ACTA SCIENTIARUM POLONORUM *Acta Sci. Pol., Zootechnica 10 (2) 2011, 37–50*

CHEMICAL COMPOSITION AND NUTRITIONAL CHARACTERISTICS OF SEVERAL CEREAL GRAIN

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Abstract. An analysis chemical composition of 33 samples of five cereal grains harvested in one-year led to a conclusion that the greatest variations and statistically significant differences (P≤0.01) among cereals existed in their content of crude protein, crude fibre and the following fractions of dietary fibre: NDF, ADF, TDF, IDF and SDF. Analyzed winter wheat and winter rye varieties differ significantly (P≤0.01) from other cereal grains in their content of magnesium, potassium, sodium, phosphorus, manganese, zinc and show a statistically significant difference (P≤0.05) in the content of calcium and copper. The average total content of amino acids was highest in wheat and lowest in winter barley. Lysine was found to be the first amino acid limiting (CS) the quality of protein in all analyzed varieties of cereal grains, with the exception of rye, while tryptophan was found to be such an amino acid for animals (WE). The high content of essential amino acids (EAA) was reflected in EAAI, which for WH ranged from 71% (spring barley) to 84% (winter triticale), and for WE from 51% (winter barley) to 60% (winter triticale).

Keywords: amino acids, cereal, chemical composition, nutritive value

INTRODUCTION

One of the fundamental tasks of modern agriculture is to ensure sufficient food supplies. Cereal grains and their derivatives are an important nutritive component both in developed and in developing countries. Cereal grains are also an optimal source of energy, carbohydrates, protein, fibre, and macronutrients, especially magnesium and zinc. The growing interest in cereal grains and their derivatives is caused by their bioactive components and the potential benefits of regular consumption of cereals and cereal products [McKevith 2004]. In view of the unsatisfied demand for animal products, it is necessary to ensure an increase in livestock population. To this end sufficient fodder supplies should be ensured, as well as the existing worldwide deficit of cereal grains should be eliminated predominantly by relying on yielding and reliable crops. Therefore, a special attention is given to intensive cultivation of cereal grains intended both for production of fodders and for the food industry. Cereal grains, thanks to their adaptability to various cli-

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matic and environmental conditions and their strength, thanks to which they may be stored for a long period of time, still rank highest among crops all over the world. Poland ranks third in Europe, next to France and Germany, among leading producers of cereals, producing 47% of all cereals in the EU. Among cereal livestock fodders the following continue to be most popular: wheat (2,112,000 ha), barley (1,232,000 ha), triticale (1,260,000 ha), and rye (1,316,000 ha) from GUS [2007]. Cereal grains cultivated in Poland have a low or medium content of general protein. However, due to their presence in fodders, they provide livestock with a significant quantity of protein. Cereal grains are also the richest source of protein in human consumption [Charalampopulos et al. 2002, Ragaee et al. 2006, Comai et al. 2007, Shewry 2007]. The highest content of protein was found in wheat, spring barley and spring triticale, which exceeded the content of protein found in winter triticale, winter barley and even in rye [Ragaee et al. 2006]. The quality of protein depends first and foremost on the content of exogenous amino acids [Ragaee et al. 2006, Shewry 2007]. Nevertheless, due to deficiency of lysine and treonine, the quality of protein in cereal grains fails to fully satisfy the dietary needs of livestock [Molina-Cano et al. 1995, Ragaee et al. 2006]. Rye protein has the highest content of lysine, while triticale protein has the highest content of treonine [Heger and Eggum 1991, Fabijańska 1992]. Among other amino acids limiting the biological value of protein in cereal grains are isoleucine, methionine and phenylalanine [Sokół 1995]. The highest calculated nutritional value of cereal protein presented as Essential Amino Acid Index [Oser 1951] amounts to 60 (triticale) and 51 (winter barley). Cereal grains are first and foremost a source of carbohydrates and, thus, of energy [McKevith 2004]. Their main ingredient is starch, followed by non-starch polysaccharides, which decrease the nutritional value of cereals [Selvendran 1984, Raven et al. 1992, Serena and Bach Knudsen 2007]. Barley has the highest content of non-starch polysaccharides among all cereal grains [Boros et al. 1996]. Non-starch polysaccharides include pentosans, β-glucans, pectines, cellulose and hemicelullose. Furthermore, arabinoxylans and β-glucans ensure a significant content of dietary fibre (defined as the total of NSP and lignin) [Selvendran 1984, Boros et al. 1996, Charalampopulos et al. 2002, Serena and Bach Knudsen 2007], which forms gels in aqueous environment, which lowers digestibility of other food components [Crittenden and Playne 1996]. The research conducted by confirmed a similar effect of the abovementioned compounds [Bedford and Classen 1992, Charalampopulos et al. 2002, Langhout 1999]. As emphasized the content of β-glucans in barley is several times higher than in wheat and triticale [Serena and Bach Knudsen 2007]. The nutritional value of barley grains is reduced by the value of raw fibre, which depends on the particular variety [Åman and Hesselman 1984, Bach Knudsen 1997, Kőksel et al. 1999]. Furthermore wheat, triticale and barley have a similar content of ether extract [McKevith 2004]. Stated that barley is the basic grain used universally in production of fodder for pigs [Leek et al. 2007], which satisfies the dietary needs of this group of animals both in terms of energy and protein deficiency [Shewry 2007] and of poultry. Barley may be used as a component of fodders for laying hens, breeding chicken and broilers. Broilers, however, should not be fed too much barley due to its negative impact on production results in view of relatively too high a content of chaffs and β-glucans, which decrease usability of dietary components and thus the caloric value of cereal grains [Bach Knudsen and Jørgensen 2001].

