



## DIVERSITY OF AMINO ACIDS COMPOSITION IN CEREALS

Zorica M. Tomičić<sup>\*1</sup>, Lato L. Pezo<sup>2</sup>, Nedeljka J. Spasevski<sup>1</sup>, Jasmina M. Lazarević<sup>1</sup>, Ivana S. Čabarkapa<sup>1</sup>, Ružica M. Tomičić<sup>3</sup>

<sup>1</sup>University of Novi Sad, Institute of Food Technology, 21000 Novi Sad,  
Bulevar cara Lazara 1, Serbia

<sup>2</sup>University of Belgrade, Institute of General and Physical Chemistry, 11000 Belgrade,  
Studentski trg 12/V, Serbia

<sup>3</sup>University of Novi Sad, Faculty of Technology, 21000 Novi Sad,  
Bulevar cara Lazara 1, Serbia

**Abstract:** The quality of protein is based on their amino acid composition, especially on the content and availability of essential amino acids. Cereals are important sources of protein for human nutrition, but are limited in the amounts of essential amino acids, notably lysine. The aim of this study was to analyze the chemical composition and amino acid profiles of different cereals that are important for nutritional purposes in human diet. The content of protein, moisture and crude fat in cereals varied significantly from 7.83 to 13.22%, 11.45 to 13.80%, and from 1.67 to 6.35%, respectively. The obtained results showed that oat had the highest contents of crude protein (13.22%), crude fat (6.35%) and crude cellulose (9.42%) compared to other cereals. Significant ( $p < 0.05$ ) variation existed in the content of essential and nonessential amino acids among samples with the highest level in oat and wheat. Essential amino acids accounted for one-third of the total amino acids in the tested cereals. Glutamic acid was found to be the most abundant amino acid. It could be concluded that the amino acid composition of oat is the most favorable among cereals due to its high protein content and the content of lysine which can be found in limited amounts in most of the cereals.

**Key words:** *essential amino acids, non-essential amino acids, chemical composition, nutritional profiling, dietary reference intakes*

## INTRODUCTION

Cereals play a key role to satisfy the global food demand of a growing population, especially in developing countries where cereal-based food production is the only predominant source of protein and energy (Ramadas, Kumar

& Singh, 2019). Along with oilseeds and legumes, cereals represent an important source of protein for the majority of populations in developing countries, while plant proteins in developed countries make up a low percentage

compared to animal sources. Plant proteins supply 65% of total global protein intake, and cereal grains account for 47% (Ferreira, Varisi, Meinhardt, Lea & Azevedo, 2005). Protein content in cereals can vary considerably, and this variation may be due in part to genetic differences, while agronomic factors are of greater importance such as soil properties, weather conditions during the year of cultivation and plantation of cereals. It is known that high temperature, sunlight and inadequate amount of precipitation during the grain filling stage increase the protein content (Laze et al., 2019).

The quality of protein is based on their amino acid composition, especially the content and availability of essential amino acids that play an important role in the growth, reproduction and maintenance of the human body (Ferreira et al., 2005; Ufaz & Galili, 2008; Caire-Juvera, Vázquez-Ortiz & Grijalva-Haro, 2013).

Wheat is one of the major cereal crops grown worldwide and is the main staple food crop for nearly 2.5 billion people (Shewry, 2007; Siddiqi, Singh, Rani, Sogi & Bhat, 2020). Global wheat production in 2021 amounted to 784.7 million tons, 1.2 per cent higher than in the 2020 year (FAO, 2021).

Cereal grains are low in total protein compared to legumes and oilseeds. Although not generally considered a good source of protein, many cereals offer humans an adequate amount of energy.

However, the quality of the protein must be taken into account, since the cereal diet tends to be deficient in one or more essential amino acids. The inability of people to synthesize certain amino acids has caused great interest in increasing the levels of essential amino acids in crop plants.

Research in genetics and genetic engineering has been successfully used to enrich the content of some essential amino acids in cereals, which has an economic and humanitarian interest (Shewry, 2007; Ufaz & Galili, 2008).

The first limiting essential amino acid in cereals is generally lysine, while threonine and methionine may also be limiting in some cereals (Lea, Chua & Lea, 2016). Compared to other cereals, oat protein contains a higher content of the essential amino acid lysine (Henchion, Hayes, Mullen, Fenelon & Tiwari,

2017). Due to different production systems, it is difficult to obtain comparative values for protein content in different cereals. However, previous research indicates that there are relatively small differences within and between species, ranging for maize from 9-11%, barley from 8-15% and these ranges almost certainly reflect environmental impact as well as genotype (Shewry, 2007; Ufaz & Galili, 2008).

Nutritional profiling of plant foods, primarily cereals, has become of great importance due to the growing demand for plant proteins and the growing trend of organic and vegan diets.

