Nutritive effect of protein composition and other grain properties of doubled haploid wheat lines with/without translocation 1B/1R in a model feeding test

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ABSTRACT: The frequent presence of rye translocation 1B/1R in common wheat is well known as well as its unfavourable effect on bread-making quality. These translocated materials make up more than one tenth of all wheat varieties registered in the Czech Republic and due to their lower technological value they are predominately used for livestock feeding in spite of the lack of information about their desirability for monogastric animals. Our study was aimed at a general effect of 1B/1R translocation, including other grain characteristics in model feeding tests with laboratory rats. Triennial evaluation of selected chemical and technological characteristics of winter wheat grain, including feeding characteristics in the model set of 18 DH lines with/without 1B/1R translocation, confirmed a highly significant effect of year on evaluated parameters. Wheat lines with the presence of 1B/1R translocation showed a significantly higher value of relative viscosity, crude protein content and higher proportion of the albumin + globulin fraction. This was manifested negatively in the technological characteristics of the gluten index (GI) and the Zeleny sedimentation test of these wheat lines. Detected values of relative viscosity, grain hardness (PSI) and albumin-globulin fraction were significantly influenced by the genotype of the wheat line. The relationships of evaluated grain characteristics to the results of feeding test were not unequivocal. The presence of 1B/1R translocation significantly decreased the values of balance in these characters: net protein utilization (NPU) and biological value of proteins (BV), however the effect of the 1B/1R translocation on protein efficiency ratio (PER) was not confirmed. Correlation analyses showed low mutual relationships among the parameters of balance and growth tests. A lower but significant positive correlation of the albumin + globulin fraction and a negative correlation of storage proteins with growth parameter PER were also observed. It is possible to summarize that individual relation between albumins + globulins and gluten protein composition of grains influenced the values of PER more significantly than the presence of 1B/1R translocation.

Keywords: common wheat; 1B/1R translocation; protein fractions; nutritive value; model feeding test

The world's annual production of common wheat is 600 million tons and about 17% of this total amount is used for animal feeding. Nevertheless, common wheat in north-western Europe including the Czech Republic is predominantly used for livestock feeding (Rose, 2003). The ratio of this commodity utilized for animal feeding in the Czech Republic in the marketing year of 2004/2005 was 58.5% according to the Ministry of Agriculture (Vaculová and Horáčková, 2007).

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Besides the basic source of energy, cereals in a feed ration are also an important source of proteins (Zeman et al., 2003). In animal nutrition it is necessary to calculate with a lower nutritional value of wheat proteins due to the lower content of more easily digestible albumin and globulin fraction and totally lower content of the essential amino acids lysine, threonine, tryptophan and sulphuric amino acids (methionine, cysteine) especially in the gluten storage proteins (gliadins and glutenins) of grain (Henry and Kettlewell, 1997). Kasarda et al. (1976) classified wheat proteins soluble in dilute salt solutions (albumins and globulins) as cytoplasmatic proteins. These "soluble" proteins differ distinctly in their amino acid (AA) composition from the gluten storage proteins and are nutritionally important because the essential AAs amount to about 45% of the total AAs content.

Because of its agronomic benefits (yield increase, rust and powdery mildew resistance) the chromosome 1R of rye (*Secale cereale* L.) has been widely used in wheat (*Triticum aestivum* L.) breeding, essentially in the form of the Robertsonian translocation 1B/1R. Several hundreds of wheat cultivars are known to possess this translocated chromosome and many others will bear it unrecognized (Rabinovich, 1998). More than one tenth of wheat varieties currently registered in the Czech Republic bears this 1B/1R translocation and, in connection with their lower bread-making quality (Bartoš, 1993; Graybosch, 2001) they are predominately used for livestock feeding.

The relationship between wheat varieties and their feeding values is not investigated and published frequently in comparison with technological (bread-making) quality. For example, wheat variety experiments with rats, broilers and pigs were published in the eighties and nineties. All results referred to variety differences in feeding value (Fuller et al., 1989; Heger et al., 1989; Annison, 1991). The recent work of Pirgozliev et al. (2003) tested selected grain parameters in 23 wheat varieties in relation to true metabolisation energy (AME_N) obtained from a broiler feeding test. On the basis of calculated step regression, the highest signification for the explanation of AME_N variability was confirmed for starch, protein and fat content in grains.

Rose (2003) reported significant negative correlations between the content of nonstarch polysaccharides (NSP) and apparent metabolisable energy (AME) in chicken broilers. Boros et al. (1993) and Saulnier et al. (1994) confirmed a medium strong or even strong correlation between NSP and relative viscosity of aqueous extract. Higher values of NSP and viscosity in connection with the presence of 1B/1R translocation were documented by Choct and Annison (1992). Thus, it is possible to expect a lower feeding value especially for poultry in such "translocated" wheat materials. Nevertheless, present feeding tests with materials with and without 1B/1R translocation did not confirm this hypothesis unambiguously and feeding test results were enough variable without significant evidence of the lower feeding value in translocated materials (McCracken, 2001; McCann et al., 2006). Besides the lack of general criteria of the high feeding value of wheat grain, only little information is still available about the effect of 1B/1R translocation on this area of wheat application.

This submitted study still represents only a part of wider research focused on the determination of wheat grain properties and parameters with higher relation to feeding value for monogastric animals (poultry and pigs). This part was aimed at the effect of 1B/1R translocation as well as at the impact of selected chemical and technological characteristics of wheat grain on biological parameters of model feeding test.

MATERIAL AND METHODS

A set of 80 doubled haploid (DH) wheat lines was developed by Ladislav Kučera, from the crossing of wheat cultivar Šárka with advanced line UH 410 (donor of 1B/1R translocation) in the Department of Molecular Biology of CRI in Prague. A set of selected 18 DH wheat lines with a higher agronomical potential and according to the presence or absence of allele Gli 1B3 characterizing 1B/1R translocation was subsequently divided into two numerically comparable subsets (8 lines with 1B/1R translocation and 10 lines without translocation).