The purpose of this thesis is to examine the content of dietary components of five cereals widely grown in Poland and to determine their nutritional value. The analysis focused on the chemical content of cereal grains, with a special emphasis on the content of dietary fibre and the nutritional value of protein. Also, the analysed samples were examined for their content of selected macro and micronutrients. All marked parameters may be used in order to rationally balance dietary compounds and doses for monogastric animals. Furthermore, the content of minerals, P, K, Mg, Ca, Zn, fibre, and essential amino acids as important nutritional components of cereals is of key importance for selection of cereal grains in production of functional foods [Nardi et al. 2003, Sidhu et al. 2007].

MATERIAL AND METHODS

Cereal grains samples. As research material were used five spring varieties of barley widely grown in Poland, i.e. Atol, Boss, Bryl, Edgar, and Rambo (nitrogen fertilization 70–80 kg N · ha^{-1}) and five winter varieties, i.e. Bażant, Gil, Gregor, Kroton and Marinka (nitrogen fertilization 60–80 kg N · ha^{-1}).

The following spring barley varieties were analyzed: Bryl, Boss, Edgar, Atol, Rambo, as well as the following winter varieties: Gil, Bażant and Marinka, supplied by Bąków Division of The Plant Breeding and Acclimatization Experimental Station, winter varieties of barley: Gregor and Kroton supplied by The Plant Breeding Station in Szelejewo. As research materials were also used six varieties of winter wheat, i.e. Almarii, Elena, Jawa, Olcha, Sakwa, Zyta (nitrogen fertilization 80–100 kg N · ha^{-1}), four varieties of spring triticale, i.e. Gabo, Kargo, Migo, Wanad (nitrogen fertilization 60–100 kg N · ha^{-1}), and seven varieties of winter triticale, i.e. Alzo, Bogo, Malno, Marko, Prado, Tornado, and Ugo (nitrogen fertilization 60–110 kg N · ha^{-1}) supplied by Strzelce Division of The Plant Breeding and Acclimatization Experimental Station. Also six varieties of winter rye, i.e. Amilo, Dańkowskie Złote, Dańkowskie Nowe, Motto, Walet and Warko (nitrogen fertilization 80–100 kg N · ha^{-1}) supplied by The Plant Breeding Station in Choryń were analyzed. The varieties after one-year harvest were used.

Chemical composition. The chemical compositions of all samples were determined by the procedures: dry matter, by drying in an oven at 105°C until a constant weight was obtained; 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 [AOAC 1990]. Nitrogen-free extract (NFE) calculated as 100 – % (moisture + crude protein +lipid + ash + crude fibre). All determinations were expressed on a dry matter basis.

Total, insoluble and soluble dietary fiber contents were quantified using the enzymatic gravimetric procedure [Asp et al. 1983]. The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined with the Ankom 220 Filter Bag Digestion System (Ankom Technology Corporation, 140 Turk Hill Park, Fairport, NY) content of barley were analysed according to the methods [Van Soest et al. 1991]. Hemicellulose content was estimated by subtracting ADF from NDF and cellulose content by substracting lignin from ADF.

Prior to marking macroelements and microelements, samples underwent mineralization in presence of dipping acid and perhydrol, and wet mineralization in presence of perchloric and nitric acid mixture prior to marking microelements. Minerals were determined using atomic absorption spectrophotometer (Unicam, model SP 90A). Mean values of these determinations are reported in this study on dry weight basis.