Better knowledge and understanding of the chemical properties of different cereal varieties, protein quality and amino acid composition will be beneficial not only to plant growers but also to food manufacturers (Siddiqi et al., 2020).

The objective of this study was to analyse the chemical composition and amino acid profiles of different cereals that are important for nutritional purposes in the human diet.

## MATERIALS AND METHODS

### Materials

Samples of different cereal species such as barley (*Hordeum vulgare L.*), maize (*Zea mays L.*), oat (*Avena sativa*), rice (*Oryza sativa*), rye (*Secale cereale L.*) and wheat (*Triticum aestivum*) were provided and analyses were performed at the Institute of Food Technology in Novi Sad.

### Analysis of chemical composition

Chemical composition analyzes, such as moisture content, crude protein content, crude fat content, ash and crude cellulose, were determined by AOAC methods in two replicates (AOAC, 1998). The content of carbohydrate of the samples was determined by calculating the percentage remaining after all the other components have been measured: %carbohydrates = 100 - %moisture - %protein - %fat - %ash.

### Analysis of amino acid composition

Amino acids analyses of six cereal samples were performed by ion exchange chromatography using an automatic amino acid analyzer Biochrom 30+ (Biochrom, Cambridge, UK), according to Spackman, Stein and Moore (1958). The technique was based on amino

acid separation using strong cation exchange chromatography, followed by the ninhydrin colour reaction and photometric detection at 570 nm, except for proline, which was detected at 440 nm. Samples of the cereals were previously hydrolysed in 6M HCl (Merck, Germany) at 110 °C for 24 h.

After hydrolysis, samples were cooled to room temperature and dissolved in 25 mL of Loading buffer (pH 2.2) (Biochrom, Cambridge, UK). Subsequently, prepared samples were filtered through 0.22 µm pore size PTFE filter (Plano, Texas, USA) and the filtrate was transferred into a vial (Agilent Technologies, USA) and stored in a refrigerator prior to analysis.

The amino acid peaks were identified by comparison of retention times with retention times of amino acid standard purchased from Sigma Aldrich (Amino Acid Standard Solution (Sigma-Aldrich, St. Louis, USA)). The results were expressed as mass of amino acid (g) in 100 g of sample (Tomičić et al., 2020). The weight of cereal samples was uniform in terms of dry matter before the amino acid analyzes.

### Statistical analysis

Results were expressed as mean  $\pm$  standard deviation of three independent replicates for amino acid determination. Post ANOVA Tukey's HSD test was used to analyze the difference in means between samples, on  $p < 0.05$  level.

The principal component analysis (PCA) has been applied to classify and segregate the different samples. All data were processed statistically using the software package StatSoft Statistica, ver. 10 (IBM, Armonk, NY, USA).

## RESULTS AND DISCUSSION

The chemical composition of the different cereals tested in this study is presented in Table 1. Moisture content varied from 11.45 to 13.80%. Grains with high or very low moisture content commonly contribute to loss in quality.

The moisture content in the wheat genotypes usually ranged from 7.8% to 14.8% (Qamar, 2002; Laze et al., 2019), which is in line with the result observed in our study where the moisture content of wheat was 12.92%. The concentration of crude protein among the six

tested cereal grains ranges from 7.83 to 13.22% and was found to be higher in oat.

Cereals are grown in large quantities around the world and are the dominant source of carbohydrates, providing the major source of energy and contributing significantly to protein intake in the human diet, especially in developing countries.

For humans, carbohydrates are quantitatively the most important dietary energy source, usually make up 45-70% of the total energy intake and have a special role in energy metabolism and homeostasis. Carbohydrates account for about 65-75% of the mature wheat grain, with similar values being reported for other major cereals (Lafiandra, Riccardi & Shewry, 2014).

Rice, wheat and corn are the most cultivated crops and are responsible for approximately 60% of the world's food energy intake (Kowieska, Lubowicki & Jaskowska, 2011; Cervantes-Pahm, Liu & Stein, 2014; Laze et al., 2019). Proteins provide energy to the body as do carbohydrates, that is, 4 kcal/g (Zafar, Naz, Nazir, Abbas & Khan, 2014).

The protein content of rice, approximately 7-9%, is relatively low compared to the content of other cereals. However, the total amount of potentially available rice protein is significant due to a large amount of rice produced worldwide (Likittrakulwong, Poolprasert & Srikaeo, 2019).

Ash content was observed in the range of 1.21 to 3.91%. The ash content of wheat in our study was 1.69% which is in agreement with research conducted by Laze et al. (2019) where the values of ten wheat samples ranged from 1.45% to 1.88%.