Each selected DH line was genetically evaluated by means of gliadin alleles to confirm the lines with/without 1B/1R translocation. Gliadin blocks were identified according to Metakovsky (1991) in conditions of Acid-PAGE.

The lines including two standard cultivars Šárka and Nela were multiplied in large plot experiments with plot size from 0.3 ha (2004) to 0.7 ha (2006) in the Kralovice locality for three years (2004–2006). Fertilization was applied according to soil analysis in the nitrogen range of 120–135 kg N and 50 to 60 kg P_2O_5.

The following grain parameters were tested: content of crude protein – Kjeldahl method; Zeleny sedimentation test; wet gluten content (WG) and gluten index (GI) – Glutomatic 2200 (AACC 38-12); content of protein fractions (albumins + globulins and their proportions in crude protein; gliadins) – modified Osborne method according to Dvořáček et al. (2001). Content of total glutenins was calculated as a difference between the content of crude protein and the sum of albumins + globulins and gliadins.

Relative viscosity was measured with an Anton Paar micro-viscosimeter according to Saulnier et al. (1994). Grain hardness – Particle Size Index (PSI) – according to AACC Method 55-30.

The content of the two selected essential amino acids lysine (Lys) and methionine (Met) was measured with an AAA 400 automatic analyzer according to Kacerovský et al. (1990). Other chemical analyses of grain were also carried out according to the same author: content of crude fat – Soxhlet's extraction; content of crude fibre – two-step alkaline and acid hydrolysis on Fibertec; content of ash – mineralization method at 550°C; gross energy (GE) – calorimetric method – burning of grain sample in oxygen atmosphere; content of nitrogen free extract – according to the equation: NFE (%) = 100 – water content – crude nitrogen content – crude fat content – crude fibre content – ash content.

Biological testing performed at an accredited station of the Czech University of Life Sciences in Prague was based on balance and growth experiments with model animals – male laboratory rat (*Rattus norvegicus*) of outbred race Wistar. All the used animals were of the age 21 days and their body mass was 55 ± 3 g. They were kept individually and grouped by the principle of maximal similarity.

Growth and balance experiments *in vivo* were carried out according to the methodology of Heger et al. (1989) with minimally 10 animals in each group and for the period of 25 days (growth experiment) and 28 days (balance experiment). The experimental diet contained ground grains of the tested wheat samples (as the sole source of protein) on a suboptimal level of 10% protein ratio in the whole diet, vitamin and mineral supplement (U-aminovitan 331), uniform source of energy (soybean oil), icing sugar for flavouring and a uniform starch vehicle.

The following parameters were measured: protein efficiency ratio – (PER) in growth experiments, biological value of proteins (BV), net protein utilization (NPU) and coefficient of protein digestibility (CPD) in balance experiments. Nitrogen balance (NB) is the expression of the difference in nitrogen accepted and excreted by excrements (faeces and urine). The coefficient of true digestibility of protein (CPD) shows the ratio of digested nitrogen (diminished by the percentage of metabolic N) to accepted nitrogen. The biological value (BV) was determined according to Thomas and Mitchell as the relationship between nitrogen balance (enlarged by metabolic and endogenous nitrogen) and true digestibility of nitrogen. Net protein utilization (NPU) expresses the relationship between nitrogen balance (enlarged by metabolic and endogenous nitrogen) and nitrogen intake.

Faecal metabolic nitrogen (Y) in mg/day and urinary endogenous nitrogen (Z) in mg/day were calculated from the average weight (W) of laboratory rats (g) in balance period according to the formula:

$$Y = -3.601 + 0.110\ W \text{ and } Z = 10.30 + 0.076\ W$$

Protein efficiency ratio (PER) expresses the relationship between live weight gain and consumption of crude protein.

The software "Statistica 7.0 CZ" was used for the evaluation of results. Significance of evaluated factors (genotype, year and translocation) and differences among grain parameters of DH-lines were tested by ANOVA/MANOVA with subsequent Tukey's HSD test. The application of correlation analysis, PCA (Principle Component Analysis) and also multiple stepwise regression enabled to analyze relationships among biological testing and wheat grain parameters. The parameter transformations because of the high year impact were carried out according to the following equation:

$$A_{trans\ (Lx;\ y)} = A_{(Lx;\ y)}/\hat{A}_{(y)}$$

where:

A = the value of the respective tested parameter

Lx = the respective tested wheat line

Y = the respective year

$\hat{A}_{(y)}$ = the average value of the parameter in the year (y)

RESULTS AND DISCUSSION

Triennial averages of wheat grain protein composition including further technological characteristics and parameters of feeding test are summarized in Tables 1, 2 and 3. The results confirmed a high