Amino acids were determined using an AAA 400 automatic amino acid analyser (INGOS, Czech Republic). Samples were subjected to acid hydrolysis in the presence of 6 M HCl at 105ºC for 24 hours. Sulphur-containing amino acids were determined separately in 6 M HCl after oxidative hydrolysis (formic acid + hydrogen peroxide, 9:1 v/v, 20 h at 4ºC). Tryptophan was determined according to the method [AOAC 1990].

The quality of protein was estimated by determination of total amino acids (AA), as well as the fractions of the exogenous amino acids (EAA). The nitrogen content in human food and fodder varies between 16 and 18 g · 100 g^{-1} of protein isolate (16 g · 100 g^{-1} for plants) [FAO/WHO/UNU 1985, FAO/WHO 1991]. Because the nutritional significance of much of the non-peptide nitrogen is unclear, nitrogen analysis of foods is much more precise than the single amino acid analysis, and nutritional significance can then be given to it. Amino acid determinations were expressed on a g · 16 g N^{-1} basis, equivalent to g · 100 g^{-1} of protein.

The chemical score (CS) was calculated on the basis of the procedure [Rakowska et al. 1978], 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 ($CS = (a_i \cdot a_s^{-1}) \times 100$). Two standards were used: amino acids of food protein composition appropriate for a mature human (MH) [FAO/WHO/UNU 1985, FAO/WHO 1991] and amino acid composition of whole egg protein (WE) [Hidvégi and Békés 1984], considered a complete and balanced food and fodder protein. The recommended levels of exogenous amino acid were as follows: Lys – 5.5 and 7.0 g · 16 g N^{-1}, Met+Cys – 3.5 and 5.7 g · 16 g N^{-1}, Thr – 4.0 and 4.7 g · 16 g N^{-1}, Ile – 4.0 and 5.4 g · 16 g N^{-1}, Trp – 1.0 and 1.7 g · 16 g N^{-1}, Val – 5.0 and 6.6 g · 16 g N^{-1}, Leu – 7.0 and 8.6 g · 16 g N^{-1}, His – 0 and 2.2 g · 16 g N^{-1}, Phe+Tyr – 6.0 and 9.3 g · 16 g N^{-1}, respectively, for mature human and egg protein standards.

The exogenous amino acids (EAA) were estimated in accordance [Oser 1959] in terms of the geometric mean of all the concentrations of participating exogenous amino acids compared to the concentration of a corresponding standard (in g · 16 g N^{-1}):

$$EAA = \sqrt[10]{a_1/a_{1s} \times 100 \cdot \ldots \cdot a_n/a_{ns} \cdot 100}$$

where *n* is the number of participating amino acids, ns is the number of corresponding amino acids in the standard. In the classical method [Oser 1951, 1959], concentrations of Lys, sum of Met+Cys, Thr, Ile, Trp, Val, Leu, His and Phe +Tyr were considered, whereas the standard for mature human (MH) excludes histidine.

The essential amino acid index (EAAI) was calculated as follows:

EAAI = 10 log EAA,

where *log EAA* [Rakowska et al. 1978]:

$$\log EAA = \frac{1}{10}\left(\log \frac{a_1}{a_{1s}} \cdot 100 + \log \frac{a_2}{a_{2s}} \cdot 100 + \ldots + \log \frac{a_n}{a_{ns}} \cdot 100\right)$$

Statistical analysis. The admissible error for the determinations of chemical components was 5% while, in the determination of amino acids it was 10%. One-way analysis of variance was carried out on the experimental results using the species as an independent variable. The significance of differences between means was compared by Duncan multiple range tests. All calculations were performed using an ANOVA package from Statistica®6.0 pl.

RESULTS AND DISCUSSION

The chemical composition of analyzed varieties of cereal grains is presented in Table 1. As cereal grains are rich in nutrients, cereal germs are a valuable component in production of functional foods [Ragaee et al. 2006, Sidhu et al. 2007]. The content of marked components in individual varieties shows relatively insignificant variations. Such differences, however, may have a practical significance in feeding livestock.