The "ash content" presents the total quantity of minerals in a certain food sample. The crude cellulose content varied from 1.89% in rice to 9.42% in oat, while the content of crude fat was lower in rice (1.67%) and higher in oat (6.35%).

The chemical composition can be greatly influenced by climatic variations, irrigation practices and agricultural practices, soil fertility, as well genetic differences, which might explain the difference among various studies (Siddiqi et al., 2020; Shewry, 2007).

**Table 1.**  
Chemical composition of cereals

Parameter	CHEMICAL COMPOSITION					
	Barley	Maize	Oat	Rice	Rye	Wheat
Moisture (%)	11.85 ± 0.09 <sup>b</sup>	11.45 ± 0.06 <sup>a</sup>	13.14 ± 0.10 <sup>e</sup>	12.51 ± 0.08 <sup>c</sup>	13.80 ± 0.11 <sup>f</sup>	12.92 ± 0.14 <sup>d</sup>
Crude protein (%)	11.64 ± 0.13 <sup>d</sup>	9.11 ± 0.14 <sup>b</sup>	13.22 ± 0.12 <sup>f</sup>	7.83 ± 0.06 <sup>a</sup>	9.47 ± 0.08 <sup>c</sup>	12.35 ± 0.11 <sup>e</sup>
Crude fat (%)	2.11 ± 0.11 <sup>b</sup>	3.76 ± 0.16 <sup>c</sup>	6.35 ± 0.07 <sup>d</sup>	2.20 ± 0.11 <sup>b</sup>	1.67 ± 0.09 <sup>a</sup>	1.78 ± 0.08 <sup>a</sup>
Ash (%)	2.12 ± 0.07 <sup>e</sup>	1.36 ± 0.04 <sup>b</sup>	3.91 ± 0.07 <sup>f</sup>	1.21 ± 0.10 <sup>a</sup>	1.88 ± 0.07 <sup>d</sup>	1.69 ± 0.05 <sup>c</sup>
Crude cellulose (%)	4.86 ± 0.15 <sup>d</sup>	2.32 ± 0.08 <sup>b</sup>	9.42 ± 0.06 <sup>e</sup>	1.89 ± 0.13 <sup>a</sup>	3.13 ± 0.06 <sup>c</sup>	2.35 ± 0.10 <sup>b</sup>
Carbohydrates (%)	66.36 ± 0.13 <sup>b</sup>	72.07 ± 0.16 <sup>e</sup>	62.03 ± 0.25 <sup>a</sup>	75.20 ± 0.18 <sup>f</sup>	69.85 ± 0.13 <sup>c</sup>	70.96 ± 0.24 <sup>d</sup>
Energy value (kcal)	353.47±0.35 <sup>c</sup>	365.34±0.41 <sup>d</sup>	389.13±0.32 <sup>f</sup>	368.00±0.16 <sup>e</sup>	335.33±0.31 <sup>b</sup>	326.53±0.41 <sup>a</sup>

Values represent the average of duplicate experiments ± standard deviations. Different letters in the same row represent a statistically significant difference ( $p < 0.05$ ) among the tested samples

