Wheat Hardness in Relation to Other Quality Factors

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Abstract

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The analysis of the wheat hardness relation to other quality features was done with a set of 281 variety and commercial wheat samples, planted during the years of 2003–2006 in Central Bohemia and south Moravia areas. Technological quality was evaluated for grain, milling process, and flour analytics with the standard laboratory methods. The grain hardness was measured using NIR spectrophotometer Inframatic 8600. Tukey's test (ANOVA) of the grain hardness was performed for comparison between the means of wheat variety, wheat origin, crop year, growing locality, and farming intensity. As expected, the grain hardness of wheat varieties belonging to different quality classes was independent of either their classification or winter/spring type. Between all four locality means, the grain hardness among 281 samples differed insignificantly, while in the crops of 2004 and 2006 a provable increase of the kernel compactness was observed. The correlation analysis confirmed a role of the grain hardness in the milling quality assessment because of the proved correlation with 11 grain and milling quality features from the 12 tested. The strongest relation was calculated with the grain ash content, semolina yield, and flour protein content (–0.55, 0.52, 0.42, respectively).

Keywords: wheat variety; commercial wheat; grain hardness; Tukey's test; correlation

Wheat is considered of to be the greatest importance among cereals because of its processing characteristics, it is basically classified into hard, soft, and durum categories. Wheat quality cannot be simply defined since it changes depending on the workers (from the farmer to those in the processing industry) and end-use (from flour to bread, pasta, or cookies). 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 evaluation for commercial purposes and plays an important role with regard to the suitability of grinding on a commercial mill. Hardness and softness are the milling characteristics related to the way of the endosperm breaks down. In hard wheat, the fragmentation of the kernel tends to occur along the lines of the cell boundaries. One view is that hardness is related to the degree of adhesion between starch and protein. Another one is that hardness depends upon the protein matrix continuity. 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 *et al.* 1999; Morris & Massa 2003; Wanjugi *et al.* 2007).

Pomeranz and Williams (1990) summarised the environmental factors affecting the grain hardness: the growing location (soil type, elevation, planting type, irrigation, fertiliser, and cultivation practice), growing season (precipitation and temperature during maturation and postripening), storage condition, protein content, moisture, kernel size, and other factors. Environmental conditions can modify the manner in which the available protein is arranged by sufficient planting regime. Glenn *et al.* (1991) studied the influence of water on the endosperm mechanical properties and found that its compressive strength exhibited the most consistent relationship with the moisture content.

Although the measurement of wheat the texture has been studied and characterised at a material property level (Glenn *et al.* 1991; Delwiche 2000), it is still predominantly 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. The extender Do-Corder Brabender is suitable for the evaluation of grains by the wheat hardness index (WHI). During grinding, a recorder registers the torque value and the acquired meal is sieved for 3 min using 0.140 mm sieve. WHI depends on the peak height on Do-Corder tester and the meal weight sieved through the sieve (Faměra *et al.* 2004). The particle size index (PSI) values (Method 55-30, AACC 2000) obtained by grinding wheat samples through grinder LM 3303 Perten and by sifter (0.075 mm sieve) correlate significantly with the flour yield. A large meal proportion passing through the sieve is indicative of the grain softness. The single-kernel characterisation system (SKCS 4100) measures the kernel texture by crushing, recording the force required, and reporting the results as the hardness index (HI) (Method 55-31, AACC 2000) (Satumbaga *et al.* 1995; Williams *et al.* 1998). For the research purposes, hardness is measured objectively by determining "pearling index", defined as the percentage of the material pearled-off from a sample in the laboratory equipment (McGluggage 1943; Rodney *et al.* 2007). Contrary to PSI hardness, the grain softness is indicated in the PR by the removal of a relatively large proportion of the outer layers of the kernel, leaving small pearls. An acoustical, single-kernel wheat hardness instrument (Massie *et al.* 1994) analyses the level of sound above 15 kHz produced as a kernel is ground and improves the ability to classify mixed wheat samples. At present, the grain hardness is routinely determined by near infrared (NIR) spectroscopy, either with whole grain or milled samples, but the respective equipment must be calibrated on the basic of the PSI or PR results (Norris *et al.* 1989; Brown *et al.* 1993; Faměra *et al.* 2004; Hrušková *et al.* 2008). The relations between the wheat hardness categories and the proper PSI and NIR values are summarised in Table 1.