The greatest variations and statistically significant ($P \leq 0.01$) differences among individual varieties were found in the content of general protein (the highest content in spring barley, i.e. 131.6 g · kg^{-1} d.m. ($P \leq 0.01$), and the lowest in rye, i.e. 93.7 g · kg^{-1} d.m. ($P \leq 0.01$). The second statistically most significant component ($P \leq 0.01$) differentiating the analyzed varieties of cereal grains was raw fibre (the highest content was found in winter barley, 49.2 ($P \leq 0.01$), and the lowest in spring triticale, 25.8 ($P \leq 0.01$) and individual fractions of dietary fibre marked both with NDF and ADF detergent method [the highest content was found in spring barley, respectively 269.4 ($P \leq 0.01$) and 107.1 ($P \leq 0.01$) while the lowest content of NDF was found in wheat 108.4 ($P \leq 0.01$) and of ADF in spring triticale 29.4 ($P \leq 0.01$). The highest content of ADL fraction was found in winter barley, 24.9 ($P \leq 0.01$), similarly as in case of the fraction marked by means of enzymatic method, TDF 265.2 ($P \leq 0.01$), IDF 191.3 ($P \leq 0.01$) and SDF 73.9 ($P \leq 0.01$) [Ragaee et al. 2006]. Winter wheat and triticale had the lowest content of enzyme fractions, i.e. TDF 147.8–146.3 ($P \leq 0.01$), IDF 120.7–119.7 ($P \leq 0.01$) and SDF 27.1–26.3 g · kg^{-1} d.m. ($P \leq 0.01$) respectively and in winter triticale the lowest content was obtained also for ADL fractions, 13.68 ($P \leq 0.05$). In view of the fact that cereal grains with a low content of fibre are in the highest demand especially for production of livestock fodders, where it is recommended that doses for fatteners contain 5–6% of fibre. Therefore, the most popular cereals are spring wheat and triticale characterized by a similar content of fibre and its fractions, as well as the key dietary components. The above data should constitute the basis for advocating the need to continue selection and breeding in order to reduce the fibre content, especially in spring and winter barley most widely grown in Poland, which constitute 50% of the dose for fatteners, as these values seem to be overestimated, respectively 37.1 g · kg^{-1} dm in case of spring barley ($P \leq 0.01$) and 49.2 g · kg^{-1} d.m in case of winter barley ($P \leq 0.01$). Analyzed varieties of spring and winter barley were also characterized by the highest content of all fibre fractions, both detergent and enzymatic.

Table 1. Chemical composition of cereal grains (g · kg^{-1} dry matter) (x – arithmetic mean, ± SD – standard deviation)
Tabela 1. Skład chemiczny w ziarnach zbóż (g · kg^{-1} sucha masa) (x – średnia arytmetyczna, ± SD – odchylenie standardowe)

Specification Specyfikacja	Dry matter, g · kg^{-1} Sucha masa, g · kg^{-1}	Crude protein Białko surowe	Oil Tłuszcz	Crude fibre Włókno surowe	Crude ash Popiół surowy	NFE BAW	NDF	ADF	ADL	TDF	IDF	SDF
Barley spring Jęczmień jary	894.9^{B}	131.6^{Aa}	21.7^{C}	37.1^{B}	19.8	684.7^{B}	269.4^{D}	107.1^{a}	15.9^{ab}	226.8^{D}	159.2^{E}	67.6^{C}
SD	±4.08	±16.86	±2.72	±3.18	±4.51	±19.00	±8.82	±1.46	±2.68	±1.00	±2.14	±2.81
Barley winter Jęczmień ozimy	883.8^{C}	113.8^{B}	22.9^{D}	49.2^{C}	22.1^{b}	675.9^{B}	253.3^{D}	104.7^{b}	24.9^{c}	265.2^{E}	191.3^{D}	73.9^{D}
SD	±5.67	±14.62	±1.90	±6.00	±2.53	±24.84	±2.14	±1.30	±4.39	±5.25	±1.01	±6.32
Wheat Pszenica	870.75^{A}	138.52^{A}	17.77^{Aa}	29.49^{A}	17.15^{a}	797.06^{Aa}	108.38^{B}	36.80	21.74^{ac}	147.76^{Aa}	120.65^{A}	27.06^{A}
SD	±5.92	±8.72	±2.04	±5.54	±2.68	±9.73	±15.19	±9.49	±2.85	±3.79	±0.60	±3.12
Rye Żyto	872.22^{A}	93.68^{C}	14.26^{B}	30.39^{A}	19.86	841.81^{C}	217.30^{C}	51.41	19.12^{ac}	197.86^{B}	144.52^{B}	53.38^{B}
SD	±7.93	±3.87	±1.53	±0.88	±2.71	±5.03	±15.11	±4.65	±3.38	±1.45	±1.23	±0.66
Triticale spring Pszenżyto jare	894.25^{B}	130.80^{A}	14.65^{Bb}	25.76^{A}	20.05	808.27^{Aab}	151.44^{A}	29.38	15.98^{a}	160.25^{C}	132.74^{C}	27.44^{A}
SD	±7.80	±7.68	±1.92	±2.47	±4.29	±8.47	±38.95	±4.06	±9.05	±0.64	±0.63	±0.29
Triticale winter Pszenżyto ozime	900.17^{B}	116.96^{Ba}	16.15^{AB}	26.36^{A}	18.21	822.60^{Db}	166.48^{A}	33.24	13.68^{b}	146.33^{Aa}	119.74^{A}	26.26^{A}
SD	±3.06	±13.66	±2.17	±2.19	±2.43	±14.37	±16.89	±8.15	±5.90	±13.00	±12.01	±0.85