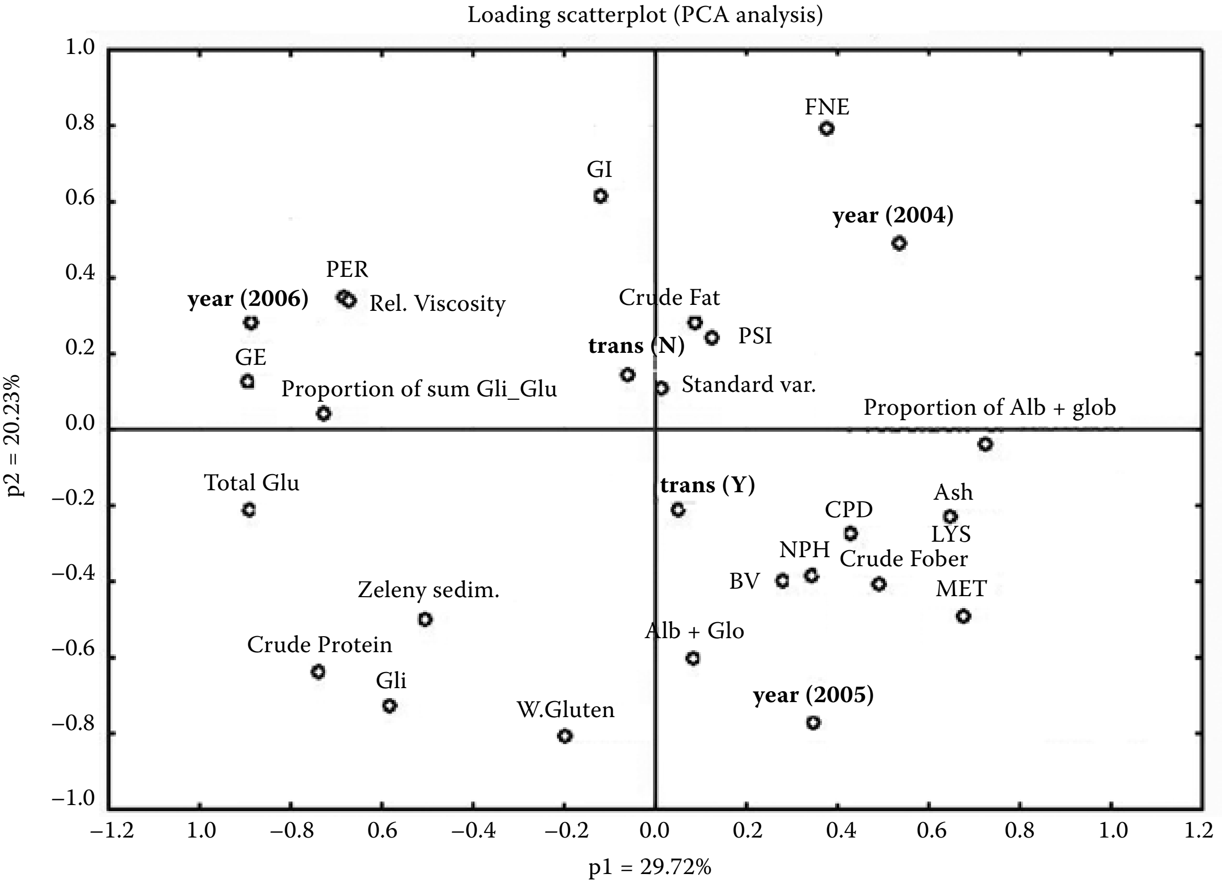

Figure 1. Mutual relationships among tested parameters and evaluated factors (2004–2006)

significant effect of annual weather conditions with their dominant incidence on the variability of monitored traits, which is documented in Figure 1. Different positions of the particular years are evident along with their influence on the monitored parameters which correspond with their tabulated statistical significance e.g. the effect of the warmer year 2006 on GE, relative viscosity and PER (Table 1). The effect of weather conditions on changes in chemical and technological properties in wheat grain is documented in many publications and the significant effects on parameters of feeding tests were also confirmed by Svihus and Gullord (2002) or Pirgozliev et al. (2003).

In accordance with the results there was a significant increase in the presence of 1B/1R translocation in DH lines, in crude protein content, content of albumin + globulin fraction, its proportion in crude protein and in the content of gliadins as well. In spite of the gliadin increase, the total proportion of storage proteins was on average significantly lower in the translocated lines namely on behalf of a nutritionally more valuable proportion of albumins and globulins (Table 1). The observed higher contents of two important essential amino acids (Lys and Met) in translocated DH lines were not significant. Among the other technological parameters, the 1B/1R translocation significantly decreased the values of GI and Zeleny sedimentation tests, on the contrary it induced the growth of grain relative viscosity (Table 3). Worse technological (baking) properties of the material with translocation are usually explained by losses of alleles GLU B3 and GLI B1 which affect the properties of LMW glutenins and gliadins, respectively, and total quality of gluten macropolymer (Martin and Stewart, 1990).

In spite of similar technological and chemical parameters of parental components, published in our previous paper (Dvořáček et al., 2006), highly significant differences in the albumin + globulin fraction and its proportion in crude protein and in some technological parameters (Zeleny sedimentation, PSI, relative viscosity) were detected

Table 1. Protein and selected amino acid composition of grain in wheat DH lines (2004–2006)