Table 1. Scale of the relative wheat hardness

Category	PSI (%)	NIR (1)
Extra hard	lower than 7	higher than 84
Very hard	8–11	73–84
Hard	13–16	61–72
Medium hard	17–20	49–60
Medium soft	21–25	37–48
Soft	26–30	25–36
Very soft	31–35	13–24
Extra soft	higher than 35	lower than 12

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 relation 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 work presented here is aimed at the variety and commercial wheat hardness in relation to the external and internal quality factors including the wheat cultivar, crop year, planting locality, and farming intensity.

MATERIALS AND METHODS

For the present study, a set of the wheat varieties and commercial wheat were collected during a period of 2003–2006. The wheat samples in a complex group of 281 named WHEAT could be divided according to the origin within the Czech Republic area into four subsets as follows:

- S1: in total 51 Czech wheat varieties grown during 2003–2005 in the Central Bohemia,
- S2: containing in total 60 international wheat varieties grown during 2003–2005 in the Central Bohemia,

– S3: containing in total 90 Czech wheat varieties grown during 2004–2006 in the South Moravia,
– S4: containing in total 80 samples of commercial wheat grown during 2003–2006 in the Central Bohemia.

Furthermore, 4 subsets were created by the samples re-arrangement according to the harvest years including: groups 2003, 2004, 2005, and 2006 (57, 87, 87, and 50 samples, respectively).

The performed process of the wheat milling quality assessment involved 12 assessments – the quality and technological characteristics measured are specified in Table 2 with the used abbreviations. The grain quality was evaluated according to ČSN 46 1011-5 (TW) and internal method (TKW). The grain hardness as well as ash and protein contents was measured using the Inframatic 8600 and the Falling Number type 1400 (both Perten Instruments, Sweden) according to ČSN 56 0512 and ČSN ISO 3093. The wheat samples were milled under standard conditions on the laboratory mill CD-1 Auto (Chopin, France) following the internal procedure. For the flour analytical features assay, the Inframatic apparatus was employed comparably to the grain analytics. Zeleny's sedimentation test (ČSN ISO 5529, respectively) complemented the flour protein composition.

Statistical data processing in the terms of ANOVA and correlation analysis was performed in Statistica CZ, Version 7.1 (StatSoft Inc., USA), while for the plot construction both Statistica and MS Excel 2003 were used. At the first stage, the influence of the factors as wheat variety, crop year, and planting intensity was documented by ANOVA in single subsets. The wheat hardness relations to the other quality factors were verified by correlation analysis. The relation of three grain parameters (GH, TW, and TKW) was described by quadratic smoothed surface.

RESULTS AND DISCUSSION

Wheat quality evaluation

The technological quality within the set WHEAT showed the highest oscillation for TKW, GFN, SY and ZT (Table 2). With the exception of the GFN, it corresponds to the different quality profiles of the wheat varieties grown in the individual localities S1–S4. The reflection of the diverse climate during the crop years taken into account could be seen just for the amylases stage due to its extent of FN (62–477 s – Table 2). Especially for GH, box plots were constructed both for the planting locality and the crop year to compare the impacts of these factors (Figures 1 and 2). Each box and whisker plot indicates the average, standard deviation and its 1.96-multiple of GH. It is not surprising, that the varieties of subsets S1–S4 predestine GH, but the crop year causes its shifting to higher or lower values.

