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CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF SPRING HULLED BARLEY VARIETIES

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Abstract

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The objective of this research was to evaluate the chemical composition and nutritive value of four spring hulled barley varieties (Antek, Skarb, Nagradowicki and Granal) grown in one location in Poland. In the study were determined: chemical composition, amino acids composition and coefficients of nutritive value of protein, namely chemical score (CS), essential amino acid index (EAAI) and biological value (BV). The apparent digestibility coefficients (ADC) of nutrients were examined on 32 Wistar rats (n=8 rats per barley variety). The chemical components: ash, crude protein, ether extract, starch, dietary fibre, lignin and pentosans differed statistically ($P \leq 0.05$) between the barley varieties. The higher crude protein content in barley was accompanied by lower contents of the starch and dietary fibre. The Granal variety had a lower ($P \leq 0.05$) crude protein content however; the lysine content and quality of protein (CS, EAAI and BV) were higher than in the other three varieties. On the other hand, the ADC of crude protein and of other nutrients in the Granal variety were lower (not significantly, excepting the pentosans; $P \leq 0.05$) than in the remaining varieties. In contrast to Granal variety, the Antek variety with the highest ($P \leq 0.05$) protein content had the lowest lysine and threonine levels and quality of protein however, the ADC of crude protein was higher ($P \leq 0.05$) in comparison with the remaining varieties. Lysine was the most limiting the quality of grain barley proteins in all examined varieties. The coefficients of nutritional values (CS, EAAI, BV) of the proteins of all examined barley varieties showed the good quality of a protein for monogastric animals.

Key words: Barley varieties, Chemical composition, Amino acids, Rats, Digestibility

Abbreviations: AA - total amino acids; ADC - apparent digestibility coefficients; BV - biological value; CS - chemical score; DM - dry matter; EAA - essential amino acids; EAAI - essential amino acid index; NFE - nitrogen-free extract; NSPs - nonstarch polysaccharides; WE - whole egg protein

Introduction

The barley (*Hordeum vulgare* L.) is the fourth most produced cereal in the world after wheat, maize and rice. It is mainly used as animal feed but there is a growinginterest in it for human food. In general, barley has been used in the feeding of adult monogastrics and ruminants, all of which have an important digestible capacity. In most European countries, wheat and barley are the most common used cereal grains in poultry and pig feeds (Bergh et al., 1999). In spite, that barley grain is mainly energetic feed, is important source of protein for the nutrition of animals, but is deficient in certain essentional amino acids when used as food for monogastric animals.

Barley varies greatly in chemical composition, nutritive value and bioavailable energy content, due to genetic and environmental factors and interactions between the two (Zhan et al., 1994; Valaja et al., 1997; Andersson et al., 1999). The major components of barley are starch, dietary fibre, and crude protein, constituting: 60, 20, and 12% of dry matter, respectively (Åman and Newman, 1986; Oscarsson et al., 1996). However, considerable variation exists in the dietary fibre and starch content of barley grain (Reynolds et al., 1992; Oscarsson et al., 1996; Bowman et al., 2001) which results in a tremendous amount of variation in digestible energy content. The increase dietary fibre content in the pig diets has a negative influence on the nutrient digestability and utilization of metabolizable

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energy (Lindberg and Andersson, 1998; Fairbairn et al., 1999). High starch content is a desirable quality trait, as it increases the energy level of a feed ration (Hunt, 1996).

Barley protein is rich in prolamin storage proteins (hordeins) and has moderate nutritional quality, being particularly deficient in lysine (Pomeranz et al., 1976; Jørgensen et al., 1999). The increase of protein content is accompanied by decreases in essential amino acids, mainly lysine (Pomeranz et al., 1976; Jacyno, 1989). Shewry (2007) suggested that nutritional quality of the grain decreases with increasing grain protein contents as an increasing proportion of the nitrogen is incorporated into prolamin storage proteins. Fuller et al. (1989) and Valaja et al. (1997) showed that nitrogen fertilizer supply increased the crude protein content and digestible crude protein content in barley grain and lowered the lysine content in the protein. The reduced amount of lysine in protein is so slight that the total content of lysine in grain increases due to higher protein content (Thomke, 1976).