DH line/parameter	1B/1R trans-location*	Crude protein (%)	Albumin + globulin (%)	Gliadins (%)	Total glutenins (%)	Proportion of albumin + globulin (%)	Proportion of the sum Gli_Glu (%)	LYS (g.16 g/N)	MET (g.16 g/N)
110	Y	13.36^{a,b}	3.87^{c,d}	4.22^{b,c}	5.26^{a,b}	29.18^{c,d,e}	70.82^{a,b,c}	2.18^{a}	1.45^{a}
112	Y	12.39^{a,b}	3.77b^{c,d}	3.68^{a,b,c}	4.94^{a}	30.44^{e}	69.55^{a}	2.31^{a}	1.50^{a}
119	Y	14.30^{b}	3.66b^{c,d}	4.69^{c}	5.96^{a,b,c}	25.57^{a,bc,d}	74.43b^{c,d,e}	2.38^{a}	1.48^{a}
121	N	12.89^{a,b}	3.25^{a,b}	3.67^{a,b,c}	5.97^{a,b,c}	25.37^{a,bc,d}	74.63b^{c,d,e}	2.32^{a}	1.51^{a}
126	Y	13.15^{a,b}	3.87^{c,d}	3.72^{a,b,c}	5.55^{a,b,c}	29.44^{d,e}	70.56^{a,b}	2.43^{a}	1.49^{a}
131	N	11.69^{a}	3.19^{a,b}	2.96^{a}	5.54^{a,b,c}	27.34b^{c,d,e}	72.66^{a,bc,d}	2.50^{a}	1.49^{a}
136	N	12.36^{a,b}	3.24^{a,b}	3.61^{a,b,c}	5.51^{a,b,c}	26.19^{a,bc,d,e}	73.80^{a,bc,d,e}	2.56^{a}	1.66^{a}
139	Y	13.59^{a,b}	3.60^{a,bc,d}	4.10^{a,b}	5.88^{a,b,c}	26.61^{a,bc,d,e}	73.40^{a,bc,d,e}	2.47^{a}	1.56^{a}
144	N	13.61^{a,b}	3.36^{a,b,c}	4.00^{a,b,c}	6.24^{a,b,c}	24.60^{a,b,c}	75.40^{c,d,e}	2.19^{a}	1.50^{a}
146	N	13.32^{a,b}	3.24^{a,b}	4.07^{a,b,c}	6.02^{a,b,c}	24.33^{a,b}	75.67^{d,e}	2.28^{a}	1.53^{a}
157	Y	12.66^{a,b}	3.32^{a,b,c}	3.85^{a,b,c}	5.50^{a,b,c}	26.36^{a,b,c,d,e}	73.64^{a,b,c,d,e}	2.05^{a}	1.40^{a}
159	N	12.92^{a,b}	3.20^{a,b}	3.84^{a,b,c}	5.88^{a,b,c}	24.99^{a,bc,d}	75.01b^{c,d,e}	2.04^{a}	1.30^{a}
163	N	13.60^{a,b}	3.03^{a}	4.11^{b,c}	6.46^{b,c}	22.40^{a}	77.61^{e}	2.10^{a}	1.32^{a}
164	Y	14.54^{b}	3.61^{a,b,c,d}	4.30^{b,c}	6.63^{c}	24.87^{a,b,c,d}	75.14b^{c,d,e}	2.21^{a}	1.29^{a}
167	N	12.74^{a,b}	3.52^{a,b,c,d}	3.62^{a,b,c}	5.60^{a,b,c}	27.60^{b,c,d,e}	72.40^{a,b,c,d}	1.94^{a}	1.40^{a}
171	N	13.40^{a,b}	3.25^{a,b}	4.16^{b,c}	5.99^{a,b,c}	24.24^{a,b}	75.76^{d,e}	2.24^{a}	1.20^{a}
174	Y	13.06^{a,b}	4.00^{d}	3.60^{a,b,c}	5.46^{a,b,c}	30.81^{e}	69.19^{a}	2.52^{a}	1.37^{a}
176	N	12.41^{a,b}	3.26^{a,b}	3.65^{a,b,c}	5.49^{a,b,c}	26.34^{a,bc,d,e}	73.66^{a,b,c,d,e}	2.37^{a}	1.34^{a}
Nela	SC	12.87^{a,b}	3.17^{a,b}	3.93^{a,b,c}	5.77^{a,b,c}	24.79^{a,b,c}	75.21^{c,d,e}	2.23^{a}	1.41^{a}
Šárka	SC	12.82^{a,b}	3.54^{a,b,c,d}	3.54^{a,b}	5.74^{a,b,c}	27.89^{b,c,d,e}	72.11^{a,b,c,d}	2.52^{a}	1.37^{a}
Translocation	Y	13.38^{b}	3.71^{b}	4.02^{b}	5.65^{a}	27.91^{b}	72.09^{a}	2.32^{a}	1.44^{a}
	N	12.89^{a}	3.27^{a}	3.76^{a}	5.85^{a}	25.34^{a}	74.66^{b}	2.25^{a}	1.42^{a}
Year	2004	11.93^{a}	3.22^{a}	3.39^{a}	5.32^{a}	27.05^{a}	72.95^{a}	2.24^{a}	1.43^{b}
	2005	13.44^{b}	3.73^{b}	4.12^{b}	5.59^{a}	27.86^{a}	72.14^{a}	2.63^{b}	1.70^{c}
	2006	13.88^{b}	3.40^{c}	4.09^{b}	6.39^{b}	24.49^{b}	75.51^{b}	2.01^{a}	1.15^{a}

the values of parameters marked by different letters are significantly different at $P \le 0.05$

*Y with translocation; N without translocation; SC – standard cultivar

Table 2. Chemical composition and technological parameters of wheat DH lines (2004–2006)