Table 2. Descriptive statistics of the set WHEAT

Feature		Valid cases N	Average	Minimum	Maximum	SD[b]	RSD[b] (%)
Test weight	TW	281	81	71	90	3.1	3.9
Thousand kernel weight	TKW	221	42.6	30.7	70	5.5	12.9
Grain hardness	GH	281	51	36	60	5.0	9.9
Grain ash content[a]	GA	281	1.82	1.62	1.99	0.1	3.6
Grain protein content[a]	GP	281	13	9.2	16.3	1.1	8.4
Grain Falling Number	GFN	281	321	62	477	65.2	20.3
Semolina yield	SY	281	52.9	21.1	67.6	8.8	16.6
Semolina reduction	SR	281	82.4	66.9	98.4	5.1	6.2
Flour yield	FY	281	65.9	43.8	73.2	3.8	5.7
Flour ash content[a]	FA	281	0.58	0.48	0.76	0.1	10.4
Flour protein content[a]	FP	281	12.2	8.6	16.1	1.2	10.2
Zeleny's test	ZT	281	48	20	72	11.2	23.6

[a]Dry matter basis; [b]Standard and relative standard deviation, respectively

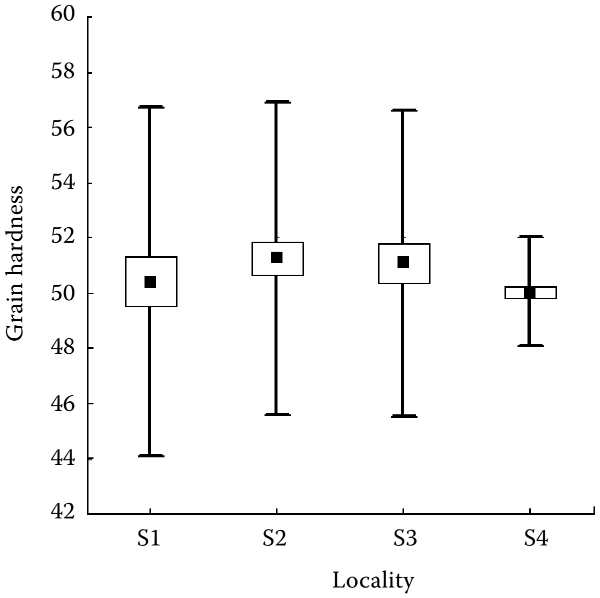

Figure 1. Comparison of wheat grain hardness between subsets S1–S4. Each box and whisker plot indicates the average, standard deviation and its 1.96-multiple of grain hardness

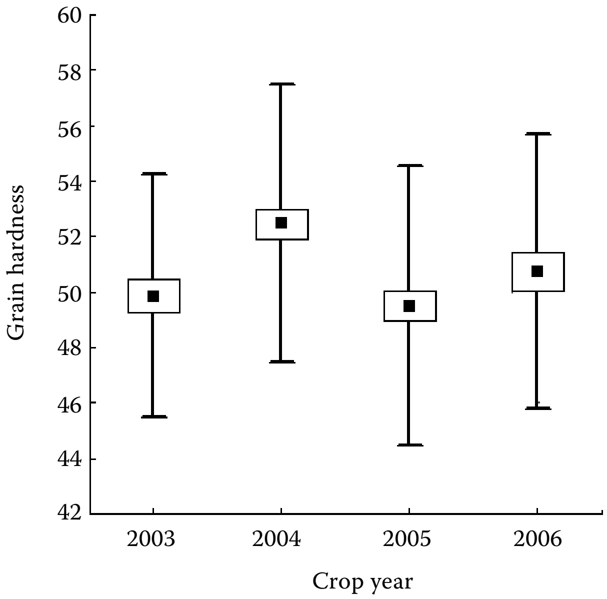

Figure 2. Comparison of wheat grain hardness between crop years 2003–2006. Each box and whisker plot indicates the average, standard deviation and its 1.96-multiple of grain hardness

In an overall view, the set WHEAT covers the requirements for the technological quality of the Czech food wheat appropriately for partial generalisation of the variety, crop year, planting locality, and intensity impact on GH.