The objective of this study was to evaluate the chemical composition and nutritive value (amino acids composition and nutritive value of protein and digestibility of nutrients on rats) of spring hulled barley varieties from Poland.

Material and Methods

Four spring hulled barley (*Hordeum vulgare* L.) varieties (Antek, Skarb, Nagradowicki and Granal) were analyzed in this study. All varieties were grown in 2011 in the same Crop Cultivation Station in nort-eastern of Poland.

Thirty-two male Wistar rats (age 7−8 weeks, 180±5 g body weight, from Experimental Animal Breeding, Warsaw, Poland) were used to determine digestibility of nutrients in barley grain. After a 3−day acclimatization period, the animals were randomly allocated to the four experimental group (n=8 rats per barley variety). The groups were fed one of the barley variety supplemented with mineral and vitamin mixture. The rats were individually housed in stainless steel cages in a room kept at 21±3 ºC with a 12 h light and 12 h dark cycle. The individual cages allowed separate, and quantitative, collection of uneaten food and faeces. Each rat had free access to its respective diet and drinking water during the experimental period. The digestibility experiment lasted 18 days with an adaptation period to the diets of 4 days and a collection period of faeces of 14 days.

Faeces were quantitatively collected during the 14 days of the collection period and were stored at 4°C until analysis. The faeces samples of each day were pooled for each rat freeze-dried and homogenized. The chemical compositions of the faeces samples collected, which were used to calculate the apparent digestibility coefficients of organic matter, crude protein, ether extract, crude fibre, nitrogen-free extract, pentosans and cellulose, were determined. Apparent digestibility coefficients (ADC) of nutrients in barley grain were determined using the following equation:

ADC (%) = [(intake of nutrient − fecal nutrient)/intake of nutrient × 100]

All samples to analyses were finely ground in a Knifetec 1095 Sample Mill (Foss Tecato, Hoganas, Sweden). The chemical compositions of all samples were determined by the following AOAC (1995) procedures: dry matter, by drying at 105°C to constant weigh; ether extract, by Soxhlet extraction with diethyl ether; crude ash, by incineration in a muffle furnace at 580°C for 8 h; crude protein (N×6.25), by the Kjeldahl method using the Büchi Distillation Unit B−324 (Büchi Labortechnik AG, Switzerland), crude fibre was determined with fibre analyzer ANCOM 220 (ANKOMTechnology, USA). Nitrogen−free extract (NFE) was calculated as follows:

NFE (%) = 100 − %(moisture + crude protein + lipid + ash + crude fibre)

Cellulose was isolated with acetic-nitric acid mixture (80% CH_3COOH and concentrated HNO_3) and lignin was isolated with 2 *M* HCl and 72% H_2SO_4 (Jacyno et al., 1983). Total pentosans were determined by the Hashimoto et al. (1987) method. Dietary fibre content in the barley grains was determined according to Asp et al. (1983) method, starch with enzymatic method (Åman et al., 1994) andsugars after inversion were determined using the Luff-Schoorl method. Amino acids were determined using an AAA 400 automatic amino acid analyser (INGOS, Czech Republic). Samples were subjected to an acid hydrolysis in the presence of 6 *M* HCl at 105 °C for 24 hours. Sulphur-containing amino acids were determined separately in 6 M HCl after an oxidative hydrolysis (formic acid + hydrogen peroxide, 9:1 v/v, 20 h at 4°C). Tryptophan was determined according to a method described in AOAC (1995). The Amino acid composition was displayed as g per 16 g of nitrogen.

The quality of protein was estimated by determination of total amino acids (AA), as well as the fractions of essential amino acids (EAA), chemical score (CS) and essential amino acid index (EAAI). The contents of different amino acids are presented as g/ 16 g of nitrogen and are compared with the of whole egg protein (WE − reference pattern) (Hidvégi and Békés, 1984).