NDF – neutral detergent fiber; ADF – acid detergent fiber; ADL – acid detergent lignin; TDF – total dietary fiber; IDF – insoluble dietary fiber; SDF – soluble dietary fiber. Means in the same column with different letters are significantly different; A, B – P≤0.01; a, b – P≤0.05.
NDF – włókno neutralno-detergentowe; ADF – włókno kwaśno-detergentowe; ADL – lignina kwaśno-detergentowa; TDF – włókno pokarmowe całkowite; IDF – włókno pokarmowe nierozpuszczalne; SDF – włókno pokarmowe rozpuszczalne
Wartości w tej samej kolumnie z różnymi literami różnią się istotnie; A, B – P≤0,01; a, b – P≤0,05.

The content of plant based fodders depends on their content of mineral compounds. As shown in Table 2, analyzed varieties of cereals are valuable within the abovementioned extent. There are also statistically significant differences among analyzed varieties. Analyzed varieties of winter wheat and winter rye differ significantly ($P \leq 0.01$) from other cereals in their content of magnesium, potassium, sodium, phosphorus, manganese, zinc and are statistically different to a significant degree ($P \leq 0.05$) in their content of calcium and copper. The least significant differentiation between analyzed cereal grains was noticed in the content of copper (statistically significant differences ($P \leq 0.05$) was shown between spring and winter barley) and iron (statistical differences ($P \leq 0.05$) were shown in rye in the content of iron, as against wheat and spring and winter triticale). The content of calcium in analyzed cereals was low, with the highest content of calcium was found in winter barley, i.e. 543 mg · kg^{-1} (where average values should amount to approx. 800 mg · kg^{-1} [Ragaee et al. 2006] or 677 mg · kg^{-1} [Ereifej and Haddad 2001], and the lowest content was found in spring triticale 341 mg · kg^{-1}. The low content of calcium in analyzed varieties of cereal grains influences the ratio of calcium to phosphorus, which amounted to an average of 1:10 (the lowest in winter barley, i.e. 1:7, the highest in w spring triticale, i.e. 1:12).

Such a disadvantageous ratio of the abovementioned elements in consideration of the practical requirements for fodders is characteristic for most cereal grains. The average content of phosphorus in analyzed varieties of cereal grains amounts from 6,500 mg · kg^{-1} for spring triticale to 3,700 mg · kg^{-1} in spring barley. Furthermore, analyzed spring barley grains were characterized by the highest content of the following micronutrients: zinc, copper and iron, respectively 34.5 ($P \leq 0.01$), 6.4 and 74.4 ($P \leq 0.05$), as well as the lowest content of manganese, 16.8 mg · kg^{-1} ($P \leq 0.01$) [Ereifej and Haddad 2001]. Analyzed winter wheat was poor in potassium 2,700 mg · kg^{-1} ($P \leq 0.01$), sodium 111 mg · kg^{-1} ($P \leq 0.01$), zinc 21 mg · kg^{-1} ($P \leq 0.01$) and iron 6 mg · kg^{-1} ($P \leq 0.05$). Analyzed varieties of cereal grains did not differ much also in their content of magnesium. The highest content of this component was recorded for spring barley, i.e. 1,300 mg · kg^{-1} ($P \leq 0.01$), and the lowest in winter rye, i.e. 990 mg · kg^{-1} ($P \leq 0.01$). The average content of potassium and magnesium in analyzed cereal grains complies with the average content of the abovementioned elements [Ragaee et al. 2006].

Table 3 presents a profile of amino acids in analyzed cereal grains and the nutritional value of protein. Cereal grains and legumes constitute the major source of protein in the human diet [Comai et al. 2007]. Despite of a relatively high quality of wheat protein, evaluation of this quality requires verification. People, as well as animals, are able to synthesize only 9 (non-essential amino acids) out of the 22 amino acids. The remaining amino acids (essential amino acids) must be provided in food. Arginine is one of the EAA for birds and fish. In view of the above, it is considered as a semi-essential amino acid. Also cysteine and tyrosine are considered as semi-essential amino acids, as they can be synthesized only from methionine and phenylalanine [Boisen et al. 2000]. Wheat and triticale protein is characterized by a high content of exogenic amino acids, whose germs are a valuable component of functional foods [Sidhu et al. 2007]. The level of almost every amino acid is higher in wheat than barley, which is used without any limits in fodders intended for pigs sensitive to such a quality of protein [Kosieradzka and Fabijańska 2001].

