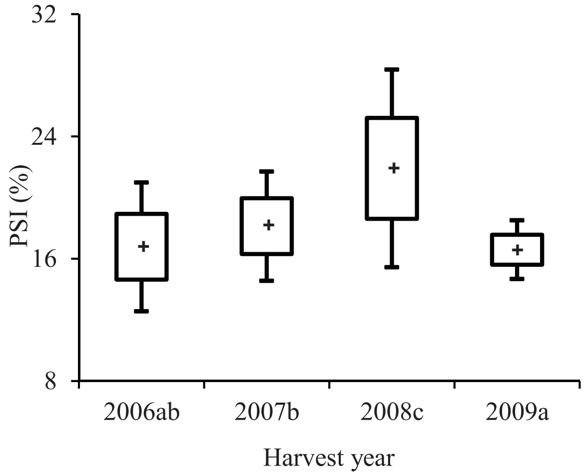


Fig. 1a. PSI profile during the monitored period

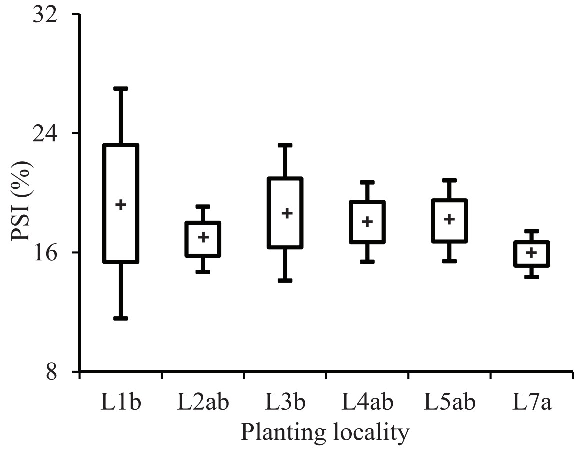


Fig. 1b. PSI profile in the monitored localities

Within the tested commercial wheat set, analytical data scatter through monitored localities (Table 1) was similar to one caused by four observed harvests. The mean values were understandably closer together, affirming breeding of wheat varieties of the standard quality for food usage (mainly those belonging to A and B Czech quality class as estimated by Š v e c et al., 2009). In different planting localities, ANOVA showed the lowest deviations for the test weight feature – six regions were split into three groups. A bit different grain analytics level for the region L4 (Table 1) demonstrates either planting of the cultivars of better technological quality or more intensive agricultural treatment.

**Wheat hardness and milling quality**

Correspondingly to the grain chemical composition, commercial wheat milling quality was levelled between six monitored localities more than the four harvest years. According to the PSI test results, commercial wheat could be categorized as hard and medium hard (frequency of 37% and 52% of cases, respectively). During the observed period, the harvest PSI means were 17%, 18%, 22% and 17% – thus crop 2008 samples were softer compared to the others (Fig. 1a). Statistically significant difference between hardness means in years 2008 and 2009 was confirmed also by NIR technique, although the reached values were close together – 57 and 58 units. The yield of one-stream flour was in agreement with PSI measured – the calculated means were 58.2%, 60.7%, 54.9% and 49.1%, respectively. Summary of the corresponding data from viewpoint of the milling quality for the planting localities is given in Fig. 1b and Table 2. As tested wheat set extreme, hard wheat samples from locality L7 could be considered (mean PSI of 16%; Fig. 1b). Due to inverse relation of the PSI and the NIR hardness, items from the L7 locality considerably reached the highest NIR values. Stronger effect of planting year in comparison to wheat locality origin can be connected with determination of PSI hardness, which is related to tertiary protein structure. Furthermore, those samples disintegrated on the mill FQC 109 rendered smaller amount of flour (Table 2), though a pair correlation between the grain hardness and the flour yield was positive (Table 4b).