DH line/parameters	1B/1R translo-cation*	GE (kJ/g)	Crude fat (g/kg)	Ash (g/kg)	Crude fibre (g/kg)	FNE (g/kg)	PSI (%)	Zeleny sed. (ml)	W. gluten (%)	GI	Rel. viscosity
110	Y	18.35^{a}	14.33^{a}	13.14^{a}	29.79^{a}	809.17^{a}	26.30^{a,b}	31.67^{a,b}	24.43^{a,b}	46.81^{a}	2.37^{c}
112	Y	18.40^{a}	14.86^{a}	17.06^{a,b}	28.86^{a}	815.32^{a}	22.78^{a,b}	29.00^{a}	21.07^{a,b}	43.11^{a}	2.16^{a,b}
119	Y	18.52^{a}	16.57^{a}	17.51^{a,b}	29.23^{a}	793.65^{a}	17.78^{a,b}	40.33^{a,b,c,d,e}	28.45^{a,b}	44.89^{a}	2.14^{a,b}
121	N	18.50^{a}	16.25^{a}	17.01^{a,b}	29.57^{a}	808.24^{a}	22.45^{a,b}	48.33^{b,c,d,e}	23.68^{a,b}	95.21^{b}	2.10^{a,b}
126	Y	18.41^{a}	17.42^{a}	14.61^{a,b}	28.34^{a}	808.15^{a}	22.82^{a,b}	36.33^{a,bc}	18.97^{a,b}	75.78^{a}	2.24^{c}
131	N	18.30^{a}	20.31^{a}	14.17^{a,b}	30.39^{a}	818.19^{a}	27.78^{a,b}	36.67^{a,bc}	14.72^{a}	93.40^{b}	2.17^{a,b}
136	N	18.51^{a}	17.16^{a}	16.48^{a,b}	35.13^{a}	807.64^{a}	21.74^{a,b}	44.67^{a,b,c,d,e}	23.45^{a,b}	85.86^{a,b}	2.15^{a,b}
139	Y	18.78^{a}	17.73^{a}	17.47^{a,b}	36.80^{a}	792.10^{a}	20.71^{a,b}	40.00^{a,b,c,d,e}	27.45^{a,b}	55.99^{a}	2.08^{a,b}
144	N	18.56^{a}	18.39^{a}	18.03^{a,b}	31.37^{a}	796.14^{a}	15.86^{a}	55.00^{de}	27.73^{a,b}	80.35^{a,b}	2.06^{a,b}
146	N	18.67^{a}	17.38^{a}	17.09^{a,b}	29.91^{a}	802.38^{a}	20.25^{a,b}	56.67^{e}	25.98^{a,b}	89.74^{a,b}	2.18^{a,b}
157	Y	18.59^{a}	15.21^{a}	19.16^{b}	30.58^{a}	808.42^{a}	15.76^{a}	37.33^{a,bc}	23.47^{a,b}	68.75^{a,b}	2.30^{c}
159	N	18.56^{a}	14.79^{a}	15.95^{a,b}	27.68^{a}	812.34^{a}	26.83^{a,b}	38.67^{a,b,c,d}	24.32^{a,b}	88.10^{a,b}	1.72^{a}
163	N	18.63^{a}	16.33^{a}	16.33^{a,b}	31.72^{a}	799.62^{a}	25.27^{a,b}	41.00^{a,b,c,d,e}	26.80^{a,b}	87.23^{a,b}	1.97^{a,b}
164	Y	18.77^{a}	16.10^{a}	17.37^{a,b}	30.63^{a}	790.53^{a}	23.99^{a,b}	43.00^{a,b,c,d,e}	28.72^{b}	67.22^{a,b}	2.35^{c}
167	N	18.60^{a}	16.83^{a}	17.17^{a,b}	31.53^{a}	807.07^{a}	29.41^{a,b}	37.00^{a,b,c}	24.55^{a,b}	73.80^{a,b}	2.18^{a,b}
171	N	18.70^{a}	18.25^{a}	19.03^{b}	28.76^{a}	799.96^{a}	17.72^{a,b}	51.67^{c,d,e}	26.22^{a,b}	87.33^{a,b}	2.31^{c}
174	Y	18.63^{a}	16.47^{a}	18.37^{a,b}	31.39^{a}	803.17^{a}	28.12^{a,b}	35.67^{a,b,c}	23.07^{a,b}	63.81^{a,b}	2.16^{a,b}
176	N	18.46^{a}	15.55^{a}	16.48^{a,b}	29.13^{a}	814.77^{a}	31.92^{b}	40.67^{a,b,c,d,e}	24.35^{a,b}	87.78^{a,b}	2.15^{a,b}
Nela	SC	18.56^{a}	18.40^{a}	15.94^{a,b}	28.95^{a}	808.04^{a}	20.90^{a,b}	39.67^{a,b,c,d,e}	23.97^{a,b}	84.87^{a,b}	2.22^{a}
Šárka	SC	18.42^{a}	20.12^{a}	17.68^{a,b}	27.48^{a}	806.55^{a}	27.42^{a,b}	42.33^{a,b,c,d,e}	20.93^{a,b}	84.23^{a,b}	2.19^{a,b}
Translocation	Y	18.55^{a}	16.09^{a}	16.83^{a}	30.70^{a}	802.57^{a}	22.28^{a}	36.67^{a}	24.45^{a}	58.30^{a}	2.23^{b}
	N	18.54^{a}	17.48^{a}	16.78^{a}	30.14^{a}	806.75^{a}	23.92^{a}	44.36^{b}	23.89^{a}	86.49^{b}	2.12^{a}
Year	2004	17.95^{a}	18.19^{b}	18.71^{a}	31.79^{b}	811.99^{b}	23.09^{a}	32.65^{a}	21.43^{a}	82.38^{b}	2.06^{a}
	2005	18.20^{b}	15.77^{a}	18.02^{a}	32.49^{b}	799.34^{a}	23.28^{a}	45.95^{b}	27.68^{b}	61.06^{a}	1.94^{a}
	2006	19.48^{c}	16.81^{a,b}	13.68^{b}	26.81^{a}	803.89^{a}	23.51^{a}	45.25^{b}	23.25^{a}	82.19^{b}	2.49^{b}

the values of parameters marked by different letters are significantly different at $P \leq 0.05$

*Y with translocation; N without translocation; SC – standard cultivar

Table 3. Balance and growth characteristics of feeding test with wheat DH lines (2004–2006)