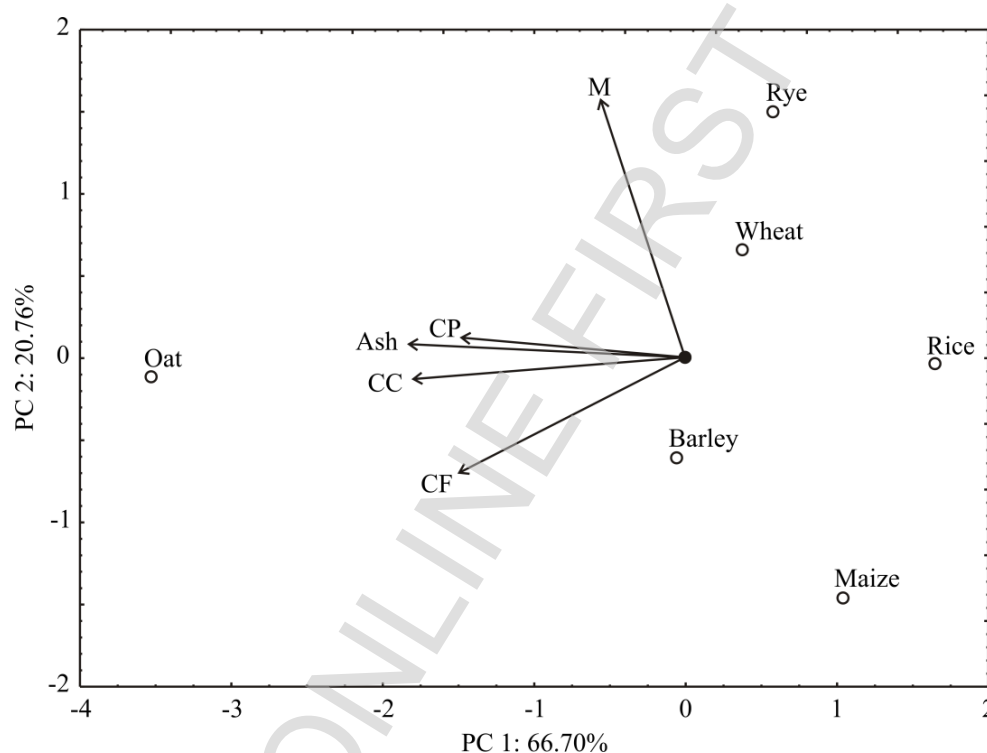


Figure 1. The PCA biplot diagram, showing the relationships among chemical composition of cereals  
*M - Moisture; CP - Crude protein; CF - Crude fat; CC - Crude cellulose*

To better explain the obtained chemical composition data of cereals, similarities and differences among observed samples, PCA was used, and the extracted results are presented in Figure 1.

The first PC explained 66.70%, and the second explained 20.76% of the total variance within the observed data.

The separation between samples could be realized from the PCA figure, where barley, maize, rice, rye and wheat are grouped on the right side of the graphic, while the oat sample

is grouped on the graphic's left side, having increased values of crude protein, crude fat, ash and crude cellulose content. The rye sample had the highest moisture content.

Adequate intake of amino acids from dietary protein can be defined as the need, in appropriate amounts, of all amino acids required for protein synthesis/renewal and utilization of amino acids in other metabolic pathways (Blachier et al., 2021). The topic of protein and amino acid requirements has generated substantial controversy over the past 20 years.

The report of the Joint Expert Consultation FAO/WHO/UNU Consultation (2007) on protein and amino acids requirements in human nutrition highlighted several aspects of protein quality that still required consideration. The report also provided new reference patterns based on amino acids requirements for different age groups (Boye, Wijesinha-Bettoni & Burlingame, 2012).

The nutritional quality of protein in the diet is related to the concentration of essential amino acids, which cannot be synthesized and therefore must be acquired through nutrition (Shewry, 2007; Sterna, Zute & Brunava, 2016). The amino acid profile of the cereals tested in this study is summarized in Table 2.

The results showed a considerable difference in the quantity of individual amino acids. The sum of essential amino acids (EAA), which included threonine, valine, methionine, isoleucine, leucine, phenylalanine, histidine, and lysine, varied depending on the species in the range from 2.68 g/100g in rice to 4.12 g/100g of sample in oat and accounted for 30.58-37.76% of the total amino acids. It is known that the content of lysine and methionine in cereals is not at a satisfactory level.

However, when combined with other food proteins such as legumes, oilseeds or animal products, cereal proteins show excellent dietary quality (Laze et al., 2019).

Firstly, although lysine is the limiting amino acid for all cereals, the amount varies among species, being highest in oat and lowest in maize and rice. However, rice protein contains lysine that is considered hypoallergenic and therefore favourable for human consumption (Helm & Burks, 1996).

The results of the present study support the observation made by Kosieradzka & Fabijańska (2001) where lysine was the first limiting amino acid in all cereals, but its content was higher in oat than in wheat and maize.

Therefore, the amino acid composition of oat is the most favourable among cereals due to high protein and lysine content, of which the latter is limited in most cereals.

Further, according to FAO/WHO (Joint FAO/WHO/UNU Expert Consultation, 2007), the recommended intake of total essential amino acids is 83.5 mg on kg of body weight

per day. Taking this into consideration, the recommended intake of essential amino acids could be provided with 100-110 g of oats (Sterna et al., 2016).

Threonine is very important in a diet, present at low concentrations in cereal proteins and found to be limiting essential amino acids as observed in the previous study by Knežević, Đukić, Madić, Paunović and Zečević (2007). It is estimated a daily dose of about 19 mg/kg (Wilson, Rafii, Ball & Pencharz, 2000). Histidine was found to be highest in oat (0.33 g/100g) while lowest in rice (0.16 g/100g).

This amino acid was initially considered essential only for infants, but now studies have revealed their significance in terms of essentiality for adults as well, current expert opinion for histidine is 8 and 12 mg/kg of body weight per day in adults (Zafar et al., 2014; Gheller, Bender & Thalacker-Mercer, 2019; Moro, Tomé, Schmidely, Demersay & Azzout-Marniche, 2020).

Phenylalanine is essential for growth and development and young children can consume small amounts (Laze et al., 2019). Leucine, an essential amino acid, has been shown to play a unique role in stimulating muscle protein synthesis and helps in the formation of sterols in adipose and muscle tissue (Zafar et al., 2014; Jackman et al., 2017).