Table 2. Mineral composition of cereal grains (mg · kg^{-1}) (x – arithmetic mean, ± SD – standard deviation)
Tabela 2. Skład mineralny w ziarnach zbóż (mg · kg^{-1}) (x – średnia arytmetyczna, ± SD – odchylenie standardowe)

Specification Specyfikacja	Calcium Wapń	Magnesium Magnez	Potassium Potas	Sodium Sód	Phosphorus Fosfor	Manganese Mangan	Zinc Cynk	Copper Miedź	Iron Żelazo
Barley spring Jęczmień jary	463^{a}	1290^{B}	3265^{AC}	196^{D}	3696^{C}	16.8^{C}	34.5^{BCb}	6.4	74.4^{a}
SD	±20.2	±88.4	±379.8	±19.5	±803.1	±2.21	±5.5	±1.08	±15.0
Barley winter Jęczmień ozimy	543^{bB}	1217^{ABa}	3982^{C}	275^{C}	3822^{C}	17.2^{C}	26.7^{BCb}	5.9	73.9^{b}
SD	±81.13	±26.15	±441.99	±57.72	±490.64	±0.94	±4.85	±1.06	±20.84
Wheat Pszenica	441.33^{a}	1165.67^{A}	2680.17^{Aa}	111.33^{A}	5121.83^{A}	28.31^{A}	21.35^{Aa}	5.80^{a}	49.34
SD	±52.71	±118.15	±199.75	±14.45	±337.25	±8.43	±3.98	±0.70	±9.43
Rye Żyto	440.83^{a}	987.67^{C}	4690.67^{B}	281.67^{B}	3713.67^{B}	46.40^{B}	27.55^{b}	7.12^{b}	63.30
SD	±41.35	±17.74	±147.49	±58.75	±1053.42	±8.25	±3.29	±0.56	±27.93
Triticale spring Pszenżyto jare	341.25^{bA}	1198.25^{AB}	3640.75^{b}	118.25^{A}	6494.25	28.06^{A}	35.92^{B}	6.51^{a}	53.69
SD	±40.93	±97.19	±953.6	±7.14	±701.65	±3.07	±1.68	±0.23	±6.66
Triticale winter Pszenżyto ozime	497.57^{a}	1097.86^{Ab}	3495.00^{b}	111.0^{A}	5808.14^{A}	29.97^{A}	31.83^{C}	5.59^{a}	56.81
SD	±74.18	±48.25	±802.28	±23.63	±244.91	±3.87	±2.44	±0.69	±3.88

Means in the same column with different letters are significantly different; A, B – P≤0.01; a, b – P≤0.05.
Wartości w tej samej kolumnie z różnymi literami różnią się istotnie; A, B – P≤0,01; a, b – P≤0,05.

Table 3. Amino acid composition and nutritional value of cereal grains (g · 16 g N^{-1}) (x – arithmetic mean, ± SD – standard deviation)

Tabela 3. Skład aminokwasowy oraz wartość odżywcza ziaren zbóż (g · 16 g N^{-1}) (x – średnia arytmetyczna, ± SD – odchylenie standardowe)