DH line/parameters	1B/1R translocation	CPD	BV	NPU	PER
110	Y	$84.70^{c,d,e}$	$58.18^{a,b}$	$50.59^{a,bc}$	1.37^{d}
112	Y	79.50^{a}	50.90^{a}	42.85^{a}	$1.19^{a,b,c,d}$
119	Y	$82.37^{a,b,c}$	$57.38^{a,b}$	$49.07^{a,b}$	$1.13^{a,b,c,d}$
121	N	$81.13^{a,b}$	$64.14^{b,c,d}$	$54.26^{b,c,d}$	$1.16^{a,b,c,d}$
126	Y	$83.32^{b,c,d}$	$63.64^{b,c,d}$	$55.58^{b,c,d}$	$1.30^{b,c,d}$
131	N	$84.77^{c,d,e}$	$66.56^{b,c,d}$	$58.14^{b,c,d}$	$1.20^{a,b,c,d}$
136	N	86.90^{e}	71.48^{d}	64.34^{d}	$1.27^{b,c,d}$
139	Y	86.81^{e}	$61.65^{a,b,c,d}$	$54.94^{b,c,d}$	$1.03^{a,b}$
144	N	$84.05^{b,c,d,e}$	$66.84^{b,c,d}$	$57.85^{b,c,d}$	$1.23^{a,b,c,d}$
146	N	$84.74^{b,c,d,e}$	$65.90^{b,c,d}$	$57.42^{b,c,d}$	$1.20^{a,b,c,d}$
157	Y	86.02^{de}	$68.04^{b,c,d}$	$60.61^{c,d}$	$1.29^{b,c,d}$
159	N	85.91^{cde}	$67.84^{b,c,d}$	$59.94^{b,c,d}$	$1.21^{a,b,c,d}$
163	N	$85.41^{c,d,e}$	$58.04^{a,b}$	$51.08^{a,b,c}$	0.96^{a}
164	Y	$86.09^{d,e}$	$63.95^{b,c,d}$	$56.60^{b,c,d}$	$1.12^{a,b,c,d}$
167	N	$85.55^{c,d,e}$	$63.47^{b,c,d}$	$55.47^{b,c,d}$	$1.24^{b,c,d}$
171	N	$86.09^{d,e}$	$67.88^{b,c,d}$	$60.37^{c,d}$	$1.09^{a,bc}$
174	Y	$84.98^{c,d,e}$	$59.71^{a,bc}$	$52.31^{a,bc}$	$1.33^{c,d}$
176	N	$85.07^{c,d,e}$	$63.14^{b,c,d}$	$55.67^{b,c,d}$	$1.20^{a,b,c,d}$
Nela	SC	$84.22^{b,c,d,e}$	$65.15^{b,c,d}$	$56.41^{b,c,d}$	$1.10^{a,b,c,d}$
Šárka	SC	$83.58^{b,c,d,e}$	$69.37^{c,d}$	$59.84^{c,d}$	$1.31^{c,d}$
Translocation	Y	84.25^{a}	60.84^{a}	53.20^{a}	1.20^{a}
	N	84.97^{a}	65.09^{b}	57.07^{b}	1.19^{a}
Year	2004	85.73^{b}	62.74^{b}	55.82^{b}	0.98^{a}
	2005	86.27^{b}	71.05^{c}	62.85^{c}	0.98^{a}
	2006	81.86^{a}	58.78^{a}	49.70^{a}	1.58^{b}

the values of parameters marked by different letters are significantly different at $P \leq 0.05$; SC – standard cultivar

among the particular DH lines. These differences reflected a tighter genetic linkage in comparison with other characteristics. Strong genetic conditionality of the parameters PSI and relative viscosity was also proved by Martinant et al. (1998) and Greffeuille (2006). Significant differences among DH lines were also found in the contents of total and storage proteins, which had a dominant impact on the variability of technological properties similarly like on the Zeleny sedimentation test, wet gluten content and GI, as mentioned above. On the contrary, statistically insignificant differences among the lines were detected in contents of both amino acids (Lys and Met), determined level of GE, content of crude fat, and NFE (Tables 1 and 2).

The results of feeding tests were not markedly influenced by the years as above-mentioned, but by the 1B/1R translocation, which significantly decreased the parameters of balance test (BV and NPU), however without a significant effect on PER.

Significant differences in the parameters of feeding tests were also noted between the particular DH lines. The highest parameters of balance test were determined in line 136 (without 1B/1R translocation), and on the contrary, line 112 (with translocation) showed the lowest values. Despite the insignificant influence of the translocation on the growth of PER parameter, the first three lines with the highest value of this parameter in growing test (110, 174 and 126) showed the presence of 1B/1R

Table 4. Correlation coefficients among tested parameters obtained after data transformation by reason of the high year impact (2004–2006)

	GE	Crude fat	Ash	Crude protein	Crude fibre	FNE	PSI	Zeleny sed.	W. gluten	GI	Albumin + globulin	Gli	Total Glu	Rel. viscosity	Proportion of albumin + globulin	Proportion of the sum Gli_Glu	LYS	MET	PER	CPD	NPU	BV
GE	1.00																					
Crude fat	–0.04	1.00																				
Ash	0.28*	0.29*	1.00																			
Crude protein	0.20	–0.07	0.04	1.00																		
Crude fibre	0.12	0.15	0.33**	0.13	1.00																	
FNE	–0.25	–0.23	–0.37**	–0.86**	–0.54**	1.00																
PSI	–0.12	–0.08	–0.21	–0.28*	0.01	0.29*	1.00															
Zeleny sed.	0.21	0.24	0.25	0.39**	0.13	–0.45**	–0.34**	1.00														
W. gluten	0.24	0.10	0.27*	0.66**	0.27*	–0.69**	–0.20	0.37**	1.00													
GI	–0.06	0.17	–0.01	–0.38**	–0.16	0.34**	0.09	0.27*	–0.38**	1.00												
Albumin + globulin	–0.13	–0.18	–0.05	0.34**	0.03	–0.25	0.14	–0.32*	0.03	–0.57**	1.00											
Gli	0.15	–0.16	0.02	0.89**	0.11	–0.74**	–0.37**	0.32*	0.70**	–0.40**	0.25	1.00										
Total glu	0.29*	0.12	0.07	0.77**	0.10	–0.70**	–0.25	0.59**	0.53**	0.04	–0.21	0.54**	1.00									
Rel. viscosity	0.20	–0.02	–0.04	0.08	–0.10	–0.02	–0.15	–0.03	–0.16	–0.14	0.20	0.06	–0.04	1.00								
Proportion of albumin + globulin	–0.26*	–0.13	–0.08	–0.41**	–0.08	0.40**	0.34**	–0.58**	–0.47**	–0.26*	0.70**	–0.42**	–0.76**	0.15	1.00							
Proportion of the sum Gli_Glu	0.27*	0.12	0.07	0.42**	0.06	–0.40**	–0.34**	0.61**	0.47**	0.27*	–0.70**	0.43**	0.78**	–0.14	–0.98**	1.00						
LYS	0.11	0.20	–0.09	–0.27*	0.09	0.18	0.07	–0.12	–0.20	0.07	0.06	–0.25	–0.29*	0.13	0.27*	–0.27*	1.00					
MET	–0.05	0.09	–0.01	–0.19	0.36**	0.01	0.01	0.03	–0.15	–0.13	0.11	–0.13	–0.29*	–0.02	0.24	–0.24	0.39**	1.00				
PER	–0.02	–0.11	–0.03	–0.35**	–0.13	0.37**	0.22	–0.29*	–0.22	0.01	0.10	–0.33**	–0.39**	0.14	0.35**	–0.37**	0.21	0.06	1.00			
CPD	0.14	0.12	0.01	0.02	–0.03	–0.03	–0.04	0.19	0.24	0.24	–0.34**	0.01	0.23	–0.13	–0.37**	0.35**	–0.07	–0.21	0.09	1.00		
NPU	0.01	0.17	–0.02	–0.05	0.00	0.01	–0.24	0.26*	0.11	0.32*	–0.36**	–0.04	0.15	–0.06	–0.32*	0.30*	0.12	–0.10	0.25	0.71	1.00	
BV	–0.01	0.18	–0.03	–0.06	0.01	0.01	–0.25	0.26*	0.09	0.31*	–0.34**	–0.04	0.14	–0.04	–0.29*	0.28*	0.14	–0.08	0.26*	0.59**	0.99**	1.00