Statistical analysis of external factors effects on grain hardness

The subset S1 was used for the demonstration of the variety influence on the grain resistance in milling. The Czech varieties in this subset could be tagged in correspondence with Table 1 as medium soft or medium hard ones (NIR hardness 38–58). One way ANOVA applied on 17 wheat cultivars grown over a three-year period proved a genetic base of the GH, regardless of the winter/spring type (Table 3). Moreover, as concerns the Czech wheat varieties, this feature is not suitable for the varieties quality class sorting. This fact is well illustrated within the homogenous group 5, in which winter and spring varieties as well as the representatives of all four wheat quality classes were involved (Table 3).

The commercial wheat samples S4 were grown in three different districts of the Central Bohemia – Zena in west-north, Primagra in west-south, and Jesenice in south-east. It is known that for the

Table 3. ANOVA of wheat variety effect on grain hardness (P = 95%, subset S1)

Wheat variety[a]	Quality class	GH	1	2	3	4	5
Simila	C	38	****				
Saskia	A	41	****				
Vlasta	B	41	****				
Sirael	C	42	****				
Saxana	A	50		****			
Svitava	B	50		****	****		
Vinjet	A	51		****	****	****	
Samanta	B	52		****	****	****	
Aranka	A	53		****	****	****	****
Zuzana	B	53		****	****	****	****
Meritto	B	54		****	****	****	****
Sulamit	E	54		****	****	****	****
Ebi	A	54		****	****	****	****
Rheia	B	55			****	****	****
Leguan	B	55			****	****	****
Alana	A	56				****	****
Mladka	C	58					****
Group average			40	52	53	54	55

[a]Spring ones are marked by *italic* font

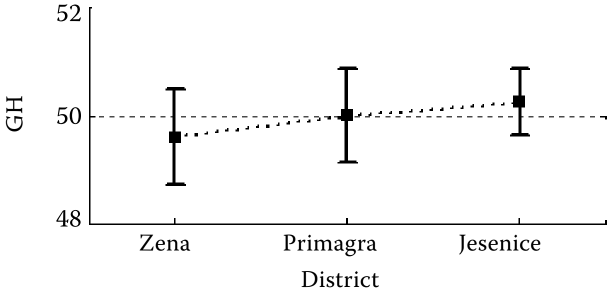

Figure 3. ANOVA of region factor impact on commercial wheat grain hardness (subset S4, P = 95%)

wheat commercial utilisation only several of the recommended varieties are grown characterised by a low oscillation of the technological quality. As Figure 2 indicates, also GH variance in the commercial wheat samples was the lowest compared to one of the varieties tested. However, in three localities slight differences could be noticed between GH average values and standard deviations (the whisker height). Hence, ANOVA of the growing districts in subset S4 did not distinguish from one another (Figure 3) in agreement with Hrušková *et al.* (2008).

Table 4 adapted from the paper by Švec *et al.* (2007) outlines the weight of wheat variety, crop year, and growing intensity factor on the 12 parameters of the food wheat milling quality. The comparison presented is an extract of the Tukey's test results (P = 95%) in terms of the numbers of homogenous groups for the selected parameters within the dataset S3. Ten wheat varieties of the definite technological quality (classification in agreement with the Czech legal system) were subjected to 3 growing intensities, which simulated 3 localities with diverse planting conditions. Due to this, the behaviour of those wheat varieties in a three-years period gave an appropriate dataset for the factors impact generalisation. As obvious, wheat the variety predetermines genetically the overall quality profile (47 groups in Tukey's test were identified), while the climate of the crop year and agro-treatment specify it with different efficiencies (28 and 15 groups, respectively).