Table 3. Analysis of variance of four harvest years (A), six planting localities (B) and their interactions for PSI hardness

| Source of variation | Sum of squares | Degree of freedom | Mean square | F-value | p-value |
|---|---|---|---|---|---|
| Factor A | 610.0 | 3 | 203.3 | 62.635 | 0.000 |
| Factor B | 19.6 | 1 | 19.6 | 6.044 | 0.016 |
| A × B | 232.9 | 3 | 77.6 | 23.913 | 0.000 |
| Total error | 350.6 | 108 | 3.2 | | |

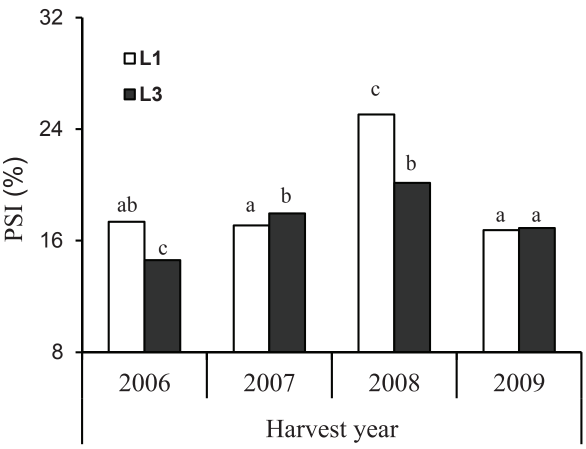


Fig. 1c. Grain hardness – wheat origin effect
L1, L3 – planting localities

Food wheat origin effect on wheat hardness was statistically examined by multiple ANOVA for 116 samples bred in the local localities L1 and L3 through all four years. 'Factor A' is the four harvest years, and 'factor B' is six planting localities. The results of the test are in Table 3. It was shown that all sources of variations and all interactions were found to be statistically significant giving F = 62.64 for factor A, and F = 6.04 for factor B. There is confirmation of different harvests year causing higher commercial wheat quality variation. Based on $p$-value lower 0.05 ($p$-value 0.000, Table 3), furthermore, the multiple comparative HSD analysis was carried out. As could be noticed in Fig. 1c, the most diverse interaction of harvest year and planting locality occurred in the year 2008 – PSI value for L1 wheat samples was about 25% higher than for L3 ones.

#### PSI hardness relation to wheat quality features

Puroindoline genes A and B are responsible for grain firmness via proteins structure and mechanical properties (M o r r i s , M a s s a , 2003; W a n j u g i et al., 2007). PSI hardness is included among milling quality parameters, thus it is affected by wheat chemical composition and influences milling test results. Correlation analysis turned out known bounds of the grain hardness from both the stated aspects (Tables 4a, 4b). In majority of cases, pair correlations to technological quality features were significant for grain hardness measured either by PSI or by NIR method ($r$ = –0.73 for interrelation of PSI × NIR). Higher agreement of those methods was achieved by F a m ě r a et al. (2004) in the winter wheat variety collection of the PSI from 10.9% to 25.9% planted during a period of 1997–2001 ($r$ = –0.93).

For the presented commercial wheat, protein properties influenced the grain hardness; the strongest impact was detected on the protein quality (the Zeleny's test value, $r$ = –0.21 and 0.37 for PSI and NIR hardness, respectively; Table 4a) similarly to the previous study (Švec et al., 2009). A little bit stronger bond of those two characteristics ($r$ = 0.38) proved Pasha et al. (2009) for spring wheat with PSI of 16–29%. Also test weight as an external characteristic of wheat is moderately

Table 4a. Correlations between the analytical features and the grain hardness ($a_N$ = 191, r0.05 = 0.14; $b_N$ = 116, r0.01 = 0.18)

| Feature | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Test weight[a] | *A* | 1 | | | | | | |
| Wet gluten content[a] | *B* | –0.36** | 1 | | | | | |
| Protein content[a] | *C* | –0.35** | 0.98** | 1 | | | | |
| Zeleny's test value[a] | *D* | –0.02 | 0.41** | 0.52** | 1 | | | |
| Falling Number[a] | *E* | 0.01 | 0.07 | 0.07 | –0.02 | 1 | | |
| PSI[a] | *F* | 0.35** | –0.14 | –0.15* | –0.21** | –0.17* | 1 | |
| NIR[b] | *G* | –0.24** | 0.33** | 0.27** | 0.37** | –0.03 | –0.59** | 1 |