*$P \leq 0.05$; **$P \leq 0.01$

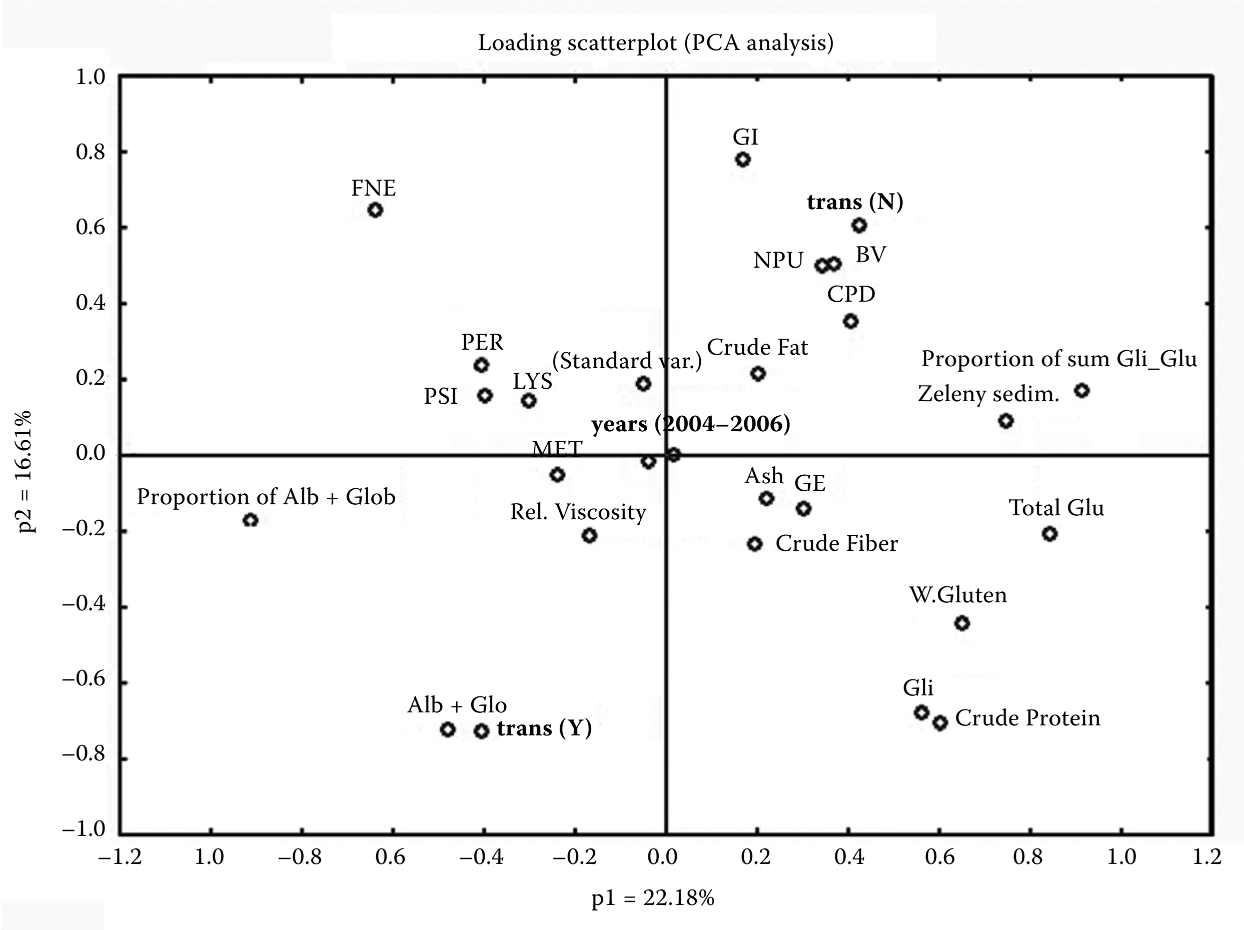

Figure 2. Mutual relationships among tested parameters and factor of translocation after data transformation by reason of the high year impact

translocation. On the other hand, the lowest weight gain was recorded in non-translocated line 163 (Table 3). Thus, these results also confirmed the equivocation of this factor on the level of feeding tests described by McCracken (2001) and McCann et al. (2006). It is necessary to emphasize an important fact that all three lines (110, 174 and 126) and also parental cultivar Šárka showed a high content and proportion of albumin + globulin fraction and a low proportion of storage proteins (mainly total glutenins), respectively.

Mutual relations among chemical and technological parameters and also their effect on the parameters of feeding tests were studied in detail using correlation method and PCA analysis, see Table 4 and Figure 2. With regard to the strong effect of years and to the requirement of their elimination (Figure 1), the values of all tested parameters were transformed in the particular years by the quotient of achieved annual average for each corresponding parameter. The transformed PCA graph documents an elimination of the influence of the year factor and thus it reveals significantly different properties of lines with/without 1B/1R translocation (Figure 2).