Table 4. Comparison of wheat variety, crop year and planting intensity effects on wheat quality (subset S3)

Feature	Variety	Crop year	Intensity
TW	+++	+++	+
TKW	+++++	+++	+
GH	++++	++	+
GA	++++++	++	++
GP	+++	+++	++
GFN	++++	++	+
SY	+++	++	+
SR	++++	+++	++
FY	++	++	+
FA	+++	+++	+
FP	+++++	++	+
ZT	+++++	++	+
Total	47	29	15

Table 5. ANOVA of wheat variety origin (P = 95%, subset S2)

Wheat variety origin	Grain hardness	1	2
Czech	45	****	
Foreign	53		****
Group average		45	53

A supplementary viewpoint offers a comparison related to subset S2 (Table 5). GH of the 12 Czech wheat samples was provably lower then that of the 48 international wheat samples (P = 95%) grown in the Central Bohemia district during the period of 2003–2005. Finally, the differences between subsets S1–S4 and the analysed crop years in terms of wheat grain rigidity analysed by ANOVA at the level of α = 0.05 are summarised in Table 6. The former factor (wheat variety and growing locality) did not have a provable impact on that quality trait, although within the pairs S1–S4 and S2–S3 a little difference in the average hardness could be noticed. The calculated standard deviations (6.3, 2.0 and 5.5, 5.7, respectively) show the reason for this statistical result. On the other hand, a GH dependence on the crop year within the 281 wheat

Table 6. Comparison of overal effect of locality and crop year factors (P = 95%)

Locality	Grain hardness	1	Crop year	Grain hardness	1	2
S4	50	****	2005	49	****	
S1	50	****	2003	50	****	
S2	51	****	2006	51	****	****
S3	51	****	2004	52		****
Group average		51	Group average		50	52

samples studied was confirmed, as suggested by Figure 2. The effects of the crop years 2004 and 2006 were comparable in terms of GH increase as well as those of the triple crops 2003–2005–2006 in terms of GH decrease.

Relation of the grain hardness to other quality factors

It has been known for some time that the grain properties predetermine both the milling quality and final end-use of food wheat. For their description, TW, TKW, and GH as well as grain analytics (GA, GP and GFN) are usually used the research by many cereal scientists is still focused on these parameters interrelations, (e.g. Slaughter *et al.* 1992; Ohm & Chung 1999; Kouřimská *et al.* 2004; Souza *et al.*, 2004). The correlation analysis results for the quality traits of the set WHEAT are presented in Table 7. The confirmation may be observed of the important role of GH for the milling quality evaluation within the set WHEAT. The strongest relations were detected to GA and SY. Moreover, the protein properties GP, FP, and ZT were also correlated with GH. In the paper of Slaughter *et al.* (1992), more than 2000 HRW and HRS samples were used to identify the best distinguishing features of the HRW and HRS wheat classes. The wheat samples were collected over a three-year period (1987, 1988, and 1989), and the grain hardness was evaluated by using a NIR apparatus similar to the set WHEAT. Correlation analysis was performed for single crop years to document, the effect of the crop year factor. The results are summarised in Figure 4, for which the quality parameters adequate for own research were extracted from the data table of the cited author. The expected shifting can the noticed in the grain parameters relations – a cause could be found in the different conditions during both the years 1987, 1988, 1989 (Figures 4a–c) and the years 2003–2006 (Figure 4d) due to both the diverse correlation coefficient values and eventual pair-relations non-significance. Regardless of it, a major role of GH in the wheat milling quality description was confirmed.

Kouřimská *et al.* (2004) evaluated the kernel hardness using the reference method (AACC 5-30, particle size index, PSI) in groups of both very hard and medium soft cultivars. Wheat samples milling quality was evaluated in terms of the break and flour yields reduction using the Bühler laboratory mill. Both these characteristics were then correlated with the evaluated grain hardness, and for the flour yield reduction a significant correlation coefficient $r = -0.81$ was found. Related to the set WHEAT, SY corresponds to the reduction of the flour yield. However, it proved a reverse relation to GH ($r = 0.52$) indicating different milling qualities (including the effect of the mill type) between the compared wheat sets.