Specification Specyfikacja	Wheat Pszenica	Rye Żyto	Triticale spring Pszenżyto jare	Triticale winter Pszenżyto ozime	Barley winter Jęczmień jary	Barley spring Jęczmień ozimy
Essential amino acids – Aminokwasy egzogenne						
Lysine – Lizyna	2.24±0.2^{A}	3.05±0.3^{B}	2.93±0.2^{B}	3.05±0.3^{B}	2.64±0.5^{A}	2.60±0.3^{A}
Methionine – Metionina	1.19±0.1^{a}	0.96±0.1^{A}	1.38±0.1^{B}	1.52±0.3^{Bb}	1.08±0.1^{A}	1.17±0.2^{A}
Cystine – Cystyna	1.76±0.3^{A}	2.25±0.2^{B}	1.49±0.1^{A}	1.76±0.2^{A}	1.68±0.2^{A}	1.73±0.2^{A}
Threonine – Treoniona	2.67±0.4	2.86±0.3	2.78±0.5	3.24±0.6	2.66±0.5	2.84±0.5
Isoleucine – Izoleucyna	3.22±0.6^{A}	3.01±0.3^{A}	3.16±0.2^{A}	3.29±0.3^{A}	2.26±0.7^{B}	3.23±0.8^{A}
Tryptophan – Tryptofan	0.96±0.1	0.61±0.1^{A}	1.01±0.1	0.99±0.1	0.98±1.1^{B}	0.93±0.2
Valine – Walina	4.71±2.1	4.26±0.4	4.53±0.5	4.52±0.5	3.83±0.3	4.53±0.8
Leucine – Leucyna	6.05±1.0	5.24±0.5	5.79±0.4	5.89±0.5	5.16±1.7	5.41±1.1
Hisidine – Histydyna	2.40±0.6	2.38±0.2	2.35±0.2	2.64±0.4	2.02±0.9	2.52±1.7
Phenyloalanine Fenyloalanina	4.47±0.8^{a}	4.14±0.4	4.04±0.2	4.36±0.7	3.56±0.5^{b}	4.33±0.8
Tyrosine – Tyrozyna	1.64±0.8	0.97±0.2	1.11±0.1	1.62±0.5	1.31±0.7	0.99±0.2
Non-essential amino acids – Aminokwasy endogenne						
Arginine – Arginina	4.36±0.5	4.69±0.3	4.07±0.1	4.30±0.4	4.16±0.8	3.90±0.9
Aspartic acid Kwas asparaginowy	5.52±0.6^{A}	6.92±0.6^{B}	5.13±0.1^{A}	5.33±0.5^{A}	6.01±1.1	5.66±1.1^{A}
Serine – Seryna	4.25±0.9^{A}	3.94±0.4^{A}	3.02±0.2^{B}	2.99±0.3^{B}	3.44±0.9	3.47±0.8
Glutamic acid Kwas glutaminowy	34.22^{a}±7.0	25.98^{b}±2.7	26.51^{b}±0.5	30.26±3.3	22.10^{b}±7.7	26.37^{b}±6.0
Proline – Prolina	9.92±2.5^{A}	8.74±1.1^{A}	5.66±0.4^{B}	6.08±0.8^{B}	9.3 ±0.5^{A}	10.09±1.9^{A}
Glycine – Glicyna	3.99±0.7^{a}	4.22±0.4^{a}	3.87±0.3	3.95±0.3^{a}	3.15 ±0.6^{b}	3.65±0.8
Alanine – Alanina	3.15±0.5	3.46±0.3	3.50±0.3	3.48±0.3	3.06±0.5	2.98±0.5
Nutritional values^{b} – Wartość odżywcza^{b}						
Total – Całkowity AA	96.72^{a}±16.0	87.67±7.9	82.31±2.5	89.25±8.0	78.56^{b}±14.6	86.34±16.4
EAA^{cMH}	26.56±4.1	24.97±2.5	25.85±0.9	27.72±2.9	25.18±1.9	27.76±4.7
CS	40.73^{A}±4.2	55.30 ^{B}±4.4	53.18^{BC}±3.3	55.38^{BC}±5.0	48.0±7.9	47.3^{AC}±6.2
EAAI	77.97±9.6	73.88±6.7	78.95±3.1	84.01±6.7	70.9±4.7	77.5±13.1
EAA^{cWE}	28.95±4.6	27.35±2.6	28.2±1.1	30.2±2.8	27.2±1.8	30.22±5.2
CS	32.0^{A}±3.3	35.78±3.3	41.79^{B}±2.6	43.51^{B}±3.9	37.7^{B}±6.2	37.1±4.9
EAAI	56.05±6.9	53.18±4.8	56.73±2.2	60.4±4.8	51.0±3.4	55.7±9.4

^{a} Amino acid levels expressed as % of standards; MH – mature human; WE – whole egg protein standards; ^{b} AA – amino acid participation; EAA – essential amino acid participation; CS – chemical score of restrictive amino acid; EAAI – essential amino acid index; ^{c} calculated on the basis of MH or WE standard. Means in the same row with different letters are significantly different A, B – P≤0.01; a, b – P≤0.05.

[a] Poziom aminokwasów wyrażony jako % normy; MH – wzorzec dla ludzi; WE – wzorzec dla jaja kurzego; [b] AA – udział aminokwasów; EAA – udział aminokwasów egzogennych; CS – wskaźnik aminokwasu ograniczającego; EAAI – wskaźnik aminokwasów egzogennych; [c] wyliczenia w oparciu na wzorcu MH lub WE. Wartości w tej samej kolumnie z różnymi literami różnią się istotnie; A, B – P≤0,01; a, b – P≤0,05.