The closer relation of the DH lines with 1B/1R translocation and content of albumin + globulin fraction is evident from positions of the particular parameters. A similar trend of angular coefficients was characteristic of relative viscosity. On the contrary, the parameters of balance test jointly with technological parameters GI, and/or also Zeleny sedimentation test showed a positive increase in the group of the lines without 1B/1R translocation. The position of the growth parameter PER situated more closely to the centre of the graph (similarly like parameters GE, ash, crude fibre, crude fat) confirmed a low effect of the 1B/1R translocation. It is in accordance with the analysis of variance of untransformed data (mentioned above) and lower correlation coefficients of these parameters (Tables 3 and 4). In spite of that there evidently exist opposite relationships between PER on the one hand and contents of total and storage proteins on the other hand or a positive correlation of PER with NFE and proportion of albumin + globulin fraction.

The PCA graphical expression of parameter relations generally corresponded with correlation analysis (Table 4), which enabled to quantify relations among these transformed data including their evaluation of statistical significance. It is possible to emphasize a mutual highly significant medium or highly strong correlation among grain protein fractions including closer relationships with indirect technological parameters of baking quality (Zeleny sedimentation and GI). A close relationship of storage proteins with properties of gluten results logically from the chemical composition of gluten, which is composed of gliadins and glutenins. Negative correlations among the growth of albumin-globulin fraction and evaluated technological parameters are particularly related to the presence of 1B/1R translocation in these materials and production of secalins which significantly decreases the technological quality of gluten as detected by Zeller et al. (1982) and Martin and Stewart (1990).

Positive correlations were noted between both evaluated amino acids including their negative correlation with an increase in total protein, which leads to an increase in nutritionally less valuable gliadin and glutenin fractions (Wrigley and Bietz, 1988).

Lower but highly significantly negative correlations between PER and the content of crude and storage proteins (sum of gliadins and total glutenins) described already by PCA analysis were also confirmed by correlation calculation. It is evident that a higher storage protein content in grain decreased the efficiency of protein utilization for weight gain of animal body. Petr (2003) came to analogous results about the influence of storage proteins on PER. The generally accepted statement that elite baking wheat varieties have lower feeding value is possible to be indirectly explained by our results as well. These varieties show a generally higher ratio of gluten proteins – especially glutenins responsible for the firmness and elasticity of gluten. The protein composition of three of the best DH-lines in our growth test indicates, besides a higher detected content of albumin + globulin fraction, a lower content of glutenin fraction which could be, in the case of a comparable content of albumin + globulin fraction among tested materials, a crucial factor for the prediction of feeding value.

An interesting fact was provided by a comparison of the effects of albumins and globulins and storage proteins on growth and balance parameters. Whereas an increase in the proportion of albumin + globulin fraction and a simultaneous decrease in gluten storage proteins (gliadins and glutenins) evoked an increase in PER, the effect of these protein fractions on balance experiments was opposite. The reasons for these findings can be explained only hypothetically. In suboptimal levels of protein content in feeding rations we can expect a limiting position in any of the essential amino acids which are deposited mainly in the albumin and globulin fraction. For instance, Wrighly and Bietz (1988) indicated a 5–7 times higher content of lysine in the albumin and globulin fraction. So, in the lines having a lower proportion of albumin + globulin fraction, the energy requirement for nitrogen retention increases in dependence on the growth of less valuable grain storage proteins. Such an increase in energy requirements jointly with metabolic stress of an organism could decrease the productive efficiency of wheat protein despite of its higher digestibility. Metabolic stress, caused by the feeding of rats with unbalanced amino acid composition, was already reported by Heger et al. (1989).

In our tests no negative effects of relative viscosity on the parameters of feeding test were proved. On the contrary, all three lines that reached the highest values of PER including the standard variety Šárka had on average the highest level of relative viscosity. The negative role of this character, observed mainly in feeding tests on chicken broilers by Rose (2003), was not confirmed in the case of our model feeding test. In spite of the published negative role of higher grain viscosity on digestion, our results could indicate its possible positive effect because of an absorption decrease in unbalanced proteins from the gluten part of grain.

On the basis of the evaluated chemical and technological parameters transformed by reason of the year impact, there was a combination of parameters searched as having the best ability to predict the growth parameter $PER_{(trans)}$. The obtained significant regression equation for prediction of transformed parameter PER (see below) had total correlation $R = 0.48$, measurement error = 0.14 and statistical significance = 0.013.

$PER_{(trans)} = 1.62 - 0.50 \times Gli - 0.46 \times Total\ Glu + 0.33 \times Rel.\ Viscosity + 0.19 \times W.\ gluten - 0.18 \times Fat$

This output must be approached as a mathematical model valid for the existing set of materials and it is not possible to generalize it due to the lower correlation. Nevertheless, we can emphasize the importance of storage proteins again. Their increase significantly decreases values of PER. In contrast to published findings, a positive effect of relative viscosity was also confirmed. The last two parameters (wet gluten and crude fat) did not have a strong influence on PER modification because of their low partial significance and index coefficient in the equation.

Finally, we can conclude that the relationships of evaluated grain characters to the results of feeding tests were not fully unambiguous. The presence of 1B/1R translocation significantly decreased the values of balance parameters (NPU and BV). Nevertheless, no similar effect of the translocation was proved in growing test (PER). A lower, but significantly positive correlation of albumin + globulin fraction and a negative correlation of storage proteins with PER parameter were confirmed by correlation analysis. The calculated correlation coefficients in frequently declared characteristics (grain hardness and relative viscosity) with relation to the feeding value PER were low and not statistically significant. It is possible to assume that individual ratios between albumins + globulins and gluten protein composition of grains influenced the values of PER more significantly than the presence of 1B/1R translocation, which is only one of many genetic factors participating in the protein composition of grain.

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