In our study, leucine varied in the concentration range from 0.66 g/100g to 0.94 g/100g in the tested cereals. The FAO/WHO (Joint FAO/WHO/UNU Expert Consultation, 2007) requirement for leucine is 39 mg/kg daily dose.

Oat and wheat were characterized by the largest number of the determined essential amino acids, indicating high nutritional value.

Finally, as mentioned, the requirements are different for adults and children; in adults, amino acids are required for maintenance whereas for children they are required for growth.

A comparison of the studied cereals regarding their contribution to the intake of amino acids expressed as the percentage of relevant Dietary Reference Intakes (DRI) recommended for children aged 4-8 years and adults by the Institute of Medicine (2006) is presented in Table 3. Although these data are from a range of cereal sources they clearly illustrate several important points.

Firstly, although lysine is the limiting amino acid for all cereals, the amount varies between species, with the highest recommended amount provided by oats and the lowest by rice.

Similar differences also occur in the proportions of other essential amino acids with methionine being particularly deficient in barley and rye. In adults, the daily requirement for valine is 24.0 mg/kg body weight/day, however, the results of our study showed that the content of valine in oat and wheat is markedly above the requirement, while for isoleucine is 19.0 mg/kg body weight/day, and thus once again corresponds to requirement.

The nonessential amino acids (NEAA) of cereals comprising aspartic acid, serine, glutamic acid, proline, glycine, alanine, cysteine, tyrosine, and arginine (Table 2), constituted 62.24–69.42% of the total amino acids. Significant ( $p < 0.05$ ) variation existed in both EAA and NEAA among samples.

The level of essential amino acids was lower than the level of nonessential amino acids in the tested samples, while the highest total number of essential and nonessential amino acids was found in oat and wheat.

Among nonessential amino acids (NEAA), aspartic acid, serine, glutamic acid, proline, glycine, alanine, and arginine showed significant ( $p < 0.05$ ) differences, whereas alanine, cysteine and tyrosine varied non-significantly ( $p > 0.05$ ).

Glutamic acid was found to be the most abundant amino acid, with concentrations ranging from 1.39 to 2.94 g/100 g of sample. The highest concentration of glutamic acid was observed in the wheat and was lowest in rice.

The results are consistent with those of Jiang, Tia, Hao and Zhang (2008), who found glutamic acid as the most dominant amino acid having a concentration range of 24.79-37.05 g/100 g protein in 17 wheat-related species.

Glutamic acid is synthesized in the body and plays a major role in amino acid metabolism and in maintaining nitrogen balance in the body, which is essential in stressful and illness situations. Glutamic acid is also a well-established excitatory neurotransmitter in the cen-

tral nervous system (Laze et al., 2019). According to NHANES III (1988–1994), the mean daily intake of glutamic acid is 15 g/day (Zafar et al., 2014).

The level of almost every amino acid was slightly higher in wheat than in barley and these results confirmed the research conducted by Kowieska et al. (2011).

Moreover, the amino acids composition of wheat and barley showed the lowest content of cysteine, methionine and histidine, and the highest content of glutamic acid, proline and leucine, an observation that was consistent with the study of Bandegan et al. (2011).

Further, the results showed that oat contained higher amounts of aspartic acid, threonine, glycine, valine, methionine, tyrosine, histidine, lysine and arginine while serine, glutamic acid, proline, alanine, cysteine, isoleucine, leucine, phenylalanine were found in similar or smaller amounts compared to other cereals. Glutamic acid and proline were the most abundant amino acids in all tested cereal samples.

The graphical representation of the amino acid profiles data of cereals among the observed samples, the PCA was used, and the extracted results are presented in Figure 2. The first PC explained 62.44%, and the second explained 19.56% of the total variance within the observed data.

The separation between samples could be realized from the PCA graph, where barley, maize, rice, rye and wheat are grouped on the right side of the diagram, while oat is grouped on the plot left side.

The oat sample was marked as having high levels of aspartic acid, threonine, glycine, valine, methionine, leucine, tyrosine, histidine, lysine and arginine.

The oat sample was characterized as the sample with the highest content of total essential amino acids and total amino acids.

The wheat sample contained the highest content of serine, glutamic acid, proline, isoleucine and phenylalanine, and also the highest content of total nonessential amino acids.