Souza *et al.* (2004) selected 7 spring wheat genotypes on the basis of the grain hardness (hard and

Table 7. Significant correlations between wheat quality traits (P = 99%; N = 281, r_{crit} 0.01 = 0.15; *N = 221, r_{crit} 0.01 = 0.17; set WHEAT)

	ZT	**FP**	**FA**	**FY**	SR	SY	GFN	GP	GA	GH	TKW*
TW	0.18		–0.52	0.19			0.17		–0.55	0.26	0.58
TKW*			–0.19	0.28				–0.40	–0.51	0.24	
GH	0.32	0.42	–0.16	0.20	–0.27	0.52		0.19	–0.55		
GA	–0.22	–0.19	0.32	–0.24	0.15	–0.30					
GP	0.57	0.83	0.33		–0.28						
GFN			–0.19			–0.17					
SY	0.17	0.29		0.48	–0.29						
SR		–0.51	–0.55	0.26							
FY			–0.24								
FA		0.40									
FP	0.52										

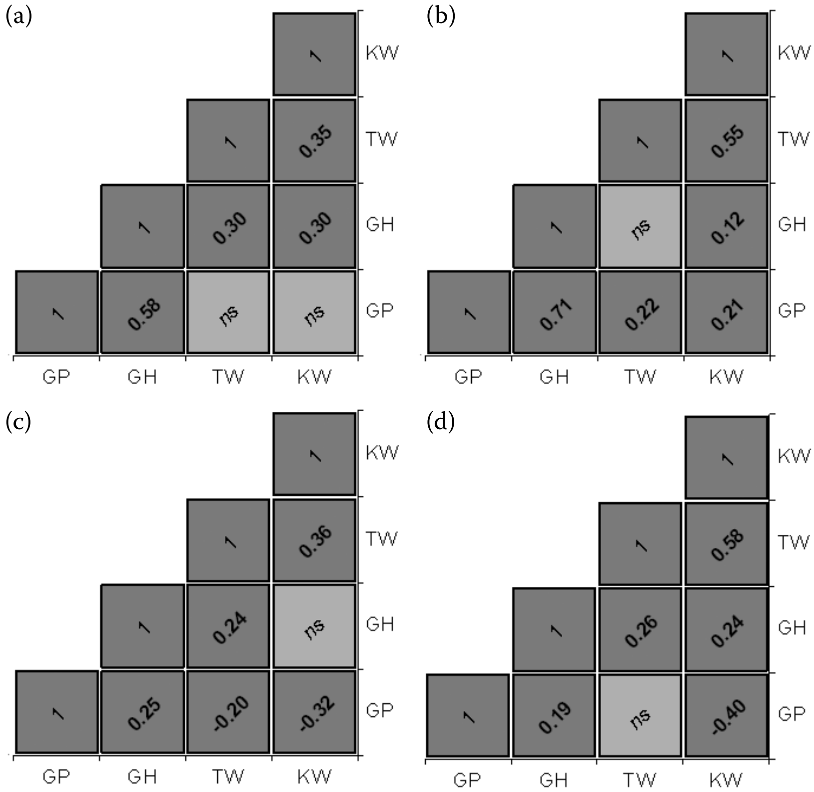

Figure 4. Comparison of the significant correlations between wheat grain features. (a)–(c) Results of correlation analysis of Slaughter *et al.* (1992) for crop years 1987, 1988, 1989, respectively; (d) Set WHEAT analysis (for abbreviations see Table 2; *ns* – non-significant)

soft white) and gluten strength (strong, moderate, weak) analyses across a range of environments (different locations, moisture regimes, and N-levels supply). Technological quality test consisted of the milling and baking qualities determination with the use of Brabender Quadrumat Senior mill and mixograph for full-recipe dough preparation. In this work, FA was correlated with TW, GH and GP, and the significance of the calculated relation depended on the wheat genotype – provable correlations were identified in 1 case for TW, 3 cases for GH, and 5 cases for GP (from 7 in total). The mean coefficient values were –0.16 (non-significant), 0.29 (non-significant), and –0.48 (significant) for FA versus TW, GH and GP, respectively. Compared to Table 7, all these correlations within the set WHEAT were significant and, except for TW, both others had an opposite sign. A reason for this discrepancy found could be related to different wheat collections and growing localities.