CS was calculated on the basis of procedure described previously by Block and Mitchell (1946), based on comparison of the concentration ratio of the amino acid having the shortest supply a_i (receive amino acid) to concentration of this amino acid in the standard a_s (WE- reference pattern):

$CS = (a_i/a_s) \times 100$

EAAI was calculated as the geometric mean of the ratios of the essential amino acids in a protein to those of the WE − reference pattern (Oser, 1951).

Biological value (BV) was calculated according to Oser (1959) using the following equation:

$BV = 1.09 \times EAAI - 11.7$

All chemical analysis are reported as an average of at least duplicate analyses. Differences in chemical composition, nutritive value of protein and apparent digestibility coefficients among the barley varieties were evaluated by analysis of variance and Tukey's multiple range tests using the Statistical computational software (STATISTICA PL, version 8.0).

Results and Discussion

The results of the present study for composition of barley grain (Table 1) are fairly typical for hulled barley and are comparable to those reported by Åman and Newman (1986), Oscarsson et al. (1996), Xue et al. (1997) and Baik and Ullrich (2008). The highest constituents were starch (59.1−61.6% DM), followed dietary fibre (18.16−21.46% DM) and crude protein (11.74−13.64% DM). These three constituents together make up more than 90% of the dry matter of grain. The remaining components of barley grain (ash, ether extract and low molecular weight sugars) were minor constituents.

Nutritional components of barley are generally reported as averages; however, the barley may differ greatly in chemical composition due to genetic and environmental factors. Stekar and Stibilj (1988) and Metayer et al. (1993) found a big variability in chemical composition of different barley varieties. The differences in chemical composition of barley varieties of the present study may be attributed primarily to genetic background, since all varieties were grown under the same environmental conditions.

Our study showed that the chemical components (starch, crude protein, ether extract, ash, dietary fibre and his components: lignin and pentosans) differed statistically ($P \leq 0.05$). The lignin content in the examined samples (2.03−2.39% DM) is similar to results Xue (1992). The contents of pentosans (7.91–9.02% DM) and cellulose (4.32–4.34% DM) in barley varieties analysed in our study they are consistent with earlier reports (Oscarsson et al., 1996). Xue et al. (1997) reported cellulose levels in the range from 4.1 to 4.8% in hulled barleys also. Pentosans and cellulose are the major nonstarch polysaccharides (NSPs) in barley. In contrast to starch and sugars, NSPs are not digested by the monogastric animals digestive system, thus reduces metabolizable energy.

The crude protein content of Antek variety (13.64% DM) was highest, followed by Nagradowicki (12.99% DM), Skarb (12.48% DM) and Antek (11.74% DM). Åman and Newman (1986) showed the negative correlation between protein content and starch and dietary fibre levels in barley. Similar relationships were also showed in our study. The barley Antek variety had the highest protein content and the lowest starch and dietry fibre contents. However, the lowest protein content as well as the highest starch and dietary fibre contents were noted for Granal variety.

The present study showed differences in amino acids composition of protein between the barley varieties (Table 2). According to Newman and Newman (2008), the differences

Table 1
Chemical composition of barley grain

Components	Varieties			
	Antek	Skarb	Nagradowicki	Granal
Dry matter, %	90.0	88.2	88.3	88.6
In % dry matter:				
Ash	2.13[a]	2.22[a]	2.26[a]	2.60[b]
Crude protein (N × 6.25)	13.64[c]	12.48[b]	12.99[b]	11.74[a]
Ether extract	2.42[a]	2.69[b]	2.39[a]	2.75[b]
Crude fibre	4.63	4.75	4.44	4.73
NFE	77.2	77.8	77.9	78.2
Starch	59.1[a]	60.0[a]	60.2[a]	61.6[b]
Sugars	2.93 [b]	2.63[a]	2.61[a]	2.85[b]
Dietary fibre	18.16[a]	19.98[b]	19.55[b]	21.46[c]
Cellulose	4.32	4.56	4.34	4.34
Lignin	2.11[a]	2.07[a]	2.39[b]	2.03[a]
Pentosans	8.01[a]	7.91[a]	8.25[a]	9.02[b]