**Table 2.**  
Amino acid profiles of cereals presented in g/100g of sample

Amino acid (g/100 g )	Barley	Maize	Oat	Rice	Rye	Wheat
Aspartic acid	0.60 ± 0.02 <sup>a</sup>	0.56 ± 0.04 <sup>b</sup>	0.87 ± 0.04 <sup>c</sup>	0.72 ± 0.03 <sup>d,e</sup>	0.73 ± 0.05 <sup>d</sup>	0.70 ± 0.06 <sup>e</sup>
Threonine*	0.33 ± 0.03 <sup>a</sup>	0.35 ± 0.05 <sup>a,e</sup>	0.42 ± 0.02 <sup>b</sup>	0.27 ± 0.01 <sup>c</sup>	0.32 ± 0.04 <sup>a,d</sup>	0.37 ± 0.02 <sup>e</sup>
Serine	0.40 ± 0.06 <sup>a</sup>	0.49 ± 0.03 <sup>b</sup>	0.53 ± 0.05 <sup>c</sup>	0.38 ± 0.05 <sup>d</sup>	0.41 ± 0.04 <sup>a</sup>	0.63 ± 0.04 <sup>e</sup>
Glutamic acid	2.87 ± 0.02 <sup>a</sup>	1.68 ± 0.01 <sup>b</sup>	2.57 ± 0.03 <sup>c</sup>	1.39 ± 0.04 <sup>d</sup>	2.30 ± 0.05 <sup>e</sup>	2.94 ± 0.06 <sup>f</sup>
Proline	1.17 ± 0.07 <sup>a</sup>	0.76 ± 0.03 <sup>b</sup>	0.77 ± 0.04 <sup>b</sup>	0.37 ± 0.03 <sup>c</sup>	0.89 ± 0.03 <sup>d</sup>	1.28 ± 0.05 <sup>e</sup>
Glycine	0.46 ± 0.04 <sup>a</sup>	0.33 ± 0.05 <sup>b</sup>	0.58 ± 0.03 <sup>c</sup>	0.47 ± 0.06 <sup>a</sup>	0.42 ± 0.02 <sup>d</sup>	0.52 ± 0.03 <sup>e</sup>
Alanine	0.37 ± 0.01 <sup>a</sup>	0.55 ± 0.06 <sup>b</sup>	0.52 ± 0.06 <sup>c</sup>	0.45 ± 0.04 <sup>d</sup>	0.39 ± 0.05 <sup>a</sup>	0.47 ± 0.04 <sup>d</sup>
Cystine	0.24 ± 0.02 <sup>a,d</sup>	0.18 ± 0.07 <sup>b</sup>	0.23 ± 0.02 <sup>a,e</sup>	0.12 ± 0.05 <sup>c</sup>	0.20 ± 0.04 <sup>b,f</sup>	0.22 ± 0.03 <sup>d,e,f</sup>
Valine*	0.44 ± 0.05 <sup>a</sup>	0.43 ± 0.08 <sup>a</sup>	0.61 ± 0.07 <sup>b</sup>	0.39 ± 0.04 <sup>c</sup>	0.45 ± 0.07 <sup>a</sup>	0.57 ± 0.06 <sup>d</sup>
Methionine*	0.16 ± 0.03 <sup>a</sup>	0.24 ± 0.02 <sup>b</sup>	0.28 ± 0.01 <sup>c</sup>	0.21 ± 0.02 <sup>d</sup>	0.15 ± 0.03 <sup>a</sup>	0.19 ± 0.01 <sup>d</sup>
Isoleucine*	0.31 ± 0.04 <sup>a</sup>	0.30 ± 0.06 <sup>a</sup>	0.45 ± 0.03 <sup>b</sup>	0.34 ± 0.02 <sup>c</sup>	0.35 ± 0.08 <sup>c</sup>	0.51 ± 0.07 <sup>d</sup>
Leucine*	0.72 ± 0.04 <sup>a</sup>	0.92 ± 0.07 <sup>b</sup>	0.94 ± 0.04 <sup>b</sup>	0.66 ± 0.07 <sup>c</sup>	0.67 ± 0.07 <sup>c</sup>	0.82 ± 0.08 <sup>d</sup>
Tyrosine	0.21 ± 0.02 <sup>a</sup>	0.26 ± 0.01 <sup>b</sup>	0.36 ± 0.04 <sup>c</sup>	0.23 ± 0.02 <sup>a</sup>	0.23 ± 0.01 <sup>a</sup>	0.27 ± 0.03 <sup>b</sup>
Phenylalanine*	0.52 ± 0.08 <sup>a</sup>	0.46 ± 0.04 <sup>b</sup>	0.65 ± 0.07 <sup>c</sup>	0.42 ± 0.06 <sup>d</sup>	0.46 ± 0.05 <sup>b</sup>	0.66 ± 0.05 <sup>c</sup>
Histidine*	0.23 ± 0.01 <sup>a,d</sup>	0.22 ± 0.03 <sup>a</sup>	0.33 ± 0.01 <sup>b</sup>	0.16 ± 0.02 <sup>c</sup>	0.24 ± 0.04 <sup>a,d</sup>	0.25 ± 0.04 <sup>d</sup>
Lysine*	0.33 ± 0.03 <sup>a</sup>	0.29 ± 0.05 <sup>b</sup>	0.44 ± 0.03 <sup>c</sup>	0.23 ± 0.04 <sup>d</sup>	0.34 ± 0.05 <sup>a,e</sup>	0.36 ± 0.03 <sup>e</sup>
Arginine	0.58 ± 0.06 <sup>a</sup>	0.48 ± 0.09 <sup>b</sup>	0.97 ± 0.06 <sup>c</sup>	0.59 ± 0.08 <sup>a</sup>	0.52 ± 0.02 <sup>d</sup>	0.65 ± 0.05 <sup>e</sup>
<b>TEAA</b>	3.04 ± 0.31	3.21 ± 0.40	4.12 ± 0.28	2.68 ± 0.28	2.98 ± 0.43	3.73 ± 0.36
<b>TNEAA</b>	6.90 ± 0.32	5.29 ± 0.39	7.40 ± 0.37	4.72 ± 40	6.09 ± 0.31	7.68 ± 0.39
<b>TAA</b>	9.94 ± 0.63	8.50 ± 0.79	11.52 ± 0.65	7.40 ± 0.68	9.07 ± 0.74	11.41 ± 0.75