PSI – wheat grain hardness determined according to the Particle Size Index method, NIR – wheat grain hardness determined by NIR spectroscopy

Table 4b. Correlatons between milling test characteristics and grain hardness

| Feature | | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|
| PSI | *F* | 1 | | | | | |
| NIR | *G* | –0.73** | 1 | | | | |
| YFQC | H | 0.67** | –0.56** | 1 | | | |
| YBF | *I* | 0.82** | –0.52** | 0.66** | 1 | | |
| YRF | *J* | 0.19 | –0.19 | 0.30 | 0.43** | 1 | |
| YCD1 | *K* | 0.68** | –0.46** | 0.62** | 0.92** | 0.75** | 1 |

PSI – wheat grain hardness determined according to the Particle Size Index method; NIR – wheat grain hardness determined by NIR spectroscopy; YFQC – flour yield on the FQC mill; CD1 milling test: YBF – break flour yield; YRF – reduction flour yield; YCD1 – total flour yield

Table 5. Portion (%) of the data explained variability

| Feature | PC1 | PC2 | PC3 |
|---|---|---|---|
| Test weight | *27* | 3 | 23 |
| Wet gluten content | 91** | 5 | 1 |
| Protein content | 92** | 1 | 2 |
| Zeleny's test value | *30* | 23 | *30* |
| Falling number | 2 | 0 | *34* |
| PSI | 10 | *46* | 20 |
| YFQC | 8 | *74** | 4 |
| Total | 37 | 22 | 16 |

PSI – wheat grain hardness determined according to the Particle Size Index method; YFQC – flour yield on the FQC mill.; *, **pair correlation provable at P = 0.05 and 0.01 level, respectively; for underlined italic values correlation coefficients were higher than 0.50

correlated to the PSI, as testified by Slaughter et al. (1992) for the set of 2000 wheat samples. Their results demonstrated link strength dependence on crop year ($r$ = 0.30; 0.01 a 0.24 in the years of 1987, 88, 89, respectively). Kleijer et al. (2007) reported dependency of the test weight and the grain hardness on the Swiss winter/spring type of wheat for over 4500 samples ($r$ = –0.30, and –0.28, respectively; P = 0.001). Very strong bound of both milling quality parameters ascertained also Bordes et al. (2008) in the collection of 372 bread wheat varieties ($r$ = –0.37, P = 0.01).

Better fitting pair correlations were recorded between the grain hardness and the milling test features (Table 4b), partially due to lower count of items analysed. Except for reduction of flour yield, both the PSI and NIR hardness influenced milling test process. Generally, food products extraction rate depends on wheat quality, milling machine and technique. In this study, two laboratory mills of different type were used, and amount of flour obtained was expressed by four parameters. Between yields of break flour (YBF), reduction flour (YRF), total flour (YCD1) and one-stream flour (YFQC), the former turned out to be the most dependent on the PSI ($r$ = 0.82, 0.19, 0.68, and 0.67, respectively; Table 4b). Using the fluted cylinder operating with higher movement for kernel disintegration, important role of kernel compactness could be considered. For the case of the NIR hardness feature, the corresponding correlations are weaker probably with respect to limited accuracy of the spectrophotometer calibration. Hrušková, Švec (2009) milled 281 of the variety and commercial wheat samples (harvests 2003–2006) on the CD1 mill and came to similar conclusions that the grain hardness measured by NIR technique affected milling test results – correlations were provable to flour yield, semolina reduction and yield ($r$ = 0.20, –0.27 and 0.52, respectively). A complex study of the NIR hardness and flour yield carried out by Wu et al. (1990) by testing of 13 soft red/white winter and hard red winter/spring varieties. The NIR hardness was evaluated between 12–70 and break flour yields were from 25.5% to 37.0%. Any trend between those characteristics has been noticed, thus correlation was provable at the level P = 0.05 ($r$ = –0.54).