[a b c] Means with different superscripts within rows are different ($P \leq 0.05$)

in amino acids levels in barley grain are due to differences of amino acids composition in the four classical Osborne fractions and the considerable prevalence of low-lysine hordein in high-protein barley. Pomeranz et al. (1976) showed that the increase of protein level in barley is associated, mainly, with the increase of the nonessential amino acids: glutamic acid, proline and glutamine.

Furthermore, the higher protein content in barley is accompanied by lower contents of the essential amino acids, particularly lysine and threonine that are the most limiting amino acids in cereals' protein for monogastric animals (Jacyno, 1989; Newman and Newman, 2008). These relationships were also observed for examined barley varieties in our study. The Granal variety with lowest protein content had the higher lysine and threonine levels, at about 15% and 9% respectively, than the Antek variety with highest protein content. In addition, the content of total essential amino acids in grain protein of the Granal variety was higher (39.5% per cent of total AA) than in grain protein of the Antek variety (37.7% per cent of total AA) (Table 3).

The coefficients of nutritive value of barley grain protein (Table 3) showed that the Granal variety had the highest qual-

Table 2
Amino acids composition of barley grain protein (g/16gN)

Amino acid	Varieties			
	Antek	Skarb	Nagradowicki	Granal
Essential amino acids				
Lysine	3.39	3. 68	3.59	3.98
Methionine	1.58	1.56	1.63	1.56
Cystine	1.34	1.32	1 48	1.44
Threonine	2.91	3.37	3.10	3.20
Isoleucine	3.59	3.36	3.10	3.26
Tryptophan	1.18	1.06	1.23	1.26
Valine	4.29	4.18	4.45	4.48
Leucine	6.23	6.27	6.31	5.93
Histidine	2.19	2.45	2.11	2.96
Phenylalanine	5.04	5.00	4.97	5.07
Tyrosine	2.53	2.56	2.48	2.54
Non-essential amino acids				
Arginine	3.98	3.78	4.41	3.96
Aspartic acid	5.89	5.62	5.93	5.58
Serine	4.00	4.03	4.23	3.99
Glutamic acid	25.83	23.84	24.83	24.47
Proline	9.29	9.65	9.26	9.95
Glycine	3.75	3.63	3.99	3.49
Alanine	3.78	3.98	3. 82	3.66
AA	90.8	89.3	90.9	90.8

Table 3
Coefficients of nutritive value of barley grain protein

Coefficients	Varieties			
	Antek	Skarb	Nagradowicki	Granal
EAA (g/16 g N)	34.3	34.8	34. 5	35.7
EAA as per cent of total AA	37.7	39.0	37.9	39.3
CS (Lys)	48.4[a]	52.6[ac]	51.3[a]	56.9[bc]
EAAI	67.0	67.1	67.5	68.9
BV	61.3	61.4	61.9	63.4

[a b c] Means with different superscripts within rows are different ($P \leq 0.05$)

ity of a protein; however, the Antek variety had the lowest. This suggests that protein quality of barley does not improve with an increased level of protein, which is most often due to increases in the lysine-poor prolamines. Some authors reported that quality of the barley protein of high lysine genotypes was considerably better than the low lysine genotypes (Eggum et al., 1995; Jood and Singh, 2001).