Values represent the average of triplicate experiments ± standard deviations. Different lowercases in the same raw represent a statistically significant difference ( $p < 0.05$ ) among tested samples. Essential amino acids are indicated by an asterisk (\*). Abbreviations: TEAA, total essential amino acids; TNEAA, total nonessential amino acids; TAA, total amino acids

**Table 3.**

Contribution to the intake of essential amino acids (EAA) in relation to the relevant Dietary Reference Intakes (DRIs) by 100 g of cereals

EAA (%)	Barley		Maize		Oat		Rice		Rye		Wheat		Nutrient recommendations (DRI)* (mg/kg/d)	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Threonine	68.75	23.57	72.92	25.00	87.50	30.00	56.25	19.29	66.67	22.86	77.08	26.43	24.00	20.00
Valine	78.57	26.19	76.79	25.60	108.93	36.31	69.64	23.21	80.36	26.79	101.79	33.93	28.00	24.00
Methionine	36.36	12.03	54.55	18.05	63.64	21.05	47.43	15.79	34.09	11.28	43.18	14.29	22.00	19.00
Isoleucine	70.45	23.31	68.18	22.56	102.27	33.83	77.27	25.56	79.55	26.32	115.51	38.35	22.00	19.00
Leucine	73.47	24.49	93.98	31.29	95.92	31.97	63.35	22.45	68.37	22.79	83.67	27.89	49.00	42.00
Phenylalanine	63.41	22.51	56.10	19.91	79.27	28.14	51.22	18.18	56.10	19.91	80.49	28.57	41.00	33.00
Histidine	71.89	23.47	68.75	22.45	103.13	33.67	50.00	16.33	75.00	24.49	78.13	25.51	16.00	14.00
Lysine	35.87	12.41	31.52	10.90	47.83	16.54	25.00	8.65	36.96	12.78	39.13	13.53	46.00	38.00

\*Joint WHO/FAO/UNU Expert Consultation (2007)