**Statistical analysis of harvest year and planting locality effects**

The principal component analysis (PCA) of the commercial wheat quality showed that 75% of the variations could be explained by the three first principal components (PCs), 37% by the PC1, 22% by the PC2 and 16% by the PC3 (Table 5). The first and the third PC explained a grain morphology (test weight) and chemical composition (wet gluten content, protein content, Zeleny's test value, Falling Number). The PC2 satisfactory combined two milling quality features – the PSI hardness and the one-stream flour yield. The loading plots of the PC1 and PC2 (Fig. 2a) showed major importance of the wet gluten or the protein content and quality (Zeleny's value) in commercial wheat quality, and a minor role of the amylases activity (Falling Number). For a higher variability in the test weight, analysis allowed its explanation from 53% for the three first PC – there was turn out in its middle relevance in commercial wheat quality assessment. Although grain hardness affected milling results, PCA in this set revealed higher contribution of the one-stream flour yield than PSI hardness to wheat quality (explained variability of 74% and 46% by PC2, respectively). Considering studied factors, the harvest year effect covered generally a variation in commercial wheat quality (compare Fig. 2b and Fig. 2c), likewise the multiple ANOVA test demonstrated for the PSI hardness (Table 3). On the score plots, there could be deduced higher protein content and flour yield prevailing in years 2006 and 2007, while in the year 2009 wheat was characterised by higher test weight and protein quality. According to the performed multivariate statistical analyses, wheat of the best technological quality resulted from the year 2006 and L3 or L4 region.

Information on quality differences among six local planting sites is useful for recommendation to industrial mill owner. PSI hardness seemed to be important milling feature and the calibration curve for screening value on Inframatic 8600 must be validated for every year crop.

## CONCLUSIONS

Quality of commercial wheat was examined with respect to the harvest year and the planting locality influences. Five grain traits in the emphasis of hardness and milling test characteristics were used