In comparison to the reference pattern (whole egg protein − WE), lysine turned out to be the most amino acid (CS) limiting the quality of grain barley protein in all examined varieties. CS value of Granal variety (56.9) was highest followed by Skarb (52.6), Nagradowicki (51.5) and Antek (48.3) varieties: the lower the CS value, the more limiting amino acid. CS value differed statistically (P≤0.05) between the barley varieties. This is conforming with results the Kawka et al. (2009), which analyzed four spring hulled barley varieties and reported that lysine was the first limiting amino acid (CS, average 57.9). The content of essential amino acids (EAA) is reflected in EAAI values, which in relation to reference pattern (WE) was slightly higher in Granal variety (69) than in the Antek variety (67). Similar EAAI values (68−71) were obtained in previous research on ten another barley varieties (Jacyno, 1989).

Biological value (BV) of Granal variety with higher lysine was also slightly higher in comparison to the other varieties with lower lysine. It was confirmed in studies on rats in which the BV of the barley protein was positively correlated with the lysine concentration_(Tallberg and Eggum, 1981; Gabert et al., 1995; Jood and Singh, 2001). The coefficients of nutritional values (CS, EAAI, BV) of the proteins of all examined barley varieties showed the good quality of a protein for human and monogastric animals.

The apparent digestibility coefficients (ADC) of nutrients in the Granal variety were lower than in the remaining varieties (Table 4). However, the differences in the ADC of nutrients were not significant between the barley varieties, excepting the pentosans. The ADC of pentosans in the Granal variety (48.3%) was significantly lower (P≤0.05) compared with the Nagradowicki (52.3%), Antek (52.7%) and Skarb (55.1%) varieties. The ADC of crude protein in the Granal variety with the lower protein content and higher lysine was lower than in the Nagradowicki and Granal varieties with the higher protein content and lower lysine (about 3.3 and 3.9 percentage points, respectively). This may be partly caused by alterations in the proportion of endosperm proteins, where lysine-rich albumin and globulin in barley protein are less digestible than the low lysine proteins (hordein) of barley (Bhatty and Whitaker, 1987; Jood and Singh, 2001). Furthermore, the Granal variety had the higher dietary fibre content and lower (P≤0.05) the ADC of pentosans in comparison to the other varieties. The dietary fibre is low digestible and reduces the apparent digestibility of other dietary components, in this crude protein (Noblet and Le Goff, 2001). Jensen et al. (1995) reported that the indigestible protein fraction in the feed might be bound to, or encapsulated by fibrous components and to shift the nitrogenous substance digestion from the small intestine to the hindgut.

The ADC of organic matter and crude protein were similar to the results obtained on pigs by Perttilä et al. (2002) (83.9 and 78.7%, respectively) whereas the ADC of ether extract was higher (53.9%) and of crude fibre was considerably lower (4.2%) than in our experiment. Jood and Singh (2001) obtained similar the ADC of crude protein for the high lysine barley genotypes in research on rats.

Conclusion

The present study showed considerable differences in chemical composition between the barley varieties. The major components of examined barley varieties were starch, dietary fibre, and crude protein. The higher crude protein content in barley was accompanied by lower contents of the starch and dietary fibre.

Table 4
Apparent digestibility coefficients of nutrients in barley varieties (%)

Components	Varieties				SEM
	Antek	Skarb	Nagradowicki	Granal	
Organic matter	85.9	84.7	85.9	83.9	0.21
Crude protein	77.2	73.9	76.6	73.3	0.30
Ether extract	44.7	44.2	43.3	44.8	0.39
Crude fibre	23.9	23.2	22.6	21.4	0.41
NFE	91.1	91.6	92.2	90.7	0.13
Cellulose	23.7	24.5	23.0	22.9	0.38
Pentosans	52.7^{b}	55.1^{b}	52.3^{b}	48.3^{a}	0.41

$^{a\,b\,c}$ Means with different superscripts within rows are different (P ≤ 0.05)

The barley varieties with the higher crude protein content had the lower lysine content and quality of protein. On the other hand, the apparent digestibility coefficients of crude protein and of other nutrients in these varieties were higher. Lysine was the most limiting amino acid in all examined barley varieties. The coefficients of nutritional values (CS, EAAI, BV) of the proteins of all examined barley varieties showed the good quality of a protein for monogastric animals.

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