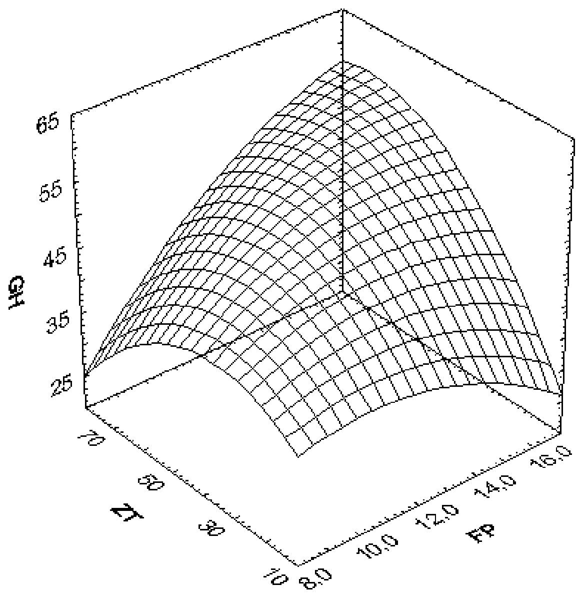

Figure 5. Relation between the wheat kernel quality parameters. For abbreviations see Table 2. Surface was smoothed quadratically

As cited above, the grain hardness is linked to the puroindolines content (Morris *et al.* 1999; Morris & Massa 2003; Wanjugi *et al.* 2007). Generally, the correlation analysis within the set WHEAT showed medium strong relations between GH and wheat protein properties, thus a quadratic model for the GH estimation was calculated as a function of FP and ZT (Pearson's r = 0.42 and 0.32, respectively). As indicated by the correlation coefficient values, the contributions of both traits were quite equal. The quadratically smoothed surface corresponds to this fact, and the presumption of a link between the grain hardness and wheat protein content and quality was also testified on the wheat sample set studied.

CONCLUSIONS

The wheat hardness is an important milling quality descriptor, according to which wheat is divided into soft, hard, and durum. It is considered as the friability of the grain endosperm, especially protein matrix cohesiveness as has been proved by many cereal researchers. This study was aimed at the wheat hardness in relation to the other 11 wheat quality features, and a set of 281 food wheat samples grown during the years 2003–2006 within the Czech Republic area was analysed. The influence of the wheat variety and origin, growing year and locality on the grain hardness was evaluated statistically by ANOVA.

The tested wheat samples hardness was analysed in terms of NIR spectroscopy. They could be designated either medium soft or medium hard ones (NIR hardness 37-60). Between the growing localities taken into account, differences in the grain hardness were found in correspondence with diverse varieties profile planted. Approximately twofold impact on the grain hardness was found with the crop year factor. Thousand kernel weight, grain Falling Number, Zeleny's test and semolina yield were identified as the best indicators for the technological quality distinguishing.

ANOVA performed in the four individual subsets confirmed the expected results. With 17 Czech wheat varieties, the grain hardness did not correspond with both the quality classes and winter or spring wheat types. In comparison of the wheat variety, crop year, and intensity effects, Tukey's test demonstrated a decreasing impact in the order mentioned. As concerns the test weight, the grain protein content, flour ash content, and milling yield only, the influence of the crop year was comparable to that of the wheat variety. Finally, the measured differences were more provable between the wheat varieties then between the growing intensity levels.

In the set of all 281 wheat samples, the growing locality did not affect the grain hardness comparably to the subset of 80 commercial wheat samples, where 3 localities were involved. The crop year impact was also assessed for all 281 samples, and comparable rates of the grain hardness increase having been observed for the years 2004 and 2006.

Correlation analysis confirmed the important role of the grain hardness for food wheat processing and final end-use. The strongest relations were identified to grain ash content ($r = -0.55$), semolina yield (0.52), flour protein content, and Zeleny's test (0.42 and 0.32, respectively).

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