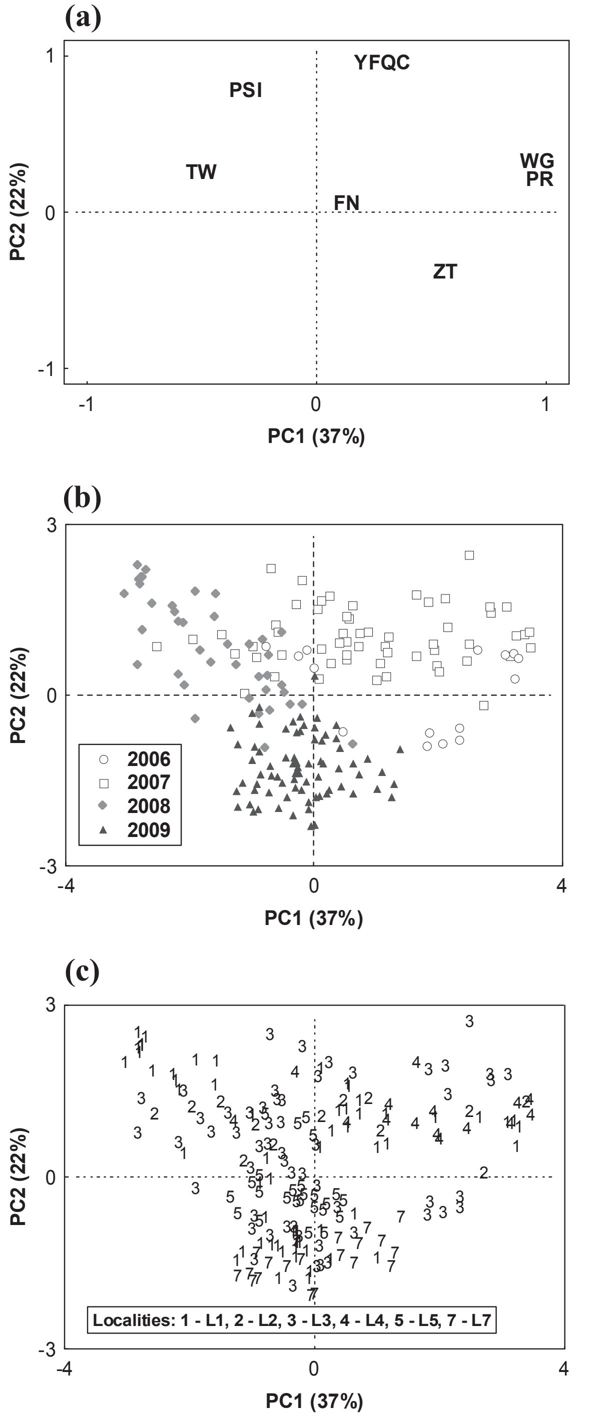


Fig. 2. Loadings (a, c) and score plots (b, d) for the first two principal components (PC's) for commercial wheat quality evaluation in terms of the harvest year and planting locality effects

TW – test weight; PSI – grain hardness; YFQC – one-stream flour yield; ZT – Zeleny's test value; PR – protein content; WG – wet gluten content; FN – falling number

for technological quality distinguishing between four crop years and six localities within the Central Bohemia region.

The PSI grain hardness was evaluated in a range of 13–29%, and over 80% of tested samples were sorted at least as 'medium hard'. NIR screening measurement of the grain hardness was performed for 116 samples, and its correspondence with the reference PSI method was verified adequately ($r$ = –0.73, P = 0.01). Dependence of wheat milling quality on the grain hardness was proved by one-stream milling test on laboratory mill FQC 109 ($r$ = 0.67, P = 0.01). Fraction milling performed on CD1 Auto mill shown similar trend for break and total flour yields ($r$ = 0.82 and 0.68, respectively; P = 0.01). Monitoring of grain hardness can be useful for prediction of flour yield in mill industry. For practical application it is necessary to adopt some standard for hardness measurement, probably by NIR technique (e.g. DA 7200 apparatus).

The harvest year influence on wheat quality was statistically more significant than the planting locality one – for the PSI trait, multiple ANOVA documented this by $F$-values of 62.6 and 6.0, respectively. Principal component analysis verified the harvest year majority impact, and turn out primary role of the protein content and quality as the Zeleny's test value and the one-stream flour yield in technological quality of commercial wheat.

Grain hardness is not used as Czech standard milling parameter for commercial wheat evaluation. Testing by PSI methods and screening procedure by using NIR apparatus with proved significant correlation can give a useful information for milling procedure due to connection with flour yield. The hardness depending on crop season and locality farming was also confirmed. According to the used statistical analysis of representative set of commercial wheat samples we can validate our hypothesis that grain hardness belongs to important wheat quality features.

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**Vztahy mezi tvrdostí zrna a ostatními znaky kvality pšenice**

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Kvalita potravinářské pšenice byla popsána základními znaky, PSI a NIR tvrdostí a výtěžností jednomleté a pasážní mouky (mlýny FQC 109 a CD1 AutoMill). Užité statistické metody byly zaměřeny na potvrzení hypotézy, že tvrdost zrna patří mezi významné jakostní znaky komerční pšenice a je jako ostatní parametry ovlivněna ročníkem a lokalitou pěstování. Testovaný soubor zahrnoval 191 vzorků sklizených v letech 2006–2009 v 6 lokalitách Středočeského kraje. Kolísání mlynářské a pekařské kvality (např. objemové hmotnosti, obsahu bílkovin nebo Zelenyho hodnoty) způsobené ročníkem sklizně, resp. lokalitou pěstování bylo hodnoceno jako statisticky srovnatelné. Podle PSI tvrdosti patří 57 % vzorků do kategorie středně tvrdá a 37 % do kategorie tvrdá pšenice (PSI 13–29 %). Byla potvrzena průkazná korelace tvrdosti zrna s obsahem mokrého lepku a výtěžností mouky (0,35 a 0,67 pro výtěžnost jednomleté mouky, resp. 0,68 pro celkovou výtěžnost mouky; P = 99 %). Statistickými metodami ANOVA a PCA byl doložen větší vliv ročníku sklizně na jakost komerční potravinářské pšenice. Mezi důležité znaky potravinářské pšenice patří vedle obsahu bílkovin a Zelenyho sedimentační hodnoty také tvrdost zrna a výtěžnost jedlých mlýnských výrobků.

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