The ratio of individual amino acids is comparable with their content in corn or soy [Cave and Burrows 1993]. The average total of all amino acids in wheat protein was the highest and estimated to amount to 96.7 g · 16 g N^{-1}, while the lowest content was found in winter barley, i.e. 78.6 g · 16 g N^{-1}. The content of lysine obtained in presented research, i.e. 2.24 (wheat) to 3.05 g · 16 g N^{-1} (rye) was relatively lower than results [Serena and Bach Knudsen 2007]. As against the standard for humans (MH) and for animals (WE), lysine was found to be the first amino acid limiting (CS) the quality of protein of all analyzed varieties of cereal grains, with the exception of rye, while tryptophan was found to be the first limiting amino acid (CS) for animals (WE). The high content of essential amino acids (EAA) was reflected in the calculated Essential Amino Acid Index, which, as against the standard determined for people, ranged from 71% (spring barley) to 84% (triticale), and in case of animals: 51% (winter barley) to 60% (triticale). The protein of analyzed cereal grains is also poor in lysine, which limits their nutritional value. The varieties cultivated in Denmark are also deficient in this amino acid [Serena and Bach Knudsen 2007], as well as varieties cultivated in the UK [Shewry 2007]. The amino acid profile presented in research was confirmed [Shewry 2007], for varieties of wheat and barley cultivated in Denmark and Scandinavian countries [Just et al. 1983, Leek et al. 2007, Serena and Bach Knudsen 2007]. The analyzed wheat and rye grains differed among themselves and from other cereal grains to a statistically significant degree in their content of some essential amino acids: lysine (P≤0.01), methionine (P≤0.01), cystine, while rye and winter barley in the content of isoleucine (P≤0.01) and tryptophan (P≤0.01). Nevertheless, the total of essential amino acids in analyzed samples of cereals was not significantly different, which was confirmed by the obtained values of Essential Amino Acid Index of essential amino acids.

Differences in the content of individual amino acids among analyzed cereal grains were statistically significant in their content of other amino acids: serine (P≤0.01), proline (P≤0.01), as well as glicine (P≤0.05). Three amino acids, i.e. lysine, treonine and methionine, are synthesized from aspartic acid [Shewry 2007]. All cereal grains are poor in lysine, but are an optimal source of sulphuric amino acids, which was confirmed [Mossé and Huet 1990]. Therefore they may constitute a perfect supplement in blends with legumes, in which [Hossain and Becker 2001, Sujak et al. 2006], the quality of protein is limited by methionine and cistine.

The above presented research indicates the need to undertake an evaluation of the nutritional value of new varieties of cereal grains as an integral part of growing of these valuable crops, which are so widely grown in Poland.

CONCLUSIONS

Analyzed winter wheat and winter rye varieties differ significantly (P≤0.01) from other cereal grains in their content of magnesium, potassium, sodium, phosphorus, manganese, zinc and show a statistically significant difference (P≤0.05) in the content of calcium and copper. The least significant difference among analyzed cereal grains was found in the content of copper (P≤0.05) and iron (P≤0.05). The average total content of amino acids was highest in wheat and lowest in winter barley. Lysine was found to be the first amino acid limiting (CS) the quality of protein in all analyzed varieties of cereal grains, with the exception of rye, while tryptophan was found to be such an amino acid for animals (WE). The high content of essential amino acids (EAA) was reflected in EAAI, which for WH ranged from 71% (spring barley) to 84% (winter triticale), and for WE from 51% (winter barley) to 60% (winter triticale).

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SKŁAD CHEMICZNY ORAZ WARTOŚĆ ODŻYWCZA WYBRANYCH ZIAREN ZBÓŻ

Streszczenie. Analiza składu chemicznego próbek z pięciu odmian zbóż (33 próby) zebranych w jednym roku doprowadziła do wniosku, że największe zmiany i statystycznie istotne różnice (P≤0,01) wśród zbóż istniały w ich zawartości białka, włókna surowego oraz następujących frakcji węglowodanowych: NDF, ADF, TDF, IDF i SDF. Analizowane ziarna pszenicy ozimej i żyta ozimego różnią się istotnie (P≤0,01) od innych ziaren zbóż w ich zawartości magnezu, potasu, sodu, fosforu, manganu, cynku i wykazano różnicę istotną statystycznie (P≤0,05) w zawartości wapnia i miedzi. Średnia całkowita zawartość aminokwasów była najwyższa w pszenicy, a najniższa w ziarnie jęczmienia ozimego. Lizyny to pierwszy aminokwas ograniczający (CS) jakość białka we wszystkich badanych odmianach zbóż, z wyjątkiem żyta, gdzie to tryptofan okazał się aminokwasem ograniczającym wartość odżywczą dla zwierząt (WE). Wysoka zawartość aminokwasów egzogennych (EAA) znalazło odzwierciedlenie w indeksie EAAI, który dla WH wahała się od 71% (jęczmień jary) do 84% (pszenżyto ozime) oraz WE z 51% (jęczmień ozimy) do 60% (pszenżyto ozime).

Słowa kluczowe: aminokwasy, skład chemiczny, wartość odżywcza, zboża

Accepted for print – Zaakceptowano do druku: 29.04.2011