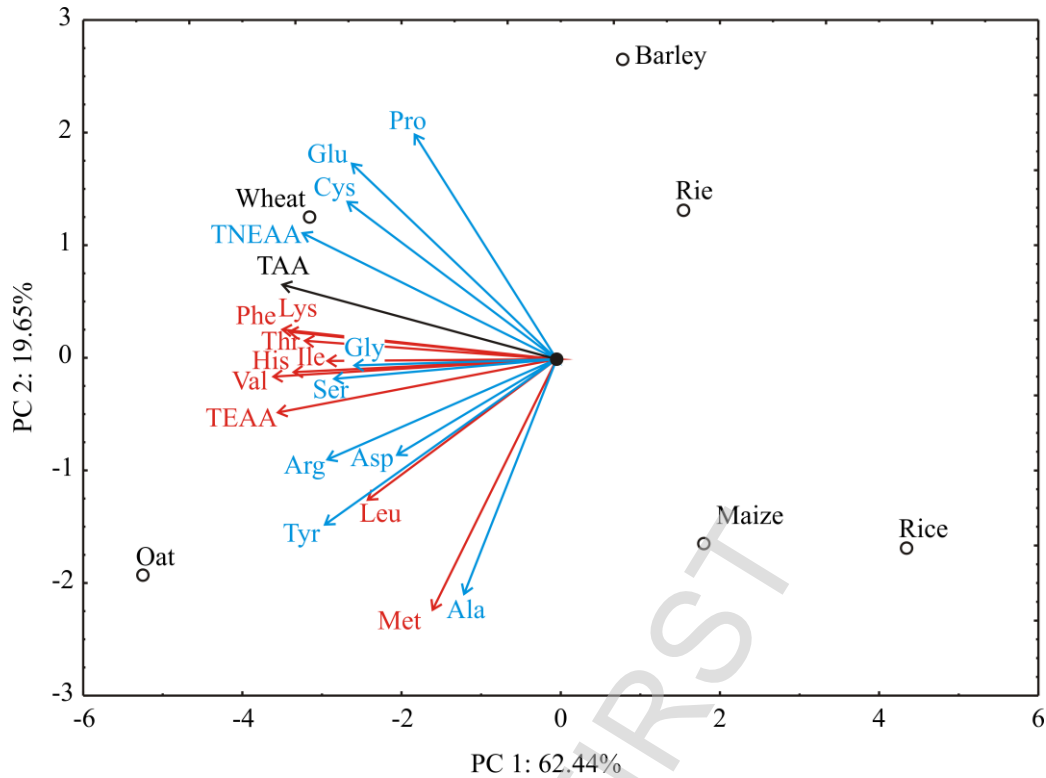


Figure 2. The PCA biplot diagram, showing the relationships among amino acid profiles of cereals

Asp - Aspartic acid; Thr - Threonine; Ser - Serine; Glu - Glutamic acid; Pro - Proline; Gly - Glycine; Ala - Alanine; Cys - Cystine; Val - Valine; Met - Methionine; Ile - Isoleucine; Leu - Leucine; Tyr - Tyrosine; Phe - Phenylalanine; His - Histidine; Lys - Lysine; Arg - Arginine

## CONCLUSIONS

The results obtained in our study showed the quality of cereal proteins through the amino acid profiles that provide added value in understanding the diversity of amino acids in cereals for human consumption. The total content of amino acids was highest in oat and lowest in rice. The study concluded that the essential amino acids made up one-third of the total amino acid content in the tested cereals. Also, the amino acid composition of oat is more favourable in comparison to other cereals due to the high protein and lysine content. To improve the nutritional value of food products, more significant consideration of plant species as a source of amino acids and possible complementarity of use in the combination of seeds and seed products of the studied plant species is needed.

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## RAZLIČITOST AMINOKISELINSKOG SASTAVA U ŽITARICAMA

Zorica M. Tomičić<sup>\*1</sup>, Lato L. Pezo<sup>2</sup>, Nedeljka J. Spasevski<sup>1</sup>, Jasmina M. Lazarević<sup>1</sup>, Ivana S. Čabarkapa<sup>1</sup>, Ružica M. Tomičić<sup>3</sup>

<sup>1</sup>Univerzitet u Novom Sadu, Naučni institut za prehrambene tehnologije, 21000 Novi Sad, Bul. cara Lazara 1, Srbija

<sup>2</sup>Univerzitet u Beogradu, Institut za opštu i fizičku hemiju, 11000 Beograd, Studentski trg 12/V, Srbija

<sup>3</sup>Univerzitet u Novom Sadu, Tehnološki fakultet, 21000 Novi Sad, Bulevar cara Lazara br. 1, Srbija

**Sažetak:** Kvalitet proteina zasniva se na njihovom sastavu aminokiselina, posebno na sadržaju i dostupnosti esencijalnih aminokiselina. Žitarice su važni izvori proteina za ishranu ljudi, ali su limitirajuće u količinama esencijalnih aminokiselina, posebno lizina. Cilj ove studije bila je analiza hemijskog sastava i profila aminokiselina različitih žitarica koje su važne za ishranu ljudi. Sadržaj proteina, vlage i sirovih masti značajno je varirao od 7.83 do 13.22%, 11.45 do 13.80%, odnosno od 1.57 do 6.35%. Dobijeni rezultati su pokazali da ovas ima najveći sadržaj sirovih proteina (13.22%), sirove masti (6.35%) i sirove celuloze (9.42 %) u poređenju sa drugim žitaricama. Značajne ( $p < 0.05$ ) varijacije postojale su u sadržaju esencijalnih i neesencijalnih aminokiselina među uzorcima sa najvećim nivoom u ovsu i pšenici. Što se tiče udela esencijalnih aminokiselina u ukupnim aminokiselinama, moglo bi se zaključiti da je on iznosio jednu trećinu u testiranim žitaricama. Utvrđeno je da je glutaminska kiselina najzastupljenija aminokiselina. Moglo bi se zaključiti da je aminokiselinski sastav ovasa najpovoljniji među žitaricama zbog visokog sadržaja proteina i lizina koji se u ograničenim količinama nalazi u većini žitarica.

**Ključne reči:** *esencijalne aminokiseline, neesencijalne aminokiseline, hemijski sastav, nutritivni profil, referentni unos u ishrani*

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